How Ergonomics Works

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Contents

Introduction

How Ergonomics Works

An introduction or preface should explain the motivation for writing a book; it should identify those previous authors and other individuals who have helped to form the conceptual image for the book and who, through their content and style, have helped to focus this attempt to advance the understanding of our profession – ergonomics, human factors, human factors engineering or the myriad of other attempts to describe succinctly the most complex and worthwhile profession in the world, and beyond.

Over the years I have sought many sources of information about my profession in my various roles as a researcher, teacher, and practitioner. The flagship journals – "Human Factors and Ergonomics" and "Ergonomics" now, after 50 years in the profession, fill my bookshelves. I would like to say that I have read them all, but that would be a stretch; I can say however that I have read most of the abstracts and scanned many of the tables and graphs and read quite a lot of the articles in detail. I believe that I have just described the activities of a typical consumer of information; although I hesitate to describe myself as "typical", knowing what I have learned about human variability. A common consumer of information is attracted by a concept – the title – tries to fit this concept into his or her set (*sic*) of mental models, and then seeks to improve their perceptions through the well documented process of learning. Having read the titles and abstracts of the learned articles, I then turn to the pictures – photographs, tables, charts and graphs – the conclusions come next and then, if I am still interested, I check out the methods and discussion and finally go to the background to see how this article fits into the bigger scheme of things. This 'bigger scheme of things' to me must provide a pipeline from some theory to some application in the real world. Sometimes, however, our journal articles are not pipelines, rather they are "stovepipes" – they contain theory (hypotheses, models) without data or application, data without theory or application without either.

My next sources of information, particularly as a teacher, have been the classic textbooks. I have taught general courses using Sanders and McCormick, Bailey, Grandjean, Kroemer, the "Kodak" books by Rodgers, and Konz and specialist courses out of Chaffin and Astrand and Rohdal. I have also used one of the earliest textbooks in the field – "Ergonomics" by Murrell. These are all outstanding books and well suited to traditional didactic teaching, where one addresses in turn such things as anthropometry, biomechanics, work physiology, vision, perception, memory, motor skills, motivation and so on. Some develop their chapters from outside in, by addressing work place design, manual materials handling, the thermal environment, inspection, assembly, web page design etc. Either way, the material tends to focus on particular areas of human capabilities and limitations or some subdivision of the application. Thus, these classic textbooks do their job very well – they teach the building blocks of ours profession. It is left up to the user – the practitioner – to put these building blocks together when addressing a particular situation, such as a design problem, accident investigation or legal evaluation or even explaining the many ramifications of say human strength or memory. Unfortunately, in my experience, students often discard these wonderful sources, once they leave school and enter the workplace. Students should keep their textbooks, not sell them!

The next kinds of material that researchers, teachers and practitioners find useful are the handbooks that have proliferated over the past decades. Those by Salvendy, Karwowski, Corlett and Stanton are particularly notable in that they attempt to cover broad spectra of our profession, with very readable and well organized chapters by contributors with specialized knowledge of particular aspects of human characteristics, behavior, performance or preference, or particular application domains. These collected works are generally not well suited as course textbooks, because of their cost and their sometimes too great specialization. They are well suited as reference books and provide excellent descriptions of the theory and applications of the profession. They should be on the shelves of all teachers and practitioners, and not gather dust.

Perhaps the most useful material for practitioners is contained in the books generally classified as "design guides". Authors such as Tillman, Tillman and Woodson (Human Engineering Guide to Equipment Design), and Boff come to mind. These books attempt, very successfully, to consolidate the theories into "how to" rules, along with supporting data, such as reach curves, font sizes and symbol design. Supporting these design guides, other textbooks, handbooks, design guides address specialized areas of our profession. These sport such titles as "Situation

Awareness", Workplace Design", "Accident Investigation", "Human Computer Interaction" and so on. These attempt to consolidate the theory, technique sets or application domains and provide very useful sources for either specialized courses or researchers and practitioners in specialized areas.

Finally, there are "outside – in" books. These are the ones that are scenario oriented and which backtrack into the human physiology or psychology that underpin the reasons for human or system failure. Naturally, they generally present the sometimes-biased opinion that the human operator would not have failed if the designer of the system had had at least an introductory course in ergonomics or human factors. Perhaps the best known books of this kind are "Set Phasers on Stun" by Steve Casey and the books by Donald Norman: "User Centered System Design", "The Psychology of Everyday Things" and its second title "The Design of Everyday Things", "Turn Signals are the Facial Expressions of Automobiles" and "Things that Make us Smart". Steve Casey focuses on big catastrophes with often, but not always simple causes, like Three Mile Island, Bhopal, Salyut, Exxon Valdez, X-Ray machines and 'that newfangled technology – radar' which could have prevented the US fleet from running aground. Donald Norman addresses the myriad of small design shortcomings that pervade our technology centric society, like 'which way should a door open'.

The style of both authors is instructive. It is both informative and entertaining; it links practice to underlying theory, often in a single sentence or paragraph. Both authors are, sometimes unfairly, critical of designers. While they recognize that design in the real world is often a compromise with constraints of cost and time and other performance requirements, they emphasize the common fact that the problem in question could have been prevented with knowledge that was currently available. Norman is credited with the origination of the expression "human or user centered design", however this has always been the cry of our profession. The relatively recent, optimistic movement towards "universal design" unfortunately does not recognize the constraints of real-world design. Norman's books are pipelines that go both ways – from theory to practice and from practice to theory. These books can be used as texts, but they require a very different way of teaching; they are not linear, rather they branch around complex concepts and attempt to articulate the causal links in a spatial way, albeit through linear text. Stephan Konz attempts to apply ergonomics theory to textbook design to address this challenge of complexity through the media of integrated text, diagrams, tables, descriptive inserts, and examples. The relatively recent developments of concept mapping and web-based hypertext provide an alternative, powerful alternative to linear text that comprehends the challenges of complexity. These techniques have great potential in the areas of ergonomics and human factors research, teaching and practice.

Over the past few years, I have also attempted to describe 'how ergonomics works' through a series of articles in "Ergonomics in Design". These articles are grouped under an umbrella column entitled "The Laws and Rules of Ergonomics in Design". Each article selects a particular law from either basic science or from ergonomics / human factors. Parenthetically I would venture the opinion that most of these laws were not invented by ergonomists; rather we take our theories from other professions, such as physics, biology and psychology and adapt them to our own needs. For example, I have addressed Newton's Laws, Fitts' Law and Murphy's Law with applications to our profession in such areas as stopping a truck, assembling Barbie Doll clothes and airport security. I have attempted to mimic Norman and Casey by using real world examples as a way of backing into theory. I have also attempted to be both informative and entertaining because ergonomics really can be very dry. This collection of articles is now available in book form – "Ergonomics in Design."

Throughout my career in ergonomics I have had many opportunities to apply my knowledge of human characteristics, capabilities and limitations to real world problems, such as mass transit railway design, promotion systems, tax forms, retail establishments, cars, manufacturing processes, instructions and warnings. I have also been involved in projects that address how to prevent airplanes from flying into mountains and cars from hitting each other. Perhaps my greatest challenge was as program manager for the General Motors "ACCESS Car." This was a concept that was aimed at transportation for the elderly; it addressed physical, cognitive, and social 'access.' Whereas the inputs to the design included such human centered information as anthropometry, biomechanics, vision, attention, motor skills, learning and social needs, the outputs were recommendations for the design of seats, seat belts, displays, foot pedals, trunks, turn signals, owners' manuals, roadway design, emergency response systems, neighborhood cars and "rideshare" systems. A common theme throughout all these design experiences was that no aspect of the problem could be resolved by knowledge of a single human capability or limitation, although all problems had to be addressed eventually by combinations of single design specifications. Give the engineer a number! This requirement highlights the fundamental challenge of ergonomics and human factors. People vary; there is variation between people in shape and size and strength and stamina and skill and sophistication, and of course age; there is also variation within people over time - people become fatigued and distracted, they also learn. “Give the engineer a number!” But which number? I used to argue that a prerequisite for all ergonomics / human factors courses should be a course in descriptive and analytic statistics and investigation / experiment design. I have softened a little now – I believe that these quantitative subjects may be a co-requisite – it is possible to back into statistics and probability through ergonomics. “Give the engineer a number;” which number? The fifth percentile is no use; it is only meaningful in particular contexts and the data don’t exist outside the relatively simple area of anthropometry and even there once one gets beyond a single dimension one gets lost very quickly – particularly with the compromise between fit and reach.

One way of dealing with this problem is to avoid the responsibilities of design. We should excel in the role of “ergo-cop”. This is of course a euphemism for “usability specialist.” Let the engineer (hardware or software or organizationware) design something, get a bunch of strangers to check it out and then go back to the engineer and tell him or her that his or her “baby is ugly.” No wonder our profession gets a bad name. But what number should we give the engineer up front? That is the subject of the rest of this book. Read on.

This book attempts to explain the theory and practice of ergonomics through the medium of case studies and scenarios of varying degrees of complexity. First it addresses systems theory as it is affected by the inclusion of the human subsystem and the inevitable consequences of variation, both in design inputs and process outcomes. This approach to design will use the medium of grammar to articulate the communications between users, designers and their advisors, including ergonomists, as a design passes through its life cycle of requirements, specifications, concepts, implementations, outcomes, evaluations and continuous improvement.

As noted earlier, ergonomics is not one-dimensional. Users bring physical, sensory, motor, cognitive and social characteristics to the same table. Vehicle drivers, assembly line workers and operators of remote-controlled devices all have bodies, brains, and brothers to contend with, and the eventual system failure in a particular context may result from any one of many vulnerabilities. However, when we break down this complexity into its contributory parts and the particular design opportunities, we usually must address individual dimensions, albeit with their interactions. Therefore, the book addresses scenarios that can be decomposed into predominantly physical, informational, or social dimensions and their corresponding human attributes. This will enable the ergonomist to attempt to “give the engineer a number” that can be used to accommodate independently but interactively human size, strength, stamina, skill, senses, and stupidity.

Each of the chapters contains descriptions of multiple situations that attack particular human shortcomings that require similar investigation and design approaches. For example, the design of stadium seating involves anthropometric compromise, as also does the size of buttons on a cell phone and both these design challenges may be met with similar ergonomics processes. Similarly, in terms of vision and understanding web page design for paying utility bills are not unlike your tax forms or your vehicle’s navigation system – they all involve the speed – accuracy tradeoff. Deference to learning theory suggests that transfer of training is a key indicator. Thus the reader will be provided with many exercises that are from different contexts but which require similar ergonomics knowledge sets and approaches. Participation learning is the key, both for the student and the casual reader.

The title of this book was stimulated by a book entitled “How Science Works” by Steven Jenkins. This book is mostly about statistics in the medical and biological world. It deals with such topics as “Is coffee good for you?” and “Are sniffer dogs reliable?” These and other eye-catching topics are how the author addresses confounding and significance and robustness in investigation design. The book is both entertaining and informative; it links practice and theory. That is what this book on “How Ergonomics Works” attempts to emulate. The title is also opportunistic – “Ergo–nomos” – the laws or measurement of work. Perhaps this book should be titled Ergonomicsnomics?

Chapter 1

The Semantics of Human System Design

System and Process Design

The technology of system design has grown over the past half century from roots in human factors engineering (Singleton 196?), manufacturing process engineering, product design, and, more recently, software systems design. Contemporary complex systems are characterized by many agents: human, hardware and software subsystems collaborating in an integrated organization to carry out a mission in a context of environmental uncertainty and time constraints. The technology has developed its own esoteric jargon and in some instances the tools of system design have become so cumbersome that they add unnecessary complexity, cost and delays to the process. The purpose of this paper is to explore the semantics of system design and some of the more useful tools in the context of space exploration, with occasional detours into automobile manufacturing for explanatory purposes. The paper concludes with some simple rules for human system design.

The fundamental semantic challenge is to separate the concepts of entities and activities, agents and functions, systems and processes, nouns and verbs. Entities, agents and systems are described by nouns. Activities, functions, and processes are described by verbs. A system (noun) can only be designed by specifying its characteristics – adjectives - in a quantitative way. Give the engineer a number! Systems by themselves are inert. It is only when they interact with other systems that a purposeful process occurs. Processes are described by verbs and quantified (qualified) by adverbs. Peacock (1995)

Systems, subsystems, components, and elements may be comprised of hardware, software, humanware or organizationware. Extra vehicular activity requires a suit, software for control and communications, an organizational structure for supervision, and last but not least, the person in the suit and his or her support entourage. Extravehicular activity, per se has no specific purpose – activity is a generic term for a collection of purposeful functions, such as inspection, assembly, maintenance, translation, manipulation, protection etc. that can be measured. Driving to work requires a car (nowadays with a lot of software), a driver, a road and an organizational structure, including the highway patrol. Driving to work is also dependent on many supporting processes, such buying, taxing and insuring the car, filling it with gas and maintaining it. Failure of any sub process can have outcomes that vary from the catastrophic to minor inconvenience.

Process Outcomes

These two activities (verbs) – EVA and driving - have common general purposes. First there is quality or effectiveness – achieving a stated objective. Next there is efficiency or productivity – consuming the minimum amount of resources, such as fuel, money or time, to achieve the objective. The third general purpose of all processes is safety – there should be no (or minimal) harm done to any of the collaborating systems, except where the conversion of systems is the purpose of the process, as in propulsion. Harm in this context includes both acute damage to a system or cumulative damage, such as wear of moving parts, radiation sickness or undue fatigue. Parenthetically, all processes result in change to some or all of the contributing subsystems, such as “normal wear and tear” or in the case of the human subsystem, temporary fatigue or learning. A unique purpose of complex processes that include human subsystems is that of satisfaction. People or their organizational supervisors must find some intrinsic satisfaction in the activity and not be overly affected by the dissatisfiers such as discomfort or insufficient rewards.

Processes take place in environmental contexts, which add uncertainty to the outcomes. Space exploration involves extremely hostile environments and the lack of complete or timely information regarding these contexts can be catastrophic. The weather or the other drivers may complicate the process of driving to work. These uncertain extrinsic contexts may interact with any of the intrinsic subsystems and where these subsystems are vulnerable, process failure or subsystem damage may occur. A solar flare may tax the effectiveness of the radiation protection subsystems and a wet road will attack worn tires (Haushalter, 1971). In the case of the human subsystem, a cold drunk driving which contributes to almost half of the 40,000 fatalities a year in the USA, but on balance driving is a very reliable process and most drivers who are "under the influence" don't have accidents and most drivers who drive faster than the speed limit don't get caught.

Risk Assessment

The technology of risk assessment has progressed over the past few decades and there exist various standard processes for linking outcomes and likelihoods. These methods typically use nonlinear probability scales and ordinal outcome or severity scales, which are sometimes converted to a common currency, such as dollars. A fundamental shortcoming of these risk assessment approaches is that they do not usually address the tradeoffs that must be made with positive outcomes – benefits. Where a common currency approach is adopted it is possible to develop key ratios that relate costs and benefits (Peacock, 1998). A common metric in space flight engineering is equivalent system mass (ESM); this also fails to comprehend tradeoffs between costs and benefits and is therefore an insufficient decision tool. More sophisticated analytical processes are essential if we are to comprehend how space flight tradeoff decisions are made. Another challenge is related to the costs of development of countermeasures as well as the countermeasures themselves. For example, the development of a planetary surface suit that is both protective and offers good mobility and where there may be acceptable tradeoffs between protection and mobility, may have vary high development costs and conflicting operational advantages and disadvantages. Very few car buyers purchase Hummers in order to increase their personal safety, but the evidence is clear that vehicle mass is a major contributor to accident outcomes). The issue of the tradeoff between "production and protection" is also very apparent in high volume manufacturing and materials handling processes. The shareholders and management want "productivity" whereas the union fight's for "protection" and this tradeoff has been escalated to the highest circles in the country with the debate about ergonomics standards. (Peacock, 1993)

The Design Process

The engineer cannot do his job effectively without requirements that can be validated. In other words, the requirements statements must contain verbs and their associated adverbs that define process performance and the conditions or tests under which this performance is to be evaluated. For example, a sports car may be expected to go from 0 to 60 in 6 seconds. A suited astronaut may be expected to travel 100 meters over a planetary surface in 5 minutes, with a heavy load of equipment.

Given these validatable operational or process verbs and quantitative adverbs, together with contextual information, the engineer and operations designers are in a position to start addressing the systems that may be needed to satisfy these requirements. Designers create things – nouns – and can only design them with quantitative information – adjectives. For example, s 0 to 60 in 6 seconds may be achieved with a big heavy car with big powerful engine or with a mall, aerodynamic car with a small, efficient power train. The planetary surface astronaut's task may be achieved with a rucksack or a golf cart. Once the engineer has the process requirements, he can then explore the systems (nouns) and their characteristics (adjectives) to develop concepts that may satisfy the requirements.

Unfortunately, the design process does not always work in this tidy way. The customer may not articulate clear requirements but may seek to specify design options and impose requirements after the fact. For example, the customer may ask for a small, aerodynamic sports car and may be disappointed when his luggage doesn't fit in the trunk. An exploration program manager may specify a lunar rather than an orbital launch platform. Conversely, the engineer sometimes seeks requirements that fit his predetermined design specifications, much like the health care specialist with a limited set of interventions may seek diagnostic information to justify those actions. Such conservatism is sometimes justified as the system design characteristics may be well evaluated. The challenge occurs when the system is expected to meet new requirements. "If your only tool is a hammer, very soon everything begins to look like a nail." These possibly unfair references often occur because of a shortage of research and development funding, but in the long run the new challenges of long duration space travel will require new technologies.

Quality Function Deployment

An adaptation of Quality Function Deployment (McHugh, 1986) can provide the discipline of separating systems, processes, nouns, verbs, adjectives, and adverbs. Quality Function Deployment employs a series of matrices that transfer information from market research through product design, manufacturing and production processes to sales and the rest of a product life cycle, including maintenance and recycling. The vertical axes of the matrices contain information about customer requirements and their quantitative adverbs, often obtained by benchmarking tests. For example, a space suit user may expect good shoulder mobility and the adverb may require this to match unsuited shoulder girdle function (an impossible task with current hard upper torso technology). A vehicle maintenance function may involve visual, hand and tool access and the quantitative adverb may expect spark plug change in 5 minutes – a process performance standard derived from comparison with other similar vehicles.

The horizontal axes contain descriptions of the systems (nouns) and their quantitative adjectives. These are system design specifications. For example, maintenance access may require a cone with a minimum diameter of 20 centimeters. Radiation protection may require a material thickness of x millimeters. Eventually, the engineer must design the system with these quantitative values. Give the engineer a number. Unfortunately, no single number will ever be "correct," at least where human subsystems are concerned. A tradition in engineering has been the inclusion of tolerances in specifications – a range of values around a point that is acceptable. Commonly, the engineer may assume that if he or she stays within the upper bound of the tolerance range then the implications in terms of performance will be acceptable. Unfortunately, tolerances have a way of "stacking up" and although all subsystem designs may be within tolerance, the total system may fail. For example, a space suit may have sets of different sized modules that accommodate a range of expected crew member segment sizes, but because of human body size and shape complexity, including imperfect correlation of segment sizes and changes due to microgravity, performance of an EVA activity may be compromised.

An alternative to traditional "tolerances" is the use of loss functions. This involves the identification of a target value that will be ideal and not interact adversely with collaborating subsystems, and a non-linear function that "penalizes" deviations. As the system design develops, these penalties are amalgamated, and a total system score is calculated. (Peacock, 2001) The decision process for system acceptance is based on a policy statement regarding total system score and identification of those subsystem deviations where the greatest impact may be made regarding process performance. For example, a vehicle interior may specify loss functions for headroom, shoulder room, knee room and eye height as well as many other parameters (Roe, 1993). In the final assessment of perception of interior spaciousness or performance in a standard entry – egress test the design compromise will optimize the amalgamation of these multiple loss functions.

Formal testing of the relationship between individual (or sets) of system adjectives (independent variables) and process performance outcomes or adverbs (dependent variables) is the very basis of human factors engineering and its regression or analysis of variance tools. A shortcoming of this reductionist approach is that experimental management of many interacting and concomitant variables is often prohibitive, because of system complexity. An interesting alternative approach is described by the paradoxical statement that " if a non-conforming system passes a [process] performance test then the system can be considered to conform." Or to use a familiar truism: "the proof of the pudding is in the eating."

Human Factors in Design

This paradox envelops the relationship between human factors engineering and their designer and user customers. When human factors enter the design process late with usability tests of the total operational process it is often too late or too costly to rectify fundamental system design shortcomings. For example ergonomics intervention in automobile manufacturing may influence workplace design, tool selection and task content, but cannot change the main design problem of inaccessibility of a particular component. The same is true of maintenance of space hardware; if a suit is to be maintained on a remote planetary surface, there will be very different challenges from those encountered in a well-equipped workshop on earth. Conversely, when human factors is involved in the life cycle requirements planning early in the design process, it is more likely that a comprehensive set of performance requirements will lead to a corresponding set of system design loss functions and the sequence of evaluations as the design matures.

System design specifications can be verified, and process performance requirements can be validated in an appropriate context. These important design evaluation processes are effective only if reliable testing processes accompany requirements and specifications. A generic phase of the design process can be described by analogy with the familiar educational process. The first component is the articulation of performance requirements – will the exiting students have obtained knowledge that fits them for their next course or phase of their careers? The proof of the pudding is in the starting salaries of graduates or better still, the final examination should include an evaluation (validation) of performance in analogous situations. Curriculum or course design specifications flow from the outcome requirements. If the outcome requires problem solving capability, then the course curriculum should specify practice in problem solving. Verification of the curriculum, like verification of system design specifications, should be straight forward if the specifications have been articulated clearly and reliable tests have been planned and implemented. All too often classes are designed based on historical specifications, rather than customer requirements. The limitation of this analogy is that the educational and design processes are extremely complex and involve many subsystems, including teachers (engineers), classroom facilities (design facilities), students (internal customers) and employers (external customers.) However the discipline of process performance requirements (verbs and adverbs) first followed by system design specifications (nouns and adjectives) will assure a more satisfactory outcome.

The root of the design and education challenge lies in human variability and adaptability. Students may succeed despite their professors; vehicle customers may tolerate poor quality if the styling is exceptional, astronauts may succeed in their tasks despite design shortcomings. Conversely unprepared students may fail despite good professors and facilities; poor drivers may fail despite well-engineered systems, and astronauts (or their support entourage) may fail if their training, experience or readiness to perform are insufficient to meet novel or emergency situations. Examples of the former performance successes, despite subsystem failures, are to be found in the Apollo 13 and Skylab solar array incidents. Evidence of the latter failures were observed in the Progress collision and the Soyuz / Salyut tragedy. (Casey, 1993)

Design for human variability may be addressed in several ways. The obvious way is to reduce the [human] variability by meticulous attention to “humanware design” - selection, training, assignment, and performance monitoring. Historically NASA has had great success in this respect although performance monitoring has always been a bone of contention among crewmembers who are reluctant to publicize their shortcomings. An analogous process in professional sport does not suffer from this shortage of evidence. The sports pages are full of the most detailed performance statistics of these highly talented, selected, trained, and paid athletes. At the other end of the design spectrum, consumer product design, including automobiles and their usage contexts, must accommodate a wide variety of minimally talented, marginally selected, inadequately trained and rarely monitored users. Only catastrophic failures are documented and the usually forgiving context allows recovery from gross human error and minimal monitoring of inappropriate behaviors.

Design for highly talented human operators is easier and more forgiving than for the broad population of consumers. But this can lead to complacency and over reliance on the human operator to accommodate for design shortcomings. It should be noted that even the best operators suffer from human fallibilities, such as inattention, fatigue, overload, and debilitation. (Hancock and Desmond, 2001). Picture a good driver finding his way through a strange city, in the fog, on icy roads, to an important meeting deadline. Translate this into an astronaut, debilitated by a long interplanetary journey (or EVA), wearing a cumbersome suit, finding his or her way to a safe haven with limited consumables. The focus of system design must acknowledge expected use and foreseeable misuse. An automobile must be designed to protect an inebriated driver in the event of a high-speed collision. Space hardware must be validated in similarly challenging contexts.

Automobile design has a considerable advantage of an enormous amount of data. Space exploration is relatively data poor. Consequently, space system design must take advantage of contemporary modeling, simulation, and analog facilities. These facilities, to be predictive of human performance in space, must address human shortcomings as well as their successes. It is one thing to winter over in the Antarctic and suffer from frostbite or run out of air in NEEMO and have your buddy lend you his spare regulator. It is altogether different with a minimally redundant crew on their way to a distant planet when the doctor gets toothache, a solar flare erupts, or a piece of software misbehaves. The Advanced Integration Matrix (AIM) program aims to answer the challenges of expected use and foreseeable misuse with a comprehensive suite of digital and analog simulations and an extensive repertoire of what if questions, with particular reference to the many sources of human performance variability.

Simple Rules for Process and System Design

- Differentiate between process requirements and system specifications.
- Develop tests for specification verification and requirements validation.
- Develop a comprehensive picture of system design interactions and process performance outcomes.
- Develop digital simulations of mission process performance and carry out sensitivity analyses of hardware, software, humanware and organizationware subsystem design ranges.
- Use contemporary tools such as Failure Mode and Effects Analysis, Fault Tree Analysis, Human Reliability Analysis, Quality Function Deployment and Discrete Event Simulation to evaluate expected use and foreseeable misuse.
- Comprehend human variability on all dimensions, including physical, cognitive and psycho-social.
- Design in redundancy and forgiveness – make space travel as safe as driving to work.

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Chapter 2

The Big Picture, but don't forget to sweat the details.

"For the want of a nail the shoe was lost
For the want of a shoe the horse was lost
For the want of a horse the rider was lost
For the want of a rider the battle was lost
For the want of a battle the kingdom was lost
And all for the want of a horseshoe nail"

This poem has its origins in the 14th century and Benjamin Franklin wrote a variation on the theme around the time of the war of independence. It is central to the understanding of ergonomics as it relates the details of our analyses to the "Big Picture." The nail is a metaphor that represents all the critical components of an integrated system as they contribute to a purposeful process. Single point failures abound and most of them involve "The User."

The Big Picture

Ergonomics researchers study many "nails, shoes, riders and horses" in great detail although they may call them "icons, web pages, users and laptops" or "handles, boxes, employees and workplaces." The reason that research ergonomists stop here is because the challenges of experimental control become unwieldy when we add complex contexts. At the other end of the spectrum the ergonomics practitioner may be a specialist in warning design but may have limited capability in or responsibility for process substitution to obviate a hazard. We are a bunch of specialists.

These fighting words perhaps merit another example. A gun is a marvelous ergonomic invention that removes many challenges of distance and participant physical, cognitive, or motor variability in combat or hunting. These system qualities however allow the same device to be misused by the bad guys or inexperienced teenagers in the wrong context. Wyatt Earp likes his hair trigger and had no use for a trigger lock, while poor Johnny might have benefitted from all sorts of safeguards when he played with his father's gun. We should design systems for intended use and foreseeable misuse.

At the risk of boring the reader with this train of thought we should consider yet another example. Back in the day Joe Caveman invented the wheel and Marie Curie the nature of radioactivity – both wonderful contributions to the improvement of the capabilities of human endeavor. But the wheel makes cars possible and therefore the deaths of some 40,000 Americans every year while nuclear power promises both energy independence and national annihilation.

Some may say that we ergonomists are only responsible for the interfaces and not necessarily the misuses or abuses of the products, activities, systems, and processes that are the foci of our attention. But we have employers, clients, students and users and it behooves us to understand their purposes, wants and needs. We cannot turn a blind eye to the business of our employers. Many ergonomists work for the military and therefore explicitly condone their actions. Others work in the transportation industry and therefore must recognize the effects of vehicle emissions on the environment. Our clients may be employers or employees, plaintiffs, or defendants. Should our advice be neutral or should we bias the interpretation of the evidence towards the needs of our client. After all he is paying the bill. What should we say to our students? A lifting limit of say 20 ponds will protect a lot of backs, but greatly increase the cost of parcel handling and the viability of the parcel handling companies. Should the government promulgate an ergonomics standard? Or should it pursue the development of a health and safety standard? Either way we should instruct our students in the nature of risks and benefits and encourage them to consider all the implications of their actions.

Finally, we come to the ubiquitous user. They are everywhere; they vary on a multitude of dimensions and have a plethora of purposes. They are designers, manufacturers, salespeople, transporters, maintainers, purchasers and last, but by no means least, they are end users. They are also managers, advertisers, lawyers, shareholders and politicians, and others who derive benefit from a single product or process design. You cannot please all the users all the time. And sometimes it is the third party who happens to be walking under the ladder and gets the dropped wrench on his noggin.

Facilitating Success or Preventing Failure – Our many Purposes

The purpose of most inventions is to facilitate and enhance human performance, convenience, or comfort. The chair, table, wheel, lever, roof, spear, and meeting provided great starting points. Then came the engine, pen and cell phone. It is the job of ergonomists to fine tune technology to squeeze even greater quality and productivity from these inventions. It is also our task to assure the safety of these technologies, especially where they are used in processes that involve people – which ultimately include most processes.

The chair changes Homo erectus into homo sedens. It makes us comfortable, steadies us for fine work, like eating and texting and makes us use fewer calories. The chair makes us fat. It is an attractive nuisance. We ergonomists can design the seat height and seat pan width to fit the 5^{th} or 95^{th} percentile of the intended user population. The former challenge begs the question of who the intended user is and to what use will the user put the chair. The latter challenge is a moving target as chair induced obesity causes a demand for more seat, especially on airplanes. Looking on the bright side these moving targets, both in girth and the steadily growing exposure to more sophisticated technology create rich opportunities for theses and dissertations. The ergonomics practitioner will also have job security. Indeed, technology now allows the possibility of sitting, standing, and walking workstations.

The cell phone is a wonderful invention; it is undoubtedly the best thing since sliced bread. It allows us to have meetings with people wherever and whomever the network reaches, which with the addition of satellites, means most anywhere and anyone. We no longer need to plan our trips – we can just call ahead and get directions or simply ask our little machine. We can order pizza and get the football results. We can also listen to the music of our choice or attend a meeting while lying in bed. This almost universal human appendage is so amazing and convenient that we can use it while driving and during classes and other meetings. We can divide our attention between our task at hand and our remote task because we have spare mental capacity; most of the time. When we don't quite get this division of attention quite right, we die or kill someone else. We may even upset some third party like the professor who is trying to profess or the passenger in the seat next to us who is trying to sleep.

So what is our purpose – facilitating success or preventing failure? Should we address the near term or the long term? The cell phone interface designer can add enormous richness to the technology. We can interact with our cell phones more accurately and quickly. We no longer need to study for exams – the answers are at our fingertips. Our memory is greatly enhanced. But it is rumored, cell phones fry our brains and Bluetooth accessories cause cervical scoliosis. Cell phones like chairs, when used improperly or excessively, result in acute or cumulative trauma. Beer is another great invention – it relaxes us and makes us happy. Too much makes us clumsy and gives us a headache. Ergonomists study chairs, cell phones and beer, but usually while wearing blinkers. We all recognize human, situational and outcome variability, but we rarely address these in our conclusions or recommendations. Instead we give our customers the partial information they desire.

Enrichment

There is another way of looking at the Big Picture. Let us take automobile manufacturing and meatpacking as the examples. Annie the Assembler brings eyes, hands, strong arms and a strong back to the job. When a spark gets in her eye or a sharp edge cuts her finger her physical subsystem fails but can be replaced with minimal cost by another pair of eyes, hands, arms and back. Marie the Meatpacker needs strong wrists and a strong stomach to withstand the sloppy mess that is her workstation. She too is dispensable. There are strong wrists in Mexico and China. But Annie and Marie also have a brain attached to their bodies. They can spot when their incoming materials or outgoing products are out of spec. They can adapt to new demands – Annie can install an engine component and a piece of door trim all in her one-minute job cycle. Marie can cut off the right leg of a chicken and, with a bit of job enlargement, also the left leg and maybe also a couple of wings in her 10 seconds job cycle. Enlargement is enrichment! Right? Or perhaps we should try rotation. Legs until lunchtime, wings in the afternoon. Annie's and Marie's brains can learn all sorts of jobs – they may even acquire sufficient skills to become a utility worker or even quality control.

But Annie and Marie also have souls. They have husbands and children and friends, and houses and mortgages and sick parents. They have cars that need new tires and really do not like fighting traffic for an hour each day after their shift. They enjoy the detective shows on TV and every few years they have an opinion about the state of the union and the competence of our political and business leaders. They like to shop and are cognizant of the price of a loaf of bread. They dream of a house with a room for each of their children. They are resigned to their jobs; they subjugate their worries to their union reps; they work because they need to feed their families. Sometimes they even go to work because they like the companionship of their workmates.

When ergonomists look at Annie and Marie, they look at their seat heights and wrist angles. Occasionally they may suggest a hanger for a tool or a sharper knife. They put incoming materials and outgoing products on racks in the name of the NIOSH Lift Equation or more likely the reduction of nonvalue added movements. Enterprising ergonomists prescribe enrichment; they create self-directed work teams, if the unions will allow it; they make the employees responsible for productivity, quality and safety improvements. They rarely suggest adding 10 cents an hour to their wage rate or recommend profit sharing. Ergonomists rarely see the Big Picture.

Globalization

Sometimes ergonomists are given "global responsibilities". Their job is to implement common processes and best practices in Europe, South America, and China.

"I'm from Detroit, I'm here to teach you a better way. "
"But young man, we have been building cars for 100 years";

or," we have a political system that is less than enthusiastic regarding workplace democracy, and anyway we have been sewing clothes for generations."
or "why didn't you listen to W Edwards Deming?"

The bottom line is that the cost of high-quality products manufactured overseas is cents on the dollar when compared with the costs in the more financially developed world. So, the minimum wage earners serving coffee or flipping hamburgers shop at the large stores who get their products from countries that have the jobs that used to be done by the coffee servers and hamburger flippers. But look on the bright side the workplaces for hamburger flipping and coffee serving are very well designed to enhance productivity, quality, and safety. Other workers who shop at the high quality, low price mega shops benefit from international labor osmosis. The United States imports legal and illegal immigrants from Central America to work in the fields and factories and building sites and nursing homes. The same thing happens in Europe where the "more developed" nations farm out their less desirable jobs to workers from Southern Europe and North Africa. We ergonomists may help to resolve some equipment and workplace issues but rarely interfere when the workers get repatriated, because society and their representatives in government are not prepared to agree on a socio-political solution. Instead they build fences.
So, "quo vadis global ergonomics?" We can share our simplistic equipment and workplace design rules. But when the recipient is at the bottom end of Maslow's hierarchy engulfed by malaria and AIDS and unemployment then our contribution barely scratches the surface of the problem. The young girl sitting on the bench of a New York borough graduated from the child welfare program to pregnancy, homelessness, and hunger. Perhaps there are some things that are bigger than ergonomics. Perhaps we should focus on the things we do well and forget the "Big Picture."

The Sky is the Limit

Aerospace is where the action is. Suited astronauts perch on the end of a robotic arm to patch the tiles that protect their taxi back to earth. They have the right stuff; they are highly selected and trained. Their equipment is costly, and their workplaces leave a lot to be desired. But one day we will be grateful for their efforts to extend the reach of human civilization. The challenges of space for ergonomists are daunting. How do we make space suits that fit the astronauts when they change length and shape due to microgravity? How do we compensate for the lack of continuous exposure to the gravity and night and day that our bodies take for granted on earth? How do we carry all the information needed to operate a space vehicle in just a handful of quite large brains? What will happen when the sun interferes to cause the need for space vehicle autonomy? "Ground control to Major Tom – You're breaking up you'll just have to perform the surgery according to your instruction book." "Don't worry about the leak, just go outside and patch it with gum." The Mars Rover performed beyond our wildest dreams, perhaps it is as well that the human driver was sitting at JPL. The dangers and challenges of manned space exploration are massive. We cannot even agree on the makeup of the crew that will first set foot on Mars. Perhaps they will be genetically engineered.

Whereas space flight is beyond the reach of most of us, flying around the lower atmosphere is commonplace. This commonplace experience involves a lot of different kinds of people, such as passengers, pilots, air traffic controllers, maintainers, baggage handlers, weather forecasters, regulators, and accident investigators to name but a few. And they all interact, either directly or indirectly. Therefore, there are many opportunities for ergonomics intervention. If the weatherman does not cooperate then the pilots and air traffic controllers must think on their feet. And the passengers may end up in Denver instead of Minneapolis. Or they may have to hurry out of the airplane after wind shear has brought it down to earth with a bump. A seat on an airplane is not just a seat; it may also be an office, bed, crash protection device or flotation device. It may not have been designed for the 95th percentile girth sitting next to you. It is worth its weight in gold to the bean counters that make commercial aviation fly. The ergonomist who works on interior design must address seat function, seat comfort, seat density and safety and work with the marketing department to maximize the profit generated by that simple seat. The same gang must also address carry-on baggage, another can of worms.

Sitting up front is the captain and the pilot who must work with en route and terminal air traffic controllers. In the future the cockpit will include super technology, like ADS-B, which will give the flight crew as much information as the air traffic controllers. "Who is in charge?" you may well ask. The captain, even with "Crew Resource Management" is ultimately in charge, but the traffic cop in the tower may have other priorities. The next generation of free flight will bring differences of opinion unless an enterprising ergonomist works out how to manage operations that are grounded in new technology and people with different priorities.

But this isn't the end of this aviation story. Soon the pilot will be sitting in an office on the ground while the "Unmanned Aerial System" flies through the clouds carrying surveillance equipment, freight, weapons and, one day, passengers. The mind boggles, but science and technology march on relentlessly. A fertile field for ergonomics and human factors.

Wikipedia – Our Information Systems

Our bookshelves are filled with books and journals that are focused on our research and practice. They are extremely broad in their scope and enormously amplified by information from other professions, such as engineering, psychology, health sciences and even business. These paper anachronisms are a visual reflection of our knowledge and importance; they impress our students and customers. But, wait; our students and customers have incredibly more information at their fingertips through their smart phones and the vast number of bits and bytes fluttering among servers small and large. Anyone can offer an idea or an opinion about anything. Wikipedia rules! But what about content management and peer review? Is the information reliable, relevant, accessible, and free of charge? We live amid an information mess. But not to worry, we are in good company. Our business leaders, lawyers and politicians have a bigger mess – more information and more uncertainty. Recent election rhetoric and financial system meltdown point to the challenges and opportunities of uncertainty and guessing. Are we a bunch of guessers too? Will this ergonomic workplace cure my bad back? Will the sleek advert regarding ergonomic dashboards sell more cars and reduce distraction? Is my sample "representative" and is my extrapolation justified? Is 95% confidence OK when safety is the purpose? Was the accident caused by bad design or human stupidity? Was Darwin an ergonomist? Will the world end because of a natural or manmade disaster?

Ergonomics Decision Making

Ergonomics researchers usually work in a laboratory where they can carefully control the experimental conditions and subject selection. But this control greatly restricts reliable and valid extrapolation to the conditions and populations in the outside world. Sometimes adventurous researchers sneak into the outside world and watch their targets in "naturalistic settings" or ask them whether they prefer this interface to that one. They use surveys and ethnography. They are flies on the wall. They even put black boxes in airplanes and video cameras in shops, on overpasses and other public places. They pore over accident and incident reports. They peruse the sales figures, the keystrokes, and the mouse movements. And still if I double click, I can pay my electric bill twice.

So where is the truth in ergonomics? We admit that it is not an exact science, although our attorney friends, marketing colleagues and political decision makers often run with our guarded recommendations if it suits their prior purpose. We love famous failures; they give credence to our advice. We told you so. "Good ergonomics is good economics", we cry. Sometimes. In the long run. More often than not, but not always. Why do the opinions of other professions sometimes trump our evidence in the law courts or in the business office?

The answer to these questions lies in the battle ground that is where the practice of ergonomics takes place. The battle ground is a table, surrounded by combatants with different information, priorities, and power. We do not have the luxury of saying "come back in a year, by which time I will have performed the definitive experiment to answer your question." There are a dozen questions on the table, and they all need answers today, because the court date is next week, or the designs will be frozen tomorrow. And 'votes equals opinion times salary.' We offer our opinion with as much confidence as we can muster. But when engineering says "it can't be done", marketing says "it won't appeal" and management says "we can't afford the change" or our attorney says "that strategy failed in my last case," we are stuck and may never get the opportunity to say "I told you so."

Back to the nail - System Integration and Universal design

Unfortunately, there are many riders, horses, horseshoes and nails in a battle, and it is not always certain "which straw will break the camel's back," if you will excuse the unashamed reliance on metaphors and clichés. The ergonomics researcher and practitioner may function happily throughout his or her career on 'nail design'. But cars now go together with threaded fasteners, plastic push fasteners and Velcro. The nail designer may become obsolete with new technology. Modern TVs do not even have the simple ergonomic on /off, channel and volume buttons on their front panels anymore. They are embedded in the forest of color and shapes and layouts that are called "the remote." Modern airplanes do not have "steam gauges". Instead they have "glass cockpits" with integrated displays that aspire to reduce the mental workload of flying. Perhaps. But what about display clutter and naïve realism? Even cell phones rely on obscure icons and symbols. Executive chairs have a plethora of features and controls that can only further reduce the need for muscular effort. We aspire to eternal weightlessness.

The bold ergonomist sees the "Big Picture" and joins the systems integration department. But he or she must serve time in the dark worlds of design, engineering, operations, and marketing to truly comprehend the "Big Picture." Universal Design is a myth because people and situations vary – both from place to place and time to time. And the kingdom will continue to be lost because either we did not find the loose nail in time or we did not have the persuasive powers to convince the decision makers that our nail really mattered.

Chapter 3

A Macro-ergonomics view of Transportation

Evolution

Bramble and Lieberman (2004) provide a detailed description of the evolutionary development of endurance runners. They suggest that, although quadrupeds exhibit considerable strength and speed, it is the biped human that developed the greatest stamina capabilities. This evolution gave man an advantage as a hunter. The human desire to travel greater distances in shorter times was given a boost by the introduction of the wheel and then the internal combustion engine. Visitors to the NASA Johnson Space Center will see an unused Atlas rocket – another "giant leap for mankind." Electric vehicles of all shapes and sizes now compete for space on the roads and sidewalks, and the sky too is rapidly becoming congested with manned and unmanned aerial vehicles. A downside of all this vehicular activity is considerable environmental pollution. Another downside of powered transport is the death of more than one million people a year on the roads as shown in this interactive graph from the World Health Organization:

(http://gamapserver.who.int/gho/interactive_charts/road_safety/road_traffic_deaths3/atlas.html

Similar statistics for aviation accidents and fatalities can be found at:

http://aviation-safety.net/statistics/period/stats.php?cat=A1

It should be noted in this context that the NASA Space Shuttle flew 135 missions, two of which (Columbia and Challenger) failed. Ironically, the use of mobile phones, even while walking, is responsible for an increasing number of collisions, due to distraction.

Vehicle manufacturers are driven by legislators to add substantial costs by the inclusion of devices that only come into effect when things go wrong. Cars have antilock brakes, seat belts, airbags, crush space, and a plethora of mechanisms to warn the driver of impending dangers and to keep the vehicle upright and stable in the event of loss of control. As the driver is often cited as the prime culprit in transportation accidents an exciting, but challenging, prospect is the evolution of the driverless vehicle. (Benenson et al, 2008). The shortcoming with most automation is when things go wrong, perhaps for contextual or technological reasons, and the driver (pilot) is unable to cope, as demonstrated by the Asiana Flight 214 crash at San Francisco:

http://www.theguardian.com/world/2014/jun/24/asiana-crash-san-francsico-controls-investigation-pilot

A more down to earth experience is the increasing likelihood of being run down by a policeman on a Segway or a small child or teenager on a motorized scooter on a public sidewalk. These issues beg the question of system design that includes the context and operational traffic management over and above the micro ergonomics of the driver and technology.

Another, more insidious, result of adding power to transportation is that people no longer have to perform as much physical work as the hunters of yester year. The evolution of sedentary lifestyles has resulted in obesity, diabetes, and other metabolic disorders. In the future we may no longer walk to the bus stop; this "last mile" chore will be aided by an electric scooter or even a moving walkway. Elevators and escalators replace the need for us to use our own energy to combat gravity. These issues beg the question of a sometimes-articulated objective of ergonomics to reduce the need for physical activity by making tasks more convenient and comfortable. In the long-term powered transportation leads to illness as well as injury.

Transportation System Purposes and Outcomes

This evolutionary introduction sets the scene for consideration of the role of ergonomics in transportation system design. First it is appropriate to consider the multiple purposes and outcomes of processes and systems that have some human involvement. Useful operational definitions are that systems themselves are, following Edward's SHEL model (Edwards 1972), things such as technology, people, contexts and operational rules that combine as an interactive process to produce multiple measureable outcomes as articulated by the E4S4 model:

- Effectiveness
  - The process should fulfill its intended function – the "quality" requirement
  - A transportation system uses vehicles to move people and goods along roads, rails and through the air, in all kinds of weather, according to many traffic rules. People are usually very competent and flexible in managing these systems in the face of technological, environmental, and regulatory complexity.
- Efficiency
  - Processes have measureable efficiency or productivity in terms of resource utilization, such as people, money, fuel, and time.
  - Mass transportation systems aspire to move many people quickly and inexpensively over long distances. Motorcycles are more efficient than cars with one or two occupants.
- Elegance
  - One expectation of systems and processes is that they should satisfy the affective requirements of their users. The affective dimensions have considerable impact on peoples' purchase and operational decisions. (Watada….)
  - The affective response to "Daisy Bell" (Harry Dacre 1892) reflects one instance of the affective domain:
    - *"If you can't afford a carriage
There won't be any marriage
Cause I'll be switched if I'll get hitched
On a bicycle built for two"*
- Ease of use
  - A familiar objective of ergonomics is ease of use by the intended user and difficulty of misuse by intended or unintended users
  - The unfamiliarity of the pilots in the Asiana Flight 214 with the auto throttle (automation) led to its crash on approach to the San Francisco airport. Many taxis on our streets have four or five aftermarket visual displays which all compete for attention with the driver's primary task. Some of these systems have not very easy to use interfaces which compound their distraction potential.
- Safety and health
  - An inevitable downside of all technology is that human health and safety will be compromised in some form and to some extent, in use, in manufacturing or in disposal.
  - Worldwide there are more than one million fatalities on the roads each year. (op cit.) Interestingly the transportation medium of these fatalities varies considerably among countries. In the USA auto accidents dominate, in much of South East Asia the culprit is the motorcycle. Pedestrian vulnerability also varies widely in different regions
  - The ubiquitous health downside is pollution, with cities in developing countries being particularly prominent; global warming is a universal unwanted outcome of transportation.
  - Trends towards central conversion of energy to electricity at fossil fueled and nuclear power plants also present the potential for catastrophic system failure.

  - The regular daily chores of sitting in a car, sitting at a desk, and sitting in front of the television are not conducive to good physical health.
- Security
  - Security issues result from the malicious actions of some system user or third party
  - Aviation security is a familiar challenge as well as vehicle theft. These system security challenges impose considerable financial loads on system manufacturers and operators.
  - The ergonomics contribution is to design access systems to only permit use by intended users, and this has become a major industry. How many passwords do we need? How reliable are scans and computer analysis of our faces, eyes and thumbs?
  - The rise in electronic controls of cars and airplanes presents the opportunity for malicious hacking.
- Satisfaction
  - There are many stakeholders associated with any system or process - the shareholder who wants to make a profit, the manufacturer who wants to cut costs, the user who may want function, elegance or efficiency, the maintainer who spends most of his life under a vehicle, and the legislator who looks for tax revenue while shouldering the responsibility of traffic management. These satisfaction issues often pit one stakeholder against another with the result being unsatisfactory compromise.
  - Most vehicle purchasers trade off effectiveness, efficiency (cost), elegance (styling) and safety. The solution to these satisfaction issues is for the manufacturer to offer a wide variation in styling and features, at various costs. But this strategy is expensive.
  - These issues of customer expectancies are well described by the Kano approach to product and service design (Kano , Hartono). This approach identifies product features as “must have”, more the better” or “excitement”. As products and customers mature the “excitement and “more the better” features become “must have.” For example, contemporary cars now include reversing and navigation aids which used to be luxury items a short time ago.
- Sustainability
  - Sustainability has two forms. First there is reliability – the system or process should continue to act as intended over the expected life cycle. Resilience on the other hand requires that the system or process performs well under unintended or extreme conditions.
  - Airplanes and cars do not perform well in bad weather or with bad pilots or drivers.
  - Complex ‘planes, trains and automobiles often have a limited useful life with the maintenance costs increasing rapidly as the vehicle ages. On the other hand, a good bicycle, properly maintained, can last a lifetime!

The challenges for system design are the many stakeholders in the system life cycle and the tradeoffs among these often-conflicting purposes and outcomes. In the transportation context it is common to see conflicts between efficiency or journey time and safety. Stationary vehicles don’t crash, but also don’t fulfill their primary purpose. The landfills are full of vehicles that have passed their useful life. Beauty is relative and the judgment of beauty is fickle, but the marketers place a lot of reliance on this elusive aspect of vehicles.

Human variability

Most ergonomists do not get to deal with this big, macro ergonomics, picture. Rather they deal with micro problems at the behest of some individual stakeholder. The most familiar stakeholders is the intended user. This produces another, sometimes insurmountable problem. This user is usually not an individual, rather he or she is a cohort or population that exhibits considerable variability on many dimensions.

To illustrate this challenge, one should consider the design of operator and passenger seats in public transport. Driver's seats are usually adjustable in two dimensions. In this way they accommodate much, but not all, anthropometric variation of the driver for the purpose of vision and control actuation. The drivers in the tails of the anthropometric distribution may need special consideration by aftermarket add-ons, or simply not get selected for the job.

The passengers are not so lucky, usually "one size fits all." In the case of an airliner or bus seat the requirements of the company to fit in as many paying customers as possible creates knee room challenges for many; Some airlines provide reclining seats to allow for more comfortable sleep but this may lead to altercations with the passenger behind. Seat heights may be a problem for shorter vulnerable passengers on long journeys. (Vink and Brauer). The height of most airline and bus seats fails miserably to match the ergonomics requirement (dogma) of accommodating the popliteal height of 95% of the passengers (5^{th} percentile female popliteal height, shod or unshod?) Similarly, the seat widths also fail miserably to match the ideal 95% hip or elbow widths. In practice the actual design of seat dimensions and materials is the prerogative of an efficiency driven policy maker, based on many other criteria, only occasionally with the help of an ergonomist.

An example of this "one size fits all" seat design challenge is found in mass transit railway vehicle design (Peacock,1978). As the distances and journey times are often quite short, it is common to have benches on either side of the carriage facing the center. This provides more space for the standing passengers who have a smaller "footprint" and can increase the payload at tolerable comfort costs. The ergonomics opportunity is the selection of the dimensions of these seats, including height, width, and depth. Again, because of short journey time the heights are usually such that many passengers' feet do not easily reach the floor but are unlikely to cause undue circulatory stress. The widths, as with airplane seats, do not accommodate many larger passengers. One solution adopted by the early Hong Kong Mass Transit seats was to allow variable widths by removing the scallops. Variants of this strategy could be adopted, perhaps with a pricing premium, in airplane seats.

Some ergonomists and customers for ergonomics advice consider that the ubiquitous seat is the be all and end all of ergonomics, but, as was illustrated in the previous paragraph advice based on this ergonomics dogma of pleasing 95% of the population, is rarely accepted. Ergonomists will be quick to insist that the profession goes beyond the design of seats, and the fact of variability and principles of accommodation on many other human dimensions sometimes stretch to the holy grail of universal design.(Erlandson, 2007) A little thought will show that such an aspiration is totally impractical unless we include selection and assignment of intended user populations to our ergonomics armory. But here again our paying customers rarely allow such a comprehensive responsibility to be undertaken by the ergonomist. A familiar response of engineers and managers of complex vehicles is simply to "train the user".

Our target populations vary considerably on physical, sensory, cognitive, and affective dimensions. Furthermore, the contexts of use also vary considerably in terms of the physical, operational and social environments. The example of seat design is presented to illustrate the challenges of human variability in a familiar context. Some of the challenges of sensory, cognitive, behavioral, and contextual variability will be explored in the following sections.

Human flexibility

In the one size fits all case of public transport seats, human musculo-skeletal flexibility allows individuals to adapt to the spatial constraints of the seats. In the broader sense of transportation system design, especially public transport and commercial aviation, human flexibility is required to adapt to the temporal restrictions of system design. Economies of scale require that airplanes, buses and trains carry large passenger loads and that full vehicles are needed to allow providers to charge the minimum price. In practice many providers try to meet the customer halfway by offering large capacity long haul and small capacity more frequent short haul options. Minibus and taxi services increase the level of ground system accommodation, using price as the way of offering more comfort, convenience and shorter waiting and journey times. Even so the slack in service offerings is taken up by human temporal flexibility. Analysis of these server–customer systems is based on queuing theory. With more complex systems, discrete event simulation is the technique of choice to search for optimal solutions – maximum profit for the provider and minimum waiting and travel times for the customer.

A more complex model of human requirements and behavior places the transportation system as one component of the larger system that includes housing, places of work and education, and other services, such as shops and recreation. Human temporal flexibility is required when their employment is in an organization that requires shift work to provide 24/7 service. In the long run there is a human cost to this flexibility in terms of fatigue and greater incidence of metabolic illness. This bigger picture implies a need for adaptation of the transportation systems to accommodate the demands of the other services. Rush hour traffic is a common problem in all large cities. Some bus services offer greater frequencies during the morning and evening rush hours. Aviation services may offer greater capacity around public holidays when demand for transportation increases. However, the costs of this adaptation in terms of capital equipment and variable manpower must be offset by the less tangible gains in passenger waiting times – customer satisfaction.

A different opportunity for human flexibility in transportation system design is through operator training and assignment. It takes a highly trained person to steer a boat, drive a bus or pilot an airplane, and some sub specialization is the norm. Greater system capacity and less reserve manpower cost can be achieved by cross training which allows flexibility in the assignment of drivers or pilots to vehicle types. Such a strategy must be offset against the cost of training and the increased possibility of error due to cognitive interference and lack of practice. As airplanes, especially, become more complex, type rating becomes more important. Similar specialization and generalization issues also occur with vehicle maintenance. Eventually the tradeoffs have to be made between the cost of waiting times for vehicles and the costs of training, hiring and assigning flexible people.

The cognitive dimension

Physical and cognitive micro ergonomics studies of cars address matters of pedal and steering wheel placement, instrument panel reach, the number, size, shape, discrimination, direction, and range of motion of knobs and switches. Similarly, the design of displays address physical issues such as size, color contrast, font and marking size, and scales and ranges of movement. One pre computer era issue was also the location and number of information sources. Classical studies also investigated the interactions between controls and displays including direction of motion stereotypes and control – display gain (Wierwille). As vehicle information systems proliferated, debates flared regarding the value of analog or digital detail and the utility of simpler status lights. Talking cars addressed the visual workload problem by repeating messages such as “please put on your seat belt.” Contemporary car navigation systems use the auditory channel to relieve the visual channel for control activity.

The modern information system era offers a considerable increase of information types, forms and details that are accessed by touch screen menus. The primary tasks of the car driver - speed and heading control - remain paramount while the secondary navigational, operational and vehicle system information tasks continue to compete for attention, with even more insistence. The tertiary tasks, such as entertainment and climate management, also contribute to a sometimes impossibly cluttered informational context. Meanwhile the driver’s capacities remain the same, perhaps marginally improved with familiarity, and the contextual demands of traffic density increase. An anecdotal instance of these cognitive workload and distraction issues is found in taxis, which often sport four or five aftermarket attention demanding displays that crowd the forward view. (GPS navigation, hand phone, fare meter, forward video recorder, toll road meter)

These well-meaning opportunistic information system interventions, driven by technology, are even more prevalent in modern airplanes. Traffic density may not be as great as on the roads but the cost of failure is infinitely greater; gravity is unforgiving. Airplanes are commonly equipped with information sources that allow the “instrument” trained pilot to fly “heads down”. Modern GPS systems make navigation and collision avoidance relatively easy, although remote management by Air Traffic Control is still needed to achieve separation and route guidance. It should be noted that with the trend towards GPS guided “free flight” there is an increasing opportunity between pilots and air traffic controllers (Avitabile). Pilots, like car drivers, are only human, albeit well trained and tested. The human factors challenge of this information management and flight control problem can be easily demonstrated in a multiplayer flight simulation environment, without the significant costs of failure. In fact, the frequent occurrence of failure that is not possible in a real flight environment can be very instructive to aviation students and hobbyists.

The Behavioral Dimension

Behavioral analysis in ergonomics is usually through the methods of ethnography in which the observer classifies and counts activities and their outcomes which are usually reflected in terms of time and error. One general observation is that different behaviors can sometimes lead to the same outcome and that the same behaviors can result in different outcomes, depending on the context. Behavioral variability among different individuals adds to the analytic noise. In these cases behavioral analysis may transition from quantitative to qualitative descriptions, in either case the analysis may lead to system outcome prediction and design opportunities. An example related to sitting behaviors of children in airplane and car seats demonstrates a plethora of alternatives, to some extent controlled by restraints. Behavioral "restraints" in the cognitive domain are achieved by training. Drivers and pilots are trained to scan the outside scene and their instruments depending on the task at hand, such as collision avoidance or navigation.

These examples are conducive to micro ergonomics investigation in which contexts are controlled, performance requirements specified, and appropriate and inappropriate behaviors identified. An example in car control is the analysis of foot behavior where, in automatic drive vehicles, either one- or two-foot behaviors may be acceptable. Anecdotal evidence is that drivers of automatic transmission taxis in some big cities habitually use one foot on the accelerator and the other on the brake, like the toggle pedal on some fork trucks. Also, in vehicles, eye movement and fixation research can clearly indicate the utility and pitfalls of variable visual behaviors. Similar approaches are used in pilot training regarding instrument scanning and the transition to glass cockpits that require deliberate selection of display content.

Whereas human overt behavior, such as foot, hand, or eye movements, is generally easily accessible using ethnographic or video methods, these approaches do not necessarily tell the whole story of those more elusive cognitive factors that predicate performance outcomes. A complementary approach is to use verbal protocol or "think aloud" techniques in which the subject describes what he is attending too or thinking or why he chose a particular action. These methods are sometimes contaminated by hindsight bias, depending on the performance outcome. More intrusive methods such as EEG are available, but interpretation requires substantial experience and expertise and may therefore be unreliable; furthermore, such methods are intrusive and may affect subject behavior.

The Contextual Dimension and Resilience

The Edwards' SHEL model (op cit) emphasizes the interactions among people, technology, operational rules, and contexts in all processes. Process outcomes (E4S4) will be dictated by the capabilities, contributions, and compatibilities the contributing systems and their interactions. Resilience is achieved by the capabilities of one component compensating for the limitations of another.

A car driving example is the introduction of anti-lock brakes which compensate for slippery roads and inadequate driver braking behavior. Also, in cars the introduction of "talking maps" reduced the navigation workload and distraction vulnerability of drivers. The advent of the glass cockpit in airplanes opened the door for powerful computer capabilities to aid the pilot in aviation, navigation, and communication. Most of these devices are aimed at compensating for driver / pilot limitations, however it is the predictive and problem-solving power of the driver / pilot that saves the day when technology is unable to deal with extreme physical and operational contexts. Drivers in traffic look beyond the vehicle immediately in front of them to anticipate the need for foot movements between pedals. This human capability places the attentive driver ahead of the technological developments in adaptive cruise control which simply reacts to the car in front.

Technocrats predict the future of driverless cars, however consideration of resilience in demanding contexts will render this aspiration unlikely. For example, one paramount duty of a car driver and pilot is to maintain separation from other vehicles. The density and two-dimensional nature of ground traffic make this separation management a greater challenge than three-dimensional airplane separations, although relative speed differences between cars and airplanes closes the temporal gap on this separation challenge. The separation challenge is also important in shipping as they navigate congested waterways. In shipping and aviation, the use of computers to calculate closure rates and suggest avoidance maneuvers has considerable promise, assuming all the participants have location sensors and responders. GPS based ADS-B technology is vastly superior to radar in terms of time and resolution and this technology enables pilots and ships captains to avoid collisions without the help of the traffic control organization. (Avitabile) Such a transition, involving greater autonomy of individuals may fail in comparison with the traffic controller's ability to optimize throughput by imposing non selfish decision making. Another hindrance to the widespread introduction of the ADS-B technology is that many small boats and airplane do not have or refuse to buy the technology. Other challenges to advanced technological innovations in cars and airplanes are aging, cost and scale. Advanced systems may demand that all vehicles in a congested traffic context be fitted with the technology. Remote radar has this capability in air and sea contexts, but there are significant temporal lags. GPS based technology such as ADS-B reduces the time delays and provides information directly to the pilot, but not all airplanes and small boats have this technology.

The density of road traffic presents a greater order of complexity. Road traffic also has to contend with large buses, trucks, motorcycles, bicycles, pedestrians and a plethora of new electric transport aides. The example of a typical South East Asian city intersection will illustrate the problem. In some city intersections there is no attempt to regulate the traffic. It is left up to the individual driver to detect obstacles and carry out collision avoidance maneuvers. It is evident that training and experience go a long way to support effectiveness, efficiency, satisfaction, and resilience in this context. However, the accidents statistics show that reliance on individual behavior and performance is far from adequate. The introduction of technology to manage separation is likely to do so at the cost of reduced efficiency – intersection throughput. Also, the cost and deployment difficulties of technology may be prohibitive.

The challenge for the proponents of driverless cars to address is to mimic the human ability to predict and anticipate. If car separation algorithms simply relied on closure rate with the car in front then, given normal speeds and variable following distances, there would still be rear end collisions. Good drivers maintain sufficient headway and monitor the behavior of vehicles ahead of the immediately preceding car to buy time for anticipatory behavior.

Transportation Safety

An articulation of the scope of ergonomics by Edwards – the SHEL model – indicates that systems consist of the interactions among, people (liveware), technology (hardware), rules and regulations (software), and the context (social and physical environment.) (op cit) A perceptive extension of this model adds interpersonal interactions – a social dimension. The importance of these concepts is that system failure may result from the failure of a subsystem or between two or more subsystems. In the transportation context there is the micro interface between a driver and vehicle but there are also other vehicles and their drivers, roads, intersections, traffic management systems and weather that may interact to cause an accident.

A macro view of transportation safety is that accidents happen due to situational changes in the interactions among technology, people and contexts, including both the physical and operational context. The accident may result from changes in individual systems over a long period of time or quite rapidly. A tire or tired driver may wear out gradually and eventually fail; similarly, a driver may accumulate bad habits over time and eventually pay the price. It should be noted that accidents rarely happen directly from a failure of their physical components, rather accident causes usually have information processing or cognitive causes, such as failures in anticipation, attention, memory, perception, decision making and control behavior. Some failures are due to deliberate risk taking or violations of correct procedures, whereas most are simply to the ubiquitous "human error. The Human Factors Analysis and Classification System (Wiegmann and Shappell, 2000) describes accidents as a combination of unsafe acts (errors or violations), preconditions (in the technology, driver or context,) a failure of the supervisory system (tolerance or even incentives for bad behavior) and finally the organizational climate which may precipitate adverse conditions by for example cost cutting in traffic management. The HFACS system is a perceptive approach to aviation accident analysis and the concepts have spread to medical error and beyond. The concepts are applicable to all forms of transportation and can apply both to accident analysis and preventative design. This HFACS analytic approach to accident reconstruction and design is greatly enhanced when amalgamated with the Edwards SHEL model, the 6Us model and the E4S4 model of design purposes and tradeoffs.

Simulation and Simulators

Simulation methods offer various degrees of realism, but usually without the stress caused by the threat of real damage to the individual, technology or the environment. The principal advantage of simulation for research and training is that scenarios can be constructed to tax various human systems and repeated for training purposes and to examine and correct erroneous behavior. The recent crash of Trans Asia GE325 in Taiwan was followed quickly by a requirement of all ATR 72-600 pilots to take remedial training and testing regarding actions following the burnout of one of the two engines. Simulators vary considerably in their level of sophistication. Low fidelity simulators are freely and widely available on the Internet as games and for more serious uses. Such simulators test the same cognitive mechanisms as their high-fidelity cousins, but with less realism. The intermediate level of simulators such as Microsoft Flight Simulator, now offered as Prepar3D (http://www.prepar3d.com/) offer realistic cognitive challenges, again relatively inexpensively. More expensive simulators are motion based on robotic arms that accurately mimic the system movement responses to pilot input and external forces.

The SIMVA (SIM University) project requires large classes of aerospace students to form teams to navigate around various airspaces. The teams consist of a pilot (attitude and airspeed), navigator (altitude and heading), communicator and ATC (route planning and separation), observer (cockpit voice recorder and activities monitor). As the team members have minimal experience with flight although variable experience with operations, the occurrence of communication and crew resource management error is frequent and informative. Distraction is a common culprit. Lack of situation awareness regarding navigation, operation and control status is commonplace. The sequel to this simulator experience is a real-world accident analysis, using the Human Factors Analysis and Classification System approach to identify the human factors causes.

Simulation based research that addressed the introduction of head up displays into cars, following their successful use in flying, offered two important conclusions. First it is important to consider context; airplanes usually do not rely on out of the window detection of other airplanes, while this mode is usual and continuous in cars. The second observation was that it was not just the visual interference of head up displays, rather it the cognitive capture of the information contained in the display that is the greatest hazard. An example of such a hazard occurs where multiple menu steps are required to obtain the required information. Such sequential procedures may take many seconds to navigate, while the view outside is ignored. Simulation based research, although sometimes criticized for lack of face, ecological and outcome validity is an invaluable medium for the demonstration of cognitive workload issues.

Human System Design

A second model – the 6Us and 2Ms will be used to explain the factors that must be considered in human system design. (Peacock and Resnick, 2009)

- Utility – Is the system useful?
    - Most technology is developed with particular functions in mind, but in the long run, technology itself is subject to Darwinism – survival of the fittest.
    - Notably the likes of the Titanic were replaced by Jumbo jets for trans-ocean transportation but survived as cruise ships.
    - The perception of utility is in the eye of the customer, again explained by the Kano model.
    - A car, bus, train, or airplane may have considerable utility, but the choice among these modes will vary according to context and customer preference.
- Usage
    - What is the intended use of a system or process?

    - Is the car intended to take the driver to work or the family on a camping trip? Such questions will give rise to alternative design solutions or compromise where the driver has only one vehicle.
- Misusage
    - Can the system be used for other than its intended purpose?
    - Is a family car also used for transporting building materials or pets? In either case the choice of make and model may change from small sedan to the more resilient large utility vehicle.
- User
    - Who is the intended user? What are his or her intentions and capabilities? Might there be many users each with a different role?
    - What kinds of variability does the user exhibit?
    - The family minivan has many users, including the driver and family members of various sizes and requirements.
    - Another source of "user" variation is their ability and interest in paying more for more features, services, comfort, and convenience. The commercial aviation industry exploits these differences by offering different classes of travel.
- Misuser
    - System security is a universal concern in transportation, from hijacked airplanes to stolen cars.
    - At a less sensational level the misuser may be legitimate but incompetent or incapacitated
    - Should a teenager be given the keys to a Corvette? Perhaps with 5^{th} and 6^{th} gears locked out?
    - How can a fatigued or inebriated driver or pilot be detected and prevented from using the vehicle?
    - At what age should an elderly pilot or driver hand over the keys?
- Utilization
    - How often will the vehicle be used and in what kinds of environments? These temporal questions of intensity, frequency or duration of use will also influence the design of a product or service.
    - The demands for maintenance of vehicles with high utilization, such as public transport, are such that the designs should be robust to reduce the incidence of component wear and failure, and conducive to frequent or regular maintenance operations.
    - What should be the denominator in transportation accident analysis, number of journeys or passenger miles?
- User error
    - Can normal or abnormal conditions be conducive to human error?
    - Can the driver hit the wrong pedal or switch at the wrong time? User errors occur all the time, but the consequences of these errors are only important in the context of a preexisting hazard
- Usability
    - Usability is a widely used word to describe how easy it is for a user to interact with some hardware or software. However, as perception is in the eye of the beholder, usability is in the hands of the user in the context of use.
    - An expensive golf club may be usable in the hands of a good golfer; conversely a rear wheeled muscle car will not be very usable in icy conditions and a large passenger airplane will require careful pilot training and selection.
    - Usability therefore begs the question of the user and the context, and this again begs the question of the accommodation assumptions in design.
    - It should be noted that the automobile is probably one of the most widely used and therefore by definition one of the most usable systems ever developed, given certain assumptions about driver training and selection.

- As automobiles, airplanes and computer technology evolve user selection may have to become more discerning.

The Kano approach

In maritime and aviation contexts passengers may have choices among competing companies which do not differ in their functional attributes – the same models and performances of airplanes are common to all the competing companies. The competition among companies is therefore dependent on cost, comfort, and service dimensions. Some airlines are low cost with minimum service levels in terms of interior design, meals, and baggage allowances. Other airlines offer greater creature comforts and luxury levels in First and Business levels, but at a premium price. Similar tradeoffs have long been exploited in many areas of public transport such as trains and passenger boats. Private cars however demonstrate by far the greatest opportunity for non-essential feature exploitation. The human factors approach to the understanding of these function and form dimensions has historically been through analysis of purchase behavior after the event and through surveys and focus groups before and after the point of sale.

It is widely recognized that product choice, given basic functional requirements, is often based on affective dimensions of likeability. The Kano model was developed for the purpose of product evaluation and has since been applied to services evaluation and to job and person(al) evaluation. The model suggests that there are three types of feature in a product or service: "Must have", "more the better" and "excitement". The absence of must have features will make the product or service unacceptable or unusable, but an increase may not increase the vehicle's attractiveness. In the case of a car, the "must have" features include four wheels, an engine and transmission, and a body containing seats and controls. More wheels, engines or seats would not help. "More (or less) the better" features may include increased speed, more trunk space, better fuel consumption, lower price, and fewer service visits. The absence of excitement features does not necessarily reduce the car's utility, but its presence may increase the car's attractiveness. Examples of these excitement features could include leather seats, a navigation system or automatic driver recognition. Another concept in the Kano model is that over time these excitement and more the better features may become "must haves".

The value of this Kano approach is that the principles can be applied to all levels of the vehicle or transportations system. Typically, data are gathered from samples of various cohorts, such as drivers, passengers, manufacturing employees, sales representatives, safety analysts, and so on. As with most kinds of ergonomics data, between subject variability is to be expected and the analysis will include various strengths of opinion.

The "Excitement" Domain

Running, driving, sailing, and flying are technically difficult behaviors in which performance improves with practice. However, they bring with them another domain and purpose – enjoyment, the affective domain. In the Kano classification, these are the excitement factors. Consider the excitement waiting to start in the Boston marathon, driving at 100 mph or more on the open freeway, fighting a gusty sea breeze or flying coast to coast at 10,000 feet. The transportation affective domain has its downsides too: "hitting the wall" at Heartbreak Hill, seeing the flashing lights in your rear-view mirror, or seeing thunder clouds ahead. The technologies themselves contribute to the enjoyment. Consider a group of runners discussing their shoe styles, classic car owners extolling the virtues of past styling arts, and dingy sailors and pilots drooling over the intricacies of their technology designs. These conversations are reflected beautifully in the discussions in Harry Potter of the Nimbus 2000 Quidditch Broomsticks and Toad of Toad Hall in the Wind in the Willows: *"Whether a Ford or a Ferrari, whatever I can get to carry me near or far, just give me any car. I love to ride the Car, an old Excalibur; yes, any motor car. And I'll be happy - ho-ho! Messing around in cars!*" Notably one 'upside' of the Boston marathon is the "traffic" – 20,000 runners (arranged by qualifying time) who have trained for months or years to participate in this prestigious event - the world's greatest foot race. Traffic on the road or in the air puts the brakes on the pleasures of powered transportation.

Segregation or Integration

Before the internal combustion engine walkers and riders of horse drawn carriages shared the same roads. The cautious walker heard the horses' hooves and moved out of the way. Over time various levels of segregation have developed. First sidewalks and roadways, and now the roadways are sometimes but not always segregated for bicycles, buses, heavy vehicles, and cars. In many cities integration is the roadway rule for wheeled vehicles. Intersections can be facilitated by costly segregation facilities, bridges, and tunnels, or by temporal management – traffic signs and lights. Other traffic management strategies use priority systems. Despite these engineering and operational interventions there remain many safety and temporal problems. The safety problem is a result of mass and speed variability where spatial and temporal sharing is permitted. The temporal problems arise when the control system is not adaptive to demand – batches of cars wait at traffic lights even though there is no cross traffic. The roundabout with various levels of complexity provides a priority based continuous flow alternative, which requires compliance by the participants to the prioritization rules. Human adaptation to these temporal and safety challenges creates situations where bicycles and now various electric vehicles use the sidewalks to escape from the cars. Another hybrid approach involves the use of the car horn or bicycle bell to create temporal segregation where the general rule is integration. These surface situations are being mirrored in aviation, which although there is an additional dimension to play with, is experiencing increasing densities that demand administrative solutions.

These segregation and integration strategies may be of theoretical interest; they may be subject to modeling and optimization approaches. However the complexity in terms of spatial and temporal capacity, and size and speed variation, the costs of engineering solutions (segregation) and fallibility, in terms of efficiency and safety, of administrative solutions is such that there is no generally acceptable solution apart from tolerance of one million road fatalities a year.

Contemporary technology, such as GPS and various sensing systems, such as near and rear obstacle detection systems, to aid the driver or pilot achieve separation provide an opportunity for the micro ergonomist to evaluate the utilities of these alternative guidance devices with regards to safety and convenience.

Conclusions – the Big Picture

Transportation is a complicated business that continually responds to technological innovation and customer demand. Managers and users seek optimal solutions in terms of effectiveness, efficiency, safety, comfort, and convenience. Transportation becomes complex with the addition of human variability and flexibility, particularly in the affective domain. Further complexity is introduced by environmental and operational forces. The system becomes chaotic due to the interactions among technology, people, and contexts, and attempts by regulators to achieve order and predictability.

Opportunities for micro-ergonomics analyses and interventions are everywhere – from seats and safety through controls and communication to artistic design and affection. These opportunities have been met over the years by piecemeal pursuit of topics that interest the researcher or are highlighted by the various customers. Many of these contributions have been extremely successful. Altimeters in airplanes were redesigned to remove confusion between orders of magnitude on the scales. The center high mounted stop light has reduced the incidence of rear end collisions by shortening the driver response time. The brake transmission interlock addressed the human causes of many unwanted acceleration incidents. The addition of a shoulder strap to the lap belt and the addition of a head restraint have reduced many injuries in cars, but this safety technology has yet to be transferred to airplanes.

Three Japanese design processes have addressed the affective domain and the broader aspects of customer requirements. The Kansei approach (Nagamachi, 2011) translates customer statements into design criteria. The Kano approach differentiates among "must have (must not have)", "more (less) the better", and "excitement" factors in product or service design, and notes that over time some "excitement" features may become "must have" as in the case of entertainment and navigation systems in cars. The third, Kaizen, approach emphasizes the importance of continuous improvement in product and service design, based on customer articulations and other system outcome feedback. These three approaches have been prominent and successful in the Japanese automotive industry and abroad over the past few decades. Collectively, these three approaches move the practice of micro-ergonomics from reductionist laboratory centered research into the broader context of macro ergonomics.

Macro-ergonomics can be articulated as a high level, comprehensive approach to addressing human centered design constrained by technological, contextual, and operational complexity. Furthermore, macro-ergonomics comprehends human physical, sensory, cognitive, social, and affective variability as they interact with external complexity and demands. Finally, macro-ergonomics accepts that there are many stakeholders associated with the design process and these stakeholders may emphasize different outcomes in terms of effectiveness, efficiency, ease of use, elegance, safety, security, satisfaction, and sustainability. Macro ergonomics is the process of making tradeoffs in design.

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Chapter 4

Why did the Chicken cross the Road?

Why did the chicken cross the road? To get to the other side! Or so the old joke goes. Why did the self-drive car crash? Because it was too late seeing the chicken and it did not know that this was a common chicken crossing area and it was late at night, raining and slippery and the tires were worn and the driver / monitor was in a hurry to get home, under stimulated, drunk, on pain killers, fatigued, complacent, inexperienced or maybe asleep. Furthermore, the vehicle was last year's model without the updated sensor technology or software and anyway, the driver was baffled by the interfaces with this new technology. A Fault Tree Analysis (Peacock, 1982) would put all these conditions together and conclude that the chicken or driver should have stayed at home.

Another model, SHEL (Edwards, 1966), of system behavior and system failure would describe interfaces, interactions, interruptions, interferences, interdependencies, and integration within and among people (and chickens), technology, processes, and contexts. An expansion of the SHEL model adds energy, information, space, time, and purpose. That said, the transition to self-driving cars, supported by ever increasing and improved technology, will take a long time. This transition period will inevitably involve interactions among the self-driving cars and conventional vehicles. The only constants will be human and situational variability. The $64,000 (or greater) question is when, probabilistically and politically, the failure rate of self-driving cars will be demonstrated to be lower than the failure rate of conventional vehicles. The lawmakers will have a field day developing constraints and conditions for this newfangled technology, including segregation and driver / monitor training and certification.

Now systems designers would realize that the many and various stakeholders in this complex system - drivers, passengers, chickens or other pedestrians, road builders, traffic managers, emergency services, vehicle designers etc. might have different and perhaps conflicting priorities related to system (and process) design purposes and outcomes. The E4S4 model summarizes these (arguably exhaustive and largely mutually exclusive) expectancies and outcomes: Effectiveness, Efficiency, Ease of use, Esthetic appeal, Safety, Security, Satisfaction and Sustainability, which may include both reliability and resilience (Peacock, 2005). For example, the driver may have wanted to get to his destination (effectiveness), quickly (efficiency) and safely while riding in his fancy new automated car (esthetic appeal). The emergency services would be out of business if the system did not fail from time to time. And the vehicle manufacturers would soon go out of business (sustainability) if there were too many failures that they could not blame on the drivers. It remains to be seen when the lawyers will focus on the designers rather than the drivers / monitors of these non-segregated vehicles and routes.

Pavlov (1927) had something to say about this situation having focused on salivating dogs rather than jay walking chickens. Pavlov suggested that if the experimenter rang a bell at the same time as providing food, soon the dog would learn to respond (by salivating) to the sound of the bell (an alternative stimulus) in the absence of the food. Dogs, but maybe not chickens, can learn to put two and two together, all they need to get to Carnegie Hall is practice, practice, practice (often attributed to Jack Benny). Chickens, on the other hand, can run, perhaps in random directions, with their heads cut off; there are various peripheral and spinal connections that make this possible! Franciscus Donders in 1869 demonstrated that there is a delay (reaction time) in response to a stimulus. Other researchers have shown that (choice) reaction time is affected by the complexity (number of choices) of a signal. Koster and Peacock (1971) determined that this response was further delayed when the signal of interest was preceded by an intense signal - psychological refractoriness. Sometime later Peacock (1972) determined that if there was too much time between the stimulus and the response then there was the opportunity for interference in the retention of the first stimulus; furthermore this (retroactive) interference could also be complicated by proactive interference, especially from intense or otherwise interesting stimuli. These observations are all well and good in the reductionist, controlled, laboratory context. But can a chicken pay attention to the noise or sight of the rapidly approaching car, perhaps based on practice, and take timely evasive action? Or go to the crosswalk? People, like chickens are subject to distraction; from time to time they do not pay attention to important signals. Sometimes they are in a hurry.

A key to all this behavior, especially in the case of people, is the innate and acquired ability to pay attention, perceive, think and anticipate, to prepare for any one of various actions ahead of time and then (re)act in a timely manner. In other words, we learn from experience or, better still, learn by being taught, having had a similar transferable experience, reading a book, searching the internet, or simply thinking about it. The processes of anticipation, attention and perception presuppose a more or less well developed mental model (framework) that is used to explore and simulate information regarding the sources and effects of various external or internal inputs over time, various model parameters and various outcomes. Sometimes the desirability of a particular outcome outweighs the risk of failure, with catastrophic consequences. Sometimes there are just too many factors related to the decision (to cross or wait) that the poor chicken becomes overwhelmed and just “goes for it”. The Bayesian, (Bayes, 1763), community has much to say on this problem, although the human capacity for forgetting makes them generally sub-Baysian. Another problem for the chicken, people with chicken brains and even ordinary people is this word “various.” The earlier described complex systems model - people, technology, procedures, contexts and their interfaces, interactions, interruptions, interferences, interdependencies, and integration - is incredibly complicated by variability within and among all these components. Furthermore, these situations are replicated all over the world (places), all through the day and night (times) and involve millions of people and transactions. No wonder people have accidents from time to time or are blamed for causing accidents, especially those playing chicken with the traffic. As suggested earlier, this probabilistic problem will be interpreted politically.

The matter of interest here is the viability of self-driving cars (primary technology) without the concomitant design, integration and otherwise management of all the supporting technology (including roadways), contexts (weather, traffic, pedestrians), procedures (drive on the right, keep a safe spacing, obey traffic signs and signals etc.) and the selection, training and assignment of all the primary, secondary and tertiary stakeholders. The solutions are technical, economic, political, legal and probabilistic. Segregation is or is not an option? Are self-driving cars safer statistically than conventionally driven cars? The lawyers are happy to assign blame and sue errant drivers. But who will they sue when the automated system fails, albeit less frequently? The driver / monitor, the traffic management, the designer of automation, the company that designed the vehicles or the traffic managers that permit the integration of automated vehicles. Of course, the lawyers will find a way and the self-driving car manufacturers have deep pockets, albeit full of equally cunning lawyers.

So, we are back to probability and statistics, perhaps even Bayesian models if the lawyers can estimate the likelihood of a particular event given the existence of other (also probabilistic) evidence. The juries may not have studied Bayesian convergence and so may revert to simpler statements of likelihood and the assignment of blame when the system fails, depending of course on who suffered the unwanted outcome and who is lined up to defend the failed system components. The applied psychologist or human factors / ergonomics practitioner or researcher may again fall into the trap of reductionist research and analysis. The astute safety practitioner will apply the 5 Whys and end up with 5 to the n^{th} power explanations. Meanwhile, in the absence of latter day Luddites, technology will develop until the automatic driving machine brains have learned, not only to learn from past experience and selectively take in (perceive) relevant and timely information but also to anticipate and make (probabilistically) sound decisions, just like or event better than drivers. Unfortunately, chickens will continue to cross the road out of habit and get to the other side, until that unfeeling automatic car decides to sacrifice the chicken as braking hard is more dangerous (to the car occupants rather than to the chicken).

This was a very brief discussion of human cognition, attention, behavior, and performance; the challenges of automation and chickens would not be complete without a handful of case studies to explore the underlying theories:

1. The first situation is a crossroads consisting of two three lane divided highways with sidewalks on both sides. It is six o’clock in the evening and going dark. The roads are full of tired and impatient drivers and pedestrians on their way home from work. It is raining cats and dogs and beginning to freeze. Fifty percent of the cars and large trucks have various generations of self-drive technology. The traffic lights have failed, and a lone policeman has stepped into the breach. The automated vehicles do not comprehend the subtleties of the policeman’s glances, nods and hand waving. Half the automated vehicles resort to manual control. The other half make a mess of the intersection,

blocking the way for the automated emergency vehicle. Meanwhile the early nightly news drone hovers to capture the details of the carnage.

2. The next situation has a genius seventeen-year-old riding in his parent's automated car. Now this seventeen-year-old has spent 90% of his waking time playing video games that are filled with exciting system failures, and has become immune to the realities of mass and acceleration. He (auto) pilots his way onto the freeway and joins the fast track. He decides to take over from the automation, with disastrous consequences.

3. A third scenario involves grandma, who uses her newfangled golf cart sized technology to go shopping, just along the street. At the same time the automated garbage collection truck is performing its start - stop regime in the neighborhood and cannot tell the difference between grandma in her private pod and the garbage bin.

These examples are offered to explore the limitations of technology and its applications, especially where it interacts with people of different abilities and motives, in different contexts.

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Chapter 5

Ergonomics and Production Lines

a. **History**

During the first part of the last century Henry Ford, Frederick Taylor and Lillian Gilbreth were among the leaders of the process of scientific management. Their focus was the measurement, simplification, and standardization of manual work, particularly in product assembly. They demonstrated unequivocally that these processes can greatly improve product quality and productivity. Towards the end of that century the Toyota Production System continued this prescriptive approach to job design but added the principles of continuous improvement and participatory quality teams. The production line can now be found in most industries around the world such as automotive, electronics, textiles, consumer products, call centers and food processing. Unfortunately these tremendous gains in productivity and product quality come with a human cost and some of this cost is due to the misapplication or narrow application of physical ergonomics by focus on the twin issues of force and posture / movement and the removal of “non value added work.” These ergonomics applications certainly contributed to continuous improvement in productivity and product quality through greater work intensity and repetition. But these gains were offset by increases of work related musculo skeletal disorders and many less tangible cognitive and social detriments, such as vigilance decrement and boredom. These issues may appear less important where labor is readily available, cheap, mobile and dispensable, but ironically, they become more important as the employee pool becomes more stable.

b. There are fortunately several variations on the theme of the production line. The first engineering approach is through mechanization and robotics for repetitive and forceful work, although these processes often require human operators to complete the task cycle through such activities as materials input, operation initiation and parts removal. The second, administrative, approach is through job structuring, rotation, and enlargement, perhaps involving a sequence of work cells within the production line. These human centered approaches can create a more knowledgeable, flexible, and stable workforce, especially where the job assignments include such tasks as inspection, materials, maintenance, and a share in the supervisory tasks of training, monitoring, health and safety etc.

c. A human centered or socio-technical systems approach to the design of production lines can maintain these gains in productivity and product quality while providing a safe, healthy, and satisfying employment. One key component of this participatory approach is a reversal of Taylor’s scientific management view that the worker “should do and not think.” There is no doubt that line workers develop considerable task knowledge and that this knowledge can be harnessed for the benefit of all stakeholders. However, where this participative approach is mismanaged sub optimization and conflict replace optimization and cooperation.

d. These concepts of human centered manufacturing will be supported by case studies in automobile assembly, textiles manufacturing, bookbinding and medical claims processing.

2. **Ergonomics Research and Ergonomics Design are two sides of the same coin**

   a. This paper discusses three ergonomics research and three ergonomics design examples to demonstrate the similarities between the two processes. The ergonomics research topics all focus on running and relate to gait biomechanics, the physiology of fatigue and aging, and the effects of terrain on performance. The design topics all focus on transportation – the design of mass transit railways, the design of cars for the elderly driver and the design of aviation displays.
   b. Research and design can both be described by a control model involving inputs, outputs, feedback, and feed forward, and adaptation and learning. In research the hypothesis is an anticipation or feed forward of the relationship between selected technological, environmental, or operational variables and a human response. Design involves the control of the technological (or operational) context to withstand the uncertainties in the operational or environmental contexts. Reliable designs maintain their performance levels over the life cycle of the product, given expected and predictable contexts. Resilient designs can withstand unpredicted and sometimes extreme contexts, often by "failing safe."
   c. A major challenge in research is validity, of the investigation design and the results. In the gait biomechanics research the investigation addressed the hell and mid foot strike variations. However, as these factors are affected by stride length and running speed as well as individual variation and shoe design the conclusions may not be widely generalizable. Indeed, the major challenges of most human factors investigations are sample selection and size.
   d. Similar challenges of validity are found in design. There are the intended users of a product and sometimes but not always predictable misusers. Also, there are the intended conditions of use and possibly more challenging unexpected conditions. For example, a family car may not be able to protect the inexperienced, inebriated or incompetent driver in heavy traffic. Similarly, the family car may not perform well in off road conditions or even on a road with ice or flooding.
   e. Research into the physiology of fatigue and aging usually relies on selected or pseudo random samples representing the ranges of interest. The analysis of differences relies on means and variances. However, these are simply reflections of the samples and not necessarily the age variable of interest – it is possible to select a sample of sixty-year olds who will run faster than a sample of twenty-year olds. One way out of this sampling dilemma is to use age-based records to model the age effect. Such analyses show very clearly the age effect without being contaminated by such things as aptitude, training, or illness. Similar approaches may be used with cognitive variables.
   f. The design of mass transit systems presents both physical and operational challenges for passengers. The physical design of features such as seats, grab rails and exits may be entirely suitable in uncrowded conditions but in rush hour and emergency conditions the abilities and behaviors of a few passengers can disrupt the intended objectives of stability and mobility.

3. Human fatigue research shows deterioration in physiological and cognitive functions as a function of time and activity. The Weibull distribution is used to model fatigue and wear out of both mechanical systems and human systems. The fatigue curve in long distance running is remarkably like that of a car, albeit with different time scales. Both curves can be changed by maintenance, or training, but only where the demands are limited. Resilient designs rely on operational and factors such as alternating periods of activity and rest / maintenance.

4. **Simple methods for system design, product evaluation and accident analysis**

a. An unfortunate trend in ergonomics teaching and sometimes ergonomics practice is the use of complex analytical methods to address either simple or complex problems. The practice of ergonomics does not always have the luxury of time – either in accident investigation (forensics) or product design. It is rarely possible to have the luxury of sophisticated laboratory equipment, a large representative cohort of subjects and a few months to conduct an experiment, sufficient to obtain a 100% reliable answer. However, ergonomics practitioners must not run the risk of simply offering their own biases.

b. This dilemma may be addressed using some simple analysis and modeling tools that are sufficiently accurate and quick and easy to use. Many of these tools have roots in industrial engineering applications in manufacturing and service operations. The contemporary processes of Six Sigma and Lean Analysis have also incorporated some of these tools into their practice.

c. The first challenge of design or accident analysis is to describe the full context. All too often designers and investigators converge too rapidly on a blinkered viewpoint. Both designers and investigators often converge on "human error" and do not explore sufficiently the causes or the missed prevention or mitigation opportunities. The investigator of a car accident may simply point to "the driver not paying due care and attention" to the road ahead rather than address the cognitive capture associated with an over complex instrument panel. Similarly the investigator of a building construction accident may simply point the finger at a careless worker rather than investigate how thermal stress and fatigue caused a cognitive lapse in tying off his safety harness or why a secondary safety net was not incorporated in the system design.

d. The first tool addresses purpose of design – E3S3+R&R - Effectiveness, Efficiency, Ease of Use, Safety, Security and Satisfaction, plus Reliability and Resilience. The 5Ws - What, Where, When, Who and Why - and a How provide a broad context. Next the 5Ms come into play – Man (and Woman), Machine, Materials, Methods and Measures. Another way of looking at breadth is through the 4Ts – Topic, Technology, Time, and Team or the 3Es – Event, Equipment, Environment. The 5 Is – Information, Interaction, Interference, Interdependence, and Independence address how all the elements of these analyses combine. The 4Cs – Causation, Communication, Calculation and Control are all processes that address processes involved in the operation of a product or process. The 5Us are then applied – Utility, Use (Misuse), User (Misuser), Usage, Utilization and Usability. These sets of questions provide breadth to an analysis, evaluation, or investigation. The 5Whys provide depth – asking a branching series of why's will usually get to the root cause of a problem. The 5Ps address the life cycle of a product or process – Product Design, Process design, Production design, Procedure design and People design. Finally, when the physical or informational context becomes too complex the application of 5S can greatly simplify and streamline an investigation. All of these tools can be articulated as Concept Maps or Activity Cycle diagrams which differentiate between Entities (or Resources) and Activities (or Processes). These simple tools should be used to complement each other

e. This workshop will describe these tools with examples from a wide variety of products and processes. Class members will be provided with kits and worksheets to aid them in the use of these simple tools. The final part of the class will involve small team collaborations in the use of these tools for design, evaluation and accident investigation.

4. Ergonomics, Safety and Resilience Engineering

a. A simple, but sometimes naïve view of ergonomics is that it is "human centered design." The problem with this definition is that most products or processes have many people who are stakeholders and these different stakeholders may have different requirements. Therefore, there will always be tradeoffs in design.
b. A somewhat trite but striking example is with the application of human factors to military equipment and operations design. Clearly there are different "customers". Similarly, there may be conflicts between efficiency and effectiveness of security systems. As screening at airports becomes more comprehensive the long lines grow longer.
c. Ergonomists have researched the speed – accuracy tradeoff for many years. This tradeoff can be easily demonstrated in both inspection and manipulation operations.
d. Traditional vehicle manufacturing systems are built with very robust equipment geared to carrying out the same operations for many cycles and years. But when customer demands change these robust systems are not agile; they cannot be quickly modified for changes in the product or operations. In the construction industry the provision of effective safety systems may greatly compromise mobility, and thus tempt the user towards circumvention.

5. The Laws and Rules of Ergonomics in Design

a. The practice of ergonomics involved human physiological, cognitive and social science, domain knowledge and a portfolio of tools. The Laws and Rules of Ergonomics in Design is a practical textbook that describes some 26 different aspects of human factors practice with descriptions of some of the theories, tools, and applications:

   i. Tight Targets Take Time, Blind Ones Sometimes Take a Little Longer: Fitts' Law
   ii. The More I Practice; The Better I Get – De Jong's Law
   iii. My Arms Are Getting Tired – Rohmert's Law
   iv. Gas Happens – The Gas Laws
   v. Murphy's Law: If It Can Happen, It Will
   vi. Wrong Number: They Didn't Listen to Miller
   vii. JNDs, SDs, HSDs, and DNDs: The Weber-Fechner Law
   viii. Bias in Human Judgment: Is Your Halo Slipping? = The Halo Effect
   ix. What Kind of Shape Are You In? Anthropometry and Appearances
   x. Stand (Sit) Straight Up: The Functional Anatomy of Posture
   xi. Pay Attention
   xii. Newtonian Moments - Biomechanics
   xiii. Expectancy and Compatibility – Equipment Design
   xiv. Hotter Than Houston: Body Temperature Control
   xv. Rule-Based Ergonomics
   xvi. Remember Hawthorne = The Hawthorn Effect
   xvii. Unwanted Energy – Vibration
   xviii. Warning: Do Not Use While Sleeping – The Role of Facilitators
   xix. Who's Agenda Is It Anyway? – Robert's Rules of Order
   xx. Boomer, Sooner and Donders = Reaction Time

xxi. You've Got to Attend to Everything – Mental Workload
xxii. A Look Back: Ergo is More Difficult than Nomos – Recent History of Ergonomics
xxiii. Just a Moment - Biomechanics
xxiv. Ethics and Ergonomics: Customer Satisfaction
xxv. Product and Process Evaluation Using the Six Us
xxvi. Time for Bed: Shift work

b. This interactive workshop will discuss a selection of these topics and evaluate the theories, tools and applications that are used by practicing ergonomists.

6. HIM and HER – Human Information Management and Human Error Reduction

a. Accidents usually have a cognitive cause and a physical result. Therefore the prevention of accidents requires attention to the failures of human information management and human error reduction. However, after the sequence of events leading up to an accident have initiated a system failure the reduction or mitigation of the physical effects usually requires a physical intervention. For example a driver may be driving too quickly at night (perhaps due to a memory or decision lapse) and fail to see another vehicle enter from a side road – a sensory, attentional or perceptual failure. The outcome of these initial cognitive failures may require a significant application of skill at the last moment, but where this fails the driver is dependent on the defenses designed into the vehicle such as crush space, seat belts, air bags and a friendly interior to reduce or mitigate the unwanted outcomes of the accident. It is hoped that the forgetful driver had also remembered to pay his insurance premium. He may also wish that he had remembered not to drink alcohol before driving or not decided to use a cell phone while driving.

b. This whole sequence of events highlights many Human Information Management processes, such as sensing, attention, perception, short and long term memory, decision making and sensory motor control as well as anticipating, planning, communicating, controlling and so on. The reduction of the likelihood of this accident could depend on just one element of the Human Information Management System. Consequently, Human Error Reduction opportunities must be addressed throughout Human Information Management process.

c. The perpetrator of this accident may not be the only one to blame. Errors may have been made by the designer of the vehicle or road system. Traffic control devices and driver selection and training may also provide opportunities to improve system robustness.

d. This workshop will explore the human capabilities and limitations throughout the Human Information Management sequences. Next Human Error Reduction strategies will be proposed to improve human performance by equipment and operations design. These HIM and HER analyses will be applied to a variety of contexts including transportation, industrial inspection, maintenance and education

Chapter 6

Ergonomics and Traffic: The Big Picture

"Beam me up Scotty." Captain Kirk and his engineers solved the need for speed (distance divided by time) but forgot to mention the tons of space junk that just might get in the way. Walking to work has its hazards, mainly from cracked pavements and wayward bicycles. Last weekend I was taken out by a child on a scooter and last year a policeman on a Segway bumped into me in an airport. As we add technology to improve speed, we greatly increase the hazards, and the congestion, and the pollution. Tens of thousands of people die each year in automobile and motorcycle crashes. Tired bus and truck drivers frequently create headlines and gory pictures of crashes and fires. A single train or airplane crash or ferry sinking may kill hundreds at a time. About 1 in 50 astronauts died in Space Shuttle missions. Traffic regularly comes to a standstill in our big cities and our commuter highways and wastes millions of hours, aside from killing the environment and those that breathe the air. Frequent drivers suffer from metabolic disorders and debilitating lower back pain. What then are the likely risks of future traffic? Are the benefits justified? How can Ergonomics contribute to the balance between our continuous search for speed (lots of distance in a short time) and the reactionary calls for health, safety, satisfaction and sustainability?

One theory suggests the "hierarchy of controls." Elimination, now that might be a good idea! Another solution sometimes pursued in our busy cities is through segregation – car, bus, bicycle, carpool and pedestrian lanes. Many cities isolate the train lines – under or over and sometimes through. The design guidelines are based on speed and size – momentum; the problems are change in momentum and "impact" in the broadest sense. The reactive engineering solutions revolve around the absorption of force by vehicle structure and roadway design and personal protective equipment – both active and passive. Administrators rush to impose administrative controls – speed limits, operational guidance (stop signs and arrows) and danger, warning, caution, and awareness signs. Behavioral approaches include training and licensing. After the event human misbehavior is addressed in the courts by punishment and (re)training. These engineering and administrative interventions have grown enormously but failed to keep up with the need for speed.

The role of big picture ergonomics (Macro ergonomics) is to ask "why?" The first analysis identifies complexity as the barrier to prevention given the need for speed. One solution, practiced in parts of some big cities, is integration rather than segregation – cars, bicycles and pedestrians all share the same space; this requires continuous vigilance by the players and reduces the common speed down to the lowest common denominator. Applying Rafaat's model, risk is determined by the probability of system failure times the consequence times the degree of exposure – a motor bike driver who covers 300 kilometers a day in heavy fast traffic would qualify as a high risk.

The next big picture challenge stems from the caution that: "Rome wasn't built in a day". Infrastructure, including technology and operations management will evolve very slowly. London and New York started early building subway tunnels. In the 1970's Hong Kong dug up Main Street shortly after Washington DC developed a state-of-the-art subway system. Tokyo sports more tunnels than a rabbit warren. Singapore aims to build more, bigger, better, and faster automated subway systems and drive the drivers off the roads, while providing surface level bike paths, like San Francisco, for the energetic. These mass transit systems take a lot of planning, a long time to build and when things go wrong, perhaps through a bad guy with a bomb, a long wait for a lot of people.

Macro ergonomics addresses the balance among effectiveness, efficiency, ease of use, elegance, safety, security, satisfaction, and sustainability. The major caution in design is that cost is causally related to the amount of mass, space, time, energy, and people. The objective of design is the minimization of cost, mass, space, time, energy, and people

Chapter 7

Ergonomics through both ends of the Telescope

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Calvin Or, Hong Kong University

Introduction

Introspective people think: what am I, what do others thing I am, what do others think that I think I am and what do I think that others think that I am? Ergonomics and Human Factors professionals and practitioners face the same dilemma. In both cases there is no right answer. It all depends on the point of view, which in turn depends on the training and experience of the observer. One observer may see a chair, a table, a mouse and carpal tunnel syndrome; another may see ambiguities in the web interface design and a third may see a job with high levels of operational stress in which errors may have catastrophic outcomes. Even the many definitions of ergonomics and human factors reflect discrepancies in understanding. The folk story of the "Blind man and the Elephant" offers an eloquent analogy of the problem. The rich history of ergonomics and human factors has benefitted, and suffered, from the interests, opinions, and activities of people with diverse backgrounds. Consequently, this paper will allow any point of view, broad or narrow. It will look at ergonomics and human factors (and many alternative descriptors) through both ends of the telescope.

Context, Purposes and Outcomes

The development of technology, from bows and arrows to nuclear weapons, or smoke signals to cell phones, has had purposes and outcomes that benefit one individual or group, sometimes to the detriment of others. Even the familiar automobile is associated with tens of thousands of fatalities every year. The mobile phone in one context is a life saver, but when used while driving is a life taker. Technology must assume, investigate, or at least respect context. A pertinent operational definition is that technology can be designed whereas context may be unchangeable and may require mitigation. Even the many definitions of ergonomics and human factors reflect discrepancies in articulation of purpose. A model of outcomes and by implication purposes is "E4S4:"

- Effectiveness – meets functional requirements
- Efficiency – optimizes the use of resources – time, money, materials, people etc
- Ease of use – by the intended user, in the intended context
- Emotional appeal – an attribute beyond functional requirements
- Safety – has acceptable risk of unwanted outcomes
- Security – is safe from the malicious or inadvertent interference by third parties
- Satisfaction – meets the requirements of all stakeholders – users, manufacturers, investors etc.
- Sustainability
    - is Reliable under intended contexts
    - is Resilient under unintended and perhaps extreme contexts

It is clear that all these purposes will not be realized in all cases. There will often have to be tradeoff decisions made in design and operation. Even the most apparently innocuous or benign design may have undesirable effects. For example, the chair, when used to excess, may give rise to metabolic disorders such as obesity, diabetes, and heart disease.

Complexity

Edwards (1972) presented the SHEL (Software, Hardware, Environment, Liveware) model of complexity. This model or framework is intended to convey the fact of interactions among People, Technology, Rules and Procedures, and

Contexts in real world situations. For example, contemporary “smart” devices may be completely useless in the hands of untrained users or if the bill hasn’t been paid; driving at the speed limit in the fog is likely to result in “system failure”, and even the best of drivers may crash if the brakes don’t work. The clear implication for technology “design” is that due consideration must be given to user capabilities, limitations and behaviors, and operational contexts. A framework for looking at the use of a product or service is the 6Us 2Ms:

- ✖ **Utility**
  - + Is the system useful?
- ✖ **Usage and Misusage**
  - + How and in what context will the system be used?
  - + What possible extreme contexts may be predicted
  - + Can the system or service be used in an inappropriate context or by an inappropriate user?
- ✖ **Usability**
  - + Is the system easy to use or misuse?
- ✖ **Utilization**
  - + How often and by how many people is the system used?
- ✖ **Users and Misusers**
  - + Who are the users and possible misusers?
  - + What kind of (between and within) user variability can be anticipated?
- ✖ **User Error**
  - + What kinds of error can be made, when and how will they be made?
  - + How frequently will errors be made and what are the possible consequences?

The Production Line

Henry Ford, Frederick Taylor, and Lilian Gilbreth nearly one hundred years ago and the Toyota Corporation more recently made substantial contributions to the development of the production line. The principal purposes of their job simplification and standardization approaches were quality assurance and productivity improvement. Quality assurance was achieved through strict process control and prescriptive operations supported by sufficient training; productivity gains were achieved through the elimination of non-value-added operations, such as “search” and “transport.” Contemporary production lines, including the supermarket checkout, have benefitted enormously from these human – technology – operations design principles. More recently, however, the identification, ready diagnosis, and epidemic spread of “repetitive strain injuries and illnesses” has reminded us that human beings, unlike well-oiled machines, are not resilient to “cumulative trauma.”

The “Production Line” from the Macro viewpoint can represent a large majority of occupations, from the field and the factory to the office, retail operations and transportation, that involve repeated transactions, often externally paced, not necessarily by a conveyor belt but perhaps by a customer or supervisor demand. A key similarity among these occupations is repetition and static physical demands on the one hand and non-value-added searches for information on the other. Another characteristic of many occupations is lack of autonomy; however, when things go wrong the lack of autonomy often transforms into responsibility for failure. These challenges require both macro and micro ergonomics interventions.

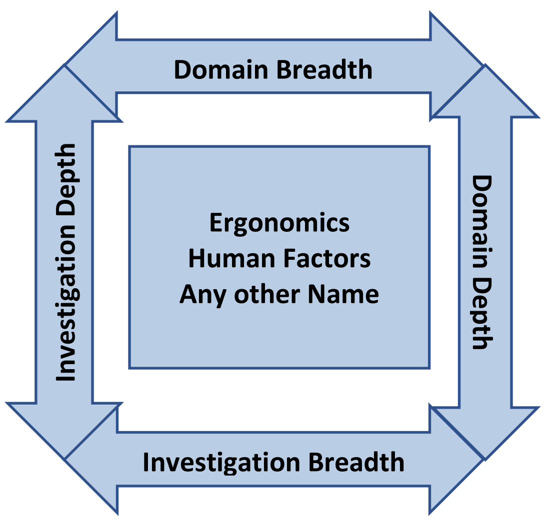
Sociotechnical Systems

Trist and Bamworth (1951) described the purposes and activities of the Tavistock Institute which was formed in 1947 to investigate the human implications of new technology implementation. From their landmark study of coal mining technology implementation failure, they demonstrated unequivocally that a failure to consider human factors in technology design and implementation will inevitably result in system failure. Around the same era Paul Fitts developed the instructive “Fitts Lists” that described those functions best carried out by machines, such as repetitive, precise motions, and those best left to people, such as judgment under uncertainty, trouble shooting and flexible responses to operational deviations. Another early proponent of ergonomics – Singleton – described the importance of assigning functions to people and machines at an early stage in the design process.

Swiss Cheese and HFACS

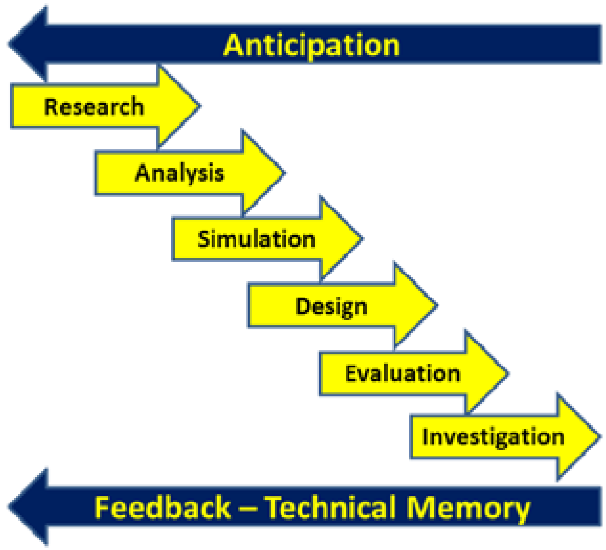
James Reason (1990) took a different, but compatible view of system failure. He developed the "Swiss Cheese" model. This model was intended to be used in accident investigation, but it is equally useful as a system design tool. It articulates four levels in the system failure chain: the unsafe act, preconditions, unsafe supervision, and organizational factors. The unsafe act may be a human error – they happen all the time to all people – or an intentional violation of correct procedure, again a common occurrence. These unsafe acts may or may not have important consequences, depending on the context. The preconditions for the unsafe act include human, technological, contextual, or procedural factors. For example, the operator may be untrained or fatigued, the technology may be faulty, the environment may be harsh, or the procedure may be incorrect for the situation at hand. Unsafe supervision may be either an error or a violation, such as where an activity is not checked, or an untrained operator is assigned to a task. Finally, the organizational climate may be such that there are shortcuts on equipment purchase or manpower or where productivity is emphasized over safety. The Human Factors Analysis and Classification System (HFACS) was developed from the Reason Swiss Cheese model by Shappel and Wiegmann(2003), primarily for application in aviation accident investigation, but widely applicable in other socio technical system investigations, and designs.

A Generic Model of Human Factors



Human Factors and Ergonomics are applicable to any area of human endeavor – from agriculture and mining to consumer products and space exploration (domain breadth). However, a failure to understand the domain, including its technology, operations, procedures, and contexts, is likely to render the involvement of Human Factors ineffective at best and potentially damaging to the image of the profession (domain depth). There are two solutions to this problem. Ideally the HFE practitioner should be informed and experienced in the domain; alternatively, the HFE practitioner should work closely with someone who has considerable knowledge of domain technology, procedures and context.

Human Factors and Ergonomics activities occur at many stages in the product development, design and operation process. (Investigation Depth)



Research will provide broadly applicable statements about human capabilities, limitations, behaviors, and performance expectations under both normal and abnormal, perhaps extreme, contexts. For example, there exist many quite robust theories and models that describe anthropometric, biomechanical, physiological, sensory, attention, memory, cognitive and motor control norms and variations. Analysis, or applied research, will describe expected success or failure with specific technologies, operations, and contexts. For example, the vigilance decrement among air traffic controllers, industrial inspectors and security personnel is well documented. Simulation of many forms is a powerful predesign tool to explore human capabilities and limitations long before system implementation. For example, it would be unthinkable to send an astronaut to the International Space Station or put a pilot into a new airplane cockpit without considerable simulator training. Unfortunately, in many industrial and service operations, on the job training is still the norm, along with on the job "human errors."

Ideally the evidence from research, analysis and simulation should contribute to the design of the eventual system or operation through prediction of the effects of alternative design features in the face of sometimes uncontrollable contexts. Unfortunately, this concurrent design philosophy often becomes an after the design evaluation of the technology (hardware or software) or service when suggested changes may be infeasible, prohibitively costly or simply ignored. In these cases, the opportunity for human factors / ergonomics intervention may be through the medium of an accident investigation after hasty system implementation, or as an expert witness in a court case. Rarely does the human factors practitioner receive accolades for successful product or service designs.

In complex systems the human factors / ergonomics professional may contribute breadth as well as depth. For example in setting up a green field manufacturing plant, the human factors / ergonomics professional will go beyond the micro design of tools, workstations and physical environments and into the macro issues of selection, training, assignments, and job, operations and shift design. Beyond the individual operator level, the socio technical approach may address safety, productivity, product quality, team structure, supervision and organizational support for employees and their families. The success or failure of the enterprise may rest on either the macro issues of organizational design or management or the micro issues of an uncomfortable chair, unsharpened tool, or unfulfilling task assignment.

First Principles and Complexity

Another way of looking at the elephant is through first principles. People exist in the context of space, time, mass, and information. Space requires that we address body size and shape through anthropometry, time brings in movement and therefore functional anatomy, and mass in the context of gravity brings along energy and physiology.

The addition of information to the mix involves communication and control which opens the door for cognitive psychology. The fact that we don't live alone brings a whole new mix of sociology, organizations, collaborations and conflicts. As we are quite advanced in our development, we are often driven by what we like or dislike, so affective and emotional behavior greatly complicates most situations. To make matters worse we live in a world where the physical, chemical, biological, social, economic, and political environments restrict our abilities to behave freely. Time once again inserts its inevitable presence – everything changes, we learn and we grow old, technology advances, rules, regulations, and procedures change with every election and promotion and new contexts are always appearing. These basic forces and their many interactions make human factors a complex challenge indeed.

An Ocean of Information is on Tap

There exists considerable data, information, and knowledge available to human factors and ergonomics practitioners, some perhaps borrowed from their parents, siblings, cousins and friends – mathematics, anatomy, physiology, psychology, medicine and engineering to name but a few. Because this information is generally available at the tap of a button, there is no excuse for getting the story wrong, other than the fact that we are generally cognitively and behaviorally limited, blinkered, and biased individuals. But here again technology can come to our aid. All we need to do is subcontract some of our needed intelligence to a, preferably portable, tablet; just like Moses read on the tablets on Mount Sinai. This early checklist approach, designed to guide human moral behavior, has been copied many times in many areas of human experience. Aviators have checklists for every circumstance; astronauts, who will go to Mars and beyond, will have checklists for system analysis, payload analysis, environmental analysis and even surgery. Down on earth we could not do without recipe books, consumer product assembly and operations manuals, and maps to guide us around cities and shopping opportunities; all at the tap of a button.

Managing Complexity in Human Factors Practice: The Ten Barriers

Most human factors professionals would argue that it is impossible to reduce our science and technology to a checklist, but given that the world wide web has more data, information and knowledge than we will ever need, we can at least put it in a tablet. The first barrier to be overcome is the reduction of uncertainty. This uncertainty is created by variability and interactions within and among people, technology, rules and regulations, and contexts. The second barrier is that of inconsistency among purposes; we must make tradeoffs among effectiveness, efficiency, and safety for example; we must also resolve the conflicts and tradeoffs among the different requirements of different stakeholders. The third barrier is that everything changes over time; the optimal answer today may not be optimal tomorrow. The fourth barrier is the sheer enormity of data, information, evidence, and knowledge; But Moses did not need a lawyer to explain the commandments. The fifth barrier is related again to uncertainty; given that most measures and interventions exist on a continuum where should we place the cut off points? What are the benefits and risks? The sixth barrier is that we must deal with culture, motivation and affect; people (often) have choices and may make these choices for apparently illogical reasons. The seventh barrier is that we do not rule the world; our analyses and advice may conflict with that of others. The eighth barrier is that we cannot get our act together – there are more checklists than ergonomists and we often find ourselves on opposite sides of lawsuits. The ninth barrier is that, with limited resources and distribution, people are competitive and there are winners and losers everywhere; Darwin was right. The tenth barrier confirms that Darwin was right; even ergonomics cannot compete with the self-destructive behaviors of some individuals.

Putting the Profession in Context: a checklist approach.

The ten challenges may be summarized as follows:

1. Variability and uncertainty among technology, contexts and people makes generalizations difficult, unreliable or impossible
2. Multiple purposes and outcomes require hard decisions and tradeoffs
3. Technology, People, Rules and Regulations and Contexts change over time

4. An overabundance of data, information and knowledge means that we can always find evidence for or against an opinion.
5. Tradeoffs, Compromises, Decisions, Benefits and Risks – the cutoff points – we can't please all the stakeholders all the time
6. Affect and likeability sometimes trump function
7. Other participants in design and operations management may have conflicting motives, evidence, and opinions
8. Our practice and practitioners are pliable, we don't always have a common voice
9. In the outside world people are competitive, there will always be winners and losers
10. There is no answer to stupidity

Ergonomist heal thyself

This paraphrase from the Gospel according to Luke (4:23) suggests that we are our own worst enemies. Other Biblical references in Isaiah (61), Matthew (5: 3-12) and Luke (6:20 - 22) discuss behavioral solutions in the form of beatitudes and woes. Religious interpretations and explanations abound. Rather than take these analogies too literally, we can take a similar approach to the healing of our profession and managing our practice:

1. Variability
2. Multiple purposes
3. Time
4. Data, Information and Knowledge
5. Tradeoffs
6. Affect
7. Other views
8. Common voice
9. Competition
10. Irrationality

Chapter 8

JPAS and Job Kano: Measuring Sedentary Work

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Introduction

Ergonomics is the profession dedicated to enhancing the positive outcomes of work and product design such as quality, productivity, and satisfaction, while reducing the negative outcomes such as errors, accidents, ill health, and dissatisfaction. Unfortunately, these challenges are not simple; rather they usually involve complex tradeoffs among various positive and negative outcomes. Sedentary work has pervaded society for centuries where the worker is mainly an information handler, and since the industrial revolution even more jobs have become sedentary as productivity benefitted greatly from the reduction, through technology, of non-value added physical movement on assembly lines. The computer revolution further manacled workers to chairs and desks, and imprisoned them in office cubicles, although the mobile revolution now facilitates information handling while on the go (with a new set of collision challenges). From some viewpoints quality, productivity and satisfaction may have risen, particularly through the harnessing of contemporary technology. However, the long-term outcomes of sedentary work are a global epidemic of obesity and metabolic disorders. The managers of work may argue that they only require 8 hours a day, 5 days a week and that the productivity gains of focused sedentary work should be complemented by physical recreation outside of the working hours, but unfortunately the employee is seduced by the attractive nuisances of television and similar sedentary recreation, together with the ready availability of high calorie food. In the long run this argument of responsibility for physical health among government, management, employees, families, and friends, as well as the medical and insurance industries, is likely to be unproductive; the scale of this problem demands a collaborative effort. Ergonomists too must comprehend the big picture.

During the 1980s and 1990s industry was plagued with an epidemic of work related musculo skeletal disorders, formally recognized as an occupational disease by the CDC in 1997, and everybody and his brother jumped on the ergonomics bandwagon. These disorders were attributed to work and therefore employers and keyboard manufacturers were held responsible. But now we have a far greater tsunami of metabolic disorders which are associated with sedentary lifestyles and may be attributed to work organization. This article presents easy to use approaches to assess the physical demands of jobs from the objective and subjective viewpoints with the objective of contributing to the prevention of work-related metabolic disorders (WRMDs)

Physical Activity Sampling

An analytic view of ergonomics is that it deals with space, force, time, information, and emotion within physical, temporal, organizational and social contexts. In the present context of sedentary work, the focus is on the physical ergonomics interventions to measure and manage space, force and time, and their interactions and human implications. Space and force deal with posture, whereas movement requires the addition of time to the mix in terms of duration, frequency, and repetition of activities. Contemporary technology, in the form of multiple sensors carried in a wristwatch, can now monitor physical activity 24 / 7. However, the well-developed statistical process of (physical) activity sampling may be adapted for widespread assessment of static / dynamic balance. The Physical Work Strain Index was developed many years ago to address the challenge of measurement and analysis of physical activity (Chen, Peacock and Schlegel, 1989). This process was improved recently to assess the physical workload of elderly employees and renamed JPAS – Job Physical Activity Sampling and DAYPAS – Daily Physical Activity Sampling.

Activity sampling involves the definition of an exclusive and exhaustive set of observable physical activities that comprise the work in question. For observation convenience each class of activities is ranked on a four-point ordinal scale in terms of physical stress (Table 1.)

	Body				Task			
	Base Activity	Arm Reach	Trunk Twist	Vertical Location	Load Force	Materials Handling	Coupling	Task Surface Orientation
0	Sitting	No Handwork	Forward	≤ Waist >Knee	No load	None	None	Front
1	Standing	Near	Minor (<30°)	≤ Chest	<5 Kg	Push/Pull/ Manipulation	Good	Top
2	Walking	Middle	Moderate (30°-60°)	≤ Shoulder	5-10 Kg	Carrying	Fair	Left / Right
3	Climbing Squatting	Far	Large (>60°)	< Knee or >Shoulder	>10 Kg	Lifting	Poor	Under / Back

Table 1. Ordinal values of physical demands

These activities are recorded through a random series of observations (or photographs) over a representative period (such as 1 hour) of job activity. Where the activities have irregular durations then regular observations will have statistical validity. Longer periods, greater frequency and replication of observations will produce greater reliability in the final picture. In practice it is possible to observe up to 5 employees simultaneously where observations are taken at, on average, 5-minute intervals, producing ten or a dozen observations per subject per hour. The DAYPASS process uses a similar set of observations while extending the observation period to 24 hours, replicated over several days.

There are two analysis phases. First a simple sum of the rank scores of each variable is divided by the sum of the observations and converted to a percentage of the maximum score to indicate the overall level of physical stress. For example, if there are 10 observations of "base activity" and they all score 0 (sitting) then the score is 0%, or, if the vertical hand location is always below knee level then this element would score 100%. The second analysis computes the (absolute) change between successive observation intervals. For example, a change from sitting to climbing would score (|0 - 3| = 3). The sum of these change measures, again converted to a percentage, reflects the static – dynamic balance of the work. For example, if the operator is always seated then the static / dynamic balance would be 0% or a high static load. Alternatively, if the vertical hand location alternates between waist height and overhead reach the static / dynamic load would be 100% indicating frequent changes or a high dynamic load.

Taken together these two analyses reflect the absolute level of physical workload and the static / dynamic balance. The interpretation of the observations over all observation variables and sampling intervals presents a comprehensive picture of the physical work demands of the job in question.

Subjective Job Analysis (Job Kano)

The Kano model was originally developed for product design, but has been adapted for service design (Hartono, Tan and Peacock, 2012) and recently for the analysis of jobs. The Kano philosophy is that products, services, or jobs have various qualities as perceived by their users. The first level is "must have" – for example if a product, such as a car, doesn't work no amount of packaging will make it acceptable; in the case of jobs, if the physical or cognitive demands are beyond the capabilities of the employee then the job will be considered unacceptable. The next quality is "more or less the better". For example, if a product is inexpensive then it will be more appealing; if a job pays more it will be more attractive. The third quality is the "excitement" quality. If a smart phone is filled with useful and entertaining applications, it may be very attractive to many users; if a job has a very collegial atmosphere then people will look forward to going to work. The Kano data capture process is carried out using a survey approach in which subjects are asked to categorize various job features into “must have”, “more or less the better” and “excitement.”

Conclusions: A Case Study

The objective JPAS tool was used together with a KANO analysis for the subjective assessment by employees of the work demands and of their own physical capabilities. The study sample was 100 currently employed Singaporeans between the ages of 55 and 75. The types of tasks observed included cleaning, food services, hospital services, maintenance, office work and transportation operations. As expected, the absolute physical workload and static dynamic balance showed differences among jobs. The KANO assessment showed that being active, collegiality and salaries had positive ratings, while lack of collegiality and long workdays were the major dissatisfiers. Notably, fifty percent of these currently employed older employees indicated no “dislikes”. Most of these older employees indicated an expected tenure in their current jobs in terms of their physical abilities as being between 5 and 10 years. The moral – keep working and walking!

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Chapter 9

IDK

A young man hobbled into the gym, with a stiff right leg and a walking stick in his right hand, just like "House", but this was in 1962. He handed me a piece of paper, signed by the emergency room house surgeon, which read: Diagnosis – IDK, Prescription – Provocative Knee Exercises. Now IDK can stand for "Internal Derangement of the Knee" or "I don't know"; in this case either or both definitions would work. In those days before sophisticated imaging, provocative knee exercises were helpful in differentiating between a tear of the cruciate ligaments or a meniscus or damage to a collateral ligament. It should be noted that the knee joint enjoys considerable rotation in the flexed position, but none when it is fully extended and that a tear in the medial meniscus, which is attached to the medial ligament may occur when the foot is firmly fixed and the player bends and twists his knee with full weight bearing. If a tear occurs, then sometimes a fragment of cartilage is displaced towards the center of the joint and the patient is unable to fully extend his knee. In less serious tears McMurray's test may be greeted with a loud and felt click as the flexed knee is externally rotated and straightened.

On the occasion in question there were some inconsistencies. The patient had his walking stick in the wrong hand and his knee was fully straight, but "locked." I applied every trick in the book to "unlock" the patient's knee, both passively and actively, but it would not budge. I did, however, elicit some, perhaps exaggerated, cries of pain. So, I sent the patient back to the ER with a confirmed IDK and the doctor signed his insurance certificate and told the patient to continue the exercises that I had prescribed and return in three weeks' time.

Dutifully, the patient returned as asked and the house surgeon sent him upstairs for me to have another try. The patient appeared in the gym with the referral slip- IDK, provocative knee exercises. But this time it was his left leg that was stiff, and his walking stick was in his left hand. I tried again to make something happen, but again without luck; so, I sent him back downstairs and the busy house surgeon repeated the return in three weeks instructions and signed the insurance certificate.

Now in those days I had a motorcycle which I parked around the back of the now demolished, Birmingham Accident Hospital. I had a motorcycle despite the fact that a good part of my day was spent in treating patients with significant limb fractures and head injuries, sustained in motorcycle accidents. A short time after dealing with the stiff legged IDK patient, I went to collect my motor cycle to run a midday errand. As I walked around the side of the hospital I bumped into my patient, happily riding his bicycle, walking stick strapped to the crossbar. I sent a cryptic note to the house surgeon entitled NIDK – Now I Do Know, Prescription – no more insurance.

George W Bush: *"There's an old saying in Tennessee — I know it's in Texas, probably in Tennessee — that says, fool me once, shame on — shame on you. Fool me — you can't get fooled again."*

Chapter 10

Moral Development in Pilot Populations

Brian Peacock and Erica Diels

Abstract

Ethical issues are being discussed more frequently in society today and, while most industries are taking steps to improve ethical decisions through education, aviation is lagging in both understanding of ethical issues inherent to the industry and ethics education. In this study three groups of pilots (students, instructors, and faculty) at Embry-Riddle Aeronautical University were examined to determine moral development level in terms of P score on the Defining Issues Test 2 (DIT2). It was hypothesized that differences would be found among the groups and that the moral development score would increase from students, through instructor pilots to faculty. This was found to be the case. The instructor and student pilots scored lower than expected in the DIT2 questions and it is suggested that this may be due to a lack of ethics training in aviation curricula.

Some Operational Definitions and Context

"For the purpose of this paper we will define morality as a set of (human) laws that aspire to assure harmony among individuals and groups. Ethics on the other hand embraces the study of morality and the practical standards that are set to define morality more precisely" (Peacock et al, 2008). It follows that "professional ethics" are the behavior standards set by well-defined professional groups, such as medicine, business, engineering, and aviation. Many professional organizations formalize and publish sets of ethical standards. Given that the purposes of all organizations are effectiveness, efficiency, safety and satisfaction, the ethical dilemma is often found in the tradeoffs among these purposes and the, perhaps different, points of view of the various providers and customers of the service.

Because aviation faces high consequences of failure, it has developed as a profession based on stringent selection, training, and oversight. In the early days, given adequate contexts the outcomes of a flight were focused on the pilot in command. The pilot was in turn charged with offering good "aviation decision making". In more recent years this focus of responsibility has broadened somewhat to include the concepts of "crew resource management," in which there may be many contributions and contributors to each "aeronautical decision". But the prime responsibility still lies with the pilot in command.

Thus, the pilot in command may be faced with many dilemmas and tradeoffs between effectiveness, efficiency, safety, and satisfaction. And the expectations of different groups of providers and customers may differ widely. One recent example of a complex aeronautical decision-making chain which had a catastrophic outcome was the weather-related crash of Continental Flight 3407 near Buffalo. The finger pointing related to this accident spreads far and wide, way beyond the pilot in command, and many people, policies and practices were identified as being lacking. Notably the pilot's last words were "Jesus Christ!"

The study of ethics in aviation is therefore aimed at the processes by which those involved approach complex decisions and tradeoffs. The development of ethical standards will be based on ethical principles from many sources. The implementation of these principles will be through education.

Introduction

Today, many leaders, businesses, and high-profile operations have brought to the forefront the issue of ethics and ethics education. Unfortunately, the reason for this is not a positive one. Poor decisions involving ethics have become more and more common, particularly in the business world (e.g. ENRON) and in the aviation field (various airlines in the news for skimping on routine maintenance inspections). To counter this problem, the application of ethics education has been increasing in many industries. Also, many professional schools include ethics courses in their curricula. Aviation on the other hand, has not seen such an increase.

As aviation moves into its second century, the challenges and issues that face it are beginning to change. Technology in the industry continues to advance, forcing all aspects from flight training to air carrier operations to keep pace. For example, widespread use of unmanned aerial systems is just around the corner (Peacock and Northam, 2007). Regulation must also be implemented to keep laws current and applicable. This is not always an easy task in such a fast moving, high risk industry. This risk pertains not only to lives, but to property and business success as well. A large amount of regulation and Standard Operating Practices/Procedures (SOPs) are an integral part of managing the risk. While these cover most operations within the industry, there are still a few "grey" areas that have little or vague regulation. This requires some application of judgment and/or ethical decision making to achieve a desirable outcome. Even with these grey areas, ethics in the industry and ethical decision making are rarely addressed in training or in consideration of professional behavior. This may be due to the argument that aviation has so many rules that ethical issues are left to the individual, since as long as one obeys the rules they are doing the "right" thing, but even if one obeys the rules there is still room for unsafe and unprofessional behavior. Even with all the regulation, SOPs and oversight, accidents occur on a regular basis. Many of these events met the rules, mostly met the rules, or resulted from bad decisions in a "grey area" of legislation. Other events occur due to individuals or groups taking shortcuts for reasons of expedience or personal convenience.

On a day to day level in the flight training environment, instructor pilots are required to make decisions regarding the balancing of mission completion, weather, personal finances, operational rules, and student benefit/relationship (Northam & Diels 2007). No strict rules or guidance exist, and very little formal training addresses such decisions. Much more time is spent on the technical and regulatory aspects while operational and ethical decision making is encompassed in what is referred to as "good airmanship."

Teaching "good airmanship" is usually left to the instructor pilot. The Federal Aviation Administration (FAA) has taken many steps to supplement and assist the instructor, but these methods are less concerned with the ethical implications of the actual decision and more concerned with the decision process and reduction of accidents resulting from poor decisions. In General Aviation (GA), poor decisions made by pilots accounted for 52% of all pilot error accidents when Aeronautical Decision Making (ADM) research was introduced by the FAA in 1975.

It was found in six different studies of different pilot groups (based on certificate level) that using ADM techniques reduced in flight pilot errors from about 50 percent to 10 percent (FAA, 1991). The techniques presented in ADM training for GA pilots focused on understanding the decision-making process and avoiding the influence of generalized "hazardous attitudes." The techniques presented to Commercial and Airline Transport Pilot (ATP) level pilots focused on Crew Resource Management (CRM).

The five hazardous attitudes are presented as a guide on what influences may affect the decision making process (FAA, 1991), but the main focus is that of recognizing a need for a decision, implementing one that does not use a hazardous attitude, and evaluating its effectiveness. The hazardous attitudes include Anti-authority, Impulsivity, Invulnerability, Macho, and Resignation. These attitudes and their associated behaviors are centered on the masculine culture that is very influential in aviation. While avoiding these attitudes when faced with a decision may reduce the likelihood of an accident any ethical implications of the decisions are purely coincidental. In a study of both male and female flight instructors in New Zealand, it was found that this influence is strong enough to change the values and methods of teaching used by female flight instructors which include less analytical methods and achievement oriented results (Ramsey & Ramsey, 1996).

Instructor pilots are forced to balance mission completion, weather, personal financial implications, operational rules, and student benefit/relationship (Northam & Diels, 2007) with no strong guidance from their experience as a student pilot. Those instructor pilots that have learned how to make ethical decisions elsewhere could be understood to have an easier time and are more likely to make a better decision, similar to the students in Latif 's (2001) study on perception of difficulty in ethical decisions in pharmacy students. Many times, if the ethical decision involves basic needs like income to support food, shelter, and lifestyle, the instructor is more likely to make less ethical decisions (Northam & Diels 2007). This same influence was also noted by Ponemon (1992) in auditors' under-reporting of time to their employer. The most common reasons presented by the auditors for under reporting time on a project included maintaining income levels by keeping certain clients and for career advancement in the firm. Reporting time in a normal fashion could prevent the auditor from keeping lucrative contracts or advancing in the firm because another auditor could be seen as taking less time to do the same job thus getting better contracts (Ponemon, 1992).

The career goal of many instructor pilots is to move on to fly for an air carrier. This means that any problems or weak areas in the instructor pilot population will at some point show up in the air carrier environment as the instructors' careers progress. More so in the past, but still present currently, is the problem of the decision-making skills and ethical decision-making skills from the instructor and student level, (or lack thereof), showing up in the air carrier environment.

The implementation of CRM training was an effort to combat poor judgment/decision making accidents and incidents (FAA, 1991, 2001). As in the case of GA decision making training, the attempt to increase crew coordination and decision making training at the air carrier level focuses more so on efficiency/effectiveness at meeting safety/regulatory goals and reducing fatal accidents as opposed to formal ethical ones (FAA, 2001). Ethical decision making is still left up to the individual, with no formal guidance.

Oderman (2002), in a multi-part study, found that there is little formal ethical decision-making training in aviation. While there is little training, the reduction of aviation accidents and management mis-decisions would indicate a need for formal ethics training (Oderman, 2002). This may indicate that the aviation industry is lagging many other industries in teaching ethics. This is quite interesting as the acquisition and application of specialized skills requires highly ethical behavior (Latif, 2001). Highly specialized skills are required in aviation which would imply that a large amount of ethics and ethical training should be present.

When examining codes of ethics for different industries and practices compared to aviation, aviation is lacking in number of codes and in content in the codes. Examples of codes examined both from inside and outside aviation include statements from the Association of Administrative Professionals, National Society of Professional Engineers, Principles of Medical Ethics as used by Physicians, Airline Pilots Association (ALPA), and National Association of Flight Instructors(NAFI) (IIT, 2007). Of these five codes of ethics, the aviation codes use less formal language and structure. The ALPA code is an example of one of the few aviation codes that is comprehensive, albeit without detailed specification language. The NAFI code is like many of the codes present in aviation, overly broad in scope and not as elaborate as others. Many occupational areas in aviation do not even have a code of ethics.

Currently, formal teaching of ethics has been recognized as an important component of education in many industries and professions including business, medicine, engineering, and law. This was not as prevalent in the past, as this may be partially due to values and ethical standards being more commonly taught to children by their communities, families, and religious institutions. As communities and families have become more decentralized, this may be one reason for the need for ethics education (Vincent and Meche, 2001).

To determine if formal ethical education is necessary in any one area of aviation, research needs to be conducted to measure the moral development level for select populations. In the present study, three different pilot populations, including student pilots, instructor pilots, and faculty pilots, were examined to determine moral development level. Given that moral development normally increases with age and education (Bebeau & Thoma, 2003), this study hypothesized that the student pilots would have the lowest moral development levels, the instructor pilots the mid-levels, and the faculty the highest moral development level. The method of measuring and scoring moral development was by use of the University of Minnesota Defining Issues Test Two (DIT2).

Background

Moral development is the level at which an individual gives order to the "interests, roles, and moral principles," that govern their lives (Beabout & Wennemann, 1994). Conflicts that are encountered in everyday activities help shape these decisions and help to increase moral development levels. The idea of measurable moral development levels was introduced by Kohlberg in 1969 to organize several ethical concepts. Kohlberg created the levels of moral development using participants' answers to certain moral dilemmas. The most famous is the Heinz dilemma (Beabout and Wennemann, 1994). In this dilemma a man steals a drug for his dying wife and the reader must decide if the man's action is morally right. The responses to this and other dilemmas indicate the individual's moral development level.

Kohlberg's theory is the most widely used way to define moral development level. Prior to Kohlberg, Jung and Freud described moral development in terms of identifications and/or attachments with the family, while Piaget incorporated it into his stages of development as a function of peer development (Needle & Lecker, 1997). Kohlberg's theory of moral development is based on a cognitive-development approach made up of three levels, with two stages per level. This approach is part of the larger personality development of an individual (Kohlberg, 1984). Kohlberg's theory of moral development is like Piaget's developmental stages of reasoning and intelligence. In fact, advancement in Piaget's stages of development is required to advance in Kohlberg's levels of moral development (Kohlberg 1984). As the levels and stages increase, so do the amount of information, processing, and complexity of factors that influence moral decisions. (Table 1)

Levels	Stages	Definition
Level I Preconventional (Child)	Stage 1 Heteronomous Morality	Egocentric point of view. Doesn't consider the interests of others or recognize that they differ from the actor's; doesn't relate two points of view. Actions are considered physically rather than in terms of psychological interests of others. Confusion of authority's perspective with one's own.
	Stage 2 Individualistic, Instrumental Purpose and Exchange	Concrete Individualistic perspective. Aware that everybody has his own interest to pursue and these conflict, so that right is relative (in the concrete individualistic sense).
Level II Conventional (Adolescent)	Stage 3 Mutual Interpersonal Expectations, Relationships, and Interpersonal Conformity	Perspective of the individual in relationships with other individuals. Aware of shared feelings, agreements, and expectations which take primary over individual interests. Relates points of view through the concrete Golden Rule, putting yourself in the other person's shoes. Does not yet consider generalized system perspective.
	Stage 4 Social System and Conscience	Differentiates societal point of view from interpersonal agreement or motives. Takes the point of view of the system that defines roles and rules. Considers individual relations in terms of place in the system.
Level III Post Conventional (Adult)	Stage 5 Social Contract or Utility and Individual Rights	Prior to society perspective. Perspective of a rational individual aware of values and rights prior to social attachments and contracts. Integrates perspectives by formal mechanisms of agreement, contract, objective impartiality, and due process. Considers moral and legal points of view; recognizes that they sometimes conflict and finds it difficult to integrate them.
	Stage 6 Universal Ethical Principles	Perspective of a moral point of view from which social arrangements derive. Perspective is that of any rational individual recognizing the nature of morality or the fact that persons are ends in themselves and must be treated as such.

Table 1: Kohlberg's levels of Moral Development (Kohlberg, 1984)

Maturity plays a large factor in moral development as shown in table 1 and by Duffield (2000) in his discussion of leadership. He describes that maturity is not necessarily a function of age. He also noted that a person in a leadership position can advance more quickly in maturity. Higher maturity leads to higher moral development. Moral development is an indicator of the cognitive moral capacity of an individual (Thorne, 2000) and ethical decision making/and or the action the individual takes regarding the ethical dilemma can be considered the behavior resulting from cognitive moral processing and the influence of other factors.

Ethical dilemmas are also used to determine ethical decision capabilities. Robbins (1998 as in Latif, 2001) suggests that ethical dilemmas define right and wrong conduct. Ethical decision making is also a process that relies on a building block concept of knowledge acquisition to solve more advanced dilemmas (Rest 1994, as in Latif, 2001). In other words, high level decisions cannot be made with low level ethical decision-making skills.

Moral development plays a large role in ethical decision making and is commonly used as the primary indicator of an individual's ethical decision-making capacity. Kohlberg in his 1971 study states that "moral judgment determines moral action. (Kohlberg & Candee, 1984)" High levels of moral development have been shown as a significant indicator of clinical performance in the medical professions in many studies (Krichbaum, et al, 1994; Latif, 2001; Sheehan, 1979). Those scoring higher on moral development tests have better success in treating patients, meeting their patients' needs, and participate in dysfunctional behaviors like lying and cheating less than their lower scoring counterparts (Latif, 2001). A recent replication study conducted by Bay (2001), concluded that this is not always the case and may be due to the fact that different populations responded to the selected instrument differently due to biases in the instrument. Overall, though, moral development is considered one of the best indicators of ethical decision making and is most widely used to demonstrate such.

Other factors along with moral development can influence ethical decision making, including a person's needs, level of competition, and environmental contexts. Kohlberg in his study relating moral judgment to moral action (1984) states that even with the demonstration of understanding at a certain moral judgment level an individual may act on a lower level in a given situation. Two types of moral reasoning and/or ethical decision making are described by Rest (1979, 1983, 1994 as in Thorne, 2000). These include prescriptive reasoning and deliberative reasoning. Prescriptive reasoning is the individual's ideal ethical outcome to the situation, while deliberative reasoning is the individual's intention to act.

One of the most common measures of moral development in the United States is the Defining Issues Test (DIT) and the newer Defining Issues Test Two (DIT2) developed by Rest (1979) and the Center for the study of Ethical Development at the University of Minnesota. Although the DIT test is better established than the newer DIT2 test, the two tests show a 0.79 correlation (Bebeau & Thoma, 2003).

Two areas of concern with the DIT and DIT2 test are that of political bias and type of moral reasoning employed by the subject. A study by Fisher and Sweeney (1998) indicated that an individual answering the DIT with a liberal bias would produce a higher P score than one with a conservative bias. This argument was countered by the producers of the test who state that while political bias, moral judgment, and religious fundamentalism are similar concepts one cannot be determined from another (Narvaez, 1999, as in Bebeau & Thoma, 2003). Ishida (2006) compared the DIT and Moral Judgment Test (MJT), the more common moral development measure used in Europe. The study concluded that if the subject taking the tests used mostly moral absolutes to come to ethical decisions, they were more likely to score high on the DIT and low on the MJT. If the individual used mostly moral relativism and situational specific moral rules, they were more likely to score higher on the MJT and lower on the DIT. This may present a difficulty when interpreting DIT scores as the results may not indicate a lower or higher moral development score, but rather a tendency to use one type of moral reasoning over another.

Self and Ellison (1998) used the DIT and DIT2 tests in a pre/posttest arrangement in an effort to determine the effectiveness in a particular ethics curriculum. They investigated the effectiveness of an ethics course on raising the moral development level of engineering students and found that there was a significant increase in scores on the DIT test after the ethics course, and that this was dependent on how the ethics course was presented. Role-playing and scenarios provided more effective results than lectures on moral principles.

To determine where aviation managers stand in relation to other industries, Reese (2000) conducted a study of aviation managers across several areas in aviation to include airline, regulatory, and military. He found that the moral development scores of these groups of individuals were lower than that for comparable high-risk fields and lower than that of adults in the general population, but higher than high school students. He also suggests that highly structured SOPs and regulations may interfere with moral development levels in individuals in aviation management, since there are very few areas that require the application of ethical decision making and that straying from the established procedure could lead to punishment and/or loss.

Oderman (2003) set out to gain an understanding of the current condition of ethics education in aviation university programs throughout the United States. He found that very little ethical training was being given in aviation management programs, though the interest of faculty and departments in ethics training was present. He also stated that many of the university programs do not address ethics and ethics education at all. This suggests to aviation students and others in the aviation community that ethics is of marginal importance. Even in the departments at the universities that showed interest in ethical education no steps were taken to formally implement ethics training.

In a small survey of instructor pilots at an aviation university flight program, it was found that some ethical decision making skills were present in the population and that most of the answers to the survey followed a consistent answer pattern of addressing safety, efficiency, outcome of the action, and personal beliefs/gut instinct (Northam & Diels, 2007). Instructor pilots responded that financial issues were a factor in their ethical decisions. Without the ability to maintain shelter, food, and lifestyle from finances the instructor pilots were focusing on maintaining basic needs before meeting higher ethical ones. The present, more comprehensive study attempts to compare the moral development level of aviation students, instructor pilots and faculty members.

Methods

Three different groups of pilots were selected for this study. All the participants were currently enrolled or employed at Embry-Riddle Aeronautical University. Participation was voluntary. The student pilot group consisted of 40 Aeronautical Science program students who were taking a CRM class. The instructor pilot group consisted of 24 currently employed at the university flight line. The faculty pilot group consisted of 10 professors from both the Aeronautical Science and Safety Science departments.

The Defining Issues Test 2 (DIT2) test was selected for the study due to its reported higher validity and reliability scores and the large amount of research already conducted with both it and its predecessor the Defining Issues Test (DIT). Ease of test administration and scoring was also a factor. The DIT2 test is a paper and pencil measure that consists of five ethical dilemmas that are based on Kohlberg's dilemmas, with the option to add two more dilemmas. Each dilemma has 12 rating questions using a Likert scale and four ranking questions relating to the most important rated questions. The test may be administered in a classroom setting, on an individual level, or in small groups, though the most common is the individual method (Nichols & Day, 1982, Bebeau & Thoma, 2003).

Test administration to students was conducted during one of the normal scheduled meeting times for the CRM class whereas the instructor pilots and faculty were requested to complete the survey in their own offices. The test packet consisted of test instructions and answer sheet.

All completed test answer sheets were returned to the University of Minnesota Center for the Study of Ethical Development for scoring. Raw data listings were provided along with common indices used in the interpretation of the data such as P score and N2 score.

Comparisons were then conducted between the three groups using the P scores and N2 scores from the DIT2 test using conventional parametric methods (Analysis of Variance, regression and post hoc tests of differences between means.)

Results

The data from this study were first transferred to an Excel spreadsheet for a survey analysis and the development of graphical descriptions of the results. Selected data were then transferred to SPSS for a detailed analysis. The initial hypothesis was that moral development would be simply related to age and education. However as seen in Tables 2 and 3 these expected relationships were not significant

	Unstandardized Coefficients		Standardized Coefficients		
Model	B	Std. Error	Beta	t	Sig.
(Constant)	8.507	17.805		.478	.634
Age	.233	.202	.174	1.152	.253
Education	1.997	2.140	.141	.933	.354

Table 2 Linear regression of P Score on Age and Education

	Unstandardized Coefficients		Standardized Coefficients		
Model	B	Std. Error	Beta	t	Sig.
(Constant)	.136	17.839		.008	.994
Age	.090	.203	.067	.443	.660
Education	3.097	2.144	.219	1.444	.153

Table 3. Linear regression of N2 Score on Age and Education

The graphical analyses of the group (faculty, instructor, and student) effects on P and N2 Scores are shown in Figure 1. Table 4 shows the descriptive statistics of the P and N2 scores by subject group. These show the predicted relationship among these three groups with faculty pilots showing the highest level of moral development and the students the lowest. However, it should be noted that there is considerable within group variation.

Figure 1, Graphical depiction of the relationship between subject group and P and N2 score.

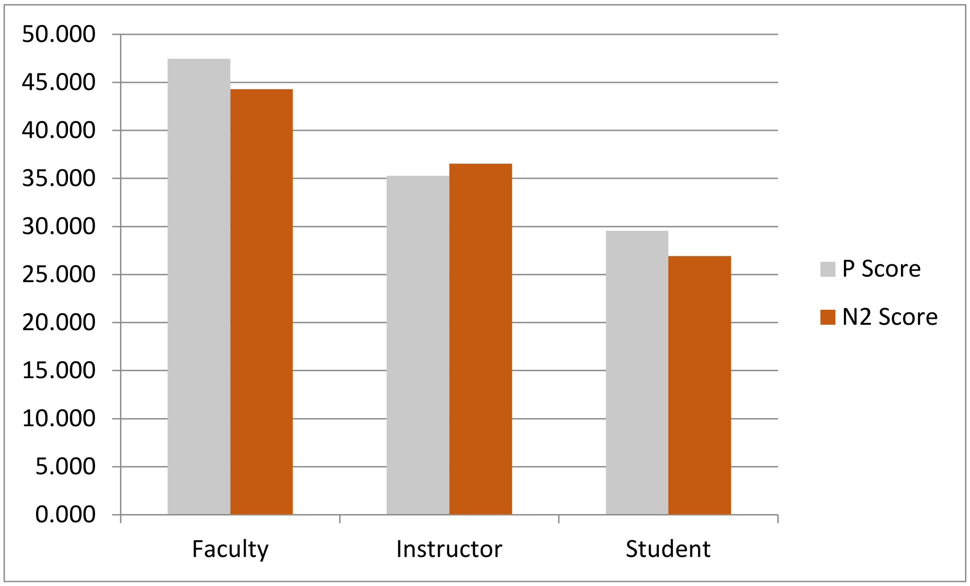

Table 4 Descriptive statistics of P and N2 Scores by subject group (Note that some subjects did not report their ages)

	Faculty			**Instructors**			**Students**		
	Age	**Pscore**	**N2**	**Age**	**Pscore**	**N2**	**Age**	**Pscore**	**N2**
Count	9	10	10	21	24	24	40	40	40
Average	53.67	47.46	44.31	26.95	35.28	36.56	21.50	29.55	26.93
STD Dev	14.37	18.53	15.44	8.02	14.26	13.76	1.71	14.55	14.82
Maximum	77.00	66.00	60.15	58.00	74.00	69.58	27.00	58.00	57.57
Minimum	34.00	20.45	20.85	21.00	8.00	9.15	19.00	2.00	4.80

Tables 5 and 7 show the analysis of variance results for the effect of subject group on P and N2 score respectively. These analyses show significant between group effects. Tables 6 and 8 show the results of post hoc tests (Tukey HSD) of the differences between the mean scores of the faculty, instructor and student groups. These analyses show significant differences between the faculty and student groups for both the P Scores and the N2 scores. However, the mean P scores for students and instructors are not significantly different. Also, for the N2 scores both the students and flight instructors and flight instructors and faculty do not show significant differences.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2625.458[a]	2	1312.729	5.813	.005
Intercept	75589.150	1	75589.150	334.731	.000
Group	2625.458	2	1312.729	5.813	.005
Error	16033.258	71	225.821		
Total	103321.000	74			
Corrected Total	18658.716	73			

Table 5. Analysis of variance showing the significance of the relationship between subject group and P Score.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3032.604[a]	2	1516.302	7.145	.001
Intercept	6722.516	1	69722.516	328.551	.000
Group	3032.604	2	1516.302	7.145	.001
Error	15067.046	71	212.212		
Total	95782.845	74			

Table 7. Analysis of variance showing the significance of the relationship between subject group and N2 Score.

Group	N	Subset	
		1	2
S	40	26.93	
I	24	36.56	36.56
F	10		44.31
Sig.		.124	.254

Table 8. Post hoc tests (Tukey) of the differences among group subsets for N2 Score.

The P Score results from this survey of aviation faculty, instructors and students were compared with the tables of different occupational groups published by Rest and Navarez (1994). These comparisons (Table 9) indicate that flight students are not significantly different from high school students (Student's T >0.1) and flight instructors score significantly below college students (Student's T <0.05). It should also be noted that the flight instructors in this sample score only marginally greater that flight students (Student's T, p<0.1)

P-score	Group
65.2	Moral Philosophy and political science graduate students
59.8	Liberal Protestant Seminarians
52.2	Law Students
50.2	Medical Students
49.2	Practicing Physicians
47.6	Dental Students
47.46	**Flight Faculty**
46.3	Staff Nurses
42.8	Graduate students in Business
42.3	College Students in general
41.6	Navy Enlisted Men
40.0	Adults in general
35.28	**Flight Instructors**
31.8	Senior High School Students
29.55	**Flight Students**
23.5	Prison Inmates
21.9	Junior High School Students

Table 9 P Score results from this survey inserted into table from Rest and Navarez (1994)

Discussion and Conclusions

Other research (Rest and Navarez, 1994) indicates that P scores generally increase with educational and maturity level. Instructor pilots have a marginally higher educational level than flight students, although many instructor pilots are themselves seniors or recent graduates, so it is consistent with other research that they have only a slightly higher P score than flight students. Faculty pilots however have higher scores. It should be noted that flight students scored lower than high school students and flight instructors scored lower than college students in general. This is a cause for concern as the behavior of pilots, particularly related to risk taking with passengers, would expect a higher level of concern for others than is indicated by these results. These findings indicate a need for ethics training in college flight schools.

Little research has been done regarding aviation and moral development. To also examine aviation P scores of different groups to non-aviation P scores (Rest & Narvaez, 1994) the data in Table9 are of interest. Both the student group (average P-score 33.8) and the instructor pilot group (average P-score 36.5) fall lower than adults in general and college students, but higher than senior high school students. The student group was significantly lower than the college students, while the instructor pilot group was only marginally lower. These findings may be due to the lack of formal ethics training, the higher technical focus of aviation education, and/or the focus on regulation as a guide for decisions as opposed to other methods. The faculty group had a slightly higher average P score (50.1). This finding is more in line with expectations than that of the instructor pilot results.

With the validated dilemmas on the DIT2 test it can be concluded that significant differences in moral development in this study were observed between the student and faculty groups. The instructor pilots scored marginally lower than expected in the P scores. The P score differences may be due to the lack of formal ethics training and/or the more technical/regulatory focus in aviation. If this is the case, then this study indicates that more attention needs to be given to ethics training in this collegiate aviation training program. The technical/regulatory focus may cause some to conclude that since we are strongly governed by rules and regulations, there may not be a need to ethical training. The lower than expected P scores, however, seem to indicate that these pilots would benefit from a classroom emphasis on ethical decision making.

This study provides a starting point for further research in this area. Larger sample sizes, different groups for comparison, refinement of additional questions, and comparisons of moral development of groups with other assessment tools are all areas that could be investigated. There is the further indication that the profession needs a greater focus on ethical issues and that flight students, who rapidly move on to become flight instructors could benefit from formal ethics training. As shown clearly by the Continental Flight 3407 incident the push must come from the top. Good airmanship, aeronautical decision making, and crew resource management must be complemented by attention to ethical issues throughout the industry through development of standards and ethics education. But more than in any other context, the pilot in command - the ultimate decision maker, must be equipped with high moral standards.

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Chapter 11

Facilitator Design

Background

This is not about the Hippocratic Oath (first do no harm); rather it is about the hypocrisy of engineers, scientists, and operations managers in their attempts to patch the interfaces between their designs and the end users. These patches are euphemistically called facilitators and cover a spectrum of devices such as labels, warnings, instructions, procedures and a plethora of other so called job aids. Modern computing technology has now made available the rich medium of augmented reality to facilitate the activities of the human operator.

A facilitator is a temporary device to supplement the user's knowledge or current situation awareness to ensure an accurate and timely transaction.

For example, a label on a switch that says on/off obviates the need for the operator to know which way to move the switch; after using the switch a few times the user no longer needs the label. Warning signs on the edge of the Grand Canyon caution the adventuresome tourist to "Be careful." Labels on food and drugs present a frequent challenge to manufacturers who have to strike a delicate balance between advertising their product and avoiding the consequences of misuse. An augmented reality example is the yellow line on the computer screen to mark the ten yards needed for a first down in football and the chains which are the (10) yardstick. In this example, the facilitator is used regularly, because the human judgment of the 10 yards is unreliable. On the International Space Station, the crew members have to perform many complex system and payload tasks and respond to contingencies which may escalate into emergencies. The complexity of these tasks is addressed by extensive training and the even more extensive use of facilitators. The usage and utility of facilitators (such as procedures) depends on the degree and currency of training at the knowledge, rule or skill level (Rasmussen, 1987 – *Cognitive Control and Human Error Mechanisms* in *New Technology and Human Error* edited by J, Rasmussen, K. Duncan and J. Leplat). At Christmas time, parents are often faced with the dreaded messages "some assembly required" and "read me first." Mothers do as they are advised; fathers, who know about these things, put the instructions on one side.

The key, as with medicine, to good facilitator design is to "first do no harm." Harm in this context includes inaccurate, cumbersome, and untimely advice. However, this raises another common human factors' engineering dilemma – the speed-accuracy tradeoff. Commonly instruction and procedure designers err on the side of accuracy, by expanding detail, and sacrifice speed. Conversely, label and warning designers often favor speed (or space conservation) in their use of acronyms and symbology, and may sacrifice accuracy, and, because of the subsequent need for recovery, ultimately, they may also sacrifice time. Perhaps the greatest mistake made by designers is the pseudo sacred cow of standardization. There are two fundamental reasons why standardization is not universally useful in facilitator design. First, not all problems are alike and second, not all users are alike. Trying to fit a medical emergency procedure into the same format as a hardware maintenance or assembly procedure begs the question of the level of training and knowledge of the user. Also, the obsession of many organizations with technical jargon and acronyms often overestimates the knowledge of the non-specialist user. A prime example of this issue is with the international crews on board the ISS, whose language differences impair the effectiveness of acronyms. On the other hand, certain conventions and forms of standardization have their place – a prime example being the familiar "Windows" interface.

The Human Factors Approach

The human factors engineering community approaches this challenge of the bridge between engineering or operational designs and the user in a number of ways. The first level is through the design of the permanent displays and controls that are normally essential for successfully carrying out a transaction or procedure. The second step is to carry out a task analysis that addresses the sequences of information and actions that comprise the transaction, including the human and system contributions. The third step is to assess the conditions and context of the transaction(s). The fourth step addresses the knowledge and skills of the intended user – it should be noted here that users' capabilities change with practice and may fluctuate with the conditions under which a particular transaction takes place. The final analytical step is to evaluate expected use and possible misuse of the interface or procedure. This step should involve formal "usability testing," in which users of varying degrees of knowledge, skill and experience perform representative tasks, under a variety of conditions and contexts with a candidate set of facilitators. Facilitators should first be designed with due regard to the expected users, possible misuses, and likely conditions, and should then be subject to formal evaluation.

These analytical activities lead to the design of facilitators to fill the knowledge and skill gaps. Because conditions and users vary, it is necessary to include flexibility in facilitator design, while remembering the important rule: "first do no harm." In the context of facilitator (e.g. procedure) design, 'harm' includes both inappropriate action as a result of the design, with various possibilities of outcome from minor inconvenience to catastrophe, and unnecessary delays in the transaction caused by the verbatim following of the procedure. It should be noted that errors in the use of facilitators (procedures) commonly cost recovery time, which in turn may lead to catastrophe in a time constrained condition, lack of productivity or simply frustration in "being treated like a child." Unfortunately, these possible outcomes are affected in their likelihood by the particular user, conditions and contexts, thus making evaluation a probabilistic process at best.

Some Cases

In case the reader is skeptical about this discussion he should consider the NW255 accident at Detroit Metro Airport in 1987:

About 2046 eastern daylight time on August 16, 1987, Northwest Airlines, Inc., flight 255 crashed shortly after taking off from runway 3 center at the Detroit Metropolitan Wayne County Airport, Romulus, Michigan. Flight 255, a McDonnell Douglas DC-9-82, U.S. Registry N312RC, was a regularly scheduled passenger flight and was en route to Phoenix, Arizona, with 149 passengers and 6 crewmembers.

Of the persons on board flight 255, 148 passengers and 6 crewmembers were killed; 1 passenger, a 4-year-old child, was injured seriously. On the ground, two persons were killed, one person was injured seriously, and four persons suffered minor injuries.

The National Transportation Safety Board determines that the probable cause of the accident was the flightcrew's failure to use the taxi checklist to ensure that the flaps and slats were extended for takeoff. Contributing to the accident was the absence of electrical power to the airplane takeoff warning system which thus did not warn the flightcrew that the airplane was not configured properly for takeoff. The reason for the absence of electrical power could not be determined.

In this instance, the use of a checklist – a facilitator – was complicated by the crewmembers' considerable familiarity with the procedure, a failed warning system (another facilitator) and the unforgiving context.

Closer to the interest of space human factors are the comments from an astronaut.

The biggest issue with all of the Payload experiments from a Human Factors perspective is that the procedures are too lengthy and are not clear (they read more like an airplane checklist as opposed to furniture assembly). The crewmember thinks they need to use fewer words and more line diagrams/drawings. They perceived this as a common problem for all payload procedures during training and on-orbit. The procedures typically resulted in very slow and inefficient operations (ex. was 20 pages telling how to remove a screw.). They mentioned that they did *comment about this in other briefings also. They stated that someone should take ownership of this issue and coordinate with all payload developers to simplify their procedures.*

A lot of time and productivity is lost when the crew must follow airplane checklist-style procedures (e.g. Medical, Payloads, and IFM.) This style of procedure writing increases the chance of errors. Simple, clear, line drawings with a few words are best for efficient procedures.

But the biggest issue with Payloads is that too many acronyms in a multi-lingual environment will cause confusion among the international crewmembers. It was not a problem of inaccurate/incomplete acronyms, but that there were "way too many" acronyms used for the hardware. They suggested that it should be stressed to the engineers to not use acronyms if possible and to spell out a name that describes what the hardware/system is and "stick with it".

Previous Work

Bailey (1982) – *Human Performance Engineering: A Guide for System Designers* - presented an extensive discussion of facilitators, including their role in supporting human performance, selection of facilitators, the design of instructions (procedures) and other performance aids. Facilitator designers who heed Bailey's advice and rules of thumb will go a long way towards achieving acceptable facilitators, but it is clear that many designers do not consider this advice or use their own flawed common sense to supplement their designs with facilitators. There are many other examples of "good" labels, warnings and instructions, often stimulated by "failure to warn" lawsuits. An extensive bibliography of research in this area is contained in Miller, Lehto and Frantz (1990) – *Instructions and Warnings- An Annotated Bibliography.* The American National Standards Institution (ANSI) and the International Standards Office (ISO) both offer extensive guidance on instructions, warnings, and labeling, usually in domain specific contexts.

http://www.ansi.org/
http://www.iso.ch/iso/en/ISOOnline.openerpage

NASA Standard 3000 (6.4.3.3.4) states simply that "Warning labels shall be provided where potentials are hazardous to crewmembers."

Despite this extensive activity, facilitators (labels, warnings, instructions, and procedures) continue to be a major source of system failure, inefficiencies and personal frustration in many domains.

Research, Measurement and Analysis

Whereas there are many "rules of thumb" for facilitator design there is no robust theory of the pervasive role that they play in everyday life and particularly in technical areas. Such a theory must address level of complexity, outcome / recovery importance, human and contextual variability, including learning, and the speed-accuracy tradeoff. Measurement of the use and utility of facilitators must consider the human capabilities to learn and forget. Analysis of facilitators requires tools that can be used both by researchers and designers to evaluate the effectiveness of alternative ways of aiding human performance.

Another research opportunity lies in understanding the relative roles and interactions among of system designs, human learning, and facilitators. For example, facilitators can become crutches that interfere with knowledge or skill acquisition and result in human performance shortcomings in the absence or other deficiencies of the facilitator. Reliance on contemporary vehicle navigation technology is a case in point.

Modeling and Development

A simple model of a facilitator places it between the varying demands of a system design and the varying capabilities of the human operator, with the purpose of assuring that the human capabilities will not fall short of system demands. Such a model although conceptually meaningful fails to capture the specific form and content of a facilitator, given the environment of complexity and variability.

Requirements and Design

The literature cited earlier presents many considerations, guidelines, and standards for the design of facilitators, but these are rarely supported by clear system performance requirements. Consequently, many facilitators are designed as an afterthought and are refined iteratively following untoward incidents or user comments. Most facilitators are static in nature and do not address the changing needs of users as they become more familiar with system behavior. There is a need therefore to develop facilitator performance requirements and detailed system and facilitator design specifications to assure safe and productive human performance.

Implementation and Evaluation

All system design processes should require the integrated design of facilitators along with formal assessment of expected human performance and performance variability. The changing role of facilitators should be evaluated as the system is validated in an analog or operational context. Formal guidelines and evaluation protocols are needed for the implementation of facilitators.

Integration

Facilitator design needs to be formalized and integrated into the system design process. This integration requires answers to the research, modeling, design and evaluation questions described in the previous paragraphs.

Opportunities for Focus

There are many opportunities in which facilitators play a key role in system effectiveness and efficiency. The first area is in the management of its complex activities and its notorious reliance on acronyms, despite the often-observed speed accuracy tradeoff. As in aeronautics, space operations rely heavily on procedures and esoteric jargon for its vehicle operations. Assembly and maintenance of space vehicles is engulfed in labels, acronyms, instructions, and procedures all of which contribute to the possibility of catastrophic system failure, inefficiencies, and inconvenience. Space vehicle payloads are notorious for their use of cumbersome and inconsistent procedures. Finally, the medical treatment procedures, full of jargon in English and Russian, and supported by minimal training, are a time bomb waiting to explode.

Chapter 12

Failure To Warn – The Role of Facilitators

This article is about the role of devices such as labels, warnings, instructions, procedures, checklists, tutorials and augmented reality that are not essential to the operation of a system but whose function helps to ensure appropriate use and to prevent misuse. Often these facilitators are temporary in that, after experience with the system, the user can perform satisfactorily and safely without their help. ***A facilitator is a temporary device that aims to supplement the user's knowledge or current situation awareness to ensure an accurate and timely transaction and prevent misuse. Unfortunately, the facilitator itself may sometimes be a precipitating cause of system failure.***

Previous Work

Bailey (1982) presented an extensive discussion of facilitators, including their role in supporting human performance, selection of facilitators, the design of instructions (procedures) and other performance aids. Facilitator designers who heed Bailey's advice and rules of thumb will go a long way towards achieving acceptable facilitators, but it is clear that many designers do not consider this advice or use their own flawed common sense to supplement their designs with facilitators. There are many other examples of "good" labels, warnings and instructions, often stimulated by "failure to warn" lawsuits. An extensive bibliography of research in this area is contained in Miller, Lehto and Frantz (1990). The American National Standards Institution (ANSI) and the International Standards Office (ISO) both offer extensive guidance on instructions, warnings, and labeling, usually in domain specific contexts: http://www.ansi.org/, http://www.iso.ch/iso/en/ISOOnline.openerpage

Despite this extensive activity, so-called 'facilitators' continue to be a major source of system failure, inefficiencies and frustration in many domains.

Labels

Contemporary airplanes, cars, process control operating consoles and home electronic equipment may be adorned with very many functions, features and associated displays and controls. Furthermore, different equipment brands that perform similar functions may sport different interfaces, although standardization of interfaces for very common functions sometimes foils the designer's attempts at using the interface as a mechanism for product differentiation. Whereas the foot pedals and steering wheel in a car do not need labels (although that extra pedal to the left of the brake has been known to confuse drivers faced with a manual transmission for the first time), the knobs and dials associated with many other vehicle systems such as climate control and entertainment usually have to share valuable real estate with labels.

This competition for real estate between the labels and the controls and displays often results in a one-sided compromise by the labeling department. The initial compromise is to reduce the label to some cryptic word or phrase that captures the essential function of the parent system and sometimes the operational alternatives, such as "- VOLUME +". A further compromise may employ an abbreviation and a smaller font, such as "VOL" with the hope that a clockwise rotation of the associated knob has a strong enough population stereotype. The enterprising facilitator designers sometimes fight back by substituting incomprehensible acronyms or obscure icons for the too large label.

Warnings

Where inappropriate function or feature use or use of a system in an inappropriate context has implications that may damage the user, system, or environment then it may be necessary to warn the unwary users to behave themselves. ***Classical guidelines for this class of facilitators require that the warning should attract attention, identify the hazard, spell out the implications of improper use, suggest appropriate behavior, identify inappropriate behavior and provide guidance to the user in the event that things go wrong.*** There are many euphemisms and synonyms for the word 'warning' such as 'danger', 'caution' or 'be careful!!' Some companies are averse to the expression 'danger' as they do not wish to admit that their product (if used correctly) can be dangerous. Other conventions add colors such as yellow and red to these words to indicate the relative severity of outcomes associated with inappropriate actuation.

A common extra purpose of warnings, by whatever name, is to remind the user that they had been warned about the implications of inappropriate use, thus rendering the equipment designers innocent of any wrongdoing – "we told you so!" Warnings may take the form of simple labels close to the point of operation or they may be contained in the small print of the owner's manual. Either way, rule number one is generally assumed – "we told you so!"

Instructions

Users of complex equipment, such as children's toys, are often faced with the threat that "some assembly is required." Many fathers throw away the pamphlet that is found immediately under the lid of the packing box and proceed to spend most of the day and night discovering the correct assembly or operational sequence. Fathers who have been bitten before start with instruction number 1 and proceed stepwise and successfully through the assembly sequence and still have time to play with the toy before bedtime. Instructions generally contain both labels of the components and warnings of incorrect actions. Instructions also contain greater detail of assembly or operational sequences.

The instruction designer is faced with riches and tools way beyond the limited imaginations of labels and warnings designers. Where the icon or warning label may consist of pictures that represent somewhat less than a thousand words, the instruction manual for my cellular telephone contains many thousands of words and a plethora of lists, pictures and diagrams that allow me to pass the time while driving at speed on the busy suburban freeway. All I wanted to know was which button I should press to answer the incoming call! Perhaps the Nobel Prize for instruction writing should go those intrepid designers of the instructions for dealing with a flat tire in a rental car, on the freeway, in the rain, at night. Perhaps the first instruction for flat tire replacement should read: "Use your cell phone to call AAA."

Procedures

Procedures generally consist of a super set of instructions that each deal with one of many interacting subsystems. For example the procedure for staring a car requires that the operator should start by arranging his or her workplace, including seats, mirrors and seat belts; next the driver interacts with the ignition system, having first been cautioned to check the status of the transmission and braking systems; finally he is referred to the troubleshooting section of the owner's manual that deals with dead batteries, which should probably contain a link to the page in the cell phone manual that provides access to the universal automotive problem solver – "AAA." The usage and utility of facilitators (such as procedures) depends on the degree and currency of training at the knowledge, rule, or skill level (Rasmussen, 1987).

If subsystem instructions may sometimes be somewhat long winded the procedure writer is the emperor of complexity. A challenge for procedure writers is to anticipate all possible sequences and failure modes. ***Their tool of choice is the flow diagram with logical branches*.** The key, as with medicine, to good facilitator design is to "first do no harm." Harm in this context includes both inaccurate and untimely advice. However, this raises another common human factors engineering dilemma – the speed-accuracy tradeoff. Commonly instruction and procedure designers err on the side of accuracy, by expanding detail, and sacrifice speed. Inevitably operators with a little more than basic knowledge may jump around and ahead and amalgamate many steps in one. Perhaps the most instructive examples of procedures are those devices that aspire to instruct lesser trained technicians and anxious parents in medical diagnosis and treatment of excessive infantile lachrymosity: First check the waste disposal subsystem – does the baby need a change of diaper? Next check the fuel input subsystem – is the baby hungry? Then check the food processing subsystem – does the baby need to burp? Finally check the emotional subsystem – does the baby want a hug? If none of these subsystems appears to be at fault, then check your cell phone memory for your mother's number.

The American Heart Association procedure for advanced cardiac life support (ACLS) may be used by knowledgeable lay people, emergency medical technicians and emergency room physicians:

http://www.acls.net/aclsalg.htm&rURL

The procedure must contend with complex differentiation among choking, stroke, heart attack and poisoning symptoms; it is also time critical and the outcome may be catastrophic. The procedure must also deal with fuzziness and dominance in that some symptoms may not be as clear differentiators as others. Whereas procedures must be correct, sometimes this obsession with precision may result in temporary fatigue or impatience among users with the result that the procedure becomes both inefficient and ineffective.

Checklists

Checklists are to procedures as labels are to instructions. The key to a checklist is that it should be succinct while assuring that the user follows each step-in sufficient detail. A classic failure of checklists is that an item may not stimulate sufficient analysis by the user before moving on to the next step. If the box is checked it is assumed that the necessary analysis has been done. One strategy for managing the weekly visit to the grocery store is to systematically walk up every isle and select those things that attract your attention. The more experienced shopper makes a checklist ahead of time only to find that the arrangement of the produce in the store is not compatible with the order of items in the checklist with the result that the shopping trolley may be pushed further than if a systematic store scanning strategy were adopted. Over time however the shopper learns to visit the key (well labeled) isles using a mental checklist and ignore the others, thus making the visit more efficient. But the cunning supermarket designer is still one step ahead by using free food samples and coffee to attract the buyer to otherwise less popular products.

Tutorials

Complexity is inversely related to learning. A first-time user of a digital camera, with all its features, behaves and performs very differently from an experienced photographer who transfers knowledge from his or her previous experiences with traditional cameras. ***The purpose of tutorials is to bring the inexperienced user up to a level of knowledge sufficient for effective, efficient and safe operation of the product in question.*** It is common for the tutorial to consist of basic operation theory, some application examples and sometimes some situations where inappropriate actions may lead to system failure or damage. The use of tutorials and walkthroughs has boomed with the growth of software packages and even some complex web pages. Some tutorials contain diagnostics that identify inappropriate actions and guide the learner towards better actions. Poorly designed tutorials, like navigation instructions provided by homeowners familiar with their environs, may only address correct actions, with the result that the unfortunate user once lost may become very lost.

Augmented Reality

Perhaps the most sophisticated of all facilitators, next to an experienced human guide, is the exciting set of technologies called “augmented reality.” A familiar example is the yellow line on the television screen that identifies the target for the next ‘down’ in football. This line gives the settee bound spectators an advantage over the referees, who only have old-fashioned chains (and a little judgment) to measure forward progress. But for the spectator, this yellow line greatly enhances their situation awareness.

Exciting new uses of augmented reality include combinations of computers and cameras to view the outside of a device and then show schematic details of the contents of the box, together with diagnostic and maintenance advice. Even more exciting is the use of augmented reality for medical diagnostics and intervention. These facilitators enable the doctor to view the normal underlying anatomy, together with examples of possible pathology and even simulations to answer “what if” questions.

It used to be joked, “to err is human, but if you really want to mess up big time then you should use a computer”. Augmented reality technology clearly faces these challenges. Imagine being presented with a map of London, England on your vehicle’s windshield while you are driving at speed through London, Ontario.

One Case

In case the reader is skeptical about this discussion he or she should consider the NW255 accident at Detroit Metro Airport in 1987:

About 2046 eastern daylight time on August 16, 1987, Northwest Airlines, Inc., flight 255 crashed shortly after taking off from runway 3 center at the Detroit Metropolitan Wayne County Airport, Romulus, Michigan. Flight 255, a McDonnell Douglas DC-9-82, U.S. Registry N312RC, was a regularly scheduled passenger flight and was en route to Phoenix, Arizona, with 149 passengers and 6 crewmembers.

Of the persons on board flight 255, 148 passengers and 6 crewmembers were killed; 1 passenger, a 4-year-old child, was injured seriously. On the ground, two persons were killed, one person was injured seriously, and four persons suffered minor injuries.

The National Transportation Safety Board determines that the probable cause of the accident was the flightcrew's failure to use the taxi checklist to ensure that the flaps and slats were extended for takeoff. Contributing to the accident was the absence of electrical power to the airplane takeoff warning system which thus did not warn the flightcrew that the airplane was not configured properly for takeoff. The reason for the absence of electrical power could not be determined.

In this instance, the use of a checklist – a facilitator – was complicated by the crewmembers’ considerable familiarity with the procedure, a failed warning system (another facilitator) and the unforgiving context.

The Human Factors Approach

The human factors engineering community approaches this challenge of the bridge between engineering or operational designs and the user in several ways. The first level is through the design of the permanent displays and controls that are normally essential for successfully carrying out a transaction or procedure. The second step is to carry out a task analysis that addresses the sequences of information and actions that comprise the transaction, including the human and system contributions. The third step is to assess the conditions and context of the transaction(s). The fourth step addresses the knowledge and skills of the intended user – it should be noted here that users’ capabilities change with practice and may fluctuate with the conditions under which a particular transaction takes place. The final analytical step is to evaluate expected use and possible misuse of the interface or procedure. This step should involve formal “usability testing,” in which users of varying degrees of knowledge, skill and experience perform representative tasks, under a variety of conditions and contexts with a candidate set of facilitators. ***Facilitators should first be designed with due regard to the expected users, possible misuses, and likely conditions, and should then be subject to formal evaluation.***

These analytical activities lead to the design of facilitators to fill the knowledge and skill gaps. Because conditions and users vary, it is necessary to include flexibility in facilitator design, while remembering the important rule: “first do no harm.” In the context of facilitator (e.g. procedure) design, ‘harm’ includes both inappropriate action as a result of the design, with various possibilities of outcome from minor inconvenience to catastrophe, and unnecessary delays in the transaction caused by the verbatim following of the procedure. It should be noted that errors in the use of facilitators (procedures) commonly cost recovery time, which in turn may lead to catastrophe in a time constrained condition, lack of productivity or simply frustration in "being treated like a child." Unfortunately, these possible outcomes are affected in their likelihood by the particular user, conditions, and contexts, thus making evaluation a probabilistic process at best.

Research, Measurement and Analysis

Whereas there are many "rules of thumb" for facilitator design there is no robust theory of the pervasive role that they play in everyday life and particularly in technical areas. Such a theory must address level of complexity, outcome / recovery importance, human and contextual variability, including learning, and the speed-accuracy tradeoff. Measurement of the use and utility of facilitators must consider the human capabilities to learn and forget. Analysis of facilitators requires tools that can be used both by researchers and designers to evaluate the effectiveness of alternative ways of aiding human performance.

Another research opportunity lies in understanding the relative roles and interactions among of system designs, human learning, and facilitators. ***For example, facilitators can become crutches that interfere with knowledge or skill acquisition*** and result in human performance shortcomings in the absence of or other deficiencies of the facilitator.

Modeling and Development

A simple model of a facilitator places it between the varying demands of a system design and the varying capabilities of the human operator, with the purpose of assuring that the human capabilities will not fall short of system demands. Such a model although conceptually meaningful fails to capture the specific form and content of a facilitator, given the environment of complexity and variability.

Requirements and Design

The literature cited earlier presents some considerations, guidelines, and standards for the design of facilitators, but these are rarely supported by clear system performance requirements. Consequently, many facilitators are designed as an afterthought and are refined iteratively following untoward incidents or user comments. Most facilitators are static in nature and do not address the changing needs of users as they become more familiar with system behavior. There is a need therefore to develop facilitator performance requirements and detailed system and facilitator design specifications to assure safe and productive human performance.

Implementation and Evaluation

All system design processes should require the integrated design of facilitators along with formal assessment of expected human performance and performance variability. The changing role of facilitators should be evaluated as the system is validated in an analog or operational context. Formal guidelines and evaluation protocols are needed for the implementation of facilitators.

Integration

Facilitator design needs to be formalized and integrated into the system design process. This integration requires answers to the research, modeling, design and evaluation questions described in the previous paragraphs.

Failure to Warn

The products liability law courts are full of plaintiff's attorneys pointing out the need for a facilitator – such as a label, warning, or instructions – after an accident. The defense counters by pointing out that the warning is in the user's manual or that the proliferation of warnings can be ineffective at best and counterproductive at worst. Where the amount of space available for a facilitator on a product is limited then the designer must resort to additional devices, such as instruction manuals. Contemporary vehicles employ computer technology to provide "just in time" facilitator information.

Expected use and Foreseeable Misuse

Design should address expected use and foreseeable misuse. For example a step ladder is used to obtain access to high places and Murphy's Law causes the item of interest to be just out of reach when the handyman gets to the next to top step which is adorned with the caution: "Do not use this step as a step!" In legal jargon this may be termed "an attractive nuisance." Some time ago a leak was caused on the International Space Station because a wiring harness that looked like a handle was placed right where a handle would be most useful.

Clear and obvious

A facilitator is not needed where the assembly, operation or hazard is "clear and obvious". Some naïve lawyers have been known to add "to the average user." The human factors profession has pointed out on many occasions the obvious fact that catering for the average user will not address the needs of half the user population. Other population accommodation strategies insist on eighth grade or fifth grade reading levels, which goes some way towards helping the less capable but often faces the need for esoteric jargon on products. Some time ago I offered a suggestion that the simple mechanics associated with a seat belt were clear and obvious – when you recline the car seat back, the seat belt will not work. Since that time, I have surveyed many intelligent people, including some engineers, who say that they "just don't think about physics when they want to take a nap in the passenger seat." **What is clear and obvious with hindsight may not be so before the event. What may be clear and obvious to the designer or experienced user may not be clear and obvious to the less experienced user.**

Usability Testing

Facilitators are made for human factors student projects – either for test and evaluation of existing facilitators or to try out some theory of attention, perception, or compliance with novel approaches. These projects sometimes address the issue of ecological validity – they test the facilitator with real people under realistic conditions of physical and time stress, and distraction. Also, it should be noted that a successful usability test does not necessarily predict all possible failure modes – It may be infeasible to address some contexts of use and conditions of users, such as inebriation.

Conclusions

Ideally systems should be designed for effective, efficient, and safe use without the aid of facilitators (labels, warnings, instructions, procedures, checklists, tutorials, augmented reality). This ideal is largely true for simple systems and experienced users. Systems should also "fail safe" so that misuse by the user is forgiven. But these ideals are usually unrealistic in practice so facilitators will always be needed. As with necessary system interfaces, the utility of facilitators is probabilistic, and it is unlikely that we will ever accommodate all the users all of the time. But we can try by integrating formally the use of facilitators in system design and evaluation.

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Chapter 13

Taylorism Revisited: Design for the Elderly

Frederick Winslow Taylor wrote "The Principles of Scientific Management" (Harper Row, 1911). This work had two major outcomes. First Taylor was demonized for his expressed views that workers are "naturally lazy", "practiced systematic soldiering" and that "a pig iron handler (Schmidt) more nearly resembles in his mental makeup the ox …. and is unable to understand the real science of doing this class of work …. and must be continuously trained by a man more intelligent than himself ….in accordance with the laws of this science." He noted that "ingenuity and incentive" by the employee alone was not sufficient to achieve progress in work method improvement. On the other hand Taylor made many statements that have given rise to contemporary ergonomics and industrial practice including: friendly collaboration between management and workers, comprehension of human variability, the value of extensive empirical data, experimental design, the application of biomechanical principles to equipment and work design, physical fatigue and the value of rest periods, the value of appropriate training, selection and assignment, continuous improvement, learning curves in process improvement. Perhaps the most perceptive of Taylor's statements was that the objectives of management are maximum prosperity for both the employer and the employee.

Henry Ford applied the principles of systematic job simplification to the automobile production line which led to massive productivity increases and cost reductions in most modern manufacturing organizations. One of Henry Ford's principles was that "work should be brought to the worker." This principle eventually gave birth to contemporary practices in lean manufacturing through the elimination of waste of all forms. Taylor and Ford's approach was extended by Frank and Lillian Gilbreth who created a science out of time and motion analysis, which led to contemporary production line planning and balance.

The Hawthorne experiments in the 1920s showed that workers in the … factory responded to interest and attention to their condition rather than the actual changes to the factory lighting. In the 1960s Hezberg suggested that people were motivated by intrinsic job content but could be demotivated by "hygiene" or contextual factors. Recently the Kano approach, developed for product and service design, was applied to work design with a result that, for relatively menial physical tasks elderly employees were motivated by "remaining active", collegiality at work, and remuneration. (Peacock et al, 2014).

What then does this brief account of management have to do with employment of elderly Singaporeans? The first message from Taylor is that enhancement of the gainful employment of elderly Singaporeans requires collaborative efforts between both parties, based on reliable evidence. A recent study (Peacock et al 2014) demonstrated a commonly observed fact that people are different in their physical abilities and that age *per se* is less of an issue than physical capability.

The Philosophy

Taylorism is a top down, but participative approach to management. Taylor emphasized the importance of a friendly collaborative relationship between employers and employees. The purpose of Taylorism is maximum prosperity for employers and employees through scientific management. Taylor emphasized strongly, perhaps too strongly, that management may know more about the science and big picture associated with a job, but that the employee may have useful local or domain knowledge. Taylor's pig iron handler, Schmidt, may have been characterized as "dumb as an ox" but he had the "ingenuity and incentive" to provide for his family in a progressive way. The application of scientific management was aimed at enhancing Schmidt's capability.

The formal development of ergonomics over the second half of the 20th century was aimed at the measurement of human capabilities and limitations and application of this knowledge to the design of equipment, workplaces, tasks and environments. A somewhat simplistic rule of thumb suggested an accommodation of 90% or 95% of the target population, given a certain degree of selection, training and assignment of that population. In certain, safety critical, situations, the accommodation levels were increased to 99% or even higher. An outgrowth of ergonomics – "universal design" had the grand aim of accommodating 100% percent of the population. Of course these accommodation targets were situation specific and constrained by feasibility and pragmatism. For example, if the "walk" light at a traffic intersection were set to accommodate the walking speed of the first percentile, then there would be no flow of traffic. The solution to this simple example is to provide alternative accommodations to the slower walkers, such as adaptive signals, motorized help or bringing the desired service to the individual concerned, thus obviating the need for crossing the road.

In the strictest sense "ergonomics" is the "science" referred to by Taylor. The *raison d'etre* and the Achilles Heel of ergonomics are human, technological, situational, and temporal variability. The essential tools of ergonomics are Statistics. The outcome of ergonomics design or intervention may be effectiveness, efficiency, ease of use, esthetic appeal, safety, security, satisfaction or sustainability (Peacock). An ergonomist may aim his / her recommendations at any one or more of these objectives. However, the tradeoffs among these objectives are the prerogative of management. Using the crossing example, traffic lights are indeed effective, but the optimization between vehicle and pedestrian waiting times is a management decision. A completely safe solution would be to add physical barriers, for both vehicles and pedestrians, at crossings to prevent system failure by inappropriate behavior by any of the interested parties. This solution is used at rail crossings, but would be prohibitively costly, both in construction and operation, for traffic intersections. It is the duty of the ergonomist to present the, albeit, probabilistic alternatives; management will always be responsible for decision making.

In the 1980s and 1990s the Toyota Production System and similar industrial developments highlighted the value of participation by management and workers in such entities as quality circles, product development teams and plant ergonomics teams. This philosophy has continued both within industry and through tripartite agreements, and through the recommendations of the International Labor Office. The underlying philosophy, as in Taylor's writings, is that the worker has important domain knowledge to complement the scientific and higher-level knowledge of management. Schmidt was a particularly good handler of pig iron. These practices – team structures with membership from all interested parties have much to offer to the challenges of design for and management of elderly Singaporeans.

Elderly Singaporeans are like elderly people in many countries, they generally deteriorate physically, mentally, and socially. But there is enormous individual variation in this deterioration and in the residual capabilities and limitations. Indeed, many old people are more capable in many ways than their younger cohorts. Consequently, chronological age should not be a universal surrogate for individual capabilities and limitations. The Marxist philosophy "from each according to his ability, to each according to his need," is a more apt description of the ideal (management, ergonomics, design) philosophy. One size does not fit all!

The safety community uses a different approach to dealing with "hazards." They propose engineering and administrative controls, based on risk level, exposure and consequences of system failure. The highest level is to remove the hazard where feasible. In the road crossing example this is achieved by creation of pedestrian precincts. The second level is substitution – bridges and underpasses are an example, but many people cannot climb the steps. The third level is through physical or operational barriers – cars and pedestrians are segregated in space and time; this is a common practice in most cities. Administrative controls include warnings, training and personal protective equipment. Both vehicles and pedestrians are inundated with warnings and instructions, which from time to time they choose to ignore. Training is an interesting alternative, perhaps we should send elderly people to the gym so that become capable with dealing with acts of daily living, such as crossing the road quickly. The last resort, personal protective equipment, presents interesting solutions; car drivers are required to fasten their seat belts and cyclists must don their helmets; perhaps elderly people should be required to wear amour.

Singapore is a strong, paternalistic country that comprehends the management responsibility to encourage maximum prosperity for all and to deal appropriately with the vulnerable members of society, such as the elderly. The tools to support this management responsibility stem from Taylor's methods, ergonomics, participative processes, the hierarchy of controls and the perceptive Marxist philosophy "from each according to his ability to each according to his need", couples with sound statistical methods to deal with the ubiquitous fact of human, technological, situational, and temporal variability.

The practice

People vary on physical, sensory, cognitive, and affective dimensions. They are also differentially sensitive to the physical, operational, social, and temporal environment. Physically people vary in size, shape, strength, speed, stamina, and skill. Sensory variation is very evident among elderly people in visual, auditory, olfactory, and tacto-kinesthetic functions; many old people die or are injured by falls stemming from these sensory failures. Cognitive slowing is complex but demonstrated by attentional deficits, memory lapses and slowed and habitual decision making. Socially elderly people may be isolated because of family commitments, mobility limitations and reluctance to explore new relationships. Older people certainly have esthetic or "likability" opinions, but often these are based on historical prejudices. Contemporary technology and operations present widespread opportunities to accommodate these human capabilities and limitations. These technological and operational opportunities (engineering and administrative controls) require participative processes to identify the issues and management decisions to remove or mitigate the hazards.

Management Decisions a Case Study

In 1988 General Motors initiated a program to design a car, dubbed "The Access Car", to accommodate the needs and wants of elderly drivers and owners. The management motives were two-fold. First, they recognized that by addressing the many ergonomics issues in car design, they would accommodate a greater number of users. Secondly, such accommodations would lead to a greater number of sales of vehicles to members of this generation who were often retiring and who had sufficient funds to buy a new car. Thus, management decisions were driven by market opportunity as well as by the many improvements in system design that could spread to other products. The research approach was through analysis of safety statistics, surveys, laboratory testing, customer clinics, focus groups and closed-circuit driving investigations. There were more than 100 design innovations developed through this program, many of which led to current designs.

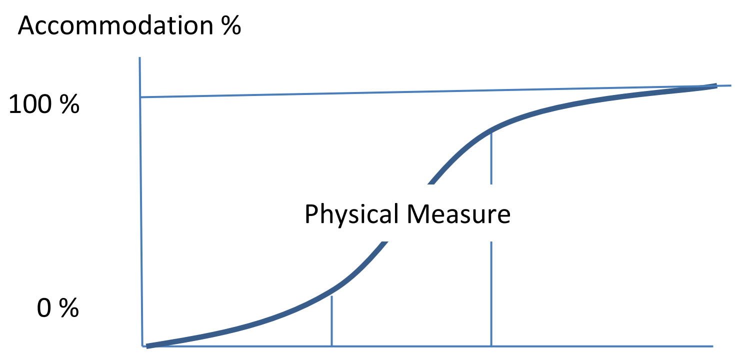
Examples of designs addressed user physical activities such as entry and egress, storage, seat comfort, controls operation and servicing. An issue stemmed from the identification of interactions among driving posture, lower limb mobility and strength, and foot pedal actuation. These issues were addressed by laboratory and closed-circuit driving investigations that identified the underlying factors associated with unintended acceleration. Sensory and cognitive issues included display and control design, night driving, windshield clearing and the design of owner's manuals. Operational factors included a keyless entry and ignition system and a GPS based emergency communication system which was a prototype for the current OnStar navigation and support service. Social issues of ownership vs leasing, together with the management of insurance, taxation and servicing were particularly useful facilitators for this generation of car owners. In the end it was the marketing / affective factors that led to the ending of the program after two years. The stigma of "an old man's car" was thought to be a marketing problem, although the subtle introduction of many of the individual concepts into other vehicle models spoke for the ultimate success of the program.

Design for Elderly Singaporeans

The results of preliminary investigations of the physical and sensory characteristics, capabilities and limitations of elderly Singaporeans are documented elsewhere (Peacock et al 2014). These studies also included questionnaire approaches, using the KANO principles, that explored factors associated with jobs carried out by elderly Singaporeans and introspection regarding individual capabilities related to these jobs. One strong result of the laboratory studies was the large between participant variability of physical capabilities and limitations that clouded the, approximately one percent per year, decline due to age. Other results, of the questionnaire investigations, were that social and economic factors were extremely important to the participants followed by operational and physical job content factors. These studies are being followed up by objective assessment of the job physical demands, including the temporal variation. This investigation confirms observation, made 100 years ago, by Taylor that strategic rest breaks can lead to greater productivity. Similar observations made in production line environments have led to the successful implementation of team structures, job rotation and horizontal and vertical job enlargement. It should be noted in this context that the concept of "job enrichment" should be viewed both from the managers' and employees' viewpoints, which may be markedly different.

The GM Access car ergonomics program offers a model for an approach to the design of equipment, workplaces, tasks and jobs for elderly Singaporeans. The investigative phase, both objective and subjective is well under way. The next phase involves design, followed by evaluation. In this context due recognition must be given to the observations of the Hawthorne studies – overt interest in and attention to the work of any cohort will strongly influence the subjective, if not the objective, responses. A second proviso, also offered by Taylor is that the investigative tools from a deep ergonomics toolbox, should lead to a scientific that is reliable, set of findings. The third, and perhaps the most important, issue may be the reluctance of management to invite active participation by the employees in intervention selection and implementation. In the product design context, also articulated by Taylor as friendly collaboration between employers and employees, reliable solicitation of the voice of the customer is a marketing must. The ACCESS car program was multi-faceted, involving the full spectrum of human characteristics, capabilities, and limitations, and applied a spectrum of tools to the extraction of the voice of the customer.

Given the fundamental variability of people, equipment, workplaces and operations design recommendations will be a two-step process. First the relationship between an objective, perhaps complex, design variable and the effect on or perception by the user will be represented by an ogive. That is low values of the objective, designable, measure will accommodate most of the target population and high values will only accommodate a minority. The second step – establishing the parameters of this ogive – high and low design cut off points – will be set by consensus of interested parties, through a participative process.



Chapter 14

Another two cases

Down the steps with crutches

Therapists are often tasked with teaching recovering orthopedic patients (of all ages and abilities) to walk with crutches to improve mobility (and mood) while eliminating or reducing weight bearing on the affected leg. The crutches may be the traditional full length ones (adjusted so the pad is not pressing into the axilla), they may be elbow crutches which provide greater mobility but less support or they may be walking sticks which are mainly used for balance rather than support. The rehabilitation progression goes from level floors to ramps and finally up and down stairs.

The basic principle is to always have support triangles, with the two crutches moving with the affected leg and the "good" leg making the triangle in front or behind. On stairs, for stability reasons, the accepted protocol is to move both crutches into one hand and use the free hand to grasp a fixed banister rail; again, the principle of triangular support for stability is important. The role of the therapist is to be always "below" the patient to actively increase the base of support. An alternative procedure, where there is no rail, is for the therapist to act as an active surrogate for the rail while moving down ahead of the patient, relative weight and strength being considered. A common hazardous situation is when patients do not use the banister and retain the crutches in both hands. This produces opportunities to remove the "triangle" and create unstable, dynamic positions.

On the occasion in question the therapist had taken an advanced and confident patient into the hospital gardens for a change from the rehabilitation gymnasium; this practice is also common as patients should become independent in a variety of contexts. The hospital grounds had a beautiful ambience and numerous short flights of steps, without the usual handrails. The "non weight bearing" patient confidently started down the steps with a crutch under each arm and the therapist at his side and fell forward sustaining serious injuries.

The Reason Swiss Cheese model (unsafe acts, predisposing causes, supervision, and organizational safety climate) may be applied to the analysis of this accident. The unsafe act was the attempt to negotiate the stairs without the use of a rigid rail. The predisposing causes were the progressive rehabilitation regime and the lack of a handrail. The supervision failure was both in the decision to allow this activity and the failure to be "below" the patient on stairs or ramps. The organizational failure was in condoning the aggressive rehabilitation regime (although this policy may be arguable) and in not insisting on correct procedure or the presence of two therapists when more advanced crutch walking activities are being conducted. The courts are likely to favor the injured party.

Tennis Elbow

Tennis elbow is not reserved for tennis players. It occurs when the hand grips an object tightly and forcibly moves it forward by flexing the wrist. This action stretches the common extensor tendon which originates from the lateral epicondyle. The result is a tearing of the attachment between the tendon and bone, and the associated inflammation, heat, swelling and pain. Unfortunately, tennis players and assembly operators are not always able to modify their actions effectively and the initial minor injury may become progressively worse with the formation of scar tissue and continued tearing.

There are various treatments for this injury. The first conservative approach is to change the causal action, apply cold and heat, prescribe pain relief medication and let nature do its thing. A more aggressive strategy is to apply deep frictional massage in which the therapist presses his/her finger or thumb across the fiber direction to break down adhesions; this is followed by ice, heat and graduated exercise. More invasive treatment involves the injection of cortisone or even surgery. A form of treatment that was considered effective, acceptable, and safe is direct current electrophoresis / ionization which causes local vasodilation and enhances healing of damaged tissues.

On the occasion in question the therapist was at his first day of work (in 1961) having recently graduated top of his physiotherapy class. The patient worked in an automotive assembly plant and complained that his particular twisting and pushing task caused and exacerbated his painful elbow until it became unbearable. The prescription by the casualty surgeon was electrophoresis and graduated mobility and strengthening exercises. The confident therapist placed the neatly folded, soaked pad on the lateral side of the patient's elbow and the other electrode on his upper arm. The therapist gently increased the intensity of the direct current and the patient noted a sharp sensation in his elbow. Following established procedure, the therapist turned off the current, took off the electrode pad, examined the patient's elbow, smoothed out the pad and reapplied it. Again, the patient complained of a sharp pain – it should be noted that the lateral epicondyle is a hard lump in the middle of soft muscle and tendon tissue. The therapist sought help from his very experienced supervisor who decided that the treatment should continue. After taking down the application for the third time the therapist and the patient noticed a nasty burn on the patient's elbow. The patient fainted and the therapist summoned help.

The unsafe act has been described in detail. The predisposing causes include the nature of the treatment, prescribed by the attending physician, and the uneven nature of the lateral side of the elbow. The therapist was trained and confident regarding this procedure. The supervisor was also experienced and confident and made the call to continue. The hospital accepted this form of treatment as being effective and safe.

It appears that this harsh treatment must have worked – the patient did not return! The therapist, however, clearly remembers his first day at work.

Chapter 15

"You've Got to Attend to Everything"

The title of this article on "workload" is an actual quotation from my flight instructor (Woolsey, 2006). The article is about workload from the receiving end. It describes some of the challenges that must be overcome while learning to fly. Hicks Law, De Jong's Law, Millers Law, and the Yerkes Dodson Law all play a part.

Introduction

Many years ago (Peacock, 1972) I studied what was popularly called working or operational memory for my Ph. D. The key ideas were decay, interference (proactive and reactive), modality specificity, consolidation and capacity, and their implications for control, attention, distraction, vigilance, learning and performance. A tall order. Since that time there has been great progress and many derived theories and applications. The popular words nowadays are situation awareness, resource theory, cognitive augmentation and workload. Over the intervening years I sought explanations of the role of working memory in medical diagnosis, industrial inspection and automobile driver behavior and performance. Recently, I started taking flying lessons and only now do I know what workload is all about. In case the reader misunderstands, I did not just say that I know all about workload, I said I know what workload is all about.

Picture this – the brand-new student pilot is overwhelmed by a whole bunch of flight, engine, navigation, weather, collision avoidance, communication and operations displays, and charts, notes and printouts and a forest of different shaped controls. Meanwhile his flight instructor is talking in a foreign language and the friendly neighborhood air traffic controller is throwing out coded instructions at a million bits per second. The student pilot brings a whole lot of baggage (negative transfer / proactive interference) from riding a bike and driving a car - the quintessential examples of the coexistence of psychomotor and cognitive skills. In an airplane, one must learn to steer with one's feet and turn by combining ones hands and feet. Sometimes one steers one way with the feet and the other with the hands to combat wind and perform controlled slips and slides. The throttle seems to vary in its sensitivity over its range and the choke (mixture) is sensitive. The throttle is really for altitude control, and the yoke (pitch) is for airspeed. The air brakes (flaps) do funny things to your pitch, especially when you are going slowly and have decided to "go around" and try again to get your approach right. Falling off a bike usually only results in scraped knees and, while car accidents kill 40,000 people a year in the USA, most of these catastrophes are caused by bad behavior such as speeding and drinking and many more accidents only result in minor disruptions to metal and insurance premiums. If you fall out of the sky, however, you will have no further need for insurance, although the airplane will generally be treated as a write off. An early comforting lesson in flying is that you can land safely even if your engine fails, providing you have acquired the appropriate knowledge, procedures and psycho-motor skills.

Early on in my flying career (a few flight-hours ago) I was complaining to a colleague about having to learn a handful of checklists that direct the pilot what to do in normal and emergency situations. My colleague, a Vietnam era F4 fighter pilot, pointed out that *"if I had a Mig on my tail I wouldn't complain about having to master the procedures embodied in the checklists."* (Polay, 2006) Recently I have enjoyed the company of many pilots – flight instructors, aerobatics experts and many more with commercial and military experience. I have one colleague who teaches accident investigation in the "crash lab" behind our safety science building. He seeks to explain what must have happened, given the clues presented by the bent and charred metal and the composite descriptions in the NTSB reports. (Waldock, 2006) A common culprit is "pilot error." Further reading of the literature (Weigmann and Chappell, 2003) indicates that a thorough analysis of the accident will show that it isn't always the pilot's fault; rather a more accurate explanation can be obtained by assessment of the prevailing pre-conditions, the supervision and the organizational climate. These authors have developed a very searching process called HFACS – Human Factors Analysis and Classification System – which seeks to explain why the "unsafe act", usually by the pilot, occurred.

Hicks and Hyman, following the earlier work by Shannon and Weaver on information theory observed that the more information one has to process, the longer it takes to make a decision or response. Miller (19--) described a general rule – Miller's magic number 7 plus or minus 2 - that reflects quite well the ability of people to retain chunks of literal information over the short term. Some explanations used the concept of a limited capacity single information processing channel. Other theories focused on the attention process, suggesting that one can only attend to one thing at a time. These simple approaches are inadequate to describe the complexities of real-world information processing. The real problem is an adequate description of the ever-changing nature and size of “a chunk.” More recent theories suggest multiple channels and multiple limited resources (Wickens). An outstanding overview of Stress, Workload and Fatigue was edited by Hancock and Desmond (2001). This book addresses both physical and cognitive issues and delves into many domains where workload is a concern, including driving and flying.

Measurement

In physical ergonomics the concept of workload is more tangible. There are clear biomechanical and physiological indicators, such as heart rate, oxygen consumption the NIOSH lifting equation (Waters 1994) and an energy expenditure prediction model (Garg, 1999). Industrial engineers' approach to the problem of workload measurement focuses on output and activity at both gross and micro levels. On the production line pre determined work standards measure and prescribe activities down to the second. These measures usually assume an average, experienced worker rate and more perceptive industrial engineers aspire to gauge how hard a person is trying, by applying "rating" methods. Snook (1978) and others developed methods, based on psychophysics, to determine the physical workloads that could be sustained over extended periods.

Borg developed a method whereby the individual rated his or her own “rate of perceived exertion” (RPE) for physical work. Similar subjective reporting techniques for cognitive work are included in the NASA TLX and other similar rating batteries.Gawron (2000) These subjective physical and cognitive workload indicators are all faced with the same problem of individual differences and reference or anchor points. They use verbal anchors such as “quite easy” and “very strenuous” or “low” and “high”. ” The perception of the physical workload of a marathon runner out for a morning jog is very different from that of lesser trained individuals. Similarly, the perceptions of a novice student pilot are very different from those of an experienced one. However, given the calibration of an individual, these subjective methods are quite reliable in assessing relative differences, especially with large samples of responders.

Physiological measures` of cognitive workload include heart rate, heart rate variability (sinus arrhythmia) and various electro encephalographic indices. Perhaps the most convenient, least intrusive, and most practically reliable measure is heart rate. A new generation of neurological measures for cognitive activity may have merit, but the equipment needed to “watch people think” is prohibitively expensive for widespread workplace application. (Green ()) An example of heart rate as an indication of workload and stress is shown in Figures 1.

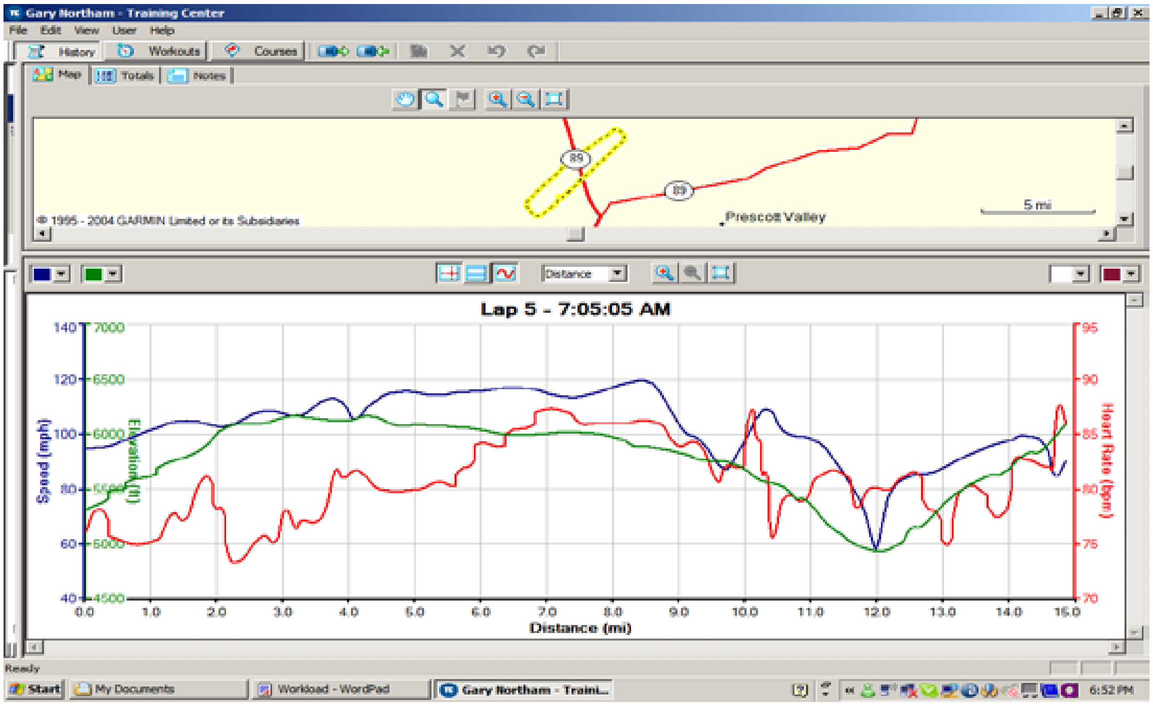


Figure 1. Measures of Altitude, Speed and Heart Rate from a Garmin Forerunner 305 GPS / Heart Rate monitor, during a takeoff and landing.

Secondary Task Methods

When I was an ergonomics student, I participated in a test to assess the mental workload associated with different levels of driving difficulty. A car, equipped with an externally controlled throttle, was driven over a slalom course with hard and soft tires at different speeds. The subject was asked to tap his now free right foot rhythmically while he was driving over the course. The results indicated that the more difficult task (softer tires and faster speeds) were associated with greater arrhythmia in the foot tapping. The theory behind this secondary task method was that the subject had a limited capacity to handle driving and tapping and as the driving task became more difficult the performance in the secondary task of tapping would deteriorate. Like most empirical investigations of this kind the secondary task performance improved with practice and after a while the driver could tap regularly, even in the more difficult primary task conditions. Anyone who has observed an accomplished drummer will be impressed by his ability to keep time on the bass with his feet, while performing circuits on the other surfaces and on occasion singing or talking to his colleagues in the band. This brings us back to the key matter of chunks and the ever-present capability of human beings to learn.

Ultimate Automation

The advent of Unmanned Aerial Vehicles has directed attention once again to the many human challenges of automation. What are appropriate levels of automation? How should dynamic allocation of function be managed? How can trust in automation be assured? What kind of user interfaces should be designed? How do humans behave in monitoring and supervisor roles? How should transitions between manual and automatic processes be managed? And how many aerial devices can one person manage simultaneously?

The ultimate form of automation is found in the interactions between the student pilot and his instructor. As far as the student is concerned the activities of flying can be totally manual or totally "automatic" – the instructor does the flying. Hand off between manual and automation is clear: "My controls", "Your controls", "I have the controls." Intermediate levels of control (by the instructor) are more subtle and vary between probing by the "automation" -

"How is your altitude, pitch and airspeed?" more direct coaching "add power, then pitch" to hands on help with the yoke and rudder. At times of high workload when the student is trying to "fly the airplane" and a busy air traffic controller calls out a long list of instructions, some of which are more important than others and must be repeated back, the instructor may simply take over the communication task and instruct the student when the airplane is stable and the workload is less.

A major challenge in all time-constrained activities, such as driving and flying, is that of distraction. The distraction afforded by the cell phone during driving is now legendary, although there is no good solution in sight because of the generally low (but variable) workload associated with driving and the high desirability of communication. Flying is remarkably similar – there are periods of low workload, especially in highly automated airplanes where the pilot is charged with the boring and vulnerable task of "monitoring", engulfed by all the forces of vigilance decrement. Distraction can occur during periods of high workload demand and during periods of low "monitoring mode" demand, which may turn ugly very quickly.

Flight planning and navigation are key parts of flying. Flight planning involves setting up a series of way points and altitudes, with due regard to weather and congested areas. It is surprising to find that all mountains and roads look alike when you are lost. Fortunately, modern airplanes have radar, transponder and GPS based task aids that can be used to confirm a location. If all else fails, then the pilot can communicate by two way radio with air traffic control or a flight service station. The instructor sometimes distracts the student pilot from his attention to navigation details – it is very humbling to be lost in space, especially in "instrument" conditions. During these moments there is a great increase in stress and workload – the pilot must fly the airplane, find his location, re-plan his heading, and, if necessary, communicate with his support services.

Contemporary aviation technology is based on the "glass cockpit". This is a primary flight display and multi-functional display that can show a wide variety of more or less situationally relevant information. The information on these displays contains the traditional information such as airspeed, altitude and heading and also information about weather and other traffic. Contemporary systems (ADS-B) allow the pilot to see (some) other traffic long before it is communicated by the air traffic control's radar. As this system spreads more widely, there will be an interesting and perhaps stressful conflict between pilot and air traffic control authority.

Perhaps the most stressful form of flying is where there is darkness, cloud or fog and you are flying in a mountainous region. Coast Guard helicopter pilots in Alaska do this all the time (Smith, 2006). In these situations, the pilot must rely on instruments and charts to prevent a Controlled Flight into Terrain (CFIT) incident. Again, stress and workload come together to affect pilot behavior and performance. Contemporary Synthetic Vision Systems are based on a terrain data base and allow the pilot to see a synthetic picture of the terrain on his primary flight display. This picture is enhanced by distance and altitude cues. In addition, audible and color-coded warnings are displayed based on distance, time, and rate of closure with terrain. The pilot can reduce both workload and stress in these situations by simply obeying the commands "pull up, pull up."

Emergencies

Much of flight training centers on how to deal with emergencies. The first class of emergency avoidance is rule based. There is a detailed set of three-dimensional airspace regulations – don't fly too close to the clouds or to congested areas, give way to sky divers!! Give way to the right and always carry a two-way radio. In the preflight procedures the pilot in command explains what he hopes to do in the case of an engine fire or failure after rotation if no runway remains - a somewhat stressful situation with oodles of workload.

Flight training involves many maneuvers aimed at teaching the pilot how the interactions between thrust, drag, lift and gravity work together in harmony. One learns to fly the airplane very slowly and still maintain control. But suddenly the whole thing starts to shudder, a warning horn blares out and then the nose drops and you are pointed downwards. You have stalled and if you are not careful the stall will turn into a spin. Talk about workload!! Meanwhile the instructor is laughing her socks off, although her feet have moved to the rudder and hands to the yoke just in case you have forgotten your procedures – Should you pull out the throttle or push it in? On occasion the the cruel instructor will tell you to close your eyes and then, because your neuro-vestibular senses don't tell you what is happening, you will be quite surprised when you find that you are pointing straight down and the air speed indicator is rocketing. Never mind, calm down and just try to remember the rule-based procedures. Tying with these "unusual attitudes" for the crown of emergency that brings on the biggest workload is when the engine fails while one is flying high. It's as easy as ABC – Aviate (fly the airplane), get the best glide speed, find the best place to land and then do your Checklists. Then just land the plane. No pressure!

Workload and Learning

Workload is simply Information over Time. If information increases and time remains constant, then you're in trouble. Similarly, if information remains constant and the time horizon diminishes your may be in big trouble. Common human strategies for dealing with increases in workload are to use less of the available information or to "buy" time. The former strategy is flawed because it increases the chance or risk of erroneous decisions. The latter strategy is simply fine if time can be bought, otherwise the response of "failing to respond" to the demands may cause catastrophe. Fortunately, the old adage "practice makes perfect" applies to workload management. With practice the pilot learns to distinguish what is more important in the air traffic controller's message. He also learns to store the less important material for future consumption. Also, the psychomotor demand of flying the air plane becomes more automatic with time. In the early stages of learning even the apparently different resources of psychomotor control and handling verbal ATC instructions interfere with one another, as also does directional control and cell phone use in an automobile. Often in these cases the challenges of navigation go out of the window. Did ATC say "clear for takeoff, runway 21L, no delay" and then "fly runway heading to the campus and then turn right after inbound 747 on the downwind at 1 o'clock" all in one mouthful (ear full)? Did you just forget the turn into your street while you were sending a text message to your home and then at the last minute try to make the corner with disastrous results? Experienced pilots learn to deal with this workload with ease, the jury is still out on the text messaging while driving.

This article has attempted to explain what "workload" is all about. One can measure the input, the physiological response, and the output (behavior and performance.) Some measures can be applied conveniently in real time - such as heart rate, others are measured after the event by questionnaires. The rest are guessed at by the accident investigator, who hangs his hat on "situation awareness." I am still hopeful that the assessment of workload will be best assessed by operational memory load.

Chapter 16

Workplace Redesigns through Ergonomics

1) Introduction

This proposal describes a pilot study of two companies from each of four industry sectors that will address ergonomics analysis and interventions in selected workplaces, followed by a review of the outcomes of the investigation by management and MOM. The selected industry sectors are:

- Wholesale and Retail Trade
- Transport and Storage
- Restaurants
- Sectors with office environments

Ergonomics is concerned with the physical, environmental, cognitive, social, affective and temporal aspects of work with the purpose of improving quality, productivity, health, safety and satisfaction of all stakeholders in a sustainable way. An ergonomics "hazard" can be any feature of the workplace, context or organization that may be the root or contributing cause of failure to achieve any of these objectives. However it must be noted that real world situations are often complex and involve interactions among many individual factors and tradeoffs among different outcomes.

A focus of this investigation will be the situation facing older workers and the opportunities that are available to provide continued, rewarding and satisfying employment for this growing cohort. Note also that many established ergonomics methods and standards were developed for Western countries, such as North America and Europe and for younger populations; consequently these methods and guidelines will have to be adapted where there are known dissimilarities among the target Singaporean cohorts.

2) Requirements of Ergonomics Investigations

Ergonomics investigations require sufficient knowledge of human characteristics, capabilities, limitations, and aspirations based on physiology, psychology, sociology, and statistics as well as a compendium of validated ergonomics analysis tools and design guidelines. In addition, ergonomics investigations presuppose knowledge of the target domain which is obtained by direct experience or substantial interaction with a local domain expert.

3) The Ergonomics Process

a) The ergonomics process starts with the establishment of an atmosphere of management commitment and employee involvement, trained and focused ergonomics advocates / monitors and a pertinent collection of ergonomics tools and methods.

b) Next ergonomics investigations conduct an **outcome** analysis; that is a review of the prevalent outcomes such as quality, productivity, health, safety and satisfaction of employees and management. This analysis can be obtained from existing production and medical records that are supplemented by surveys, focus groups and one on one conversations with employees and management.

c) Whereas ergonomics may often be applied on an individual basis a key aspect of this initial analysis is denominator data – the number of individuals in particular cohorts exposed to particular hazards.

d) The second phase involves investigation of work structures and processes, including furniture, equipment, materials, information, work environments and work practices; these investigations generally involve checklist analysis, although secondary and tertiary analysis methods may be warranted in certain situations.

e) Link analysis of the data from these two investigation phases leads to the recommendation for immediate intervention – the low hanging fruit – or more in depth investigations using validated specialized ergonomics methods, such as anthropometric and postural analysis, work and activity measurement, manual materials handling, work physiology and cognitive task analysis.

f) The results of this link analysis are then mapped into alternative ergonomics interventions that may address physical, cognitive, environmental, or operational factors. These mapping are accompanied by a risk benefit analysis to establish the costs and potential changes in outcomes, as well as the customer (employee and management) acceptance of the proposed changes.

g) A cost analysis should be made that addresses both structural and activity costs to support intervention decisions

h) The chosen interventions are then implemented, reviewed, and adjusted accordingly, using a process of continuous monitoring and improvement.

i) Finally, a case study prepared for the corporate technical memory.

4) Workplace Assessment

a) Pre-assessment Planning and Engagement

i) MOM will shortlist 8 volunteer companies, 2 each from the following industry sectors:

- Wholesale and Retail Trade
- Transport and Storage
- Restaurants
- Sectors with office environments

ii) The selected companies will be briefed regarding the scope, requirements, processes, anticipated outcomes and expected costs of the ergonomics investigation.

iii) Each company will be required to appoint an ergonomics advocate / monitor to manage the program at the workplace as well as be the liaison person between the company and vendor for the entire duration for the program. This advocate will undergo introductory training by the vendor in ergonomics theory and methods

iv) A pre-program investigation will be carried out to assess the ergonomics related **outcomes** of the organization, using company records analysis, surveys, focus groups and one on one interviews with management and employees.

(1) In this context it is proposed that a country wide health and safety investigation be carried out that includes biometric, social, economic, occupational, and medical factors. This "ergonomics" pilot study could serve as a pilot study for the proposed wider health and safety survey, which will also make use of existing demographic, occupational and medical databases

v) Preliminary assessment of likely problems and intervention options

(1) Wholesale and Retail Trade

(a) These activities have two major physical issues

(i) Front end service, such as checkout and customer interactions. Common cumulative injury and illness outcomes include cumulative trauma to the upper limbs and lower limb circulatory problems. Fatigue is a frequent contributor factor, which in turn leads to cognitive lapses in pricing etc. These duties generally involve long periods of repetitive work involving standing postures, focused reading, data entry or scanning and repetitive upper limb activity. An essential first step is to create a workplace that is adjustable to the size of the operator. Secondly the opportunity for alternative working postures – standing, sitting or lean sitting must be provided.

(ii) Behind the scenes activity involves shelf stocking and warehouse duties. These require manual materials handling of sometimes heavy loads and reaches beyond an acceptable work envelop. As space is usually at a premium the use of vertical space for storage is attractive, which brings with it safety concerns of step ladders and hazardous reaches. The major intervention opportunity lies in appropriate shelving, access facilities and materials handling aids.

(iii) Further back up the supply chain there are the logistics activities associated with the movement of materials from containers to warehouses, often on pallets, sorting and then distributing to the retail outlets. Again, the ergonomics issues relate to manual materials handling, fatigue, and sorting / distribution errors. The intervention options include a variety of materials handling aids such as scissor lifts, conveyors, shelving, hoists, and convenient powered equipment such as high loaders, fork trucks, tuggers and trains. This mobile equipment introduces potential safety hazards which are mitigated by appropriate warehouse layout, operating procedures, training, and supervision.

(iv) All these warehouse and retail activities lend themselves to job specialization which increases the opportunity for cumulative motion trauma. Furthermore, such specialization practices create inflexible operations difficulties. Both these issues can be addressed by job restructuring that involves cross training and assignments.

(v) Another issue in retail and wholesale operations is that of shift work to provide desirable customer service. Poor shift work arrangements create cumulative fatigue and long term metabolic and behavioral issues, as well as social and domestic stresses.

(2) Transport and Storage

(a) The principle ergonomics issues related to transport and storage have been covered in the previous section. However, a major challenge arises from the long duration exposure to crowded traffic and congested delivery points. These issues are complicated by fatigue due to long duration exposure to intense vigilance demands of driving. Thus, a major concern in this activity is that of traffic accidents as well as the manual materials handling demands at both ends of the delivery chain.

(b) Other cohorts in the transportation industry include bus and taxi drivers. Typically, these jobs involve shift work, long duration static sitting postures and continual demands for vigilance. Such occupations are conducive to metabolic disorders (circulation, obesity etc.) and Musculo-skeletal disorders due to extended exposure to static sitting and whole-body vibration.

(c) The ergonomics interventions to these situations include the use of contemporary vibration absorbing seats, but more importantly the formal inclusion of rest / exercise breaks throughout the daily schedule.

(3) Restaurants

(a) Restaurants present two major physical hazards – slips, trips and falls, and cuts, burns and scalds. Less acute illnesses are caused by long duration customer service activities, shift work and fatigue which are exacerbated by the continual demand for the provision of “good customer service.”

(b) The physical hazards are addressed by workplace layout, equipment choice and maintenance, appropriate training and supervision and the establishment of a work climate that is intolerant of risky behaviors.

(c) Workplace layout opportunities are found in the food preparation areas, behind the counters and among the tables. Pressure to maximize the use of limited space compounds these hazards. Again, routine, sustained attention to layout and employee behaviors can go a long way toward lowering the risk of acute incidents.

(d) Another ergonomics issue related to restaurants is caused by job specialization. The customer pressures the waiter who in turn pressures the food preparers. These pressures can give rise to considerable work stress and an increase in the likelihood of unsafe behaviors. The solutions to these operational and associated workplace layout challenges may be gleaned by observation of the efficiencies found in the major fast food chains, where strict training and adherence to procedure is instilled and sustained among all employees.

(4) Sectors with office environments

(a) The office in its various guises represents a large and growing portion of Singapore employment. A common feature of the office is the computer in its various forms, which leads to intense, sometimes complex cognitive demands. “Human error” can give rise to major operational incidents and the potential for human error is exacerbated by the physical, cognitive, environmental, social, and operational demands associated with the office.

(b) The office has become a major focus for the attention of physical ergonomists over the past two decades. Most of the attention has been towards furniture and equipment aimed at providing appropriate work postures. This is the low hanging fruit and there are many suppliers of "ergonomic" desks and chairs and operational attachments such as keyboard rests, foot stools, document holders and anti-glare screens. Whereas these physical interventions may sometimes be important they may also be used as a placebo aimed at intervening in more serious social and operational situations.

(c) Other interventions in the office that have had considerable success have been the creation of self-directed teams, with appropriate work group areas. Such operational arrangements have the advantage of allowing cross training and operational flexibility. The teams, given sufficient autonomy and time to develop mission-oriented cohesion can also take on the responsibilities of first line management, some personnel functions, process quality and safety.

b) Workplace Assessment

- i) The ergonomics vendor and company appointed ergonomics advocate / monitor will conduct a broad assessment of all workplaces and tasks using a checklist approach. The results of this screening study will be linked to the outcome analysis and recommendations made for primary intervention strategies.
- ii) The following workplace ergonomics issues will be addressed:
  - (1) Workplace factors such as:
    - (a) Collective and personal layouts
    - (b) Work surfaces
    - (c) Seats
    - (d) Equipment, including computers
    - (e) Materials storage and handling aids
  - (2) Employee activities such as
    - (a) Work postures, forces, and movements
      - (i) Upper limb, trunk, and legs
    - (b) Manual materials handling
    - (c) Work shifts and work – rest arrangements
- iii) Work environment factors such as:
    - (a) Lighting and Glare
    - (b) Ambient and specific noise
    - (c) Indoor Air Quality (IAQ) and thermal environment
    - (d) Other health and safety factors
- iv) Work stress factors
    - (a) Pacing, output requirements
    - (b) Mental workload and decision pressures
    - (c) Job scope and autonomy
    - (d) Job specialization
      - (i) Opportunities for job enlargement and rotation

c) Provide Recommendations

- i) After completing the assessment, the vendor, together with the company ergonomics advocate will meet with company management to discuss the findings and advise them accordingly on the alternative solutions that are available for them, the timelines, and costs.

5) Workplace Re-design

- **a)** Workplace and job redesign interventions that are approved by the company and MOM will be implemented, monitored, and adjusted using a process of continuous improvement
- **b)** The pilot study will address 8 workplaces (2 in each sector) in the first instance
- **c)** The vendor will train the company's ergonomics advocate and management on the alternative changes and advise on the subsequent steps that could be taken to raise ergonomics awareness in the organization

6) Submission of Workplace Report

a) The vendor will conduct post-programme survey to obtain user feedback 2-3 weeks after the re-design of the workplaces and tasks to evaluate the effectiveness of the interventions. Particular attention will be made to the opinions and suggestions of older workers.

   i) In this context it should be noted that there will be a "Hawthorne effect" in that any form of positive attention to a group of workers, such as the provision of new chairs or simply listening to their concerns, will result in a positive response to follow up surveys. Consequently, this pilot study should also include plans for longer term follow up investigations.

   ii) There is also the potential danger of a "prescription without a diagnosis, or even a sufficient investigation". Notwithstanding the possible useful short-term placebo effect, it is essential to note that sometimes "work related musculo skeletal disorders" are an indication of more deeply rooted operational and social stresses. These more insidious, long term issues need careful and sensitive analysis.

   iii) The major pathology associated with the "information revolution" is an increasing prevalence of metabolic disorders such as obesity and diabetes, , with enormous individual, company, medical and societal costs. The solutions to this "global epidemic" lie in the human centered approach of ergonomics in which occupational, domestic, social and (lack of) recreational experiences are a collective cause of ill health.

b) The vendor will obtain feedback from management of participating companies regarding the cost and impact of the program and their opinions regarding widespread implementation within the company / sector.

c) The vendor will submit a full program report for each workplace / task intervention.

d) The report will include pre- and post-program survey findings and analytic descriptions and pictures of the workplaces and tasks before and after the re-design.

7) Timeline

a) The project will be completed in 10 weeks upon award of ITQ.

b) Schedule of Deliverables:

   i) Detailed project plan and timeline – 1st week after award of contract

   ii) Pre-engagement and workplace assessments for all selected workplaces 2nd week

   iii) Development of training and analysis material 1st to 3rd weeks

   iv) Company training programs and focus groups 3rd week

   v) Workplace assessments 3rd and 4th weeks

   vi) Analysis and decision period 5th week

   vii) Interventions 6th- 8th weeks

   viii) Interim updates to MOM on results of workplace assessments prior to commencement of re-design of workplaces 3rd to 9th weeks

   ix) Submission of workplace reports 9th to 10th week

8) Content of analytic approach

a) Training of ergonomics advocate / monitor

   i) Basic anatomy, physiology, psychology, sociology and statistics

   ii) Ergonomics outcome analysis methods for productivity, quality, health, safety and satisfaction

   iii) Work related musculo skeletal, metabolic and behavioral disorders

   iv) Operational failures due to "human error"

   v) Unique characteristics of the older population

   vi) Ergonomics checklist methods

   vii) Secondary ergonomics analysis methods

   viii) Ergonomics intervention and redesign alternatives

   ix) Ergonomics process

- b) Checklist methods
  - i) Workplace arrangements / posture analysis
  - ii) Task arrangements / motion analysis
  - iii) Manual materials handling
  - iv) Cognitive task screening analysis
  - v) Environmental analysis
  - vi) Operations analysis
- c) Secondary task analyses
  - i) Anthropometry and Work place design
  - ii) RULA, REBA
  - iii) Strain index
  - iv) Hand activity Level
  - v) NIOSH lift evaluation
  - vi) Physical Work Strain Index
  - vii) Environmental measurement methods
  - viii) Survey and focus group methods
  - ix) Etc.
- d) Introduction to tertiary methods
  - i) Biomechanics
  - ii) Work Physiology
  - iii) Cognitive Task Analysis
  - iv) Environmental analysis
  - v) Field survey methods
  - vi) Formal experimental studies

9) Content of intervention deliverables
- **a)** Workplace arrangements
- **b)** Furniture design and adjustment
- **c)** Equipment / interface design
- **d)** Task and job design (administrative controls)
- **e)** Lighting design
- **f)** Display design / adjustments
- **g)** Work method design (administrative controls / training)
- **h)** Work restructuring (operational controls)

10) Personnel

- **a)** Principal investigator / Project Manager - Brian Peacock
  - **i)** Fellow of the Human Factors and Ergonomics Society (USA)
  - **ii)** Fellow of the Institute of Ergonomics and Human Factors (UK)
  - **iii)** >40 years' experience in ergonomics
    - **(1)** Currently Adjunct Professor at NUS and SIM University
    - **(2)** Physical therapist in industrial and sports rehabilitation (4 years)
    - **(3)** Academia – 20 years – ergonomics, industrial engineering, statistics, safety
    - **(4)** General Motors, Manager of Ergonomics (15 years)
      - **(a)** Responsible for industry, national and global ergonomics programs
      - **(b)** Member of NIOSH / NORA committee on Work Related Musculo Skeletal Disorders
    - **(5)** NASA / NSBRI Discipline Coordinating Scientist for Space Human Factors (4 years)
  - **iv)** Books on Statistical Distributions, Automotive Ergonomics, The Laws and Rules of Ergonomics in Design
  - **v)** Over 200 publications, presentations, and reports on ergonomics
  - **vi)** Broad ergonomics practice / consulting experience in manufacturing, automobile design, product design, office workplace design, aerospace, gas and oil exploration and transportation
- b) FAM Solutions Pte Ltd., Student assistants: Pauline Chong (SIM), Stella Ng(NUS)

Chapter 17

Ergonomics 2018

A National Strategy for Managing Ergonomics in the Workplace

1.0 Definitions of Ergonomics

The word "ergonomics" is composed of the two Latin words *"ergos"* meaning work and *"nomos"* meaning "laws." The term *"ergonomics"* was first coined by the Polish scientist Wojcieck Jastrzebowski in 1857. The terms ergonomics, human factors (HF) and human factors engineering (HFE) are often used interchangeably. The science of ergonomics, having its roots in work physiology and biomechanics, focuses on the study of the human at work. Human factors, a field of study originating from experimental psychology, has its focus on human performance and system design. Some people would refer to ergonomics as merely applying knowledge of the physical characteristics of humans in the design of workplaces. However, in many areas of the world today, these two terms are regarded as synonymous.

The International Ergonomics Association adopts the following definition:

> "*Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theories, principles, data, and methods to design in order to optimize human well-being and overall system performance."*
>
> *"Ergonomists contribute to the design and evaluation of tasks, jobs, products, environments, and systems in order to make them compatible with the needs, abilities, and limitations of people."*

1.1 Scope of Ergonomics

There are several descriptions of the scope of ergonomics or human factors. The International Ergonomics Association divides the profession into the Physical, Cognitive, and Organizational categories; whilst the Singapore Standard SS 514 (Office Ergonomics) describes the Physical, Environmental, and Psychosocial categories. A more precise categorization includes Physical, Informational, Environmental, and Organizational and Affective subdivisions, all of which interact and vary over time.

The International Ergonomics Association recognizes the following domains of specialization within the discipline of ergonomics:

> *"Physical ergonomics is concerned with human anatomical, anthropometric, physiological, and biomechanical characteristics as they relate to physical activity. (Relevant topics include work posture, material handling, repetitive movement, work related musculoskeletal disorder, workplace layout, safety and health.)*
>
> *Cognitive ergonomics is concerned with mental processes, such as perception, memory, reasoning, and motor response, as they affect interactions among humans and other elements of a system. (Relevant topics include mental workload, decision-making, skilled performance, human-computer interaction, human reliability, work stress, and training, as these may relate to human-system design.)*
>
> *Organizational ergonomics is concerned with the optimization of socio-technical systems, including their organizational structures, policies, and processes."*

1.2 Multiple Coincident Factors

For example, an office worker may sit on a non-adjustable chair in front of a desktop computer (Physical). The computer interface or web page may contain large amounts of information accessible through various links (Cognitive). The environment may be perceived as being too noisy and too cold (Environment), and the social context of co-workers and supervisors may be strained due to the pressures of company downsizing (Organizational). Employees in this office may not be permitted to have personal photographs and affects to make the small cubicle more appealing (Affective). The work may be intense and requires focused attention throughout the day (Cognitive), with only short rest breaks (Organizational). The office worker may have a long commute to work and family pressures to support children in college and retired parents. All these factors together with associated learning, fatigue, and ageing effects may interact over time, to affect the behavior, performance, mood, and health of the worker.

1.3 **Human Variability**

A major complication for ergonomics is that people vary in their characteristics, capabilities, limitations, behaviors, moods, and attitudes. Also, individuals change over time due to factors such as ageing, fatigue, illness, and experience or specific training. If people were all the same and did not change, there would be no need for ergonomics. One consequence of the differences among people is that although various products and tasks are targeted at specific groups, they may be used by unintended individuals or in unintended contexts. Such mismatches may lead to errors, accidents, or dissatisfaction. Consequently, the practices of selection, training, work hardening, task assignment, and personal choice will always complement the ergonomics design of products and tasks.

1.4 **The Singapore Population**

One implication of this issue of human variability for Singapore is that more data is needed regarding the unique characteristics, capabilities and limitations of Singaporeans and others residing or working in Singapore. At the basic level of size (anthropometry), strength (biomechanics) and stamina (work physiology) there is some scientific evidence that Singaporeans are smaller than their Western counterparts. Similarly, there is also strong evidence the prevalence of myopia amongst ethnic Chinese is greater compared to Europeans and Americans. The information processing capabilities of Singapore residents are complicated by their varied social, language, cultural and educational backgrounds. A key component of the Ergonomics 2018 strategy is research to collect data regarding the Singapore population characteristics

1.5 **Multiple Purposes**

The key purpose of ergonomics analysis and intervention is the assurance of the safety and health of the individual worker, customers and third parties. Other purposes include quality and productivity and efficiency in the use of resources such as people, money, time, and materials. Usability, comfort, and convenience are universal ergonomics aspirations.

However, the purpose of ergonomics analysis and intervention may differ among situations. . From time to time any of these purposes may be emphasized, perhaps to the detriment of others; for example the speed / accuracy tradeoff in control performance is well documented in the ergonomics literature as also is the tradeoff between productivity and effects on health and safety. Individuals may also emphasize affective over functional issues in the choice of products and activities.

1.6 Activities of Ergonomists

Ergonomics and human factors contribute to various phases of a product or process life cycle: from research through analysis and design, to evaluation and accident investigation. Ergonomics research develops the principles of product or process design regarding human characteristics, capabilities and limitations. Ergonomics analysis of structures, processes and outcomes addresses specific design opportunities. Ergonomics contributions to design deals with tradeoffs among various product features, target user populations and process outcomes. Ergonomics evaluation addresses the validation of a product or process in the real-world context of its intended use or possible misuse. Ergonomics contributions to accident or process failure investigation assess the mismatches between product or process design and human characteristics, capabilities, and limitations.

One example of ergonomics design in service industry may relate to the jobs of customer service specialists. These jobs may be found in many domains including retail establishments, banks, transportation, communications, and recreation services. The jobs may be face to face over a counter, via telephone or asynchronously through a web-based support service. They may also require 24-hour availability. A key similarity among these tasks is the pressure to assure customer satisfaction while achieving productivity aims. The ergonomics contributions to such jobs will include the full spectrum of research, analysis, design, evaluation, and investigation. The physical components of work may include appropriate furniture, equipment and work rest all of which contribute to prevention of work-related musculoskeletal disorders. The cognitive tasks may be greatly facilitated by appropriately designed information systems to prevent, detect or mitigate human error. The physical and social contexts of this externally paced work will inevitably have long run effects on the health and job satisfaction of the operators. These organizational factors often lead to high turnover in these industries. High turnover in turn leads to a continuous need for operator selection, training and job assignments which again can benefit from ergonomics contributions to task analysis and workplace design.

1.7 **Internal and External Effects**

The outcomes of ergonomics contributions may be internal to an individual in terms of health, safety, or satisfaction. It could also be external because of a human error. These errors may occur randomly or be due to routine violation of acceptable procedures or design requirements.

In the long run the failure to apply ergonomics principles to product and process design will lead to individual costs in terms of injury or illness, or job dissatisfaction. The customer may also suffer because of operator errors, and the organization will eventually pay for workers' compensation, labor turnover and customer dissatisfaction. Therefore, an ultimate purpose of ergonomics is the design of sustainable (reliable and resilient) products and processes with due regard to the variability of direct users and their customers.

For example, inappropriate work shift designs or console layouts may cause discomfort and fatigue among process operators (e.g. maintenance operator) which in turn may precipitate hazardous situations for production workers. Similarly the design of codes and procedures to be memorized and used by employees in financial institutions may compromise the accuracy of a human computer transaction to the detriment of a customer.

1.8 The Singapore Landscape

In 1978 the Singapore Society for Occupational Medicine and The National Safety First Council organized a regional conference on Occupational Health and Ergonomic Applications in Safety Control. This conference addressed topics such as Maximum Permissible Limits of work environment pollutants, Occupational Cancer, Occupational Health Education, Safety and Ergonomics applications. Since that time all the major tertiary educational establishments have developed ergonomics educational programs in engineering or life science faculties. Notably SIM University has a full undergraduate degree program in Human Factors in Safety taught by ergonomics and human factors professionals from many Singapore industries.

ERGOSS – The Ergonomics Society of Singapore was established in 1986. It has professional and practitioner members from many sectors of Singapore employment including military, education, manufacturing, computer services and health and safety. The membership of this society however is currently mainly centered on product and interface usability.

WSH 2018 provides clear targets for Singapore Workplace Health and Safety. The past and ongoing WSH focus has been to address those injuries in industries with a high prevalence of **fatalities** and serious injuries such as Construction, Maritime, Manufacturing and Transportation. A firm target is to reduce the annual fatality rate throughout Singapore to 1.8 fatalities per 100,000 workers. This achievement will place Singapore amongst the safest countries for workers in the world.

Data of fatality due to falls from height, struck by falling and moving objects and slips, trips and falls, are shown below. These incidents are often due to human cognitive and behavioral failures. The ongoing application of ergonomics principles to the design of equipment and operations will make major contributions to the achievement of the national 2018 target.

Table 1: Number of workplaces fatalities (temporary disablements) by type of incident *(data from WSH National Statistics)*

	2010	**2009**	**2008**
Falls from height	18 (1281)	24 (1632)	19 (1482)
Struck by falling objects	12 (1362)	21 (1395)	14 (1603)
Struck by moving objects	17 (1801)	9 (1375)	12 (1112)
Slips and trips	4 (1693)	3 (1214)	2 (1294)

One focus of WSH 2018 is on the widespread and enormously costly challenges of injuries due to slips, trips and falls:

Speech by Mr Gan Kim Yong, Minister for Manpower at the Workplace Safety and Health Awards 2010:

"The WSH Council also recently rolled out a series of educational advertisements at 150 bus stops island-wide. The advertisements revolve around the slogan, "Don't ignore everyday risks at work". It highlights common work hazards that employees should be mindful of. One such hazard is "slips, trips and falls" at work. This hazard has led to about 1,000 work injuries every year and even death in some serious cases."

"Simply asking people to stop making mistakes does not work.
Let us face it - people err. Workers make mistakes. Operators forget.

Human factors is about understanding why people err. What caused the error? Was it an error of commission or omission? Was the disaster a consequence of a minor slip or a major decision fault? Why did the person forget?

By understanding the cognitive abilities and limitations of human, knowing how people make decisions and the biases that cause bad decisions, perhaps we can reduce the occurrences of errors and mistakes."

The current focus of WSH 2018 now includes industries and businesses where the **injury and illness causes and outcomes are more insidious** and less clearly defined. These target industries include services, offices, recreation and entertainment, maintenance, retail, education. The injuries and illnesses may vary in severity, some may be cumulative and chronic rather than acute, but they cause pain and suffering, lost days from work and collectively substantial costs to employers and the community. For example, the table below shows data on occupational diseases by type provided by MOM. Many of these diseases are caused by inappropriate design of equipment and work environments, and operators' behaviors. Therefore, ergonomics interventions can be used to prevent and mitigate these workplace stressors.

Table 2: Number of occupational diseases by type
(data from WSH National Statistics)

	2010	**2009**	**2008**
Total	**432**	**468**	**855**
Noise Induced Deafness	364	380	743
Occupational skin diseases	43	55	66
Excessive Absorption of Chemicals	15	16	11
Chemical Poisoning	-	-	8
Compressed Air Illness	2	-	7
Barotrauma	1	1	5
Work-related Musculoskeletal Disorders	4	3	5
Mesothelioma	2	3	4
Occupational Lung Diseases	1	3	5
Others	0	6	1

> *"Simply admonishing workers for not complying is not effective.*
>
> *Why did the operator not don his mask when he was supposed to? Was it because he forgot, he does not understand the importance of doing so, or simply because the mask does not fit his small Asian face?*
>
> *Human factors is about knowing the physical dimensions of people and designing tools, protective equipment, workstations to fit them. Perhaps if it has a better fit and is more comfortable to wear, the worker might be less likely to 'forget' his mask."*

Sedentary and intense repetitive work has many deleterious effects on human health, behaviour and performance. Common effects include various Musculo-skeletal disorders, usually affecting the hand, wrist, arm, shoulders and back. Long term exposure to sedentary work, coupled with inappropriate lifestyle behaviors can result in metabolic disorders such as obesity and diabetes. A third insidious effect of stress in intense information processing activities is performance errors and aberrant psychosocial responses.

> *"Singapore has fared well so far in reducing our adult mortality but there is definitely room for further improvement, and we should not be complacent. Singapore needs to continue to combat against smoking, obesity and physical inactivity; and to detect high blood pressure, diabetes and high cholesterol and manage these conditions well, as these are the major risk factors for the leading causes of early deaths in our adult population between 15 and 60 years of age. The Ministry of Health together with the Health Promotion Board will continue to work with partners such as the Peoples' Association, Singapore Sports Council, National Environment Agency, unions, employers and family doctors to do so."*
> ***Trend in Adult Mortality in Singapore*** *By Phua Hwee Pin[1], June 24, 2010*

One focus of WSH 2018 is on the widespread and enormously costly challenges of injuries due to **slips, trips and falls**:

> *Speech by Mr Gan Kim Yong, Minister for Manpower at the Workplace Safety and Health Awards 2010:*
>
> *"The WSH Council also recently rolled out a series of educational advertisements at 150 bus stops island-wide. The advertisements revolve around the slogan, "Don't ignore everyday risks at work". It highlights common work hazards that employees should be mindful of. One such hazard is "slips, trips and falls" at work. This hazard has led to about 1,000 work injuries every year and even death in some serious cases."*

A second focus is on the vulnerabilities of the **aging workforce** and other employee cohorts with physical, sensory, cognitive and social disabilities.

> *"Singapore's Tripartite Committee on Employability of Older Worker has issued its final report, with an extensive package of recommendations to enhance the employability of older workers which have been accepted by the Government. These include introducing legislative changes within five years to facilitate opportunities for older workers to continue working beyond the age of 62, expanding the employment opportunities of older women and enhancing their employability, a higher Workfare Income Supplement payout to low income workers above the age of 55, and expanding the promotion of fair employment practices.*
>
> *In addition, the Committee will continue its work for another five years. It will work towards raising the employment rate for residents aged 55 to 64 to the medium-term target of 65% (from the current 53.7%). The Committee will also work closely with the Ministerial Committee on ageing to tackle the issues of an ageing population in a holistic manner."*

The Vision – Progressive Workplaces through Ergonomics

2.1 Multiple Aims of the progressive workplace

This Vision statement shows the unequivocal link between the application of ergonomics or a "people centered work culture" to the multiple aims of business and industry including:

- The health and safety of people at work
- Effective contributions to product and service quality
- Productivity and efficiency – the optimal use of resources, including human resources
- Satisfaction and motivation of all stakeholders, including the employees, employers, and customers
- Sustainability – products and services that continue to reliably achieve this vision under normal circumstances and which are resilient to the stresses imposed by unexpected and sometimes extreme contexts.

2.2 Commitment, Participation and Continuous Improvement

Ergonomics comprises the knowledge, science and technology needed to achieve this vision. A successful ergonomics strategy is predicated upon the following principles:

- Adhering to the principles of management commitment and employee participation
    - No program or organization will be successful without management commitment and employee participation.
    - **Management commitment** is demonstrated by active leadership in all aspects of an organizations activity, including productivity, health and safety. Tangible examples of management commitment include the inclusion of health and safety topics in all operations meetings and the active involvement of management in the investigation of system failures that led to injury and illness. It

should be noted that management commitment must go beyond "cheerleading" in which lip service is paid to health and safety, but where the responsibility for health and safety is left to the employees.

  - **Employee participation** is based on the premise that those individuals closest to day-to-day operations will be the most likely to recognize health and safety as well as quality and productivity hazards. Participation therefore harnesses this floor level knowledge for the design and modification of operations with health and safety in mind. Participation is achieved formally by the inclusion of employees in committee structures associated with quality, productivity, health, and safety.

- Involving the various customers / stakeholders in strategic decisions
  - Customers and stakeholders may be internal or external. For example, the customer for a product design, such as a computer may be the end user, the maintainer, the manufacturing / assembly employee or the person who handles the computer in the warehouse, delivery van or retail establishment. A failure of any of these customer / stakeholder interfaces can lead to product failure. Thus, it is essential that the needs of all individuals throughout the life cycle of the product be considered in strategic and operational decisions.

- Implementing continuous improvement processes through ongoing monitoring of the structures, processes and outcomes associated with work
  - Kaizen engineering is based on the premise that there is always the possibility of improvement in a product or process. These continuous improvement techniques have been widely successful in the Japanese and US automobile industry. The opportunities for improvement can come from any source, including the customer or the manufacturing or service employee. The WSH 2018 ergonomics program will benefit greatly from the inclusion of kaizen engineering principles

- Addressing the broad principles of "loss prevention," "efficient processes" and "avoidance of waste," including a focus on the costs of health and safety, equipment and environmental damage lost production.
  - The concept of waste includes the failure of any product or service, whether it is physical damage to the product or person, or operational damage to a service. Such waste will usually imply financial costs, both short and long term. For example a faulty product will affect buyer perception of the brand, an error in a service transaction will negatively affect the customer's attitude towards a company and an accident at work will have both direct costs as well as damage to the company's reputation.

Ergonomics is a broad discipline that has applicability to all forms of human employment and other activity. The focus of investigations involves knowledge of human physical, cognitive, social, environmental, affective, and temporal characteristics, capabilities and limitations, behaviors, performance and preferences. The profession of ergonomics has many analysis tools of various levels of sophistication to be applied to these varied domains. The application of knowledge and techniques to particular domains requires collaboration with subject matter experts, including the line operators and other employees.

An example may be found in the banking industry where the employee has to be familiar with many products and services and the particular needs of individual customers. Errors in advice or transaction management can create dissatisfaction with the customer and possibly long-term relationship shortcoming. The experience, training and mental workload of the employee can be complemented by appropriate software to effectively *manage customer problems and to relieve the work stress associated with having to deal all day with a wide variety of situations.*

3 Importance / Justification / Purpose

3.1 Importance

Health and safety, like productivity and product quality in the workplace are important from the human, cost and company perspectives.

The UK HSE statistics reveal the human and financial cost of failing to address health and safety:

- *More than 200 people are killed at work in the United Kingdom each year. This does not include work-related road deaths.*
- *In 2006, 30 million working days were lost in the UK to occupational ill health and injury, imposing an annual cost to society of £30bn (more than 3% of GDP).*
- *Surveys show that about two million people suffer from an illness that they believe to be caused or made worse by work.*
- *Many thousands of deaths each year can be attributed to occupational illnesses, including some cancers and respiratory diseases.*

Speech by Mr Gan Kim Yong, Minister for Manpower, at the Launch of the National Workplace Safety and Health Campaign, 29 April 2010:

> *"Like their counterparts in the higher risk sectors, employees in the new sectors are also susceptible to WSH hazards. Our 2009 statistics show that these sectors contribute to 29% of all work injuries. They also contribute to 6% of fatalities – four employees died while on the job. To these victims and their families, this is four too many."*

Clearly ergonomics analyses and interventions in product and service operations design are especially important for the physical and financial health of Singapore.

3.2 Justification

Most product or service failures, whether mechanical, operational, control or communications, have a significant human contribution during design, development, manufacturing, and especially during operations. These failures may affect the people directly involved or a third party. It is likely to also cause damage to equipment, the environment or the company's reputation. Some failures are overt, acute, and catastrophic. Others may be insidious, cumulative and have long term adverse effects on health, behavior, and performance. In either case, the outcomes may be extremely costly in terms of human life and health, or equipment, operations, or environmental damage. Some of these incidents are rare occurrences while others are pervasive. Sometimes the overt costs are obvious immediately and sometimes the cost may be delayed or span the life of the individuals concerned.

A truck accident, an injured back or a financial calculation error may have much in common; all may be due to the demands on a person being beyond their instantaneous performance capabilities. The truck accident may have been due to distraction by a mobile phone call; the injured back may have been due to a misjudgment of the weight of the load and the wrong calculation may have been due to a failure to include a currency conversion factor. These are all common cognitive failures which may have trivial or catastrophic outcomes. Ergonomics analysis and design can contribute to a reduction in the likelihood of the primary *failure, to the prevention of the unwanted outcome by the interposition of some safeguard or to the mitigation of the severity of the outcome.*

The application of ergonomics knowledge and methods can go a long way towards enhancing the human contribution to organizational success and preventing the cost penalties of system failure.

3.3 Purpose

The purpose of people centered design is to target, improve and sustain the quality and productivity of operations while assuring the safety, health and satisfaction of all concerned. Ergonomics design addresses the physical and cognitive characteristics of workplaces, equipment, products, and services. It is also concerned with the contexts, operations, tasks, and jobs associated with these products and services.

For example, the maintenance of complex equipment such as airplanes or buses can be made more effective and safer by ergonomics intervention in product, operations or environment design. Key components can be made more accessible to routine inspection and testing during product design. Also standardized tests, test equipment and procedures can be developed in parallel with the design of the product. Inspection facilities can be designed to assure good visual, acoustic, and thermal conditions for the maintainers. Maintenance schedules can be designed to ensure that inspectors are alert and not suffering from sleep loss or fatigue that results from poorly designed shift systems. Inspection and repair procedures can be developed to reduce the likelihood of inspector error. Workshop aids such as hoists and ramps can be used to relieve some of the physical burden on the maintainers.

Landscape / Scope / Stakeholders

The success of this ergonomics program requires the participation of many different stakeholders including government, employers, managers, employees, unions, designers, managers and customers.

"Trade unions affiliated to the National Trades Union Congress (NTUC) supported the government's call to move away from the traditional adversarial unionism and confrontational labor-management relations, with a shared conviction to strive for industrial peace with justice. A new spirit of tripartism was thus born, with the government, a responsible labor movement, and enlightened employers adopting a consultative problem-solving approach to address the challenges of industrialization for the mutual benefit of employers, workers, and society".
Source: Singapore Tripartism Forum.

Tripartism is a concept that includes collaboration between government, business and the trade unions. Similar concepts have included the importance of collaboration between product or service organizations and their customers. An industrial example is that of supply chain management which addresses all the organizations that contribute to the manufacture of a product or service. The broad concept of "stakeholder" includes all people that may in some major or minor way interact with a product or service. The eventual success or failure of a venture requires that the voices of all stakeholders be heard.

The retail industry in Singapore offers a good example of the importance of involving all stakeholders. Food or electronics products may be manufactured and packaged in a distant country. Inevitably the transportation to Singapore will be in a container ship. Distribution centers at the container terminal will deliver the items to warehouses and on to the stores where the goods will be placed on the shelves by store employees. After purchase, the packaging will be recycled for the production of other containers. A human error at any one of these stages may result in an injury to an employee, damage to the product, and customer dissatisfaction, all of which will have repercussions for the retail company. Ergonomics specialists within the retail company will be in an ideal position to work with all stakeholders to identify and prevent sources of error, injury and loss.

4.0 Strategic Outcomes

4.1 Strategic Outcome 1: Extending and sustaining the productivity of the ageing workforce

Whereas the ideals of "universal design" are laudable, reality may limit design of jobs, contexts, products, and services to the accommodation of the majority. The ageing workforce is an increasing minority of Singapore's employment pool that will require attention to allow them to continue to be productive members of society. Ergonomics analysis and design can address the limitations of these individuals. The Singapore Tripartism Forum offered the following statement regarding the employability of older workers:

> *"An ageing population is not only a challenge; it also presents an opportunity. Age need not be a barrier to employment. Equipped with the right skills and expertise, older workers are a valuable source of manpower. Employers can benefit from having an age-diverse workforce, where mature workers with the requisite experience and skills are able to contribute productively to their jobs. At the same time, in view of rising life expectancy, workers also need to remain in the workforce longer to ensure their retirement adequacy.*
>
> *The Tripartite Committee on Employability of Older Workers, chaired by Acting Minister for Manpower Gan Kim Yong, was set up in March 2005 to recommend measures to:*
>
> - *Enhance the employability of older workers and help them stay employed longer to raise the effective retirement age beyond 62; and*
> - *Positively shape the perceptions and mindsets of employees and the public towards the employment of older workers.*
>
> *There are four key thrusts to the Tripartite Committee's recommendations:*
>
> - *Expand employment opportunities for older workers;*
> - *Enhance their cost competitiveness;*
> - *Raise their skills and value and*
> - *Shape positive perceptions towards older workers."*

A document accompanying this report entitled: **"**The Aging Workforce – A Singapore Ergonomics Strategy" outlines many of the challenges and ergonomics opportunities in the accommodation of this growing population and includes the following sections:

1. *Data – a description of the demographic features and trends of Singapore's aging workforce*
2. *The process of ageing – a summary of the physiological, psychological, behavior and performance changes that are associated with ageing*
3. *Confounding factors – a description of generational and medical factors that accompany ageing*
4. *International Classification of Function – a proposal to formally adopt the World Health Organization's positive document that focuses on residual capabilities rather than performance shortcomings associated with ageing.*
5. *Ergonomics Intervention Strategies – a summary of specific ergonomics interventions that can be applied to enhance the performance potential of ageing workers*

6. *Operational Strategies – a discussion of the strategies that can usefully be adopted by government, business and the unions to address the needs of the ageing workforce*

4.2 Strategic Outcome 2: Ergonomics as an integral part of business competitiveness

Business competitiveness requires a strong customer focus with emphasis on sustainable product or service quality, productivity and cost. Strong drivers of these business competitiveness aims are the health, safety, and wellbeing of employees. The long-term sustainability of business operations requires that all these objectives be achieved.

4.2.1 Industrial and Information Revolutions

The recent information revolution has similar implications for employees as the industrial revolution a century ago. The industrial revolution greatly supplemented human physical capabilities by the harnessing of power and machinery. One operational result was the development of the production line which in many cases increased worker productivity dramatically. Unfortunate side effects however were the physical, cognitive and social stresses of specialized repetitive work. The ergonomics developments of latter part of the 20th century brought perceptive and effective solutions to production line work, through both engineering and administrative interventions.

4.2.2 **Administrative Interventions**

Administration interventions in work design, such as job rotation and enlargement not only reduced the repetitive stress on production line workers, but it also created a more knowledgeable and versatile workforce with cross training that could be used to counter local operator shortages. A related development has been the creation of semi-autonomous or self-directed work teams and vertical job enlargement. These teams assume responsibilities for productivity and product quality, and health, safety, and job satisfaction of the team members. Such arrangements may also reduce the need for first line supervision. They also provide a greater feeling of belonging among the team members and connectivity with the higher mission of the organization.

Contemporary computers and telecommunications have had a similar major impact on business. However, the computer workstation is the new production line in terms of its stressful static physical demands, narrow job specializations and continued focus on productivity. One result of this focus is through the well documented "speed – accuracy tradeoff" – the pressure for productivity, as in transaction time limitations, leads to greater opportunity for human error. The challenge for job designers is to anticipate the probability of error and impose mechanisms and methods to mitigate the unwanted outcomes.

The ergonomics lessons learned from the production line can be brought to bear on the design of workplaces, tasks, and jobs in the office. The physical content and arrangements of workplaces and furniture to allow postural variety are an initial step. The next step is the use of administrative interventions, such as self-directed work teams, job rotations and enlargements to create a more flexible, effective and efficient workforce. Human centered design will assure optimal performance of people at (information) work.

The earlier developments of ergonomics were in aviation, transportation, power generation, agriculture, and manufacturing. The trend towards service economies and the evolution of the computer and telecommunications have turned the focus of ergonomics to "the office". "The office" with its cubicles and desk top workstations has resulted in a trend towards a sedentary lifestyle with many adverse physical health implications. Also "human error" in routine information processing can result in latent and substantial unwanted outcomes. A third, social, challenge, brought about by the trend towards careers for both husbands and wives are the pressures of housing, commuting and care for children and elderly parents. These issues, sedentary specialized occupations, insidious human errors, and social pressures are intertwined. A broader view of ergonomics, from the socio technical systems viewpoint can make important contributions to the analysis and resolution of the many challenges of "the office."

- **5.0 Strategic Outcome 3: A progressive and pervasive people centered work culture**

5.1 Participation

A stakeholder participative framework with management commitment, employee participation and customer involvement will assure long term growth and sustainability of Singapore's manufacturing (540,000 jobs) and service (70% GDP) industry. These processes have strong precedents in the meteoric rise in automobile and consumer electronics products in Japan and Korea. A similar participative work culture will contribute to the progress of Singapore's considerable service industry.

Participation strategies are achieved by the formal integration of stakeholder (executives, managers, employees, and customers) centered processes in the day to day design and operation of the business. A strong precursor of this integration is the education of all concerned in the structures, processes and outcomes of people centered design. To this end ergonomics information, including case studies and success stories, simple analysis tools and workplace, equipment, task and job design guidelines will be distributed widely for use by all stakeholders.

Participation can be formalized by the establishment of standing and ad hoc focused committee and work group structures. An example in design includes product development teams that have representation from all related technical and operational areas. In production activities the concept of "quality circles" has demonstrated considerable success in the automobile industry. These concepts can be mimicked in service industry. A strategy widely used in the automotive industry is that of job rotation and job enlargement. Such strategies can be used to increase the versatility and flexibility of a work force and to reduce the physical and cognitive stresses of specialized jobs. The responsibilities of these teams can go beyond product or process quality and address issues of health and safety and efficiency. Such "self-directed work teams" can also take responsibility for cross training and task assignment. Whereas such teams may reduce the role of first line supervision, they provide opportunities for leadership development.

A formalization of the participation principle is embodied in the development of **The Singapore Tripartism** Forum in 2007. The purpose of this forum is stated as:

"The forum is designed to broaden, deepen and strengthen the spirit of Tripartism through a more structured framework. The forum will provide a platform for the tripartite partners - the government, unions, and employers - to table concerns and work together more effectively to overcome the more complex challenges faced by all today.

Some of the key tripartite concerns include issues such as job re-creation, raising the effective retirement age, skills training and upgrading of the workforce, promotion of fair employment practices, flexible wage system, amongst other things."

6 Strategies

6.1 Strategy 1: Building Capabilities

A major contribution to the quality of healthcare over the past three decades has been based on the concepts offered by Donabedian regarding structures, processes, and outcomes. Structures include such factors as trained personnel, appropriate equipment, and facilities. The processes include diagnostic and therapeutic techniques. The outcomes are the improved quality of healthcare.

These concepts are discussed in Donabedian, 1978. The applications of these concepts to occupational health and safety are instructive through the development of trained personnel and appropriate investigation and intervention processes, which in turn will lead to reduction in occupational health and safety incidence.

6.2 Education and Training

The primary focus is on ergonomics education, training, accreditation and certification by government, academic and business organizations. Quality assurance and sustainability of these processes will be achieved by feedback and continuous improvement and involvement of executives, managers, employees and customers. Singapore already has strong structures in place to support these processes including a newly established Worker Safety and Health Institute, an outstanding research university capability, an effective polytechnic structure, and established continuing education and training organizations. At the grass roots level, especially in Small and Medium Sized Enterprises (SMEs) there is a need for instruction in the basic principles of ergonomics supported by easy to use checklists and design guidelines. Continuous improvement to these structures and their processes will be achieved by formal collaboration among government, business, academia, and training organizations.

The are currently less than 10 professional ergonomists (with PhD) in Singapore and less than 100 Masters graduates. Currently there is no community of trained ergonomics monitors which will be needed for the implementation for a workplace ergonomics program.

The skills and facilities needed for such a program include a critical mass of researchers, a cohort of ergonomics professionals and a widespread community of ergonomics practitioners. These researchers, professionals and practitioners should be supported by appropriate laboratories, field equipment, ergonomics analysis tools and design guidelines.

6.3 Accreditation and Certification

Quality assurance of education, training and industry ergonomics programs will require the accreditation of programs and the certification of individual ergonomics practitioners. Program accreditation will involve the establishment of structure, process and outcome benchmarks and a committee of peers to review the applications for accreditation. Certification of individuals could be through the adoption of established international organizations (BCPE, EUR Erg) at the Masters and Bachelors level. **However, a more practical approach would be through the development of regional or national accreditation and certification processes.**

The WSQ competency framework should be adopted at the practitioner level. A special ergonomics endorsement – Certified Ergonomics Monitor (CEM 1 - 6) could range from the basic checklist application level, particularly suited to SMEs, through Levels 1 to 6 in the WSQ hierarchy. These accreditation and certification process and standards should be managed by a subcommittee of the WSH council.

7.0 Strategy 2: Implementing a compliance assistance framework

7.1 Standards

Compliance presumes the existence of pertinent, achievable, and understandable ergonomics standards. There is a long international history of ergonomics standards development and implementation, including the 2005 Singapore Code of Practice for Office Ergonomics (SS 514) and international sources such as the ISO, WHO, European Community, UK Health and Safety Executive, USA (OSHA), various individual States (California, Washington) and industrial organizations (General Motors)

7.2 Local and International Standards

A first step will be to initiate a process to continuously improve existing Singapore ergonomics standards and to formally adopt or adapt established international standards. This phase should pay attention to the content, pertinence and *usability of the standards, particularly as they apply to the unique nature of the Singapore population. A second step will be the widespread communication and implementation of the standards through the training programs discussed above.

**A truism is that "ergonomics standards should themselves be ergonomic" This is not the case of many national and international standards, which may satisfy legal and technical requirements but fail in their applicability to real world workplaces and analysts. The key to ergonomics standards development lies in the provision of clear workplace, equipment, and task specifications rather than vague performance outcome requirements. For example, the requirement that an office worker should lift with a "straight back" should be replaced with specific statements regarding the vertical and horizontal location and size and weight of loads. The development of such specific statements for application in Singapore requires an embedded process for consensus decisions by multiple stakeholders. These principles were widely applied and successful throughout General Motors in the 1990s and beyond.*

7.3 Research and Development

Compliance assistance will be supported by the continued development of the central government research and development organization – Worker Safety and Health Institute – similar to the National Institute of Occupational Safety and Health (NIOSH) which is a part of the US Centers for Disease Control, although local Singapore conditions may warrant an alternative structure. This body should be the coordinating center for basic and applied ergonomics research in Singapore through cooperation with many university departments of Engineering, Medicine, Health Sciences and Life Sciences.

8.0 Strategy 3: Promoting Benefits and Recognizing Best Practices

8.1 Best Practices

The Singapore Quality Award (SQA) framework is used as a basis for assessing Singapore's organisations to the highest standards of quality and business excellence. The award aims to establish Singapore as a country committed to world-class business excellence. The framework and award is administered by SPRING Singapore.

The Singapore Quality Award is based on the internationally recognized Malcolm Baldridge Award for best quality practices and outstanding processes in business and industry. Singapore has adopted this award process. These principles should be adopted in the health and safety area to reward companies for introducing, maintaining, and improving their ergonomics structures and processes. It should be noted that desirable outcomes can only be achieved by changing and improving structures and processes, not by simply asking for (cheerleading) desirable outcomes.

There is evidence in the international health and safety area that well-meaning emphasis on desirable outcomes, such as "This site has gone 1000 days without a lost time injury" can lead to serious underreporting and inappropriate complacency by all concerned.

Rewarding best practices can be achieved by developing a Voluntary Protection Program in which companies that maintain exemplary ergonomics structures, processes and outcomes receive less government oversight. Companies that fail to establish and maintain appropriate ergonomics structures, processes and outcomes should receive increased oversight. However, as in the Total Quality Management area emphasis should be placed on structures and processes, rather than outcomes.

Best practices in the ergonomics area are achieved by the development of teams, tools and tests. Company teams will include trained ergonomics practitioners, health and safety practitioners, operations, design and management representatives. Companies should also adopt and adapt, through a team consensus process, pertinent and easy to use analysis tools that are directly linked to design / intervention guidelines. The standards for compliance should also be straightforward and unequivocal.

9 Key Work Areas

9.1 Key Work Area 1: Ergonomics R&D

Singapore has some of the best universities in the world. Ergonomics expertise is to be found in many different departments and disciplines (Engineering, Applied Science and Technology, Medicine and Health Sciences, Life Sciences, Business etc.) An Ergonomics R&D strategy should focus on Interdisciplinary basic and applied projects, led by Government (WSHI) and appropriate participation by business, industry, and the unions. This R&D strategy should be used to develop a cohort of knowledgeable ergonomists at the BS, MS and PhD levels to lead Singapore's ergonomics and people centered focus over the coming decades.
Examples of R&D opportunities include:

1. Effects of sedentary work
2. Aging and performance
3. Alternative office and workplace concepts
4. Factors affecting work related musculoskeletal disorders
5. Fatigue
6. Self-directed work teams
7. Shift work

9.2 Key Work Area 2: Workplace and Job Design

9.2.1 Physical Ergonomics

Workplace design has traditionally been based on applied anthropometry, biomechanics, work physiology and motor skills assessment. Screening analysis of these factors is included in the proposed **Singapore Workability Worksheet and Index**. The key areas of analysis are: spatial factors, manual materials handling, manipulation, environmental and operational factors. Design and intervention in these areas, based on the screening analysis and where necessary more in depth ergonomics analysis tools, is principally through engineering controls. There exist many appropriate choices for furniture, storage racks, and materials handling equipment. However, costs and sometimes misleading marketing practices warrant the involvement of knowledgeable ergonomists in layout, purchase and set up decisions.

9.2.2 Cognitive Ergonomics

The replacement of physical materials by information as the focus of an employees' attention raises broader challenges of cognitive ergonomics or human factors engineering. As noted elsewhere this trend also leads to a tendency for long duration sedentary work, which has significant physical health implications. The ascendancy of the net book and the tablet, coupled with wireless networks have the potential to release the operator from the confines of the chair and table, and indeed from the office as it now exists. Innovative experiments in redesigned work areas have the potential to remove the shackles of the familiar, but insidiously dangerous desk and chair.

The physical computer interfaces may resolve the issues associated with vision and input, but it is the cognitive interface that creates the opportunities for quality and productivity on the one hand and error and resultant cost on the other. Fortunately, there exists in the ergonomics and human factors world many tools and techniques for cognitive task and mental workload analysis, situation awareness, sophisticated error and accident investigation, and proven effective guidelines for human – computer interface design.

9.2.3 Socio Technical System Design

The inclusion of the expression "job design" in this key work area opens up another aspect of ergonomics – often called "macro – ergonomics" or socio technical system design. Formal studies in this area have been conducted for over a century with a view to improving the understanding of the impacts of technology and operations design on human motivation, behavior, and performance. Taylor proposed a "scientific management" approach which was largely discredited by the Hawthorne experiments, Bloom's levels of cognition, Maslow's levels of motivation and Herzberg's intrinsic and extrinsic (hygiene) factors in motivation. Contemporary approaches to "participation" and "semi-autonomous work team" philosophies, in which employees have greater responsibility for broader aspects of their jobs including product or service quality, productivity, health and safety, have had demonstrable success in a wide variety of industries, including "the office".

These "job design" opportunities are sometimes described as "administrative controls. They include job rotation in which team members rotate around different tasks to relieve the physical and cognitive monotony, and job enlargement in which operators are given a broader range of tasks in their job cycle. These two approaches have the added advantage that they create a broader range of skills in individuals leading to greater flexibility in assignment and greater insight in problem solving. Vertical job enlargement and semi-autonomous work teams essentially delegate first line supervisor tasks, such as assignment, quality, productivity, materials management, maintenance, and safety to the operator level. This again creates greater cross training, flexibility and greater "ownership."

Key Work Area 3: Ergonomics Assessment

9.3 Ergonomics Tools

There exist many validated and incisive ergonomics research, analysis and evaluation tools and standards that vary from simple checklists, through more elaborate worksheets to high level analysis and simulations

The most appropriate primary job / task analysis level for immediate widespread application in Singapore is an ergonomics checklist that addresses the spatial, manual materials handling, manipulation, environmental, informational and operational sources of stress and their interactions, with a simple ordinal level of rating and a counting process for overall task evaluation. A prototype "Singapore Workability Worksheet and Index" device is presented in the Appendix. This device could be used with a minimal level of training – one day, and is appropriate for the WSQ 1 to 3 levels, with a certified ergonomics monitor rating of CEM 1 to 3.There is a strong precedent for this type of workplace analysis tool. Where necessary the tool refers analysts to ergonomics experts and more in depth analysis tools that have widespread use throughout the international ergonomics community. However, this tool provides sufficient information in most circumstances for the implementation of engineering or administrative controls.

Key Work Area 4: Education, Training, Accreditation and Certification

9.4 Education

Singapore has established tertiary ergonomics education programs at:

- NUS: Human Factors and Ergonomics courses in the Department of Industrial and Systems Engineering at the Bachelor's, Master's, and Doctorate levels)
- NTU: A Masters in Smart Product Design degree has evolved from a specialized Masters in Human Factors Engineering within the Department of Mechanical and Aerospace Engineering.)

- UniSIM: SIM University has recently established a full Bachelor of Science degree in Human Factors in Safety. The degree is recognized by MOM for Workplace, Health and Safety Officer Registration with two years of relevant experience.
- Various Polytechnics: Republic Polytechnic, Ngee Ann Polytechnic and Temasek Polytechnic have individual courses in ergonomics and related subjects.
- Ergonomics principles are often also incorporated in such disciplines as Engineering, Technology, Health Sciences and Psychology in various tertiary institutions.

9.5 Training

There is a well-established WSH training and certification structure in Singapore that leads to qualifications at WSQ levels 1 – 6. Training material and competency standards need to be developed to include Ergonomics in this established process. It is envisioned that an ergonomics certification – Certified Ergonomics Monitor level 1 – 6 be established which is independent of the Occupational Safety and Occupational Hygiene tracks

9.6 Certification

There are well established International processes for certification of ergonomists - BCPE (USA): CPE (Masters in Ergonomics, Human Factors or closely related subject from an International Ergonomics Society accredited program, plus 3 years' experience, presentation of work products as evidence of experience in system analysis, design, and test and evaluation, plus an examination on fundamentals, tools and applications). BCPE also offers a Certified Ergonomics Associate (CEA) qualification which requires Bachelor's Degree, evidence of ergonomics training according to the Ergonomist Formulation Model, 3 years supervised practice, evidence of practitioner experience, followed by an examination on fundamentals, tools and applications. The Committee for the Registration of European Ergonomists (CREE – Eur. Erg.) certification is based on graduation from an accredited university level program in Ergonomics, plus evidence of experience.

The Certification standards should include selective training, experience and testing in:

- *Basic physics, chemistry, and biology*
- *Human anatomy, physiology, and psychology*
- *Human sensory processes*
- *Anthropometry, biomechanics, and motor skills analysis*
- *Basic pathology, especially regarding Musculo skeletal disorders*
- *Basic mathematical and statistical analysis skills*
- *Data resource familiarity*
- *Systems engineering and systems safety tools*
- *Computer literacy*
- *Socio technical system design / macro ergonomics*
- *Ergonomics task (physical and cognitive) analysis tools*
- *Behavior and performance analysis tools*
- *Equipment and task design standards, techniques and guidelines*
- *Engineering and administrative control methods*
- *Ergonomics literature / reference material familiarity*
- *Domain technologies and practices*
- *Case analysis proficiency*

9.7 Accreditation

A multiple stakeholder committee (Government, Business, Academia, Unions, and Employees) should be established to discuss and develop ergonomics accreditation and certification process by adoption or adaptation of established programs or development of Singapore specific standards. The accreditation process should be geared to the supply of certified individuals to Singapore business and government with the knowledge, skills and abilities described above.

10 Key Work Area 5: Outreach and Engagement

10.1 Stakeholders

The pervasive workplace ergonomics program will require the involvement of multiple stakeholders including government, top and middle management, unions, academia, other ergonomics service providers and the general public, including the schools

10.2 Mass Communications

Developments in communications media over recent years should be exploited to reach out to and engage the multiple stakeholders for The National Framework on Workplace Ergonomics research, development, application processes, and case studies. These mass communications efforts should be followed up by a program of face to face stakeholders meetings through the medium of an annual ergonomics conference to bring together local and international professionals and practitioners. The success of these outreach and engagement efforts will be achieved by the following mechanisms:

- Commitment and involvement by top management
- Participation by all stakeholders
- Tangible case studies and success stories

11. International Links

A second outreach effort should be towards the international community. Workplace ergonomics has made considerable advancements throughout the world over the past two decades. Major progress has been made in the USA, Europe and Asia– the 2009 International Ergonomics Conference was held in Beijing. The World Health Organization, International Labor Office, International Standards Office and the International Ergonomics Association have coordinated global advancement of ergonomics standards and practice over the past few decades. The Singapore Society for Occupational Medicine and the National Safety First Council of Singapore hosted very successful Regional Seminar on Occupational Health and Ergonomics Applications in Safety Control in 1978. In 2010 international ergonomics conferences were held in Indonesia and the Philippines. In 2012, the South East Asian Ergonomics Conference will be held in Malaysia.

12. Implementation, monitoring and evaluation

The strategy for the implementation of the National Workplace Ergonomics Framework should be led by the creation of an oversight committee structure and processes with representatives from government, business, the unions and academia, and subcommittees to guide:

a) Ergonomics education, training and program accreditation, and certification of ergonomics professionals, practitioners, and monitors

b) Ergonomics analysis tool selection, development, deployment, and evaluation, including a review of established international ergonomics analysis tools
c) Ergonomics best practices and common processes case studies and guidelines
d) Singapore ergonomics standards evaluation and refinement
e) Implementation, monitoring and evaluation of pilot studies in a broad spectrum of industries
f) A forum for ergonomics knowledge, process and case study communication among ergonomists and other stakeholders, including an annual international conference.

13. Pilot Programs

The implementation of a National Strategy on Workplace Ergonomics in Singapore will benefit from the design, implementation, and evaluation of pilot programs in selected cooperative businesses. Such programs will require the following structures and processes:

a) The identification of business(es) willing to collaborate in a pilot program
b) Business centered teams comprising professional and practitioner level ergonomists and subject matter experts.
c) The establishment of clear objectives, goals and target areas and operations
d) The amalgamation of pertinent quantitative data to support the evaluation of the ergonomics program impact
e) A battery of ergonomics analysis tools and techniques
f) The development of executive, management, and employee training material
g) A systematic review of the identified target areas and operations through focus groups, questionnaires, and ergonomics analysis
h) The systematic implementation of changes to facilities, workplaces, equipment, operations, and procedures
i) Sufficient time to allow the effects of the interventions to take place
j) Formal, quantitative, and qualitative review of the pilot programs
k) Continuous improvement to the process.

14. Conclusions

The National Strategic Framework for Workplace Ergonomics will assure a Progressive and Pervasive People Centered Workplace Culture, making ergonomics an Integral Part of Business Competitiveness and Extending and Sustaining the productivity of Special Populations, including the aging workforce. These strategic objectives will be achieved by Building the Capabilities of the ergonomics community and their tools, Implementing a Compliance Assistive Framework through the development of clear, easy to use standards, tools and processes, and Promoting the Benefits of and Recognizing Best Practices, through widespread communication of successful case studies, and a Voluntary Protection Program in which successful companies receive less oversight.

The Key work areas of this initiative include Outreach and Engagement, Education, Training, Accreditation and Certification, User friendly Ergonomics Assessment Methods, Workplace and Job Design and Ergonomics Research and Development.

The next steps in this initiative include the formation of a participative oversight committee structure and processes to oversee education and training, standards, certifications, tool development, pilot studies and best practices communications. These leaders will manage the rapid deployment of this ergonomics framework, its evaluation and refinement.

Chapter 18

A Book Proposal
Systems Ergonomics for Quality, Productivity and Safety
Brian Peacock and Chui Yoon Ping

Target Audiences

This is a survey textbook aimed at entry level human factors and safety students and students and practitioners of engineering, business and the health professions as a stand-alone course.

Format

The book is presented in a modular format; each self-contained module will comprise a description of the concept or theory, a measurement and analysis approach, some real-world examples and case studies, practical exercises, and references. The modules will make liberal use of models and diagrams, text, and pictures. Each page / screen will be self-contained with internal / external links to subsequent and other pages for background, elaboration, case studies and exercises / activities etc. where appropriate. Subsequent textbooks will use this same approach and format to expand the range of concepts and applications. The book is designed to be compatible with hard copy or electronic media.

Education and Testing

Although this book aims to be comprehensive and sufficient for many educational purposes, it must be realized that contemporary Internet technology can provide a large amount of supplementary and complementary information on any topic. However, this challenges the student to be selective and the teacher to guide the student appropriately. Consequently, each module will present a few key words to direct an Internet search. The student will be expected to identify at least one Wikipedia source, one Google Scholar source and one other source to confirm and elaborate on the material presented in the module.

A second expectation, particularly in the context of e-learning, is that students should collaborate in small groups to facilitate the learning process. The book will contain directed examples to stimulate the collaborative process by requiring a group-based report on a topic related to the module of interest. An appendix to the book will contain examples of these reports.

Contemporary testing methods expect the student to convey higher levels of intellectual understanding, interpretation, and extrapolation. Consequently the book will contain a series of scenario based questions that will include human, technological, operational and contextual complexity and interactions, to test the student's ability to carry out selective measurement and analysis, and develop appropriate intervention strategies, processes and designs.

Contents

1) The first section of the book will introduce ergonomics as a systems approach to the optimization of quality, productivity, safety, satisfaction, and sustainability through the following modules:
    a) Tradeoffs among the Multiple Purposes of Design and Intervention
    b) Comprehension of Complexity and Interactions
    c) Appreciation of the System Life Cycle and Multiple Stakeholders
    d) Donabedian model – Structures, Processes and Outcomes
    e) Articulation of Systems, Processes, Contexts and Outcomes
    f) Variability and Statistics

g) The Scope of Ergonomics: Physical, Informational, Social, Affective, Contextual
h) Ergonomics Process – Job, Outcomes, Measurement, Decisions, Interventions, Mitigations
i) Ergonomics involvement – Research, Analysis, Simulation, Design, Evaluation, Intervention
j) The Foundations of Systems Ergonomics: Space, Force, Information and Time
k) The Principles of Usability – 6Us and 2Ms
l) Sustainability: Reliability and Resilience
m) Tradeoffs, Optimization – Benefits and Risks

2) Physical Ergonomics
    a) Measurement of Human Physical Capabilities, Limitations and Variability
        i) Size and Shape
        ii) Strength
        iii) Speed
        iv) Sensory – Motor Skill
        v) Stamina
        vi) JPAS (Job Physical Activity Sampling)
    b) Design and Intervention
        i) Size and Shape - Workspace and Interface design
        ii) Strength - Materials handling process and aid design
        iii) Speed - Task content and cycle design
        iv) Sensory Motor Skills - Target design
        v) Stamina - Job Design
3) Information Ergonomics
    a) Processes and Measurement
        i) Sensory Processes
        ii) Attention
        iii) Vigilance
        iv) Perception
        v) Operational Memory
        vi) Long Term Memory
        vii) Judgment
        viii) Decision Making
        ix) Situation Awareness
        x) Communication
        xi) Control
        xii) Mental Workload
        xiii) Fuzzy Awareness
        xiv) Expertise
    b) Information Interface and Task Design
        i) Sensory Processes – Signal / Noise design
        ii) Attention – Signal characteristics, Anticipation, Importance, Distraction
        iii) Vigilance – Task and Job Design
        iv) Perception – Framework, cue, context, and signal design; chunking, sampling and temporal factors
        v) Operational Memory – Context, Sequence, Interference design; technological aids
        vi) Long Term Memory – Cue and Context design
        vii) Judgment – Signal / Noise Ratios, Differences
        viii) Decision Making – Outcome importance and decision guidance

ix) Situation Awareness – Salience, source guidance, framework and prediction aid design
x) Communication – Semantic and physical encoding / decoding; transmission media
xi) Control – Feed forward (anticipation), Feedback, Adaptive guidance and Learning interventions
xii) Mental Workload Information, Expertise, Stress and Time factor Analysis and Design
xiii) Fuzzy Awareness – Signal and Noise management at Information Processing Stages
xiv) Expertise – Flexible interface and task design

c) Controls and Displays
   i) Analog displays
   ii) Digital displays
   iii) Symbolic displays
   iv) Representative displays
   v) Display media
      (1) Audio
      (2) Visual
      (3) Tactile
   vi) Controls
      (1) Hand wheels and levers
      (2) Knobs and Sliders
      (3) Keyboards
      (4) Mouse
      (5) Tactile and gesture inputs
      (6) Anticipatory devices
   vii) Control – Display Relationships
      (1) Compatibility
      (2) Speed and precision, control gain
   viii) Panel Design
      (1) Importance, Frequency, Sequence
      (2) Tacto-kinesthetic feedback
      (3) Visual / Audio Feedback
   ix) Inadvertent actuation and recovery

d) Facilitators
   i) Principles
      (1) Instructions
      (2) Procedures
      (3) Annunciators
      (4) Warnings
      (5) Labels
   ii) Measurement
      (1) Content and Context
      (2) Complexity
      (3) Familiarity
   iii) Applications
      (1) Product design
      (2) Public information systems
      (3) Vehicle design

4) Social Ergonomics

- a) Processes and Measurement
    - i) Collaboration and Competition
    - ii) Groups and Teams
    - iii) Hierarchies
    - iv) Group think
    - v) Participation
    - vi) Motivation – Job and Hygiene Factors
- b) Intervention, Task and Job Design
    - i) Collaboration and Competition – Articulation of Boundaries, ground rules
    - ii) Groups and Teams - Team structures, responsibilities and building, Crew Resource Management
    - iii) Hierarchies – Leadership, Cross Functional Teams
    - iv) Group think – Leadership and Rules of Order
    - v) Participation – Quality, Productivity and Safety Circles
    - vi) Motivation – Job and Hygiene Factors

5) Physical Environment
    - a) Measurement
        - i) Light
        - ii) Noise
        - iii) Vibration
        - iv) Heat
    - b) Design, Intervention and Mitigation
        - i) Light – natural and artificial light source, intensity, location management
        - ii) Noise – Communication analysis and design, Hearing loss prevention
        - iii) Vibration – Whole Body and Hand – Arm Mitigation Interventions
        - iv) Heat – Physical and Temporal Interventions

6) Affective Design
    - a) Cognition and affect
    - b) Bias in human judgment and decisions
    - c) Fashion, form and function
    - d) Product design and marketing

7) Macro ergonomics
    - a) Measurement
        - i) Human, Technology, Content, Process and Outcome Analysis
        - ii) Workability Indices
        - iii) Manprint
    - b) Design, Intervention, Mitigation
        - i) Micro ergonomics design, intervention, mitigation
        - ii) Participatory / Stakeholder design processes

8) Ergonomics Investigation Approaches
    - a) Field studies
    - b) Cohort Studies
    - c) Opportunistic Studies
    - d) Laboratory (reductionist) studies
    - e) Simulators
    - f) Simulation
    - g) Environmental chambers

9) Measurement and Analysis
   a) Ethnography
   b) Questionnaires
   c) Focus Groups
   d) Usability Studies
   e) Fitting Trials
   f) Clinical Trials
   g) Task Analysis
      i) Physical Task Analysis
      ii) Cognitive Task Analysis
   h) Question Theory
   i) Checklists
   j) Worksheets
   k) Descriptive tools
      i) 5 Ws
      ii) 6Ms, Ishikawa diagrams
      iii) 5 Whys
      iv) 5 Ps
      v) 5 Ls
   l) Mobile device tools
   m) Photo and Video Analysis
10) Statistics for Ergonomics
   a) Measurement Levels
   b) Statistical Parameters of Location, Scale and Shape
   c) Statistical Distributions
   d) Confidence Intervals
   e) Statistical Inference
   f) Differences (Students T Test and Analysis of Variance)
   g) Associations (Correlation and Regression)
   h) Non-Parametric Methods
   i) Contingency Tables
   j) Multivariate Analysis
   k) Factor and Cluster Analysis
   l) Data Mining
11) Systems Ergonomics
   a) Socio-technical Systems
   b) HFACS
   c) Event and Fault Tree Analysis
   d) FMECA
12) Rule Based Ergonomics
   a) Stress – Strain Relationships
   b) Consensus based cutoff decisions
   c) Multiple Factor Assessment
   d) Policy Decisions
13) Aging
   a) Physical, Sensory, Cognitive, Social and Affective Changes

b) Records and Discounting Analysis
c) Technology and Administrative Interventions
d) Community and Participatory Processes

14) Safety and Health
    a) Cognitive and Physical Factors
    b) Acute and Cumulative Injuries
    c) Epidemiology

15) Case Studies
    a) Transportation
        i) Human Powered Vehicles
        ii) Automobiles
        iii) Trains
        iv) Ships
        v) Airplanes
        vi) Space vehicles
    b) Gas and Oil exploration, transport, and processing
        i) Systems Analysis
        ii) FMECA and Fault Tree Analysis
        iii) Environmental Factors
    c) Agriculture and Horticulture
        i) Job Design
        ii) Handtools
        iii) Mechanization
        iv) Automation
    d) Manufacturing and Production
        i) Production Lines
        ii) Food processing
        iii) Taylorism
        iv) Participation
    e) Manual Materials Handling
        i) Product / Load Design
        ii) Spatial Factors
        iii) Frequency and Duration Factors
        iv) Interfaces
        v) Handling devices
    f) Shift Work
        i) Circadian Rhythms
        ii) Fatigue
        iii) Shift System Outcome measurement
        iv) Shift System Design
    g) Sport and Recreation
        i) Measurement
        ii) Records
        iii) Regulations
        iv) Physical and Cognitive Factors
        v) Equipment

- vi) Personal Protective Equipment
- vii) Gait Analysis

h) Construction
- i) Materials Handling
- ii) Technology
- iii) Personal Protective Equipment
- iv) Safety Management using HFACS

i) Aviation
- i) Cockpit design and operations
- ii) Cabin design and operations
- iii) Air pressure and hypoxia measurement
- iv) Air traffic management
- v) Unmanned aerial vehicles

j) Space operations
- i) Environment design and control
- ii) Space suit design
- iii) Workload design

k) Computers and Smart Devices

16) Some Sample Modules

a) Anthropometry
- i) Measurement
  - (1) Anthropometry is the process of measuring body segment size and shape
  - (2) Measurements may include segment length, width or girth
  - (3) For consistency purposes it is necessary to establish standard reference points; usually these are subcutaneous boney points
  - (4) It is usual to collect a sample of data from a defined population or cohort and use statistical methods to describe the average, standard deviation and various percentile values
  - (5) Design for reach often uses the 5^{th} percentile and for fit, the 95^{th} percentile value
  - (6) However, these simple rules are often compromised by other design criteria
  - (7) Measurement should conform to ISO standard practices
  - (8) Standard data for many world populations
  - *(9) Search the Internet for anthropometric measurement procedures and data*
- ii) Equipment and Workplace Design
  - (1) Many designs require the use of a combination of measures
  - (2) Design must comprehend the implications of non-compliance
- iii) Exercises: Discuss and Design
  - (1) How high and deep is your chair? How high and wide is the door?
  - (2) Where should the controls be placed in an airplane or car?
  - (3) How big are your shoes and shirt?
  - (4) How wide should a seat be on a bus or airplane?

b) Communications
- i) Communications comprise the following processes
  - (1) An idea
  - (2) Semantic encoding
  - (3) Physical encoding

(4) Transmission
(5) Physical decoding
(6) Semantic decoding
(7) Response
(8) Retention
(9) Feedback to the sender

ii) Communications have
(1) variable amounts of information
(2) variable importance
(3) variable amounts of noise
(4) The sender and receiver may have variable amounts of knowledge
(5) The receiver may or may not be paying attention

c) Stakeholders in Design
i) The end user is not the only stakeholder
ii) Consider also
(1) The maintenance operator
(2) The manufacturing operator
(3) The company manager who wishes to cut costs
(4) The fire department that wishes to control materials
(5) The marketing representative who wants to differentiate the product
(6) The purchasing office who wants low cost, reliability and resilience
(7) The security manager who does not want the product to be stolen or misused

iii) Discuss the requirements of the stakeholders and the tradeoffs in the design of the following products:
(1) A car
(2) A theater
(3) A plastic shopping bag
(4) A credit card
(5) A road
(6) An airplane seat
(7) A pair of shoes

iv) And services:
(1) A food court
(2) A university
(3) A grocery store checkout

Chapter 19

What do you think about your BOSS?

(Before you start, please watch the short video at http://www.kanomodel.com/)

This study will use the KANO Model to examine people in organizational hierarchies as "**Service Providers**." The Kano Model identifies features of a service that are "Basic: Must have," "Performance: The More the Better," or "Excitement: Icing on the cake." Please use the following survey form to describe yourself, your subordinates, colleagues, boss, boss's boss and customer(s) in terms of their Kano attributes. ***All individual information gathered in this survey should be anonymous and will be treated as confidential.***

Industry (please circle one)	**Manufacturing**	**Process**	**Governme nt**	**Health Care**	**Hospitalit y**	**Military**	**Other**
	Logistics	**Transport**	**Education**	**Retail**	**Financial**		
Company Size	**<10**	**10-100**	**100-500**	**500-1000**	**>1000**	**>10,000**	
Company Ownership	**Local**	**Regional**	**National**	**Multi national**			
Demographics		**Yourself**	**Your Boss**	**Boss's Boss**	**Colleague**	**Subordinate**	**Customer**
Age							
Sex							
Nationality							
Ethnicity							
Job Title							
Occupation							

Kano Attributes
Please enter 3 Descriptive Words for each category

		Yourself	**Your Boss**	**Your Boss's Boss**	**Colleague**	**Subordinat e**	**Customer**
Basic: must have e.g. Courtesy, Technical Knowledge	**Perceived**						
	Desirable						
Performance: The More the Better e.g. Spends time to listen to your problems, deals with roadblocks quickly	**Perceived**						
	Desirable						

Excitement: Icing on the Cake e.g. Extensive experience, personable	**Perceived**						
	Desirable						

Chapter 20

Setting Compliable and Enforceable Ergonomics Standards

Brian Peacock, Chui Yoon Ping, Samuel Low, Liu Shuli, Phang Chun Kai

Introduction

Some operational definitions: Ethical standards are the community's interpretation of what is moral behavior. Laws are the generalizations imposed by governments and rules are the specific measureable interpretation of laws. Business and engineering offer an alternative wording of this progression. Requirements spring from the voices of the stakeholders; guidelines provide general instructions to designers and engineers, who in turn translate these into specifications for the manufacturer or operations manager. It is possible to verify specifications, whereas requirements need to be validated by appropriate users in intended contexts. A reliable standard will perform satisfactorily under intended conditions and a resilient standard will be effective in unpredicted and possibly extreme contexts. (Figure 3.)

In the context of ergonomics many would agree that the health, safety and satisfaction of employees and users are important objectives (requirements), but most would accept that product or service quality and productivity are the primary purposes of business owners. Effective communication between these stakeholders and standards organizations is important, but often contentious. One approach to effective communication is to develop a common language with verifiable quantitative adjectives for system design and validatable, quantitative adverbs for process outcomes.

The International Ergonomics Society has published "Ergonomics Guidelines for occupational health practice in industrially developing countries[1]." These guidelines acknowledge that ergonomics is about optimization and tradeoffs. They are deliberately non- specific and general in their wording; they deal with principles. They recommend a participative approach with due regard to objective outcome evidence, such as health and safety statistics. They emphasize education and collaboration over compliance and enforcement.

Human and Contextual Variability

The raison d'être and Achilles heel of ergonomics is variability among people, technology, operations and contexts. In many situations, such as seats in public places and transport, "one size fits all" is the mantra, while in others, such as clothing and education, adjustability and adaptability are the norm. Between these two extremes it is deemed necessary to promulgate standards that address the needs of most people in a defined population most of the time. The example of speed limits is pertinent; it is common to see a maximum speed of say 100 kph on a freeway. On occasion this limit may be reduced to 70 kph for certain classes of vehicle under certain conditions, such as poor visibility. There is usually no targeted standard for drivers with lesser training or with age related capability deterioration. However, there are quantitative standards for driving under the influence of alcohol. The purpose of these quantitative driving standards is to facilitate compliance and enforcement, although the law frequently adds qualitative overrides, such as "driving without due care and attention."

Design based on anthropometry has traditionally used concepts such as the 5th and 95th percentile for spatial design of furniture, tools, and workplaces. These principles are popular but naïve. It is almost impossible to precisely define these measures for a combination of body segments, and real-world tradeoffs between fit and reach result inevitably in a compromised design specification. Also, the target populations are usually poorly defined and the accommodation levels must be modified with regard to the level of importance or severity of the possible consequences of failure to accommodate the majority of the target population. The extension of these percentile principles into such dimensions as strength, speed, stamina and skill, and even sensory and cognitive demands, although advocated by some, is simplistic at best and generally irrelevant. The philosophy of "universal design" relies heavily on adaptability for accommodation of large populations; universal design is philosophy rather than science. Guidelines of this nature are neither compliable nor enforceable, but they may be useful!

Discounting Models

Human activity should be viewed in the context of (human), technological, operational and contextual variability and interactions among and within these factors. One approach to the promulgation of standards under such conditions is using a discounting approach. The NIOSH lift equation provides an excellent example of a discounting model. Starting with a maximum weight of 23kg, a “recommended weight limit” (RWL) is calculated by discounting this value by a series of multipliers (numbers between 0 and 1) depending on various force, spatial and temporal factors such as load weight, horizontal distance and frequency of lifts per minute. The Lift Index (LI) is calculated as the ratio of the actual load weight to the RWL. Typical LI values range between 1 and 5. Some authorities require engineering interventions (e.g. load weight or horizontal distance) for a LI greater than 3 and administrative interventions (e.g. frequency) when the LI is between 1 and 3. Although this approach is widely used in physical ergonomics it has a number of shortcomings. First it does not address “nonstandard” lifting tasks, which are most lifting tasks, second it does not address operational, population or environmental context variation. Third, once an index has been calculated, it must be decomposed as there are different intervention responsibilities for the different factors, such as load weight or frequency. As with speed limits, this standard is compliable and enforceable, given a consensus on the Lift Index cut offs. But also, like speed limits there will always be a need for interpretation in particular circumstances. Complexity in physical work may be addressed by psychophysical rather than biomechanical methods. The Liberty Mutual Manual Materials Handling Tables list the “percent capable” of performing various tasks such as lifting, carrying, pulling, or pushing with regard to force and posture. The user has the choice of accommodation levels. Here again the principle of 95% accommodation may be applied, but, more often than not, the use of these standards is modulated (discounted) by cohort training and abilities, and contexts.

Loss Functions

An argument against specification limits or tolerance bands commonly seen in mechanical design is that those responsible for implementation, perhaps influenced by other factors, may stay just within the tolerance limit rather than aim for the ideal dimension. When a series of these tolerances are “stacked” the whole product may be out of tolerance even though the individual components are “acceptable.” A way to avoid this problem is to replace the tolerance bands by “loss functions” where a (linear or non linear) penalty is imposed as the measure departs from the ideal (Figure 1). This approach is also used in the fines for speed limits, with increasing fines being imposed depending on the size of the departure from the speed limit.

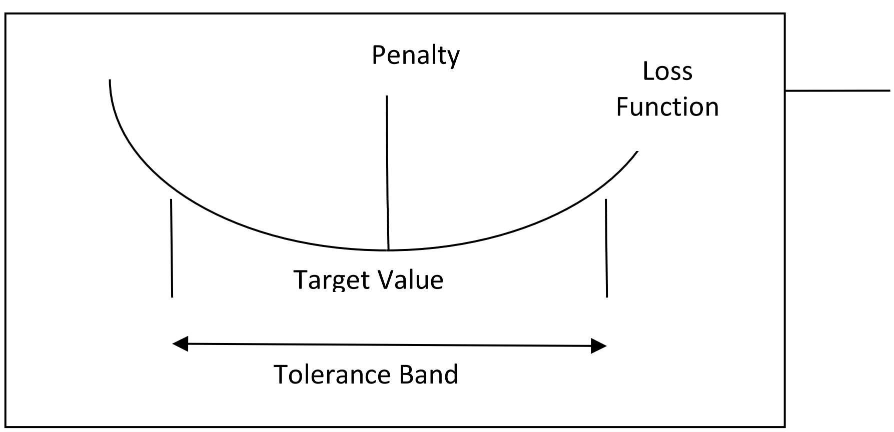


Figure 1 Tolerance Bands (two sided) and Loss functions

Physical Environment

For the physical environment, the challenge of setting compliable and enforceable ergonomics standards are often met by engineers, with loose regard to human factors / ergonomics evidence. Lighting standards are usually defined by the architectural community and rely considerably on human visual adaptability. Lighting standards are affected by the task requirements, such as target size or contrast. It is also well understood that older people generally require greater light intensity than younger ones, but such adjustability is not always practicable. Noise, because of its harmful effects is limited by quantitative intensity and exposure standards. Modern smart device applications enable convenient measurement of light and noise thus making compliance, and enforcement relatively easy procedures, given the establishment of quantitative standards. Thermal environment conditions are limited by intensity (temperature and humidity). Exposure guidelines in some jurisdictions are represented by charts showing the interactions between various components of the thermal environment, such as temperature, humidity, physical workload and sometimes clothing. These quantitative standards may be supplemented by advice on acclimatization methods and fluids intake. Noise and thermal standards are also generally supplemented by a requirement to routinely monitor outcome measures of hearing loss and heat stress.

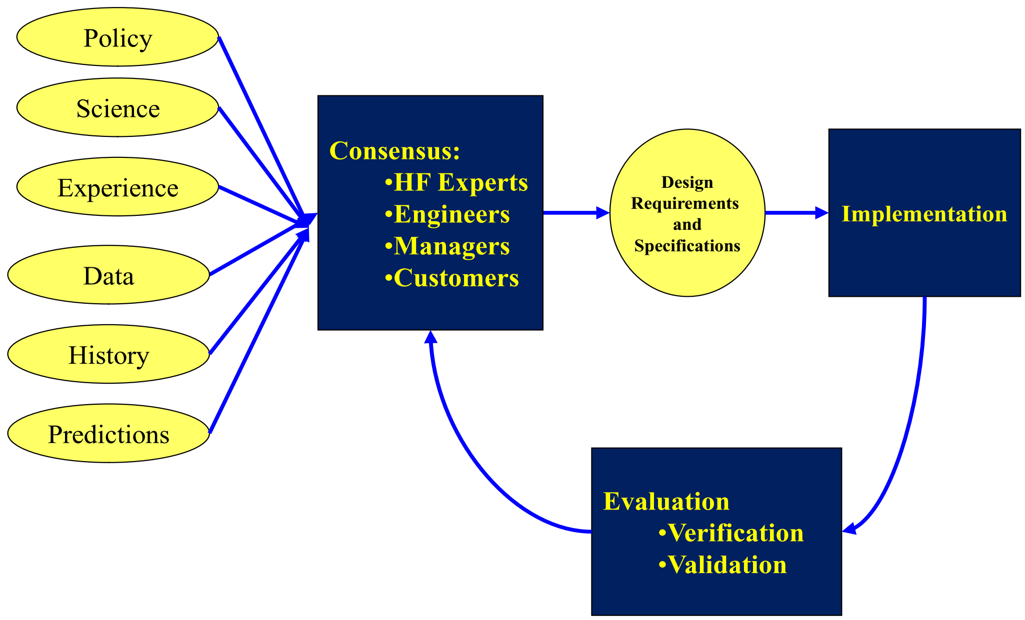
Cognition

In the cognitive domain, the wide variation in experience and knowledge and the ability of people to adapt and learn makes standards setting even more elusive. For example a set of instructions for a consumer product or web page may have to cater for people of all ages and educational / experience backgrounds. In practice the content may restrict the population of users somewhat. More experienced users may be comfortable with more technical communications and frustrated with instructions that cater for say the very young or very old. A study of income tax forms is relevant to the discussion of cognitive and system interface standards. Forms of various designs were presented to lay people and accountants. The designs mainly addressed cosmetic and readability issues but had less influence on performance than did the support material, which explained the tax laws. It was clear from this investigation that experts (the accountants) performed more quickly and accurately than lay people. In written instructions a measure of "reading grade level" may be used to as a guideline although this measure may not be reliable. Whereas forms and computer interfaces may be amenable to useful guidelines and even quantitative standards regarding formats, it is evident that the reliable articulation of content standards will remain elusive and therefore not conducive to compliance and enforcement.

Consensus

The idea of a standard also requires some common understanding of the purpose and implications of failure of compliance. For example, there may be many stakeholders, each with different requirements. One may emphasize product or service quality, another productivity and a third operator health and safety. The resulting standard may then be a compromise. Examples of this dilemma may be found on a production line or in a call center. The owners of the operation will be interested in productivity given an acceptable level of product or service quality, while the operators involved may be more concerned with health and safety, and remuneration. Clearly there will have to be tradeoffs imposed or negotiated among the different stakeholders. Therefore, a consensus-based approach to the development of standards is warranted as shown in Figure 2.

Figure 2.



A consensus and continuous improvement-based approach to setting ergonomics standards.

The issues of compliance and enforcement highlight the need for objectivity. Given the variety of stakeholders associated with a standard, each with their own biases, it is clear that standards that involve subjective interpretation will generate disagreement and tension. The issues of purpose, feasibility, benefit and cost must also be addressed in the setting of standards. Figure 3 illustrates the importance of linking workplace, equipment, task and job analysis to measureable outcomes, including epidemiology and productivity, which are articulated as "customer requirements." In the context of ergonomics, it must be clearly understood that there is a "decision link" between analysis and design or mitigation intervention. These decisions are the prerogative of management or the standards authorities with due regard to the expected costs and benefits.

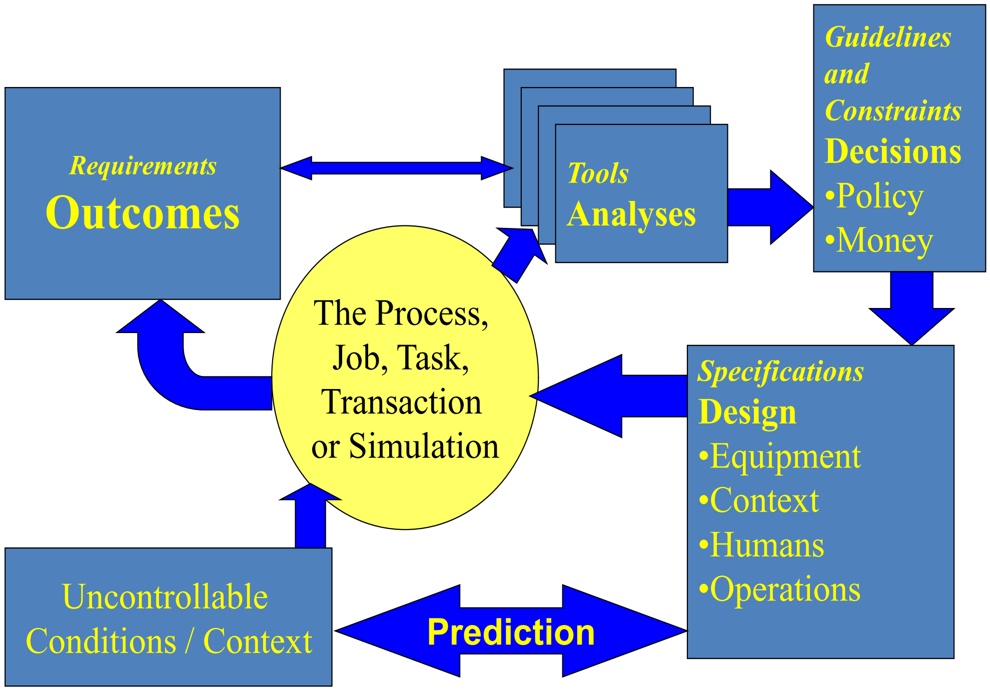


Figure 3. The cycle of analysis, decision, and design with due regard to outcomes and context.

Workplace Design

Workplace design should be based on intended users' size and movements; visual access may also be a consideration. A second consideration must be the temporal aspects of workplace usage and utilization. Finally, the outcomes and consequences of appropriate and inappropriate spatial designs must be addressed to provide benefit and cost support. The spatial arrangements of a mass transit railway system will be used to illustrate ergonomics workplace design standards. The requirements of these designs include comfort and convenience, health and safety, and functionality as measured by stability and mobility. However, there are two important constraints; first, where journeys (exposure) are short, the comfort and convenience criteria may carry less weight, unless these can be achieved with minimal cost increment. The safety outcome is achieved by the incorporation of stability devices (handrails) with easy access. Another constraint is the operational demand on public transport: crowding is an uncontrollable context based on economic necessity. Consequently, the comfort and convenience of passengers as afforded by anthropometric (percentile) accommodation will be sufficiently attained through a one size fits all approach. However, vertical grab rails implicitly provide adjustable access to all sizes of passenger. In this same context there is a current debate regarding a requirement by some airlines to ask large people to purchase two seats; a counter argument is to provide a mixture of different sized seats, or even bench style seats that accommodate a mixture of passenger sizes. First class passengers pay more for larger seats. This debate is presented to demonstrate the emotional, social, economic and political factors that influence standards setting and design.

The workplace requirements of the driver of a bus, train or airplane contrast sharply with those of the passengers, mainly because of the time domain, but also for reasons of visual access and controls reach. The adverse consequences (performance, health, and safety) of design shortcomings are much greater; consequently, the costs of adjustability are justified. The ranges of adjustability in these and automobile driver's seats is a well-honed technology, based on percent accommodation (Roe, 1993)

In both cases design is first based on traditional principles of accommodation – 5th percentile for reach and 95th percentile for fit. However, this must be followed by process of "fitting trials" in which representatives of the intended user population interact with the workplace or workplace mockup under various routine and off normal conditions. These fitting trials are essential to resolve reach and fit tradeoffs and identify operational constraints such as importance, frequency, and sequence of activities. In this way the design specification – the measureable, verifiable, compliable, and enforceable standard is established.

Equipment and Tool Design

The design of equipment and tools from the ergonomics perspective focuses on the displays and controls. The criteria include readability and understandability for the displays and accessibility and manipulability for the controls. Control – display relationships are generally based on population direction of motion stereotypes and speed and precision of control. Layout is based on importance, frequency, and sequence. Visual requirements include object size and contrast; manipulation criteria address hand size, strength and manipulation convenience. Examples include the traditional desktop computer and keyboard, the integral laptop, the tablet and the smart phone. These equipment trends demonstrate the tradeoffs between a static "right angled" desktop and the increasing mobility afforded by the smaller devices, albeit with an increasing compromise of manipulability. As equipment expands in functionality, the design criteria weightings move from the physical domain into the sensory and cognitive domains. However, this increase in functionality is commonly accompanied by an increase in intensity of information processing and the duration of static postures. Physical and cognitive requirements may interact.

Task and Job Design

Task and job designs focus mainly on content, frequency, and duration. The analysis of tasks and jobs is conveniently approached by activity sampling. The ergonomics approach to design is to create optimal physical and cognitive variety through interventions such as task expansion or rotation. Physiological factors such as fatigue and circadian rhythms interact in the time domain with task and job factors

Compliance and Enforcement

The above discussion articulates the dilemma caused by real world complexity. Standards discussion should start with requirements, based on good outcome evidence, such as epidemiology. Next, the widely familiar ergonomics guidelines should be offered as an educational background to consensus building. But finally, for the purposes of construction of environments, workplaces, equipment, and tasks there must be agreement on specifications. Figure 4 shows the general relationship between some measureable, verifiable, compliable, and enforceable measures that are mapped into a validated outcome.

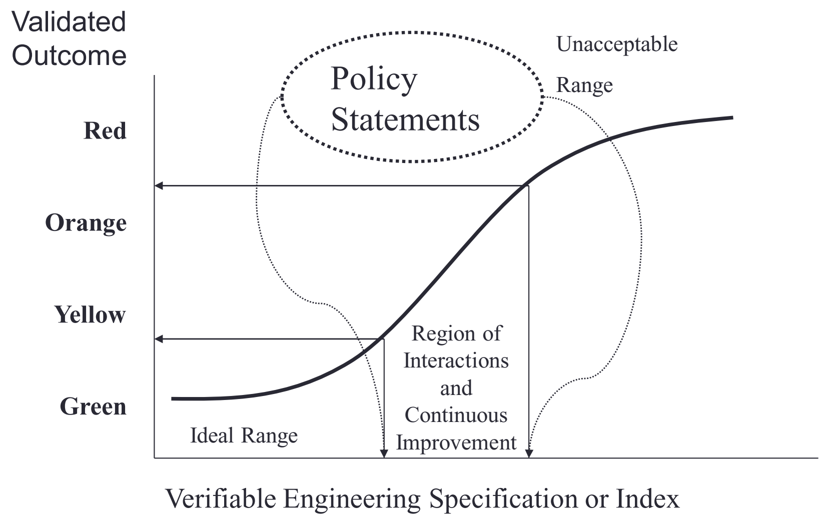


Figure 4. The consensus process of mapping verifiable, quantitative, compliable, and enforceable standards into validated ordinal outcomes.

Policy Statements

The process of obtaining the cut off points (Policy Statements) may be by the consensus process illustrated in Figure 2. The consensus makers may set a conservative policy that relates the mapping to the most vulnerable sub population, such as older workers. Alternative approaches to account for the inherent uncertainty in this standards setting process may include fuzzy set theory or the discounting approach described earlier. Given that "stressor" specifications have been established, then the compliance and enforcement cohorts must establish decision standards for multiple stressors. A successful approach is simply to use counting – the numbers of "Reds", Oranges" and "Yellows" in a scenario that involves say 10 to 20 stressors. The policy could state that all "Reds" must be addressed by engineering intervention, and multiple "Oranges" or "Yellows" must be addressed by either engineering or administrative interventions. The rationale for this "counting "approach is that higher stress values will probably have greater interaction effects with other stressors.

Examples of compliable and enforceable ergonomics specification standards are shown Figures 5a, 5b. This approach employs ordinal numbers (0, 1, 2, 3) rather than colors for the outcome ranges. The cut off points are based on a consensus approach and are easily understood round numbers. The amalgamation is by counting and the final score – numbers of "3s", "2s" and "1s" are compared with agreed upon criteria – note that in this application two "3s" are agreed to be a moderate risk, but more than two "3s" or more than seven "2s" present a high overall risk. These assessments provide clear guidance towards intervention, with the high-risk jobs being addressed first by engineering controls. The jobs presenting an intermediate risk were addressed by engineering controls where feasible, otherwise administrative controls by job rotation were implemented. This process has been used to impose compliable and enforceable standards for many years in a multinational manufacturing company.

Ergonomics Wall Worksheet

JOB/STATION NAME: ________

Analyst: ________________

PAD Number: ____________

Component/Part No.: ________

Date: ____ Rev. Date: ____

C= Current R= Revised

	Current				Revised			
	score	3s	2s	1s	score	3s	2s	1s
Prod								
Proc								

Product Factors

Component Design (C1 - C4)

C1.Weight	C	R
< 1 lb	0	0
1 to 10 lbs	1	1
11 to 25 lbs	2	2
> 25 lbs	3	3

C2.Size (Length + Width + Height)	C	R
< 1 ft	0	0
1 to 5 ft	1	1
5 to 10 ft	2	2
> 10 ft	3	3

C3.Handling Surfaces-Grip (Including Fasteners)	C	R
1 to 3 ins	0	0
> 1/4 in. to 1 in.	1	1
> 3 ins	2	2
< 1/4 in.or Sharp	3	3

C4.Container Design	C	R
Separated Parts	0	0
Small Lots	1	1
Large Container	2	2
Stacked or Tangled	3	3

Vehicle/Subassembly/Tooling (V1-V6)

V1.Vertical Height	C	R
> 3 to 4 ft	0	0
> 2 to 3 ft., > 4 to 5 ft	1	1
> 1 to 2 ft	2	2
< 1 ft, > 5 ft	3	3

V2.Horizontal Reach	C	R
< 1 ft.	0	0
1 to 2 ft.	1	1
2 to 3 ft	2	2
> 3 ft	3	3

V3.Manual / Visual Access	C	R
Top or Front	0	0
Side, 0 to 90 Deg.	1	1
Side, 90 to 180 Deg.	2	2
Under or Behind	3	3

V4.Access for Operator, Parts, Tools, etc. (All Around)	C	R
> 1 ft	0	0
> 6 to 12 ins	1	1
1 to 6 ins	2	2
< 1 ins, direct contact	3	3

V5.Placement of Part (Excluding Fasteners)	C	R
Self Aligning	0	0
Guided/ Rough locators	1	1
Limited Guidance	2	2
Operator Judgement	3	3

V6.Options	C	R
Single Option	0	0
2 to 3	1	1
4 to 10	2	2
> 10	3	3

Fastener/Conn./Seal/Hose (F1 - F6)

F1.Torque Rating -Nm (ft lbs)	C	R
< 5 (3.5)	0	0
5 to 20 (3.5 to 15)	1	1
> 20 to 50 (15 to 35)	2	2
> 50 (35)	3	3

F2.Joint Rate Type - DELETED

F3.Linear Force-N (lbs) (Requiring Use of Finger or Thumb)	C	R
< 5 (1)	0	0
5 to 10 (1 to 2)	1	1
> 10 to 50 (2 to 10)	2	2
> 50 (10)	3	3

F4.Fastener Support	C	R
One Hand	0	0
Location Aid	1	1
Finger Start	2	2
2 Hand Fast., Self Drilling	3	3

F5.Fastener Size/Surface-DELETED (see C3)

F6.Number of Fasteners per Component	C	R
1	0	0
2 to 5	1	1
6 to 10	2	2
> 10	3	3

KEY

Totals	1	2-7	>7
# of 3s	2	3	3
# of 2s	1	2	3
# of 1s	0	1	2

Figure 5a. Ergonomics specifications for product design and evaluation in an automobile assembly plant

Ergonomics Wall Worksheet

JOB /STATION NAME:__________
Analyst:______________
PAD Number:___________
Component/Part No.:________
Date:_______ Rev. Date:______
C= Current R= Revised

Process Factors

Repetition (R1-R2)

R1.Operator JPH	C	R
< 30	0	0
31 to 60	1	1
61 to 120	2	2
> 120	3	3

R2.Repetitions within Cycle	C	R
1	0	0
2 to 5	1	1
6 to 10	2	2
>10	3	3

Posture (P1-P6)

P1.General Access to Job	C	R
Bench Top, Vertical Surface	0	0
Obstructions in Job Path	1	1
Reach Inside Vehicle	2	2
Enter Job, Work in Pit	3	3

P2.Static Postures/Sustained Forces	C	R
< 1/3 Cycle	0	0
1/3 to 2/3 Cycle	1	1
2/3 to Full Cycle	2	2
Full Cycle	3	3

P3.Base Posture	C	R
Sitting with Back Support	0	0
Standing, Sitting w/o Support	1	1
Kneel, Squat, Uneven Sitting	2	2
Lying Down	3	3

P4.Back /Neck Posture	C	R
< 20 degrees	0	0
20- 45 degrees	1	1
20 - 45 degrees with twist	2	2
> 45 degrees	3	3

P5.Hand Location (Ea. Hand)	Left		Right	
	C	R	C	R
Within Box	0	0	0	0
Edge of Box	1	1	1	1
Outside Box < 1/3 cycle	2	2	2	2
Outside Box > 1/3 cycle	3	3	3	3

P6.Wrist Posture (Each Hand)	Left		Right	
	C	R	C	R
< 10 degrees	0	0	0	0
10 to 20 degrees	1	1	1	1
> 20 degrees	2	2	2	2
> 20 with Ulnar or Radial Deviation	3	3	3	3

Lifting (L1-L2)

Complete a NIOSH Lifting Calculation if the Part/Load is > 10 lbs. The Recommended Weight Limit (RWL) (NIOSH, 1991 revised Guidelines) can be calculated using a LOTUS/EXCEL program available through the Manufacturing Ergonomics Lab. The RWL can also be calculated manually.

L1.Two-Handed Lifting- The Recommended Weight Limit (RWL) is established in the revised 1991 NIOSH Lifting Guidelines.

	C	R
< RWL	0	0
RWL to 1.5 x RWL	1	1
1.5 x RWL to 2 x RWL	2	2
> 2 x RWL	3	3

L2.One-Handed Lifting	Left		Right	
	C	R	C	R
< 5 lbs	0	0	0	0
5 to 10 lbs	1	1	1	1
> 10 to 20 lbs	2	2	2	2
> 20 lbs	3	3	3	3

Energy (E1-E3)

E1.Walking (Steps per Min.)	C	R
3 to 5 steps (2.5' per step)	0	0
1 to 2 or 6 to 10 steps	1	1
0 or 11 to 30 steps	2	2
> 30 steps	3	3

E2.Carrying, Push/Pull Force	Left		Right	
	C	R	C	R
< 10 lbs	0	0	0	0
10 - 20 lbs	1	1	1	1
20 - 30 lbs	2	2	2	2
> 30 lbs	3	3	3	3

E3.Climbing Up /Down Steps, Ramps, Fork Trucks, etc. (per minute)	C	R
1 ft.	0	0
> 1 to 2 ft.	1	1
> 2 to 5 ft.	2	2
> 5 ft.	3	3

KEY

Totals	1	2-8	>8
# of 3s	2	3	3
# of 2s	1	2	3
# of 1s	0	1	2

Figure 5b Ergonomics specifications for process design and evaluation in an automobile assembly plant

Conclusions

"If you can't measure it, you can't manage it." This truism is pertinent to ergonomics standards setting if compliance and enforcement are intended. More general guidelines may be useful but these may need interpretation by trained ergonomists to translate requirements into guidelines. Because there are usually multiple stakeholders, each with different requirements, it is necessary to use a consensus approach to translate guidelines into quantitative specifications.

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Chapter 21

Laws, Rules, Suggestions and Guesses

This article is about the winds of change that from time to time blow around an organization, sometimes in the form of a pleasant breeze, sometimes like a tornado spinning here, there, and everywhere and sometimes like a targeted destructive hurricane.

Back in the day good old England was ruled by a catholic monarchy – a carryover from the days of Rome. Then this new king wanted to get rid of a wife, so rather than cut off her head, he decided to divorce her. But that idea did not sit well with the Church of Rome, so the Church of England was born, and good old England has been ruled by protestant kings and queens ever since. It should be noted that it has been the queens that have had the greatest tenure as rulers of that seafaring and cricket playing nation. In their wisdom the monarchs and the archbishops agreed that the people would be well served by the creation of a parliament, consisting of an popularly elected lower house of plebeians and a an upper "house of lords", many of which had traces of blue blood and invariably attended Harrow, Eaton, Oxford and Cambridge to receive their indoctrination into the class system. Before going into parliament, some of these lords served in the military – a brave and strong arm of expansion and imperialism. "Rule Britannia, Britannia rules the waves, Britain never, never, never shall be slaves." Graduates of other lowly trade schools often went into trade - a necessary and increasingly important feature of a growing populace and empire.

As time went by these strong institutions – the monarchy, church, parliament, military and business leaders vied for control of both their own destiny and that of the country and Empire. Meanwhile the academics cogitated the meaning of life and entertainers proved themselves to be the only universally popular profession. Greediness crept in and the imperialists exploited the colonies and purloined their raw materials and resources, such as chocolate. One upstart group of colonists, who were and continue to be somewhat unkind to the aboriginal inhabitants of that large and fertile transatlantic land, ungratefully decided to complain about taxation and representation and symbolically attacked that bastion of the British Empire – tea. They formed terrorist groups and hid behind trees and did not wear the customary uniforms of combatants. But alas and alack they were successful, but not before they had been given the wisdom of democratic government, a beautiful language and cricket, which they proceeded to butcher mercilessly. They created a novel kind of government – no kings and queens – but rather one with legislative, judicial, and executive branches. They also retained the institutions of the church, which had variable influence, a strong military, and an increasingly powerful business community. And the academics cogitated. Whereas their forefathers laid out a perceptive and powerful constitution, they proceeded to create prestigious law schools that churned out lawyers to feed the insatiable appetite of the legislative, judicial, and executive branches to interpret and butcher the constitution. Furthermore, the influence of these interpreters spread like wildfire into the business community where they apply their voracious appetites for wealth and control.

A similar development carried over into the world game of football (soccer to some) which was the meeting ground for the immigrants from all over the world. This game started out with a constitution of just seventeen laws the vast majority of which addressed administrative details such as the shape and size of the pitch and ball, and how to restart the game after a stoppage. One strong rule clearly pointed out the fact that this was a game of football, to be played generally with the feet, although occasionally with the hands in the case of the goalkeeper. Just one law addressed the conduct of the players by kicking, holding and pulling; pushing is allowed but only with the shoulders. The duty of the referee was to interpret the laws which he did by detecting advantage and by looking into the eyes of the offender to detect malice. This judicial interpretation by the referee kept the game moving but unfortunately has once again been butchered by the derivation of a million rules. But eventually the culture of *"ludum non victoriam amare"* prevails in this epitome of personal and vicarious entertainment.

Fortunately for all humanity small groups of individuals, particularly the family, ultimately provide the glue that allows organizations to function. This is called culture. It describes the behaviors of individuals and groups which transcend the laws and rules created by organizations that increasing seek to micromanage by the promulgation of laws and rules. Sometimes these collections of individuals fall apart, dissipate and reform, happily. But sometimes they coalesce into a cancer that that grows and is destructive. Eventually however the strength of small groups returns, and the inherent culture of the organization survives.

Which brings us to the Human Factors and Ergonomics Society. This was a society created by a small group of thinkers that were saddened by the unthinking designs of engineers and rule makers. They aspired to make the world more livable by spreading the gospel of design for expected use and foreseeable misuse. The Society grew and became imperialistic – they dropped "America" from their title and then appended the tautologous "ergonomics" with an "and," rather than assuming this more expressive name for their own version of this useful applied science. In their wisdom and pragmatism, they created divisiveness and misunderstanding. They created a myriad of technical groups to cover the spectrum of theory and application that is ergonomics. They created a bumpy marriage of those psychologists and engineers who were concerned with brains and bodies respectively and shunned the overtures of those from the health professions who knew more about minds and bodies. They even spurned the lawyers and the religious ministers who were simply constrainers of behavior. And they cogitated.

But then members of laity stole some of the theories and proceeded to apply them piecemeal to their products and processes. They heard about the 5^{th} percentile and applied it to the design of everything, at least where it was considered convenient.

22

Replacement Tires

Recently Michelin have issued a recommendation that replacement tires should be placed on the rear wheels rather than the front. This recommendation is accompanied by a video of vehicles spinning out of control on skid patches and under heavy rain conditions. The argument is that it is preferable to have the greatest grip / friction on the rear wheels to prevent them breaking away under low friction / abrupt steering situations. It may be that this advice is because rear wheel skids are more prevalent than other forms of loss of control and thus the strategy addresses the biggest problem in terms of frequency.

The conventional wisdom is that new replacement tires should be placed on the front wheels. This is supported by a recent survey by Wogalter (2008) that indicated that 63% of survey participants favored the front wheel placement. Whatever the evidence and motivation of Michelin, the problem is complicated by the following vehicle, environmental, operational and driver variables:

- Vehicle
  - Front or rear wheel drive
  - Presence or absence of antilock braking systems
  - Vehicle suspension
  - Vehicle mass distribution
  - Two / four wheel steer
- Environmental
  - Ice
  - Snow
  - Rain
  - Road surface
- Operational
  - Speed
  - Type of loss of control
  - Other traffic / obstacles
- Driver
  - Experience in skid control

Types of loss of control

A common type of loss of control is when heavy braking and steering avoidance maneuver are applied on a low friction surface leading the rear wheels to "break away"; if not controlled the vehicle spins and if a tripping hazard is encountered (a curb or change of surface to higher friction) the vehicle may roll. This type of skid is controlled by steering "into the skid" until control is achieved.

There is controversy in the industry whether or not to apply full braking (in vehicles without antilock brakes) or to "feather" the brakes. The argument for full braking is that the vehicle will always continue to slide in a straight direction. "Feathering" advocates argue that subtle coordination of braking and steering will lead to more effective control.
A second type of loss of control occurs when all four wheels slide. This is a very difficult situation to control, until the friction between the steering wheels and road surface is reestablished.

Hydroplaning occurs when there is standing water or slush and all four wheels lose traction.

In rear wheel drive vehicles too heavy use of the accelerator, combined with a low friction surface, results in a wheel spin (burning rubber) perhaps causing the rear wheels to break away or “fish tail.”

In front wheel drive vehicles hard acceleration can lead to “torque steer” in which the front wheels “lurch” to one side depending partly on the orientation of the front wheels with respect to the mid line of the vehicle.

Stiff suspensions may cause the vehicles to initiate a roll to the outside of a bend. The particular conditions may lead to a four wheel skid or a more serious roll. Active suspension reduces the rolling tendency and maintains a “more equal” distribution of the vertical forces over all four wheels, with consequent improved traction.

Vehicle Control

The control of skids (rear end movement) and slips (unwanted movement of all four wheels) is achieved by coordinated braking (or accelerating) and steering. Parenthetically power, aileron (bank), rudder (yaw) and elevator (pitch) control coordination are also used to prevent similar unwanted movements during turns in airplanes.

A rear wheel skid is the easiest to control, usually by judicious steering into the skid. However, this maneuver does require practice as over control can lead to a four wheel slip. As this is the commonest situation it behooves drivers to get practice – at slow speeds in a snow-covered deserted parking lot.

Loss of traction of the steering wheels is a near impossible control situation, but fortunately such situations are less common than rear wheel skids.

With antilock braking systems the usual advice is to apply full braking when traction is lost while continuing to use steering to control the vehicle.

Four-wheel steer requires more complex analytical and empirical investigation.

Conclusion

Putting the better replacement tires on the front (steering) wheels will facilitate more effective control of a skidding vehicle. However, placing the better tires on the rear wheels will help to prevent the occurrence of the more common rear wheel skids. But I guess Michelin know more about this than I do!

Chapter 23

Simulation of Emergency Evacuation from Transport Category Aircraft

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With contributions by Chris Brandon, Chris Spiva, Erik Schmidt, Erich Skoor, Isabel Ruiz Zaera

Abstract

The certification of transport category aircraft requires an emergency evacuation demonstration mandated by both FAR Part(s) 25 and 121. There are many constraints on the demonstration, including gender, age, exit availability, and time. There are no provisions in the regulations concerning use of simulation for emergency egress; yet, simulation is widely used in design considerations for buildings, roads, manufacturing processes etc. Muir et. al. (1989, 1994, 1996, 2004) have written extensively on emergency evacuation of transport category aircraft and suggested the use of simulation, as an alternative to demonstrations, in order to better understanding the influence of variability in emergency egress situations.

The simulation approach adopted here involved the development of models with varying levels of detail, such as movement durations through the sequential evacuation stages – from the seat and aisle, to the door and use of the exit slide. These times were modeled by the Gamma and Lognormal statistical distributions with parameters estimated from observations and data related to human movement in constrained evacuation situations. Constraints were placed on the activities to simulate blockages at various stages of the evacuation. These constraints were intended to represent handicapped passengers or "kin" behaviors in which groups of passengers attempt to stick together. The results of the preliminary simulations indicated the viability and validity of the approach and showed the expected effects of passenger movements and delays. More extensive investigations, planned over the coming months, will focus on the cause and effect of blockages and passenger behavioral variability.

Introduction

Aircraft accidents are relatively rare events. However, the context of high (but survivable) impact forces, release of volatile fuels, ignition sources and flammable materials is such that successful evacuation is a very time critical issue. There are examples of successful evacuation of large airplanes in a very short time – both from demonstrations and from actual accidents (e.g. the Toronto runway excursion accident involving an Air France A-340 in August of 2005; and the recent British Airways 777 in London), with minimal casualties. There are also records of unsuccessful evacuations (e.g. the Air Canada DC-9 at Cincinnatti in 1983 in which 23 of 46 people died due to the effects of fire, and the British Airtours B-737 at Manchester, England in 1985 in which 55 people perished in an aircraft that never left the ground). New airplanes are being designed with greatly increased capacity, but the time available for evacuation is unlikely to increase. The solutions to this problem are an increase in the capacity of the escape routes, improved procedures, and training. Discrete event simulation approaches will provide important contributions to these designs.

Background

The requirements for emergency evacuation demonstrations by operators were first established in Part 121.29 of the Federal Aviation Regulations by Amendment 121-2, effective March 3, 1965. Operators were required to conduct full-scale evacuations within a limit of one-hundred twenty seconds using fifty-percent of the available exits. In 1967, this established time limit was reduced to ninety seconds as Amended by Section 25-46. This exercise demonstrates the operator's ability to execute the established emergency evacuation procedures and ensures realistic assignment of functions to the crew.

The requirements for the emergency evacuation demonstrations by manufacturers were established in Part 25.803 by Amendment 25-15, effective October 24, 1967. With seating capacity of aircraft exceeding 44 passengers,

manufacturers were required to conduct full-scale evacuations within a ninety-second-time limit. It was considered that the manufacturer's demonstration illustrated the basic capability of a new airplane before the Part 121 requirement intended to account for crew training and adequate crew procedures developed by the individual operator. Hence, the test conditions were somewhat different. These demonstration tests provided data on (a) evacuation rates, (b) escape system performance, and (c) behavior of evacuees during the demonstrations.
It was proposed in Notice 75-26 that analysis, or a combination of analysis and tests, be used to show evacuation capability. By dropping the provision which allowed analysis alone and requiring a combination of analysis and tests through Amendment 25-46, this was meant to assure approvals would be based on sufficient test data since data may not be available in the case of a completely new airplane or model which had major changes or a considerably larger passenger capacity than a previously approved model. This design stage presents an ideal opportunity for simulation.

The preamble to Amendment 121-176 from the FAA study of evacuation demonstrations states, "that with rare exceptions, the rates of passenger egress are not significantly different for the same type of exit and that changes in the passenger cabin configuration, seat pitch, and aisle width have no significant bearing on the egress rates if the airplane type certification requirements for minimum aisle width and exit accessibility are met."
However, Muir, Bottomley and Marrison (1996) found that all increases in aperture width up to 30 inches produced significantly beneficial flow rates, but further width increase provided no additional benefits. Moreover, when comparing different aisle widths they concluded that, "more bottlenecks occurred in the 24 inch configuration tests than in the 20 inch tests, even though the mean evacuation time for the former condition was less than that of the latter." This suggests that aisle widths have a possible significant bearing on egress rates even when the type certification requirements for minimum aisle width are met. Therefore, the possibility for modeling or simulating the emergency evacuation with aisle variations could prove useful in understanding human behavior and safety design.

The 1985 FAA Public Technical Conference held in Seattle, Washington discussed the conduct of emergency evacuation demonstrations and the use of analysis in lieu of full-scale demonstrations. The rationale of such discussions was to discuss policy formulation on when to conduct evacuation demonstrations or analysis. However, no consensus could be reached concerning the analysis in lieu of full-scale demonstration's and the FAA issued AC 25.803-1 "Emergency Evacuation Demonstrations." So, the analysis used to ascertain if an evacuation needs to be conducted, as well as, the procedures used in conducting the evacuations are explained in the Advisory Circular. Ultimately, though, there is no mention of the use of alternative means of evacuation demonstrations, such as modeling or simulation, in the AC 25.803-1.

Modeling or simulation of emergency evacuations could provide understanding of aircraft designs without the costs, injuries, or mock-ups required in full-scale demonstrations. Muir and Thomas' study (2004) supports this perspective when they investigated passenger safety and large transportation aircraft. In their landmark study of passenger survival factors they concluded that, "In view of the numbers of passengers and , as a consequence, the potential for injury, consideration could be given to the use of a combination of modeling and partial testing rather than a full-scale evacuation test."

Methods

Evaluation of Physical Factors

The first task was to assess the physical, geometrical and temporal nature of the evacuation situation including seat configuration and location, restraint system, seat pitch, distance to aisle, width of aisle, number of available exits, distance to nearest exit, headspace in front of exit, configuration and operation of the exit, as well as associated evacuation slides. An additional set of variables will be developed regarding the environmental factors in post-impact situations. Evidence regarding environment factors will be obtained from the literature and include such things as fire ignition, development and propagation, exit availability and post-impact condition or the occupants. Additional factors relate to the condition of the fuselage (intact, partially intact, or fragmented) and compromise to survival such as smoke, toxic gases, and heat. Data will be obtained from previous accidents to identify evacuation conditions, times, failure modes and escape probabilities. Next informed assumptions will be made regarding the numbers, characteristics, and behaviors of the passengers. Finally, detailed evacuation performance requirements will be obtained from industry and FAA documents.

Flight Attendant Training

The capabilities and actions of flight attendants are important factors in successful evacuation. Given that the hardware on most passenger aircraft is unchangeable, the next line of defense is through the development of facilitators (instructions, warnings, labels and procedures) and training of both flight attendants and passengers. Regulations already require that only capable passengers be seated in the exit rows; these passengers must follow flight attendants commands and then open the exits. The first challenge for flight attendants is the variability among aircraft regarding exit hardware function and procedures. Next flight attendants are assigned different responsibilities around the aircraft when the need for evacuation occurs; these different responsibilities, together with the different exit operating procedures can be a cause for confusion. The familiar duty of the flight attendants is to carry out a preflight safety briefing, including what should happen in the case of an evacuation. This briefing supplements the largely pictorial information on the passenger safety card which is in all the seat back pockets. Although this instruction process is well intentioned and familiar to frequent flyers, it may not be adequate for many infrequent flyers, especially in the case of a real emergency. It is under these conditions that the flight attendants must be knowledgeable, assertive, and flexible depending on the conditions. Hence there is no substitute for rigorous selection and training of flight attendants, whose actions may be critical in the very unlikely occurrence of an evacuation.

Video

Video technology is a rich analysis and training aid. The U Tube video of the A380 evacuation demonstration provided a particularly good introduction to a highly orchestrated event in which 873 passengers evacuated in 77 seconds, but with one serious injury (a broken leg) and 32 minor injuries.

http://www.youtube.com/watch?v=XIaovi1JWyY

Video analysis can provide useful passenger behavior and time data for different situations, including maximum unobstructed movement speeds and speeds observed for less physically capable passengers and under more constraining conditions, such as blockages.

Simulation

The traditional methods of observing human behavior and performance, such as that in evacuation from transport aircraft, include outcome statistics (e.g accident, fatality, injury statistics), and controlled experimentation or demonstration. The former approach has considerable validity (the events actually happened) although the exact conditions are not easily replicated and analysis and therefore conclusions may be flawed by missing evidence. The latter approach has good repeatability, but often questionable validity owing to the cost and potential danger to which the participants are exposed. The current method of aircraft certification of related to evacuation is by constrained demonstration. The constraints include passenger demographic mix, exit availability and a time limit (90 seconds). Other factors affecting behavior and performance include the aircraft configuration (seat pitch, aisle width, door dimensions, blockages etc) and cabin crew training, behavior, and performance. Also, these demonstrations are usually single, orchestrated events that are not subject to statistical controls to address the various combinations of configuration, passenger, flight attendant and situational variables, such as fire, smoke, aisle blockages, door, and slide failures etc.

The alternative approach used in this investigation is discrete event simulation. This approach enables an infinite number of combinations of conditions, replications, and outcome measures. It is also very inexpensive – only requiring the availability of software, sufficiently powerful computers, and the knowledge and time of the investigators. For the present investigations, the Micro Saint Sharp discrete event simulation tool is used, although there are alternative simulation packages, such as Arena. The Micro Saint Sharp package works well on a high-end desk top computer, provided the models are not too extensive or elaborate. There are two major shortcomings with the simulation approach. The first is the validity of the models – do they realistically represent the activities associated with evacuation? These problems are addressed by using a consensus of domain and simulation experts to develop and evaluate the models. The second shortcoming is the availability of accurate, reliable and valid data to drive the simulations. Most of the data needed relate to the times taken to execute various activities and the probabilities of different branches in the model logic, such as the probability that an aisle or exit will be blocked. This shortcoming is addressed in two ways. First it is necessary to obtain data from appropriate sources, such as actual evacuations or demonstrations, or from similar operations, such as evacuation from buildings, laboratory experiments of movement in constrained conditions etc. The second approach to the application of data is through statistical assumptions and sensitivity analysis. For example one may assume Gamma or Log Normal statistical distributions (Evans et al 2000, Doane and Seward 2007, Elizandro and Taha 2008, Konz and Johnson 2000) of movement times and manipulate the parameter values in repeated simulation runs to explore worst and best case scenarios. This approach is widely used in PERT / CPM analysis.

The simulation study development includes the following levels of sophistication:

1. The basic models developed in this study included seat exit, aisle exit, door exit and slide exit. Each of these activities was further broken down into sub activities, such as moving from one location to the next in a seat row or aisle. At this level it is possible to simulate normal, orderly evacuation behavior, assuming fixed or variable movement times.
    a. The movement time variability can assume a Rectangular, Exponential, Log Normal or Gamma Distribution
2. The next level involves creating limited resources such as seat, aisle, door or slide "slots", which forces queues to develop preceding the egress activity.
3. Blockages are simulated either by a probabilistic branch back into the current activity or by simply removing the availability of an exit, seat or aisle slot resource and an activity ending effect.
    a. This feature may be modeled by having a resource branching into an "occupied" state for a variable time, or permanently.
4. Probabilistic branching to other pathways is introduced when a blockage (queue) develops.
    a. This may involve back tracking along the aisle if an exit becomes unavailable.
5. The final level of sophistication involves the introduction of aberrant behaviors by passengers
    a. There may be very large, old or handicapped passengers whose movement times are significantly slower and who may be the cause of temporary (or permanent) blockages
    b. There may be passengers who choose to take luggage with them, which can be simulated by slowing them down or by having them occupy multiple resources (e.g. aisle slots.
    c. A third behavioral feature is "kin behavior" in which groups of people, such as families stick together. This is simulated by linking individual entities (passengers) and having a group take up multiple spatial resources and / or move more slowly. This behavior will also increase the probability of blockages
    d. The fourth group of behaviors can generally be called 'panic behavior'. These are characterized by irrational acts, such as freezing or pushing or going in the wrong direction, and hysterical outbursts. As far as evacuation is concerned, these behaviors can be very disruptive and cause time consuming blockages.

Each of these variants is set up in Micro Saint Sharp by creating "Scenarios". Furthermore each scenario or combination of scenarios needs to be arranged according to an appropriate experimental design and each experimental combination needs to be replicated multiple times to understand the effects of residual random variability in the implementation of the model, whose building blocks are based on classical statistical distributions (Evans et al 2000).

Results

Micro Saint Sharp enables the investigator to display time unit to time unit status (snapshots, watches) of the various model parameters, either in a digital or graphical way (charts). The charts that are displayed at the end of a simulation run show the progress of the various parameters as the evacuation progresses, including a final status when the simulation ends by time (e.g. 90 seconds) or number of passengers processed (e.g. 180). These parameters include queue length, number of entities in service or number of entities served. Other output variables include the time spent in a queue or service activity or the time taken for an entity (passenger) to move through a part of or the whole system.

Another feature of the program (OptQuest) enables a complete simulation run to be executed which searches for an optimum level of performance given input or probabilistically occurring constraints. For example, if passengers have the opportunity to choose among exits then it is possible to determine the best possible strategies given the flow through different aisle segments.

Results to Date

Three different models were developed during the first phase of this investigation as shown below in Figures 1, 2 and 3. Each of these models added a degree of sophistication to the simulation.

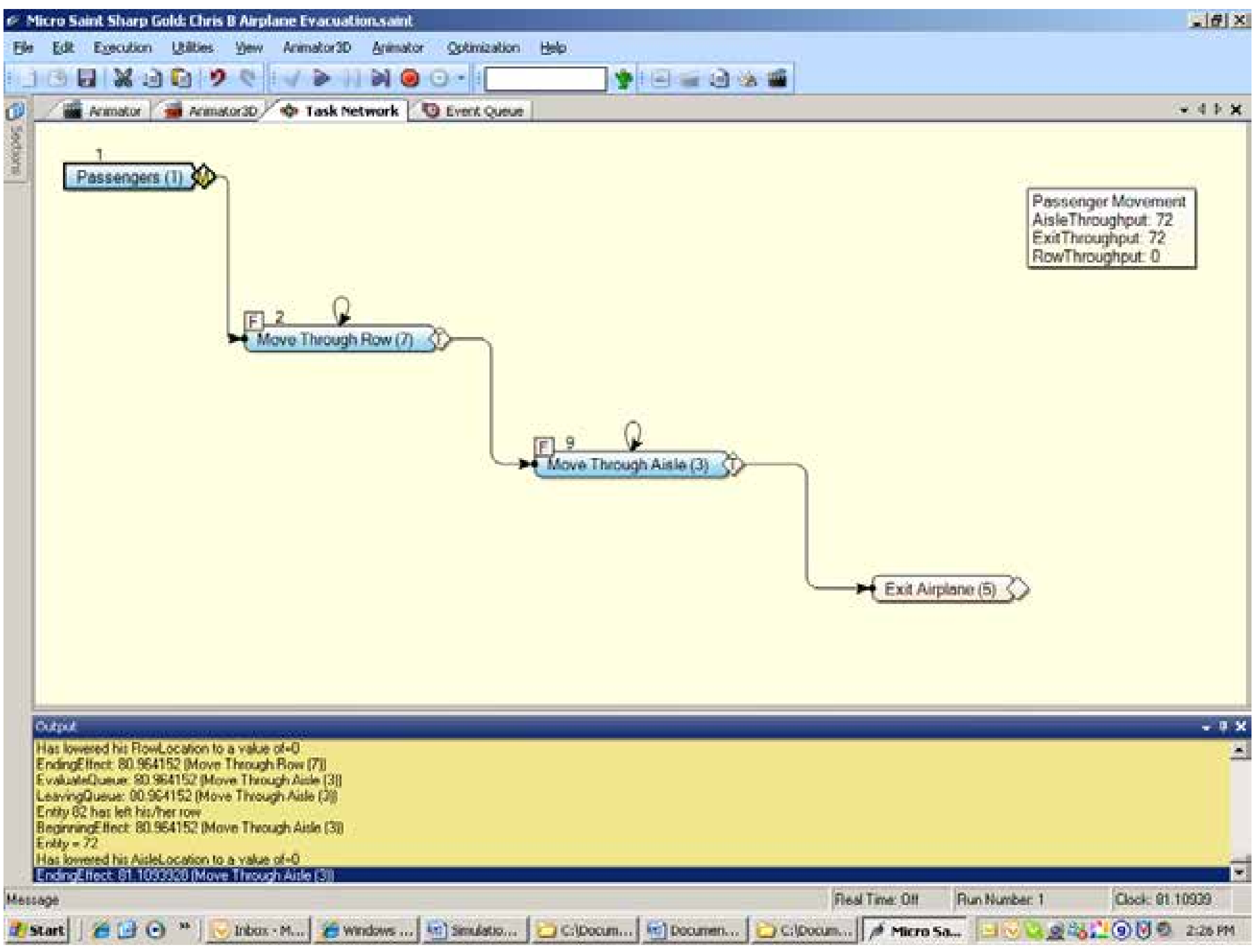

Figure 1 A basic model of evacuation processes

This basic model used exponential "service times" (Mean = 1 – 5 seconds per movement between "spaces") for each row, aisle and door exit activities and updated the location of a passenger as he /she moved incrementally along a row or aisle, or exited the airplane. Queues were allowed to form if a service "resource" (space) was not available.

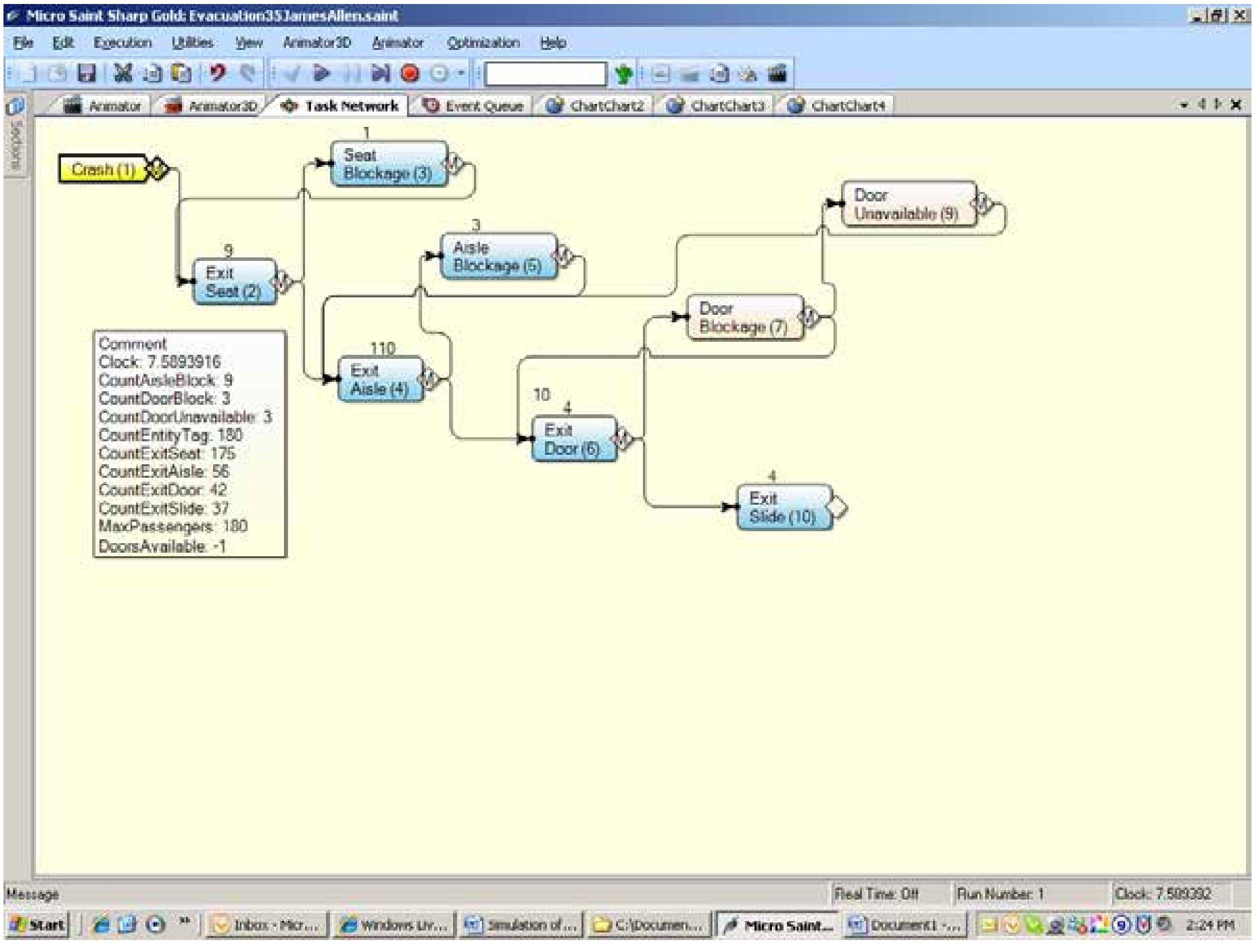

Figure 2 A model of evacuation that allows probabilistic branching to blockage conditions.

The model in Figure2 includes a probabilistic branch to a series (seat, aisle and door) of blockage conditions. Furthermore, the door blockage may develop into a "door unavailable" condition, again on a probabilistic basis. Manipulation of the activity throughput times, using a Gamma distribution with means and standard deviations calculated based on the distance of the seat from the aisle and the distance of the seat row from the door. The probabilities of seat, aisle and door blockages were systematically increased from 0.0 to 1.0.

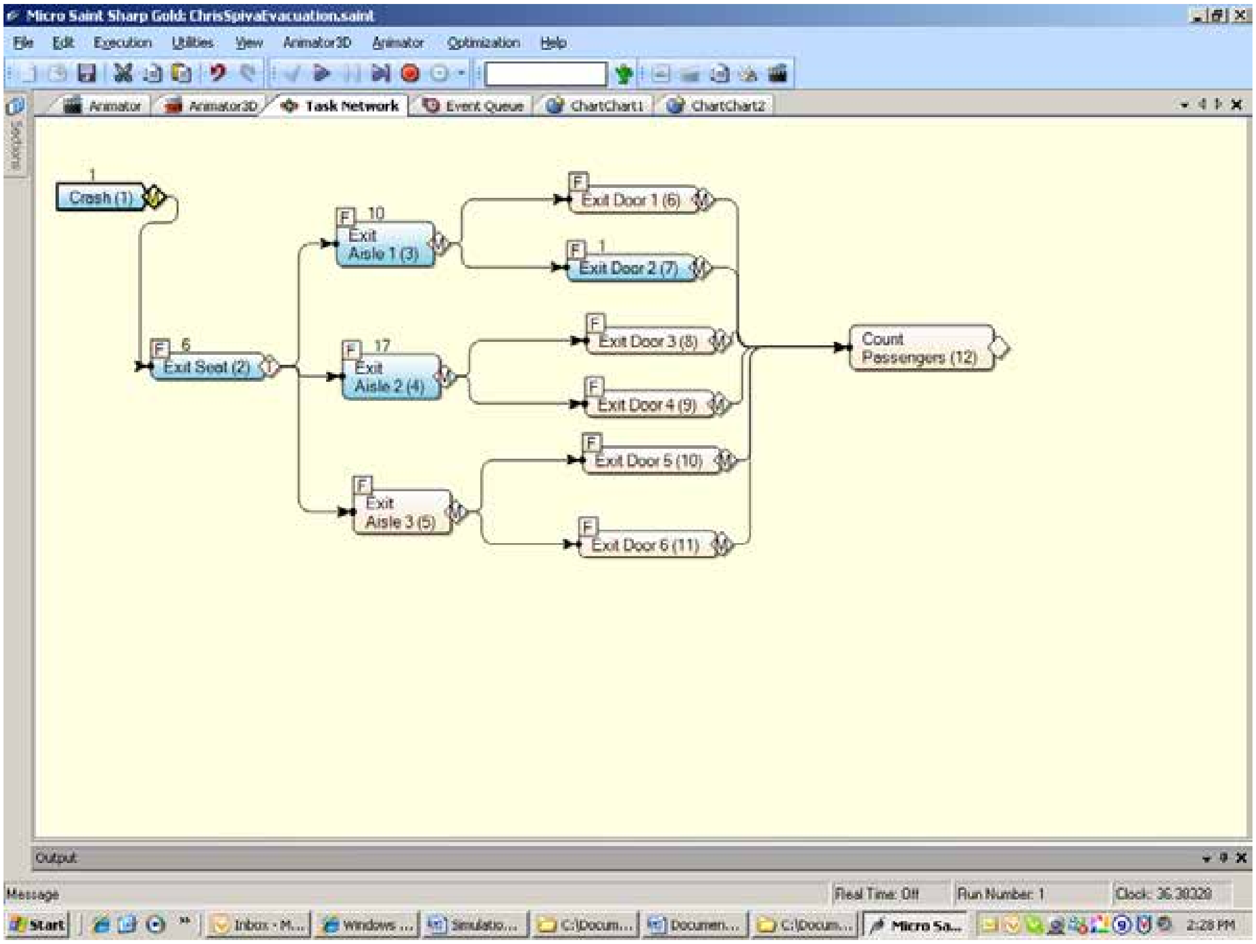

Figure 3 A model that overtly separates the different evacuation pathways

This model explored specific exit path assignments based on seat location. Exit times were related to position in row and location of row. An extension of this model addressed looping back to alternative routes if a resource became unavailable or the waiting time for the resource exceeded an assigned amount.

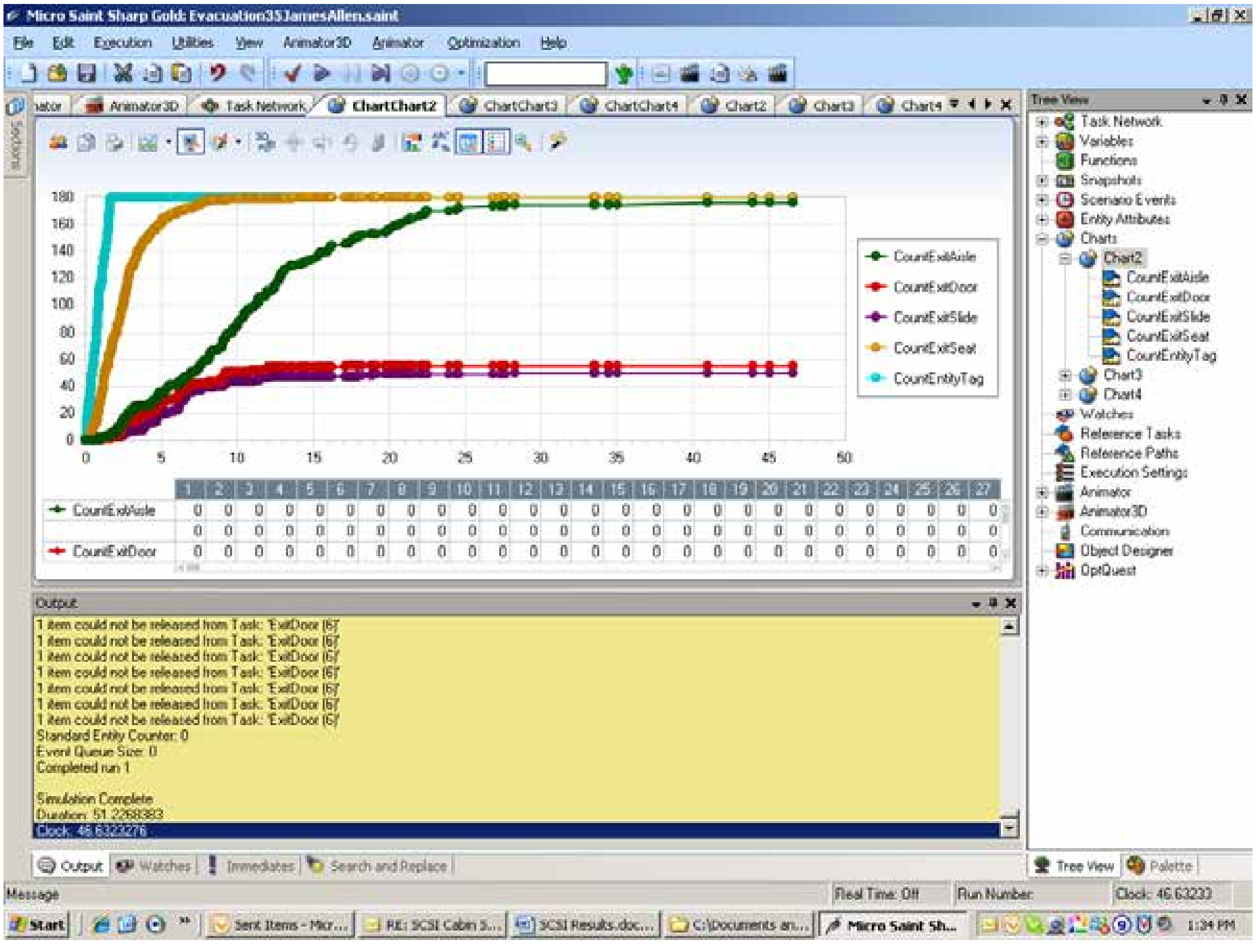

Figure 4 Typical evacuation graphs

Figure 4 shows the timeline of movement from rows, aisles, doors, and slides. In this run, there were 180 passengers who all exited the seats after 5 seconds and the aisles after about 25 seconds. However, apparent congestion at the doors indicated that only about 50 passengers exited the doors and slides.

Discussion

The project to date has reviewed a considerable amount of the extensive literature available on this topic and this activity is ongoing. The modeling effort to date has focused on the development of representative models although the scarcity of actual passenger movement times in these situations is a barrier. Despite this shortcoming and using estimated movement times and movement time variability from evacuation and industrial engineering literature, the models behave as expected. A second aspect of the modeling effort is to develop an adequate representation of passenger behavior and the resulting blockages at various locations in the exit pathway. This project is at the midway stage and further refinements of the simulation will be forthcoming over the next few months. One value of this approach is the ability to explore a wide range of conditions, such as movement times and resource (aisles, doors etc.) capacities. This demonstrated a considerable advantage over traditional demonstrations which are costly, dangerous and present only a snapshot of one single set of conditions.

Conclusions

Successful emergency evacuation from large transport category aircraft is affected by the configurations, the conditions (fire, lighting etc.) and the capabilities and behaviors of the flight attendants and passengers. Actual demonstrations are costly, inflexible, and possibly dangerous, and furthermore do not give a reliable representation of real events. Conversely computer simulations, given valid models and appropriate data, are safe, inexpensive, and flexible so that many replications of different conditions may be investigated. Simulations are therefore valuable aids to the design of hardware and procedures and evacuation performance evaluation. The current project so far has focused on the evaluation of the many factors – configurations, regulations, training, conditions, and actual evacuations of large aircraft. Moreover, exploratory models have been developed to demonstrate the utility of the simulation approach using Microsoft Excel and Micro Saint Sharp software. It is concluded that this simulation approach is both flexible and useful, warranting further research in the hopes of achieving more robust results.

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Chapter 24

The Geometry of Near Mid Air Collisions

James Howrey[1], Brian Peacock[2], Gary Northam[1]

Precis

The probability of Near Mid-Air collisions (NMACs) is likely to increase as traffic density increases and as individual pilots have greater autonomy in their flight paths. Pilots' judgments of distances are subject to error. ADS-B is a technology that can go a long way to reducing this hazard in free flight.

Abstract

Objective: To investigate the accuracy of pilots' estimations of distance in Near Mid-Air Collision (NMAC) situations.

Background: Near Mid-Air Collisions are expected to increase with increases in air traffic density and greater reliance on pilot judgments in route planning.

Method: 40 pilot reports of near misses were compared with objective data of closest point of passing using ADS-B technology.

Results: Pilots showed considerable variability in their judgments – they judged closer incidents as being further away and further incidents as being closer than they actually were. The study found no relationship between pilot experience and distance estimation accuracy.

Conclusion: Pilots are inaccurate in their judgments of the distances in NMAC incidents.

Application: This evidence provides strong support for the inclusion of technology (ADS-B) on all aircraft to support the FAA's "NextGen" initiative.

INTRODUCTION

Mid-Air Collisions (MACs) are very rare events in aviation. In 2003, there were 20 reported MACs during approximately 25 million general aviation flight hours (NSTB, 2003). A Near Mid-Air collision (NMAC) is defined by the Federal Aviation Administration (FAA) as when two aircraft pass within 500' of each other without regard to the direction of the proximity. A NMAC also exists whenever any crewmember believes a collision hazard exists. It is the pilot's responsibility to "see and avoid" other traffic, but this activity may be beyond the pilot's capabilities in some situations. Consequently, the problem has and continues to stimulate considerable technology development effort to mitigate this human limitation.

Embry-Riddle Aeronautical University has been using the Automatic Dependent Surveillance – Broadcast (ADS-B) system since 2004. This system displays traffic/target information to assist a pilot with traffic awareness and has been shown to decrease the reaction time necessary to locate an aircraft following a prompt from Air Traffic Control (Avitabile, Northam, Peacock and Tank, 2007). In the future, pilots may be able to maneuver according to information on their ADS-B display. The FAA may eventually allow controllers to make Air Traffic Control (ATC) decisions based on the position of ADS-B equipped aircraft in controlled airspace (FAA, 2008). The pilot will likely remain the final authority for a flight, but there is potential to incorporate some level of automation. The ADS-B system implementation has not yet reached the point where conflict resolution is allowed based on the displayed information and pilots are currently encouraged to use the system to help locate a target (FAA, 2008). The primary limitations for expanded ATC services include the ADS-B coverage areas and the many aircraft that currently do not have ADS-B technology. Traffic Information Service – Broadcast (TIS-B) is the capability of ADS-B to display targets under radar coverage. In most geographic areas that lack ADS-B installations, pilots must rely on ATC advisories and their own sightings to avoid conflicts. There can be considerable delay with the current ATC system and save for a few competing traffic-awareness systems, pilots do not have a display of traffic (Avitabile, Northam, Peacock and Tank, 2007).

Johns Hopkins University - Applied Physics Laboratory (JHU-APL) developed a program that tracks aircraft position and other flight parameters from ADS-B. This program is known as Comprehensive Real-time Analysis of Broadcast Systems (CRABS) and was in use by ERAU from 2004 to 2010. The output data of this program can be used to calculate relative distance between aircraft. This paper compares distance information from the CRABS program to the distance information reported by pilots when they file NMAC hazard reports.

The ERAU hazard-reporting system is a non-punitive system for identifying hazards associated with aviation. Pilots are encouraged to file hazard reports whenever they feel a hazard exists. When reviewing NMAC occurrences, the Safety Office compares the two aircraft (when possible) using a visual display from the CRABS program.

Airspace will continue to become more crowded in the future as demand for aircraft, air travel, and unmanned aerial systems, steadily increases (FAA, 2008). Understanding how experience and other human factors affect the reporting of distance would help to improve the calculation of MAC risk, direct training, and determine the point at which automation or warnings may be required to avoid collisions.

Limitations

- ERAU hazard reports are only indicative of NMACs reported by ERAU pilots in the vicinity of Prescott, AZ. The area of coverage was provided by three Ground Based Transceivers that provided ADS-B coverage in Northern Arizona.
- The intruding aircraft presenting a collision hazard must at least have a transponder and present a radar return, which inevitably leaves out some NMAC occurrences.
- If a crewmember believes a collision hazard exists, that occurrence constitutes a NMAC; but the aircraft that filed the report may be further than 500’ from the intruding aircraft. Reporting of distance can still be compared to the actual value, but the validity of the NMAC report may depend on other factors such as aircraft heading and position.

BACKGROUND

A traditional approach – “see and avoid” for determining MAC risk assumes pilot perception and reporting of distance to be accurate. Consolidated reports relate the number of NMAC reports vs. the reported distance (Brooker, 2007). Extrapolation from NMAC data may also be used to estimate the probability of an actual Mid-Air Collision.

Distance estimation has been researched with Cockpit Displays of Traffic Information (CDTI) (Xu, Rantanen, and Wickens, 2007). CDTI devices typically depict traffic information as a top-down view on an electronic display. Altitude information is a digital readout that describes the relative altitude of a target. ADS-B information also is presented in this way, although it is highly stressed to pilots that they use it to aid in visually acquiring a target and that any conflict resolution should be according to direct visual perception. Variables in the study of CDTI information include: distance, velocity, and point of closest approach. In the Xu, Rantanen, and Wickens,(2007) study distance perception was an estimated Closest Point of Approach (CPA) given an initial distance, velocity, and time to CPA. At longer distances there was a greater underestimate of the distance to CPA. The study accounted for this by saying that there may be error on the side of caution. The conclusion of such research may determine whether and how an electronic system could complement visual perception and how pilots should balance their behavior based on direct or instrument information. In this context it is well established that instrument flying in poor visibility is acceptably safe.

The Aviation Safety Foundation describes limitations of visual perception and how they affect identifying and judging an aircraft that may pose a collision risk (Wynbrandt, 2006). Wynbrandt suggests that pilot experience is not a factor when it comes to MACs. However, he also suggests that training flights are the most dangerous in terms of MAC risk. If there is any variance in how NMACs are judged, it could be helpful in determining how to best train flight instructors to manage the risks of collision.

Prior to the implementation of ADS-B technology, the only way to accurately discern the distance between two aircraft in an NMAC encounter was to review radar-data from ATC after an encounter. Due to ADS-B's reliance on GPS data, the system has the ability to generate a distance to the target. Certain ADS-B systems installed in aircraft can display distance to aircraft in a textual format as an option. Due to the visual implementation of the ADS-B technology used in this study, learning distance perception based on a textual read-out should not be a factor, although the perception performance might vary according to learning/practicing in some other way.

The Traffic Collision Avoidance System (TCAS) that is widely used in commercial aircraft is a cockpit alerting system that complements the human perceptual system in detecting or judging intruding aircraft proximity. The current implementation is as an alerting system, and it does not provide full automation or disconnect the pilot and fly away from an intruding aircraft, although automated avoidance technology has been demonstrated. There is at least one good reason against current TCAS automation – the system does not detect all aircraft. There will always be a possibility of an aircraft or Unmanned Aerial System that is not detectable, due to an equipment malfunction, deliberate masking, or no requirement for the aircraft to be equipped. Somewhat less convincing reasons for non-use of this technology is that of "distrust of automation", a commonly observed human trait in contemporary society. During the testing of the Air Force's new F-22 fighter the following was noted:

> *'Because pilots are adamant about having final authority over their aircraft, the [flight test] team initially gave the pilot an ability to always override the GCAS [Ground Collision Avoidance System]. Extensive Testing, plus discussion with F-22 test pilots, changed that attitude. During all-terrain testing, we found that even the slightest override of the GCAS autopilot in the wrong direction would blast you through the [Minimum Safe Altitude] floor.'* (Scott, 1999)

Any failure or misunderstanding of the system could also lead to distrust (Sheridan and Ferrell, 1974), which could be just as dangerous as a failure to detect an aircraft.

If it can be established that the perception of distance has enough error as to constitute a hazard in and of itself, automation or some sort of advanced warning system may be needed for the pilot to make a better resolution in a NMAC encounter. Warning and automation systems must be implemented and evaluated very carefully to ensure the success of the traffic avoidance system. This study is a first step at accurately describing pilot's abilities in the context of advanced traffic avoidance systems.

METHODOLOGY

Data within NMAC hazard reports from ERAU flight operations were filtered to ensure that all the required data fields existed, compared with data collected from the CRABS program, time-linked, and then analyzed. These data from the time of the NMAC were played back in CRABS in much the same way one would play back a recording of a television show. The exact time of closest approach required multiple observations of the CRABS data as the flight progressed. A total of 40 validated reports were analyzed. Table 1 shows a typical CRABS output.

Source Date	Longitude	Latitude	Altitude Ft	Speed Kts	Heading D	Ascent Ra	Unique Key	Seconds Since Midnight
3/8/2007 22:52	-112.395	34.6848	5675	88.6	151.7	-640	5-2033-1081	82339.8
3/8/2007 22:52	-112.395	34.6848	5675	88.6	151.7	-640	5-2033-1081	82339.8
3/8/2007 22:52	-112.394	34.6845	5650	88.3	160.1	-640	5-2033-1081	82340.59
3/8/2007 22:52	-112.394	34.6845	5650	88.3	160.1	-640	5-2033-1081	82340.59
3/8/2007 22:52	-112.394	34.6845	5650	88.3	160.1	-640	5-2033-1081	82340.59
3/8/2007 22:52	-112.394	34.68418	5650	88.1	167.5	-576	5-2033-1081	82341.4
3/8/2007 22:52	-112.394	34.68377	5650	87.6	173.4	-576	5-2033-1081	82342.4

Table 1 Typical data extracted from CRABS observations

Coordinate data from the CRABS program are presented in terms of latitude and longitude. To allow the separation distance to be computed, these polar coordinates were converted to Cartesian coordinates. The figure of 20,925,689' for the Earth's radius was used for these calculations. The formulae for the conversion of polar to Cartesian coordinates were as follows:

$$x = (\cos(Latitude) * 20925689') * \sin(Longitude)$$
$$y = (\cos(Latitude) * 20925689') * \cos(Longitude)$$
$$z = \sin(Latitude) * 20925689'$$

After determining the Cartesian coordinates, the distance between two points was calculated: $d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$.

Table 2 shows the results of this calculation.

Output distance A1 vs. B1			Distance, *x,y,z* (feet)				Altitude, z (feet)	
case 2090								
A1	B1		1233.76				939.77	
A2	B2		1060.93				759.32	
A3	B3		811.47				493.68	
A4	B4		756.89				409.87	
A5	B5		672.56				184.26	
A6	B6		587.05				56.70	
A7	B7		625.48				210.28	
A8	B8		672.16				332.75	
A9	B9		896.99				551.89	
A10	B10		998.14				725.95	
A11	B11		1257.07				952.89	
A12	B12		1426.60				1094.71	
A13	B13		1624.00				1275.19	

Table 2 – Calculated actual spacing sample records

Table 3 shows a sample of the pilot NMAC reports and Table 4 shows a sample of the actual and reported distance differences.

Case Number	Time date group	Criteria:	ADS-B vs. ADS-B	ADS-B vs. TIS-B	Type Of Training	Day
614	02/01/2005 0940	NMAC	N	Y	VFR	Y
616	02/01/2005 1730	NMAC	Y	N	VFR	Y
631	02/09/2005 1330	NMAC	N	N	VFR	Y
676	03/10/2005 1730	NMAC	N	Y	VFR	Y
695	03/29/2005 2215	NMAC	Y	N	IFR	N
720	04/20/2005 1150	NMAC	N	Y	IFR	Y
843	09/09/2005 0720	NMAC	Y	N	VFR	Y
942	11/30/2005 1210	NMAC	Y	N	VFR	Y
1015	01/20/2006 1500	NMAC	N	Y	IFR	Y
1099	02/23/2006 1330	NMAC	N	Y	IFR	Y
1110	02/16/2006 1630	NMAC	N	Y	VFR	Y
1167	02/24/2006 1400	NMAC	N	Y	VFR	Y

Table 3 Sample pilot NMAC reports

Case Number		Night	Reported Total Distance	Actual Distance	Reported Vertical Distance	Actual Vertical Distance (closest y)	Actual Vertical Distance (closest x, y, z)
			Feet	Feet	Feet	Feet	Feet
614		N	300	4790	300	978	1367
616		N	3000	3218	0	200	2625
631		N	65	749	0	189	549
676		N	112	128	50	89	89
695		Y	364	472	100	35	175
720		N	224	2648	200	109	1328
843		N	472	1049	250	479	493
942		N	206	689	200	13	29

1015		N	3000	2102	0	1003	1003
1099		N	304	931	300	414	414
1110		N	1001	1145	50	232	232
1167		N	1005	70	100	8	8

Table 4 Sample comparisons between actual and reported distances

Regression and contingency analysis was applied to assess the relationship between the reported and actual distances. An Analysis of Variance (ANOVA) was then performed to determine how the distance reporting varied due to variables such as pilot experience.

RESULTS

A weak relationship was found between the reported distance and the actual distance (Figure 1). These analyses indicate that the reported distances on the hazard reports were generally less than the actual distances. Analysis of Variance (ANOVA) indicated a significant relationship (P<.017). The wide variation in estimation error is notable.

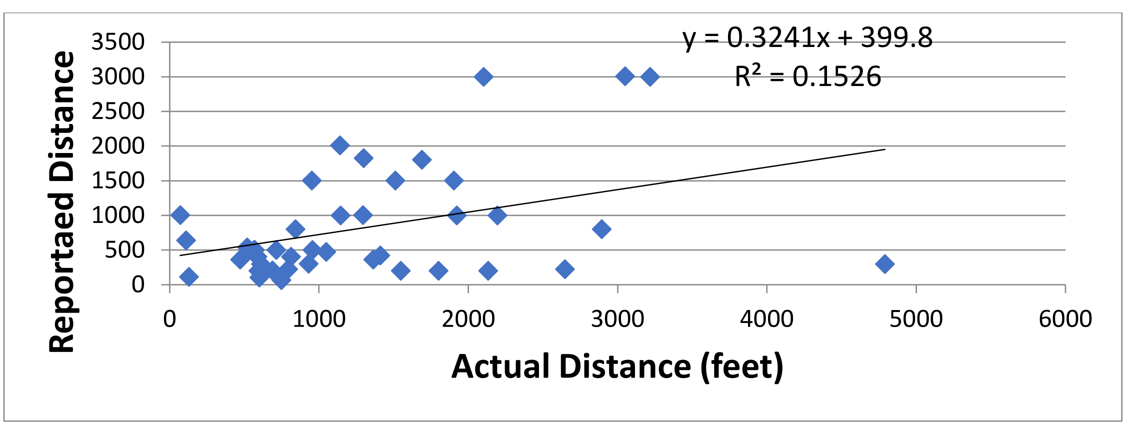

Figure 1 Actual vs. reported distance

When the actual total or vertical distances were less than 500’, the reported distances were generally greater than the actual. When the actual total or vertical distances were greater than 500’, the reported distances were generally less than the actual. These findings were confirmed by a contingency table analysis of the number of reports greater or less than the actual (Table 5).

	Reported < Actual	Reported > Actual
Actual < 500'	False	True
Actual > 500'	True	False
	Total Distance CHISQ, p< .032	
	Vertical Distance CHISQ, p< .001	

Table 5 Chi Squared analysis of the number of reports at an actual separation of greater or less than 500’

Figure 2 shows the relationship between error (Reported – Actual Distance) and Actual Total Distance. This shows that the error increases negatively as the actual separation increases.

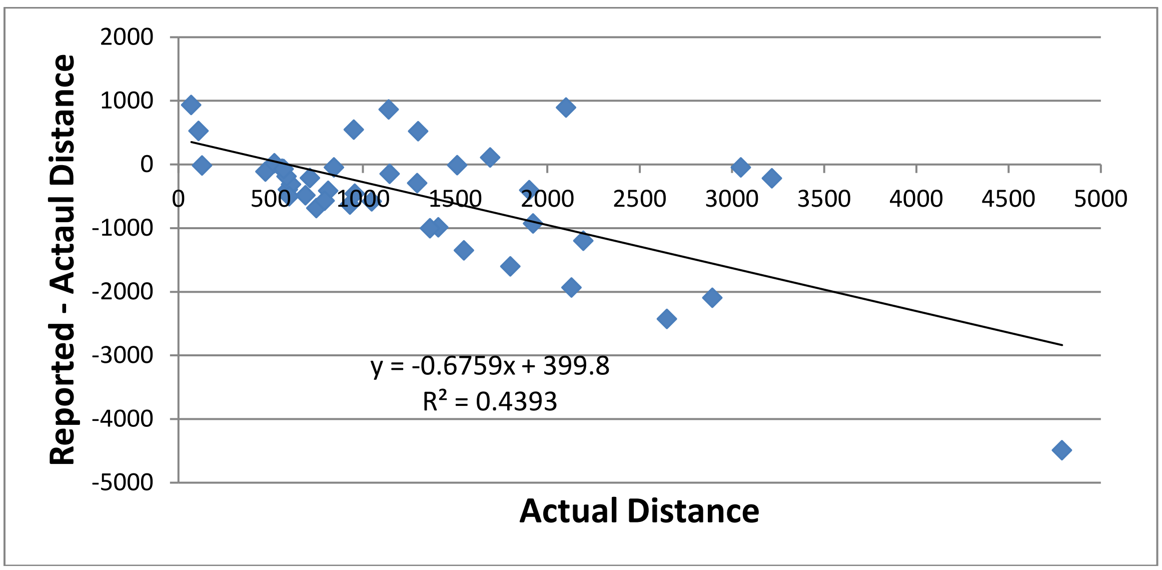

Figure 2 Relationship between estimation error and actual distance

The analysis of altitude data, or the reporting of the vertical dimension, can be either at the closest point of approach (*xyz*) or at the point of closest horizontal distance. In both cases the results were like those of actual distance and error, as the observer tended to report the vertical distance was further when the actual altitude distance was less than 500’. When the actual altitude distance was greater than 500’, the reported vertical distance was smaller than the actual. (Figure 3)

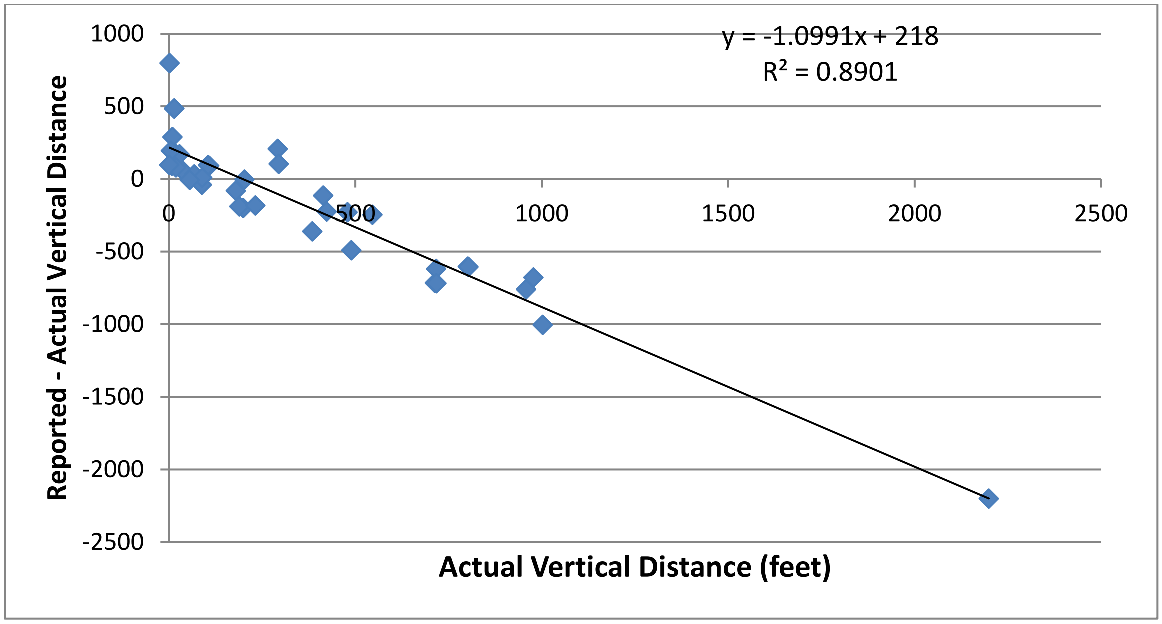

Figure 3 Regression analysis of Error vs Actual Vertical distance

This study found no significant relationship between the experience (hours of flight time) of a pilot and the amount of error in the reported distance. (Figure 4)

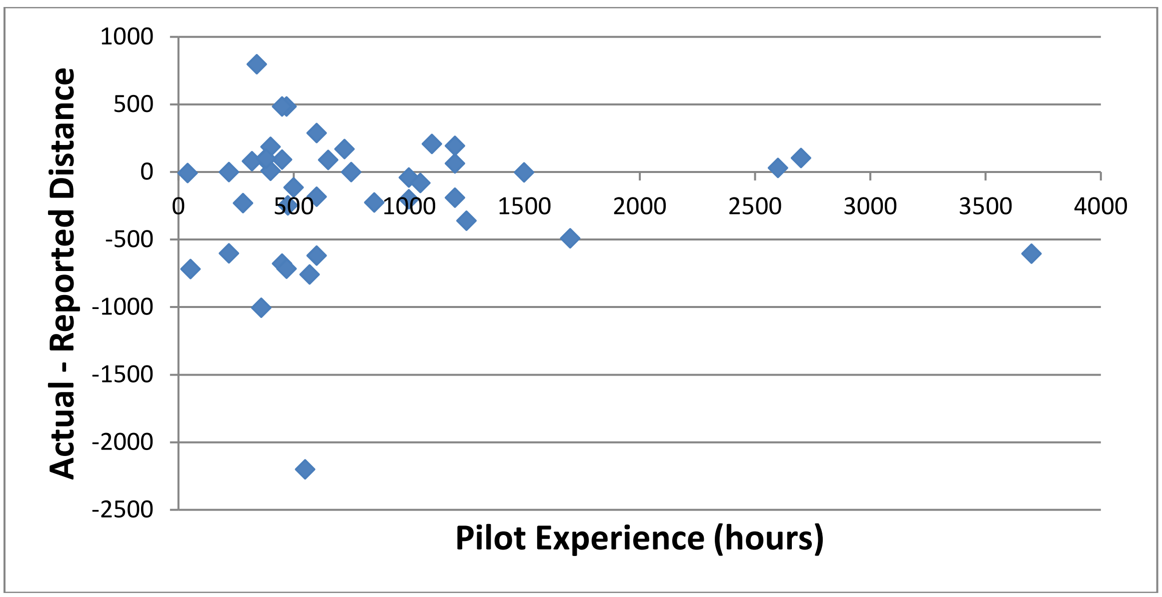

Figure 4 Pilot Experience and Error

Pilots' estimations in hazard reports were found to be significantly more accurate (Student's T test, $p<.021$) when encounters were between two ADS-B aircraft (average estimation error = -35') as compared to encounters involving one ADS-B aircraft and one TIS-B aircraft (average estimation error = -685'). In this study there were no distance estimation differences between IFR conditions (13 NMAC reports) and VFR conditions (27 NMAC reports).

DISCUSSION

Analysis of actual distance to reported distance indicated significant error in judging the distance to targets. The error of distance reporting was found to be related to the actual distance. At a range of less than approximately 500', the actual distance was closer than the reported distance. This indicates there may not be a tendency to "err on the side of caution" at these shorter distances, although that behavior was observed at relatively longer distances during the study of CDTI systems (Xu, Rantanen, and Wickens, 2007). It has been suggested that some errors in distance perception may be related to an overcorrection on the part of the viewer (Gogel, 1973) or hindsight bias. The reason for overcorrection could be due to the viewer being aware of the consequences of misjudging distance or some element of threat. Unfortunately, this does not agree with the data at closer distances, nor does it agree with the CDTI study mentioned above.

The results at distances greater than 500' were similar to the CDTI study, where there was an underestimation of distance at greater actual distances. The results for total distance and altitude were segregated into cases with both aircraft being equipped with ADS-B and only one aircraft being equipped with ADS-B (the other being equipped with a transponder). When encounters were between two ADS-B equipped aircraft, the error of distance estimation was generally less. This is a similar result to the study that found improved reaction time performance when locating targets when equipped with ADS-B (Avitabile, Northam, Peacock and Tank, 2007).

The relationship of actual distance and error was significant. As stated earlier, the size of the targets within this study were similar, and the visual angles subtended by each target would be similar if the distance was relatively constant. Other cues, such as: *linear perspective, height in the plane, aerial perspective*, and others, help to generate information about distance. While it is unlikely that each NMAC occurrence includes all of the cues that provide distance information, each NMAC occurrence likely includes more than just visual-angle for the pilot to judge distance. An error of distance perception created by a bigger target subtending a larger visual angle is unlikely in this study.

The altitude error was found to vary in a similar fashion to the error of total distance. Generally, altitude estimation can be more difficult than horizontal distance estimation due to a lack of cues. Given the already reduced-information scenario, altitude may not have significantly fewer visual cues than total distance estimation. A possible problem with analyzing the altitude information is that it may be measured by the pilot relative to his axis or the axis of the earth's surface. Most of the aircraft within this study were upright and not in unusual attitudes at the time of the encounter, but still there is some possibility for error in this area. The results of the altitude analysis indicated a strong relationship between distance and error, when assuming the pilot's reporting of altitude spacing was at the point of closest approach. At the point of closest vertical approach the results still passed the test for statistical significance ($P < 0.003$), but it seems to be a reasonable assumption that the time of closest total approach is the time when the pilot makes the judgment of vertical distance.

One must remember the dynamic flight environment and how fast aircraft converge. Even at the relatively slow speeds of the aircraft in this study (90-120kts), a head-on target will converge from half a mile in seven- and one-half seconds with a 240kt closure speed. The data in this study show that below 500' the tendency to underestimate the distance may diminish. This would remove the "safety factor" described in the preceding paragraph, and imply that an electronic system would provide greater precision. Given the 240kt closure speed scenario, this would imply that during the last second and half the pilot would not have a correct perception of distance or one that would incorporate error on the side of safety (underestimation). Current traffic-advisory/avoidance systems obviously do not wait until 1.5 seconds to give their warnings, but data from this report may be further reason to alert the pilot to a possible conflict earlier and to prompt resolution earlier so as to avoid ever reaching the area where the perception causes the pilot to believe a target is further away than it actually is.

It is common to assume that a more experienced pilot is better at most tasks than a new pilot. The assumption that more experience increases performance would apply to: accomplishing a maneuver, managing multiple tasks, scanning for traffic, judging distance, and threat of an intruding aircraft. There is no basis within this study to indicate that a more experienced pilot will judge distance more accurately. Studies have shown that experience in an environment or situation can increase the ability to judge distance (Bradley and Vido, 1984), but there is no basis to quantify the number of repetitions required to improve the distance estimation in this study. This would indicate that a given aircraft should have the same electronic warning/avoidance system whether it is intended for occasional fliers or more frequent/professional fliers.

There is currently a movement by the Aircraft Owners and Pilots Association (AOPA) to lessen the future requirements for electronic reporting and surveillance systems. The AOPA is trying to reduce the financial impact of ADS-B implementation and recognize the fact that there are many aircraft that do not have advanced avionics or even electrical systems (AOPA, 2008). These aircraft can and do fly in the same airspace as airplanes that are equipped with more complex systems and while the less complex aircraft may not be allowed to fly into some types of controlled airspace due to FAA regulations, the more advanced aircraft can fly into the uncontrolled airspace. Due to all types of aircraft having to fly in the same airspace the AOPA's position from the point of safety is largely invalidated; by not incorporating all aircraft into the future air traffic system there will be an increased hazard of collision. The lone aircraft that does not show up on the display will likely be the one that constitutes a collision hazard. The cost of ADS-B technology will also eventually decrease due to economies of scale. Given the data that the distance reporting does not appear to vary according to the experience of the pilot and the increased performance when operating with ADS-B, it should be important to equip all aircraft with ADS-B surveillance technology.

Another reason to not lessen the future requirements for surveillance equipment is simply because the reporting of distance is not accurate. It is not the intention of this report to increase the risk of MAC occurrences by trying to have aircraft fly closer to each other, but if the pilot is underestimating the distance, surveillance technology may be able to aid the pilot in reducing unnecessary maneuvers and allowing more aircraft to be present in the National Airspace System. Increased pilot awareness and performance may reduce the workload on Air Traffic Controllers.

There is the possibility of a decision-making conflict with ADS-B or any other kind of traffic information displayed to the pilot. One of ATC's primary roles is trying to keep aircraft separated from each other, and individual pilots are also responsible for separation. The question of pilot/controller authority will have to be resolved to ensure safety and to maximize the efficiency of the National Airspace System.

There must be an allowance for the error in judging distance according to something other than visual cues. As discussed earlier, there may be a tendency to overestimate or underestimate depending on the threat or consequences of misjudging the distance. It would be a logical possibility that the submitters of the hazard forms may also consciously or subconsciously provide an amount of error in their report to make it seem as if the NMAC occurrence was not as dangerous or as critical as it really was, perhaps due to organizational pressures. This error could explain the reporting of distance at closer (than 500') distances, but it would also be reasonable to assume that at further distances this is not a factor.

CONCLUSIONS

This study has determined that error and reported separation vary with the distance and that reported distance estimation is more accurate between ADS-B equipped aircraft. At closer actual distances, the pilot reported the intruding aircraft was further than the actual. At further actual distances the pilot reported the intruding aircraft was closer than it was. The *reporting* varied according to the actual distance. If the error at the closer distance was due to pilots perceiving the distance as they reported, it would be very dangerous to estimate an intruding aircraft as being further than actual distance. Likewise, estimating that the intruding aircraft is closer would lead to unnecessary maneuvering and increase the workload on pilots and controllers.

The error in judging distance and increased performance due to ADS-B validates the role of this surveillance technology in the cockpit. ADS-B allows for relatively quick position updates between aircraft. From a pilot's perspective, ADS-B is not radically different from what transport-category aircraft (airliners) currently have in the form of TCAS, but almost all other aircraft lack similar technology. The addition of ADS-B technology to these and all other aircraft should dramatically increase the ability of aircraft to avoid NMAC situations. It is a reasonable argument that those aircraft that *need* ADS-B technology are the ones that are not currently equipped with any kind of surveillance technology. AOPA's recommendation of slowing and lessening the requirements of full ADS-B implementation for General Aviation aircraft will only save costs in the short term. The cost of a MAC accident is tragic and unacceptable. Furthermore, there is an increased risk of MAC by having certain aircraft not participate in ADS-B implementation when they have to fly in the same airspace as aircraft that will be so-equipped. ADS-B technology has many benefits and creates the potential to analyze aviation hazards in ways that have not been possible previously. It is the recommendation of this study that ADS-B technology be implemented to the greatest extent possible.

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Chapter 25

Are you sure that what you just said is true?

Brian Peacock, Marv Dainoff

Ergonomics practitioners look at two ways of doing something, like loading parcels onto a conveyor, and say, with confidence, that A is better than B. When asked why, they say, “Because it is safer.” An ergonomics professional would say, “Show me the data.” An ergonomics researcher would say. “Based on a controlled experiment with 100 subjects, I have concluded with 95% confidence that there is no significant difference between the two methods.” Meanwhile the worker says, “ B is better than A because I get finished faster.”

The purpose of this workshop is to introduce ergonomics practitioners and professionals to the purposes and methods of probability, experimental design and statistical analysis. At the outset it will be emphasized that statistics is not a substitute for domain knowledge, rather it is a collection of tools that prevent an observer from drawing unjustified conclusions from the evidence. The purposes of experimental design include: identifying clearly the variables of interest – both the (independent) factors that a designer can change and the measurable (dependent) variables that are the purpose of the design, like speed, accuracy and safety. Next a good design addresses those factors that cannot be changed, but which may affect the outcome, so that the results are not confounded. Finally, a most important aspect of experimental design is to enable confident conclusions at the least cost in time and dollars. Experimental designs should be as simple as possible – just enough to keep the investigator out of trouble. This is where probability comes in. We all know that where people and casinos are concerned sometimes you win and sometimes you lose, because people vary, just like the marks on the cards. The trick is to know when to risk playing your hunch. Statistical analysis tools - like t tests, analysis of variance, regression and a host of others – provide you with the evidence to reduce the risk.

This workshop will first address some of the methods of investigation design and statistical experimental design with reference to a series of ergonomics case studies in manual materials handling, assembly work and quality control. Next a short time will be spent on probability and measurement, using common situations where human variability is important – like workplace design and baseball. The third component will address data analysis and the use of common (parametric and non-parametric) statistical analysis tools, using the familiar Excel spreadsheet functions. Finally, the workshop participants will be shown how to present evidence using graphical tools.

The attendees will leave the class with a good knowledge of why statistical methods are important and a tool chest full of easy to use methods.

Chapter 26

Thermal Environment and Worker Safety

I read with interest your recently published Bulletin on the Thermal Environment and Worker Safety and would like to offer the following observations:

1. The guidelines appear to be technically accurate
2. The guidelines are not useful for the following reasons:
    a. The concept of WBGT is not intuitive
    b. Wet bulb and Globe thermometers are expensive and not widely available
    c. The readings taken by untrained people may be cumbersome and inaccurate (technique error) or biased
    d. Guidelines should be user friendly – Ergonomics should be Ergonomic!!!
3. The concept of Heat Index is intuitive and is a widely used measure that roughly parallels WBGT
    a. Ambient Air Temperature (Dry Bulb) and Relative Humidity are readily available on line from the meteorological office at any time of day
4. The daily temperature (Air Temperature) in Singapore ranges between 25°C and 35°C and the Relative Humidity between 65% and 95%. The following chart covers these ranges:

Table 1 Heat Index (feels like) values

	Air Temperature (°C)									
Relative Humidity %	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**
100	28	32	36	40	44	49	54	60	66	72
90	28	31	34	37	41	45	49	54	58	64
80	28	30	32	35	38	41	44	48	52	57
70	27	29	31	33	35	38	40	44	47	50
60	27	28	29	31	33	35	37	40	42	45

5. The ordinal designation of Pale Yellow, Yellow, Orange and Red are familiar, but only serve as general guidelines:
    a. The Heat Index is based on "the average person" which is a problematic concept in this context – we don't want to put half the population at risk! Weak, unfit, sick, un-acclimatized, dehydrated and over worked people are more prone to heat disorders. Therefore we should be conservative in our response to the dangers of these stressors.
        i. WBGT, although an objective measure if measured accurately, must also be mapped into physiological effect.
    b. The following suggestions are offered (because the physiological evidence alone is insufficient to deal precisely with human variability):
        i. Red – Stop the job, remove the worker until engineering controls are in place
        ii. Orange – apply engineering controls where feasible, apply administrative / exposure controls such as 25% Work 75% rest in a cool place, monitor.
        iii. Yellow –apply engineering controls plus 50% work, 50% rest in a cool place, monitor

iv. Pale Yellow– apply engineering and administrative controls, monitor.

v. The following conservative chart may be of interest. I am not sure of the origin of your Table 1 or that it actually refers to WBGT.

vi.

TABLE III: 4-2. PERMISSIBLE HEAT EXPOSURE THRESHOLD LIMIT VALUES

Work/rest regimen	Work load		
	Light	Moderate	Heavy
Continuous work	30.0°C (86°F)	26.7°C (80°F)	25.0°C (77°F)
75% Work, 25% rest, each hour	30.6°C (87°F)	28.0°C (82°F)	25.9°C (78°F)
50% Work, 50% rest, each hour	31.4°C (89°F)	29.4°C (85°F)	27.9°C (82°F)
25% Work, 75% rest, each hour	32.2°C (90°F)	31.1°C (88°F)	30.0°C (86°F)

NIOSH heat exposure guidelines

6. Please note that I do not object to the use of WBGT except that its use is predicated on the availability of appropriate, costly equipment and trained users.
7. In Singapore, when the sun shines, there is inevitably a high radiant load and the air temperature is commonly above 30°C, although the RH does drop a little.
    c. Always provide radiant heat protection for workers who have a moderate to high metabolic load (> 5 kcal / min – walking, lifting, carrying, climbing, pulling and pushing) and, where feasible, for all workers.
    d. Singapore is hot and humid and will always present a potential thermal stress hazard.
8. Always provide plenty of water and electrolytes for workers who have a moderate to high metabolic work load.
    e. The issue hyponatremia (too much water, too few electrolytes) was discussed but this term was not used.
    f. The amount of electrolytes in popular sports drinks may not be sufficient replacement for workers with continuous visible perspiration, but these are better than plain water. They do contain sugar.
    g. It is the responsibility of the manager / foreman to monitor the health status of his or her subordinates.
9. The matter of acclimatization was discussed, but this discussion was misleading - "*Acclimatization to heat is fully developed within two weeks".* Although there is plenty of evidence that acclimatization does take place by altered physiological and behavioral responses, and this process may take a few weeks, the dangers of heat disorders continue to be of concern even for "acclimatized" workers.
    h. Workers from cooler climates or who are moved to jobs in a hot environment must be allowed some time to acclimatize – the best method is by gradually increasing the exposure to the thermally challenging environment over a few weeks, while monitoring the health status of the worker.
10. For comfort reasons the air temperature inside buildings should be of the order of 24 °C - 25°C; 22.5°C is costly and uncomfortable for many sedentary workers, although this may be an appropriate temperature for physically active people

i. Provide fans for enhanced convective cooling
j. Provide air conditioning where feasible.
k. Provide blinds to remove the radiant heat load

For more information please read:

"Hotter than Houston" Chapter 14 in The Laws and Rules of Ergonomics in Design by Brian Peacock
"Thermal Conditions Measurement" by George Havenith, Chapter 60 in Handbook of Human Factors and Ergonomics Methods by Neville Stanton et al, CRC Press.

Chapter 27

How do we measure awareness?

We will start by defining data, information and knowledge. Data is that ocean of descriptions of our environment that may be transformed or categorized into information to make our task of controlling our context more effectively and efficiently. Knowledge is our ability to extract and use the information for the right purpose, at the right time and in the right place.

Back in the day we kept all this information and knowledge in our heads, now we keep it in our pockets in our smart phones. In between we used writing, the printing press, computers, and telecommunications to access information and knowledge and guide us in their use.

But still we need a blend of brains and information technology to provide us with situationally relevant knowledge awareness. The challenge for systems analysts and designers is to optimize the use of technology and brains for operationally relevant purposes.

Human memory (see Appendix 1) is conveniently classified into long term or permanent storage, and short term, working or operational memory. Operational memory may be viewed as the gateway to our long-term stores, for both information and knowledge. Because we are continually changing our needs for data, information and knowledge, operational memory needs to manage retrieval, temporary storage and forgetting. Working memory necessarily has a limited capacity, tied to our attention mechanism; it operates through chunking and rehearsal. Chunking is a means of combining items of information into a single unit. For example, CAT is not A&C&T; rather it is a single word that conjures up a picture (from long term memory) of our favorite pet. Similarly, we don't remember, literally, all the words in a sentence; we simply rehearse and recall its meaning. Sometimes we consciously rehearse information and chunks in our operational memory, but even then our retention performance is severely susceptible to interference, both retroactive and proactive. If working memory is the gateway to long term memory, then attention is the pathway to working memory. We continually shift our attention due to interesting, important, and intense external stimuli and strategic internal intents and interests.

A Demonstration of Knowledge Awareness

Although these characteristics of cognition are generally familiar to us, it is difficult to isolate the mechanisms involved and to measure their effectiveness and vulnerability. This difficulty is due to our inability to experimentally control the context, focus and noise in real world situations, although case examples of success and failure of knowledge awareness abound: Where did I park my car? How do I carry out this analysis? Why did that accident happen? Our measurement challenge is to control experimentally the purposes, information and knowledge requirements, processes and performance observations. Our best opportunity is through a family of scenarios or games that lend themselves to variable complexity, resistance to noise and access to objective performance measures.

1. Simple retention and recall of numbers, words, and object features:
    a. Numbers, words, and pictures are presented to the subject in sets of variable difficulty (information content). Recall may be measures by response accuracy and time
    b. These presentation, retention and recall tasks are made more complex by the addition of other parallel tasks and distractions, with similar scoring procedures
2. Grammatical, Spatial and Logical Reasoning
    a. Computer generated reasoning / decision tasks are presented to the subjects and performance measured by time and accuracy

   b. These reasoning tasks are complicated by the addition of secondary tasks or varying complexity, with similar scoring procedures and performance measures of secondary task degradation with increasing primary task demand

3. Sensory – Motor Control Tasks
   a. The subject is required to perform a pencil and paper simulation of an emergency approach and landing in an airplane. The effect of practice on performance, and by implication the use of information and knowledge, will be documented by assessment of accuracy and time changes. (See Appendix 2)
   b. The subject will repeat the simulation using Microsoft Flight Simulator with similar observations of the, now time constrained, use of information and knowledge
   c. A variation on this simulation will involve strategic halting of the task and questions of the subject using the NASA TLX, Cooper Harper, Bedford Workload Index, SAGAT, SART and Secondary Task methods which are aimed at identifying mental workload and situation awareness knowledge and deficiencies
4. Communication Tasks
   a. Person to person communication tasks involving information of varying complexity will be used to evaluate semantic and physical encoding, transmission, physical and semantic decoding, and recall; each of these information and knowledge handling stages will be subject noise and supplementary relevant information. Performance and knowledge awareness will be assessed by objective scores of communication accuracy as affected by information and knowledge complexity and competing task performance.

Chapter 28

The key to memory is forgetting

We are continuously bombarded with massive amounts of stimuli, both through our senses and from internal memory sources. These stimuli are stored briefly in our sensory or iconic memory until they are attended to and passed on to our operational memory for processing and use in the development of decisions and actions. If the stimuli are not attended to, they are lost forever. A further filtering occurs in our operational memory because of its limited capacity. Many irrelevant and possibly relevant bits of information are lost during these brief time periods. Where we have a well-established template in which to fit new information, many items are rehearsed either in literal or symbolic form or absorbed as part of an ongoing perceptual process.
The key to this process is the discarding (forgetting) of megabytes of irrelevant information to allow the relevant information to be used in our limited capacity processing system. Unfortunately, during these two processes (iconic and operational memory) useful information may also be forgotten, and this then leads to a suboptimal decision or action. Thus, a key to effective memory is efficient forgetting. Experts in particular contexts may be better than novices at these activities, because their perceptual sets are more honed to filter the available information rapidly and accurately.

The application in which these perceptions, retention and forgetting processes may be demonstrated is in decision making in sports. Consider a soccer or basketball player who receives a pass. He or she has a limited set of options at the gross level – pass, dribble, or shoot. There are of course many subdivisions and refinements of these options in particular scenarios, which are continuously unfolding. The player is bombarded with information about the location and movements of colleagues and opponents, who may signal their availability with a gesture or call. The decision may vary between being clear – the basket or goal is wide open and there is no opponent in the way - or they may be probabilistic - the predicted success of the alternative decisions may be equivocal. Astute observers of these dynamic game situations will note that the player does indeed decide and perform some action, which may or may not have the desired outcome. Hindsight bias will modulate judgments regarding the appropriateness of the decision or execution.

Another medium for the demonstration of these cognitive processes is through observation of experts and novices in board games such as checkers or chess. These games require the sensing of a static situation, the mental simulation of alternative courses of action and their likely outcomes, given alternative responses by one's opponent. The difference between experts and novices may be in the perception, retention and use of the available information. Novices simply may not perceive readily available information, or they may perceive the scene, but not understand its implications. Experts will perceive, understand, and use the information in their mental simulation, which also considers previously learned relationships between actions and outcomes. In both cases the key to effective decision-making is attention to relevant information and discarding irrelevant information. A similarity between physical games and these board games is that the information perception, understanding, and use is constrained by time, which may be an important contributor to the underlying processes of retention and forgetting.

In real physical and board game situations there may be some evidence regarding what information is available and some overt indication of what items the player uses and, by definition, perceives. After the event, the question "why did you do that?" may result in a response contaminated by hindsight bias. The challenge for the researcher into perception, retention, forgetting, understanding and prediction is to control the available information and by implication from the player's actions the information that is used, forgotten, or discarded.

Parallel research in this area centers on mental workload and situation awareness. The premise of these two approaches is firstly on the (limited) capacity of various mental resources and secondly on the ability of a person to extract as much relevant information as possible and apply this to some prediction, decision, or action. A popular medium for this research and application is in the context of flying. The pilot must aviate, navigate, and communicate, and perhaps manage his or her payload. These activities require attention to many systems and operations displays, the use of the extracted information in decision analysis and action planning, and the ongoing monitoring and response to feedback from the results of actions and external influences.

One challenge with cognitive research in this area is that it is difficult to determine whether a subject used available external information or introduced information from his or her experience. This challenge may be met to some extent by controlling information available for both proactive and retroactive interference. An extension of this problem is in whether the proactive or interpolated information is relevant or not to the task at hand. These issues require careful experimental procedures.

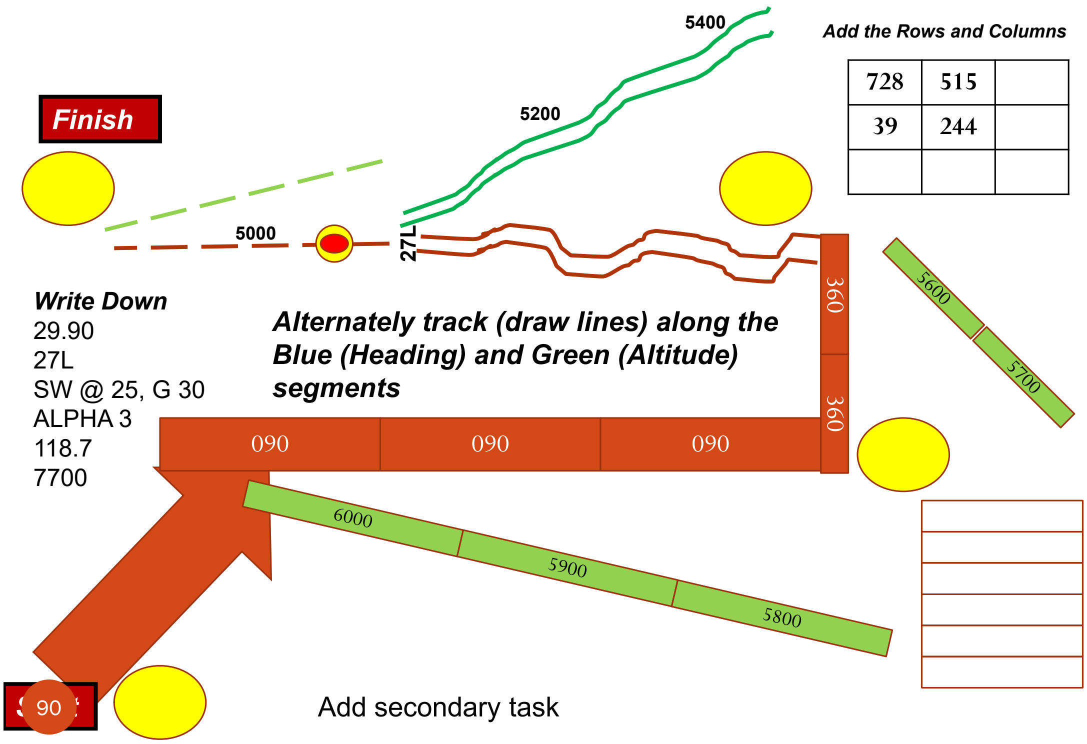
An alternative research paradigm is to focus on failure rather than success – more specifically, what available and relevant information is forgotten, not perceived or used and what irrelevant information is retained and applied to contaminate the situation and result in suboptimal performance. Analysis of these factors should indicate why these information processing activities occurred. Was it due to the design of the stimuli, the capability of the controller, the effect of time constraints, or perhaps the effect of stress due to the consequence of the decision or action?

Methods

Subjects will be presented with either static or dynamic stimuli from various domains – board games, physical games and process control such as driving, flying or a simulated manufacturing process. The complexity of the scenarios will be varied as also will be the display characteristics and subject expertise / experience level. The media for these investigations will be simulations in which the available information content and display format are controlled and the subject's responses, including time and error, will be monitored. The detailed content and format of the available information will be manipulated to assure procedural integrity in the investigation. The simulations will systematically introduce noise or remove relevant information items. Display, decision and response time constraints will be imposed to observe the effects of level of expertise in the perception, forgetting and use of relevant and irrelevant information. Subject behaviors and performance will be observed and will be followed by retrospective reporting regarding the scenario and outcome to investigate the effect of hindsight bias.
The following pilot studies will be carried out:

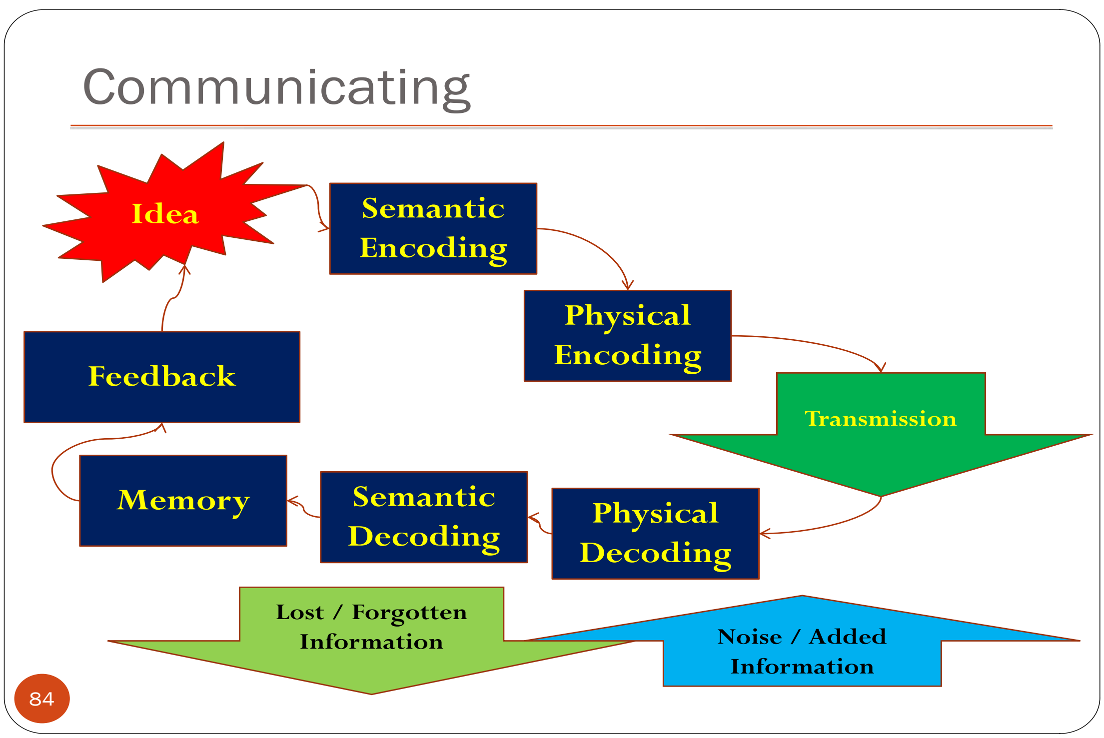
1. Checkers and chess scenarios
2. Static basketball scenarios
3. Dynamic soccer scenarios
4. Car driving scenarios
5. Flight simulations
6. The Honey Mixer process control simulator

Write down the stage times and count the tracking errors



728	515	
39	244	

Add secondary task



Chapter 29

Human Technology Integration: A History Lesson for Designers

Thousands of years ago a group of apes used bones as weapons to fight off another group around a waterhole (2001 A Space Odyssey). This was perhaps the beginning of a long history human creation or adaptation of technology to extend their capabilities, both for peaceful and military purposes. The progress of military technology has progressed apace:

In 1964, with the Cuban Missile Crisis fresh in viewers' minds, the Cold War at its frostiest, and the hydrogen bomb relatively new and frightening, Stanley Kubrick dared to make a film about what could happen if the wrong person pushed the wrong button:

In recent years technology has removed the “pilot” out of harm’s way and, like eggs and bacon for breakfast, where the chicken is involved and the pig is committed, the UAV controllers don’t need to worry about taking a nap during their long shift.

Human Error Cited in Most UAV Crashes

August 26, 2008 Associated Press

MARCH AIR RESERVE BASE, Calif. - As the U.S. military scrambles to get more robotic warplanes like the Predator drone aloft, it is confronting an unexpected adversary: human error. The drones are prized by the Pentagon for their ability to provide reconnaissance imagery and close-air support to ground commanders in Iraq and Afghanistan. But an Air Force researcher has found that operator mistakes are responsible for a growing number of Predator mishaps in recent years, a period in which the drones have been flown by increasingly inexperienced crews.

http://www.military.com/news/article/human-error-cited-in-most-uav-crashes.html

Also, with the help of GPS, Google has demonstrated a driverless car; cruise control and automatic lane keeping, and braking will keep us relaxed and safe during our commute.

Soon we will be able to commit the care of our elderly relatives to a robot with a clear conscience.

COMPUTING

A Robust Robot for the Elderly

Domo the robot is designed for the unpredictability of household chores.

TUESDAY, APRIL 17, 2007 | BY RACHEL ROSS

Audio »

For more than a decade, roboticists have worked on systems for the elderly, hoping to extend the amount of time that seniors can live at home and improve their quality of life. Now MIT researchers have built a humanoid robot with a special motion-tracking system and spring-loaded actuators that make it better equipped to deal with household chores. The robot, named Domo, can size up an object by shaking it in its hand and then put it away in a cupboard.

"Demographics are changing, particularly in Japan, Europe, and the U.S.," says Aaron Edsinger, a lead researcher on the Domo project and a postdoctoral student at MIT's computer-science and artificial-intelligence lab. "There are a lot of people that are getting older and not a lot of young people to take care of them."

But developing a multipurpose robot for the elderly hasn't been easy because the home environment is so unpredictable. Industrial robots, which are widely used in manufacturing, work with parts that come in standard shapes and sizes. Food, however, does not. So a simple task such as putting away groceries can become quite complicated.

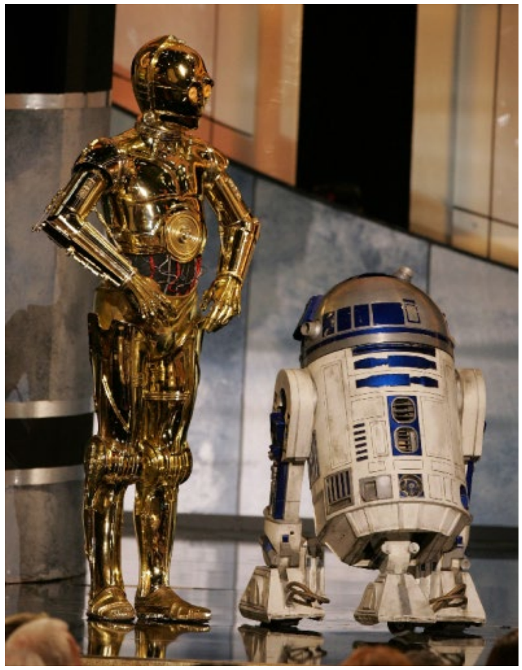
Helping hand: Domo the robot is designed to assist the elderly with basic tasks, such as putting away groceries. Domo can figure out the rough dimensions of an object by holding it in its hand and shaking it.
Aaron Edsinger

MULTIMEDIA

- View a slide show of the Domo robot.

http://www.technologyreview.com/Infotech/18537/

R2-D2 and C-3PO the famous Star Wars robots were human assistants with personalities.



Neuroscience can now decipher and direct electrical signals from the brain to control machines; the civilian and military opportunities are mind boggling if you'll excuse the pun.

DENVER AND THE WEST

PRINT EMAIL
0 COMMENTS

Think about it: CSU research could turn brain waves into remote control

By Karen Auge
The Denver Post

POSTED: 11/05/2011 01:00:00 AM MDT
UPDATED: 11/05/2011 01:14:27 AM MDT

From about the moment the device arrived in living rooms, people have joked that turning on a television was tantamount to turning off your brain.

Now, researchers at Colorado State University are investigating ways to turn on the television *with* your brain.

This is not a Las Vegas lounge act or a new-age spoon-bending parlor trick. It is complex, jaw-dropping research with the potential to change the lives of people who are losing, or have lost, the ability to pick up a spoon, or guide their own wheelchair, or work the TV remote.

The National Science Foundation has awarded the CSU research team $1.2 million, over five years, to develop technology to allow people with severe neurological impairments to complete tasks by changing what they are thinking about.

Computer would read brain waves

The goal is to observe the differences in brain waves from one activity, or even one thought, to another, then classify those differences in data a computer can use to turn thought into action, according to Chuck Anderson, CSU computer science professor and the principal investigator.

http://www.denverpost.com/news/ci_19268818

Chapter 30

It's all about me, me, me, but not I.

Education is all about me me me! Motivation, Explanation, Mastery, Examination, Management, Evaluation. Back in the day the lecture was the efficient way of delivering knowledge from one to many; the printing press threatened this venerable process but failed; now the Internet will surely lay the lecture to rest, or will it? The Internet knows more about any subject than specialists in that subject, and this knowledge is free. The tasks of the professor are motivation and explanation. The tasks of the student are Mastery and Examination – the demonstration of mastery. Administrators are obsessed with management and evaluation of the education process.

But not I! The contemporary approach to these duties is Inundation. The proponents and practitioners of e-Learning have amassed a multitude of devices and processes, which, when used without thought, serve only to Inundate, not Educate. For the past decade or so students have suffered "death by PowerPoint." Now to be fair, Microsoft PowerPoint is an enormously powerful, flexible, and easy to use tool; it can contain bullets, verbiage, pictures, diagrams and embedded video. Add in the notes pages and embed student centered activities and you have got the whole package. Next add the textbook and handouts, then the study guide, then the worked examples, and then the homework and projects and you have Inundation. At this stage the professor should just stand aside and let the MOOCs take over. We could even have the material delivered by an actor (or a robot) who would probably perform much better than many professors. The managers and evaluators will now outnumber the professors; they will be obsessed with technological based delivery and outcome-based accreditation. The professions will be left to deal with certification and licensing.

The professor's job is motivation and explanation; the student's job is mastery and examination. The challenge of numbers in delivery and examination is met by mobile learning and multiple choice evaluation of mastery. These are efficient, they may even be reliable. Their security is assured by copyright lawyers and vigilant examination management. I once sat next to a student who finished a two-hour multiple-choice aviation ground school exam in 10 minutes! The information explosion that has occurred in recent years has placed enormous stress on the course syllabus and indeed program content. One result is a decimation of programs; what was once engineering or business can now come in a hundred different flavors to feed the ravenous MOOCs. So, what lies in wait for the professors and students? And the professions?

Over the years the challenge of numbers has been met by tutorials, teaching assistants and the time-honored study group. Now even these have been replaced by technology driven and mediated "collaborative learning". The key to the success of these approaches has always been a defined objective or purpose. The lesson from business is that all meetings should have a product, which usually comes in the form of detailed or cryptic minutes. These products represent an integration of the discussion, a group consensus, an explanation and an examination. The participants have all participated, hopefully, and the product represents the outcome of deliberation and debate.
The final tool in this discussion is taken from industry, particularly the automotive industry. It is called "lean manufacturing." It is about efficient use of resources in the delivery of a product. In the current context this product is education as evaluated by examination in the broadest sense. The human products will exhibit mastery, either individually or in groups. The managers will be happy because the costs of infrastructure and technology will be minimized.

So where does this leave the professor. He could sit in his lab and produce new knowledge through research. That will get him or her tenure. He could write MOOCs and examinations; this may greatly supplement the salaries of the successful few. She could inundate students with technologically mediated explanation. But what about motivation? What indeed is the motivation of the contemporary student? Perhaps it is simply to get the ticket to ride. The cynical conclusion to this conversation is that the teacher – student relationship is an anachronism.

Chapter31

Kneejerk: Intuition, Cognition and Hindsight Bias in Team Games

Brian Peacock, Stella Ng, Lucas Tan, Pang Jin Zhou Tan Kay Chuan

Abstract

This paper discusses the importance of cognition in games like soccer and basketball. It starts with an analysis of the temporal nature of reactions and decisions and the factors that contribute to accuracy, errors, and time delays in execution. Most of these factors relate to situation awareness, strategy, and decision selection. Players, coaches, and observers in hindsight pay lip service with words like intuition to the cognitive capabilities of players, but little is done formally to address these issues in analysis, selection and coaching. The evidence in this paper comes from the human factors and psychology literature and from studies of players and referee's behavior and performance in soccer and basketball. The conclusions that are drawn are that these cognitive abilities can and should be analyzed and taught to improve the capabilities of participants.

Some Case Studies

The goal of the century: Wayne Rooney of Manchester United scored a goal under pressure with an overhead scissor kick that has been hailed by many as "the goal of the century." It was indeed a spectacular effort. However, there were many chance elements in this process. The player who made the cross was credited with a "pin-point" pass; there is no way that he deliberately anticipated and placed the ball for Rooney's kick; even if he had tried to do this it is unlikely that his accuracy (execution) could have been so precise – the ball could have equally well have been intercepted by one of the close defenders. By his own admission Rooney had only tried this athletic action once or twice in his whole career. The precise intentional placement of such a difficult shot is beyond even the greatest of footballers. The goalkeeper was taken by surprise, was slow to move and the ball entered the net just below the crossbar. It was, in hindsight, "the goal of the century" and many ordinary players could not have attempted the maneuver; even Wayne Rooney would probably have missed the goal nine times out of ten. Cynics would call it a lucky goal.

Alley-oop: In a recent NBA basketball game Kobe Bryant of the LA Lakers made a drive down the lane towards the basket. His path was blocked, but a younger Kobe would have put his shoulder down and continued with the drive – he is after all a prolific scorer. Instead he feinted and lobbed the ball high above the low post where a colleague jumped, caught the ball and dunked it in one flowing movement. This "alley-oop" is a play in basketball that requires precise timing and placement of the pass and the jump. The probability of success if executed strongly and skillfully is quite high. With hindsight the TV newscasters showed the play over and over and called it "the play of the game." The play was well practiced and planned.

Cricket hindsight: Many years ago, I introduced a visiting friend to my cricket team for a Sunday afternoon match. He was a very accomplished batsman. The first ball swung down the leg side, there was an audible click and the ball diverted in its trajectory. The wicketkeeper dived to his left and made a spectacular catch. "HOW WAS THAT?" roared the bowler. The umpire replied, "That's out" and raised his index finger. As he trudged back to the pavilion the dejected batsman rubbed his pad and complained that the ball had flicked the top of his pad and not his bat. He said to the umpire "Read the newspaper on Monday morning, they will tell the truth", to which the umpire replied: "I'm the sports editor of the newspaper; you will read that you were indeed out, and that you were very rude!"

Monday morning quarterback: Hindsight bias is formalized in American football by the expression "Monday morning quarterback." Sports fans congregate around the coffee pot at their place of work to discuss the weekend's game. The discussions are full of "ifs and buts"; praise is distributed generously on the successful teams and individuals and blame is assigned even more generously to the hapless losers. These discussions are not limited to the fans; the media reports on the games by pundits and journalists confirm the conclusions on the air and in print. The only objective part of the discussion is the result and the mandatory criticism of the referee. The evidence and assumptions are mostly subjective and inevitably biased by hindsight.

Ready, Set, Go: In sprints at the top-level winners are decided by a fraction of a second which can be gained by a fast start. Since the 1970s the legislators have ruled that 100 milliseconds is a minimum reaction time and if a pressure sensor on the push off foot releases before that time a false start is declared.

Table Tennis and Tennis: Table tennis and tennis are characterized by long rallies. Because of the size of the playing areas table tennis is a much faster game than tennis, there is less thinking time. However, because of the distances in tennis there is more movement (execution) time. Many of the rallies are simple reciprocations, up and down the lines, until one of the players surreptitiously decides and executes a change, such as a cross court, back spin or drop shot. Experienced players can multitask by embedding decisions in the parallel execution time. These maneuvers are planned, practiced and an integral part of the game; they are not reactions; they are strategically planned as part of a sequence of executions.

Penalty: The laws of the game of football relating to a penalty kick state that the goalkeeper must remain on his line until the ball has been kicked; he is allowed to move from side to side but not advance. If the goalkeeper advances before the ball is kicked and makes a save then the referee may order the kick to be retaken. As with "goal line technology" here is another opportunity for technology to come to the aid of the referee, who has difficulty from his recommended location in watching both the kicker and goalkeeper. However this objectivity would remove one more element of uncertainty and controversy which help to make football the most popular game in the world. The penalty kick is a classic two choice reaction time for the goalkeeper. He cannot make a save from a well taken shot without anticipation and strategically planned execution. The same subjectivity occurs in baseball where the first base umpire uses vision for the runner's feet and sound for the ball hitting the first baseman's glove to make his two choice judgments of closely sequenced events.

Reaction Time

In physiological terms a knee jerk is a spinal reflex in which a response to a tap on the patellar tendon causes an almost instantaneous contraction of the quadriceps muscle and reciprocal inhibition of the hamstrings. The Dutch psychologist FC Donders (1868) described simple visual reaction time as taking of the order of 190 milliseconds; response to an auditory stimulus is a little quicker, but where choices are involved the reaction takes a little longer. Eye movements, measured by electrooculography, show reaction times of less than 100 milliseconds. Sternberg (1969) used reaction time experiments to imply the contributions of various mental processes. Other delays in reaction time are described by the psychological refractory period – stimuli presented in quick succession result in a delay in the response to the second stimulus (Welford, 1952). A big first stimulus causes even greater delays (Koster and Peacock, 1969). The psychological refractory period theory explains why the "feint" works in rugby, soccer, basketball, and boxing.

This whole reaction time myth was laid wide open in the 1880s by participants in the Oklahoma Land Rush. The Boomers waited until the prescribed signal before entering the State to stake out their land claims, but the Sooners made their move before the canon went off (Peacock and Fogleman, 2006). They anticipated! It would be unthinkable for members of an orchestra to wait for the baton before making their move; they too anticipate, making a coordinated zero "reaction time." Sprinters are "ready" for the gun. Car drivers use the brake lights (CHMSL) of the cars way down the road to prepare them to move their foot from the accelerator pedal. In sport, players have already planned and practiced a coordinated action long before the "stimulus" arrives. Consider fast games like table tennis, somewhat slower games like tennis and cricket and strategic games like golf, chess, and snooker. Dynamic games like soccer and basketball require players to perceive the current context and stimulus, amalgamate this information with previously acquired information and mental models and select (or adapt) their response from a set of preprogrammed and stored responses. Goalkeepers lean to their left and then dive forward and to their right on the assumption that that is where the penalty kick is going. In practice, many ball players make up their mind what they are going to do ahead of time and ignore the intervening information; if their action (response) is robust then the "stimulus" may be incidental. Tenenbaum (2003) reported that expert athletes look at the big picture while novice athletes tend to focus on specific areas. Thus, expert athletes are able to respond quicker to changes in the game.

Bayes' Theorem

The Reverend Thomas Bayes (1763) described theoretically optimal convergent decisions by the amalgamation of current and previous information. Since that time decision theory has exploded broadly into many areas of human activity such as business, warfare, consumer behavior and sports. The general principle behind decisions under uncertainty is the amalgamation of noisy stimulus information with the probabilities and costs / benefits of various outcomes, all combined in a mathematical, computer or mental model of the transaction. A difference between abstract and human decision making models is that humans are sub-Bayesian; they do not make full advantage of all the potentially available information, either because of time limitations, subjective weighting of evidence item importance, incomplete experience, inadequate mental models or simply forgetting. Kline (2008) described "naturalistic decision making" as a way of approaching the complexity of human decisions (selections) in real world, information rich, noisy, time constrained situations. For human decision making, Bayes' theorem must be modified to reflect the fact that the probability associated with a hypothesis is a function of the subjectively weighted evidence.

Thus, for subjective decision making, Bayes' Theorem should read:

$$p_E(H) = p(H)*p_H(wE) / p(H)*p_H(wE) + p(H')*p_{H'}(wE)$$

where: H , H' are the alternative hypotheses, E is the evidence and w is the subjective weighting of the evidence

Decisions and Execution

Execution follows decisions and requires speed, strength, stamina, skill and, in some games like basketball, size. These execution elements are all observable and measureable and widely analyzed by coaches, players, and journalists. Motor skill, speed, strength, and stamina are the result of both nature and nurture, so are strategic skills like situation awareness and decision making. Whereas the physical attributes are essential to effective execution, it is the decision skill that separates the successful ball players from the pack. An observation about soccer and basketball is that the novice decision maker does not make use of all the potentially available information during a particular play, due to search time constraints, lack of situation awareness, strategy and decision making ability, and as a result makes decisions and executions that have a low probability of success. For example the probability of success of a long pass depends on the relative proportions of teammates and opponents in the general area of the destination (a "Hail Mary" in American football) and the decisions and developing actions that are unknown to the passer at the time of making the pass. Because the target accuracy of a pass (or shot on goal) is related to the distance (angular error), the long passes have less chance of success, which is affected by defense coverage. One characteristic of successful games players (experts) is that they bring a lot of history (memory) to the table. Their training and experience results in better mental models, mental simulation and predictions, search for and acquisition of relevant information, and, most of all, discarding of irrelevant information – strategic forgetting; they also have better execution skills.

Foresight, Impulsiveness, Intuition and Hindsight

Another way of addressing and analyzing reaction and decision-making behavior, particularly in the context of sports, is to consider the familiar concepts of foresight, impulsiveness, intuition and hindsight. The cynical observer, biased by hindsight, will use words like foresight and intuition to describe successful outcomes, whereas "impulsiveness" generally has negative connotations, despite similar cognitive processes. In soccer and basketball possession changes every few seconds. The long run success of all passes in soccer is around 50% and that of successful shots is much less. Basketball shooting success is much higher, but even dunks sometimes fail. In the long run some players and teams make better decisions and executions, have better luck (the random component) and are rewarded by long run greater success.

Coaching and Kano

The challenge for coaches is to analyze player characteristics, abilities, behaviors and performance for the purpose of selection, assignment and training. After the event journalists and Monday morning quarterbacks benefit from the availability of hindsight regarding outcomes. It is fairly easy to objectively measure size, strength, suppleness, speed and stamina, and these are "must have" requirements in most games. Skill is a more elusive measure, but is viable under controlled conditions. Often skill becomes a subjective impression, made by coaches, colleagues, journalists and spectators. Performance is objective and the newspapers and coaches' computers overflow with data on goals or points scored, passes made and failed and strategic defensive redundancies (cover). The Kano model (Kano, 1984), usually applied to consumer product or service evaluation, is applicable in this context. This model may be applied to the evaluation of a sports player or team, differentiates among "must have", "the more the better" and "excitement" measures and qualities (Figure 1). The elusive measures in the evaluation of games players are the "excitement" factors. "Style" in this context may be distracting. What are needed are reliable measures of situation awareness, strategy and decision making under noisy, time constrained, variable payoff conditions.

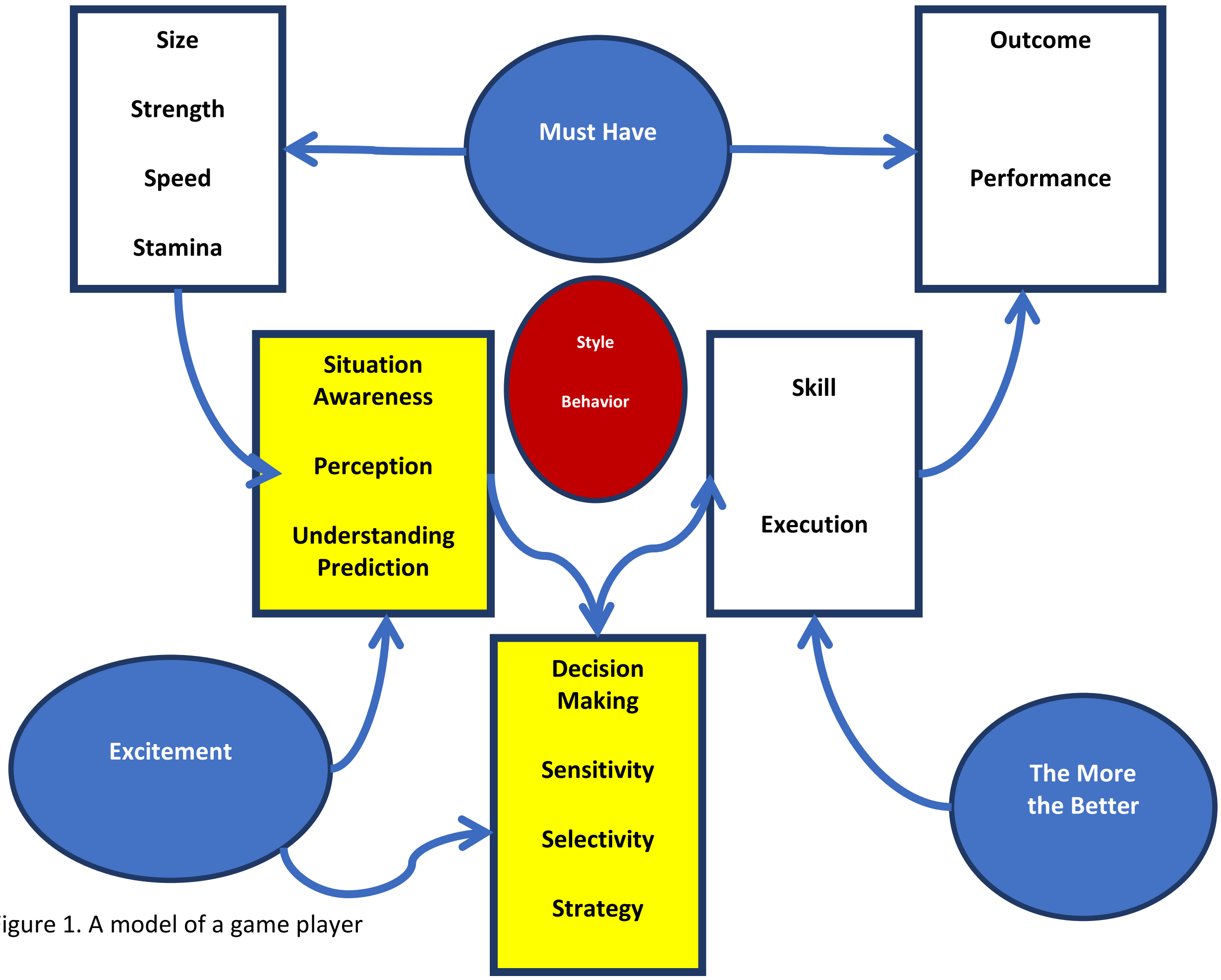


Figure 1. A model of a game player

Situation Awareness

Situation awareness is a popular concept used particularly in the aviation context for describing the pilot's ability to perceive, understand and predict. In ball games situation awareness includes spatial, temporal and operations awareness (Peacock and Chai, 2012). Spatial awareness includes the locations of other players and the goal, temporal awareness includes a prediction of how long it will take for alternative events to emerge, and operational awareness includes all the detailed knowledge of planned strategies and other players' strengths and behaviors. Situation awareness therefore is essential to effective decision making. However, the difference between a novice and an expert is the ability to use available information effectively; this may include "strategic forgetting" of some evidence and higher weighting of other evidence based on experience and habit. Some players will shoot at every opportunity from any distance, like buying a lottery ticket, despite the objective odds of success.

Buying Time

A model of mental workload, situation awareness and decision difficulty have the following general form:

Decision difficulty = (Information available * Stress) / (Time * Expertise)

Where there is a lot of information available on which to make a decision, the choice becomes more difficult. If the decision maker is under stress, perhaps related to the payoff (benefits of success, costs of failure) associated with different outcomes, the decision becomes even more difficult. On the other hand, if the decision maker can “buy time” to investigate and mentally simulate the possible scenarios and outcomes, he / she can become more “Bayesian” – make better use of available information. It is well established that experts can handle available information more efficiently than novices (they use “chunks”) and so “expertise” effectively reduces decision difficulty. Simon and Chase (1973) noted that chess masters remember a lot of chess patterns so they are able to quickly recognize these chess patterns and decide on the next move, as compared to novice chess players.

In dynamic games like soccer and basketball, players can “buy time” by holding the ball until the situation becomes clearer, or perhaps more complicated. In soccer referees are trained to apply the “three step rule” to allow advantage to the fouled player; in these cases the referee may still award a caution after the event if the foul was egregious but the outcome to the advantage of the offended player. Opportunities for referees to buy time and information in cricket, tennis and American football involve slow motion replays of the incident in question. This strategy is particularly pertinent in the current debate about goal line technology in soccer. The disadvantage of such technological interventions is interruption with the flow of the game, which, particularly in soccer, is generally considered to be undesirable.

Methods and Results

The purpose of this paper is to describe three investigations of dynamic decision making in soccer and basketball in order to gain insight into individual differences in cognitive aptitude of players and observers. This insight will be of value in coaching and selection.

Soccer decision making:

The first data set is related to subjective opinions of observers of developing scenarios in soccer, presented as video clips. These opinions involve foresight – what should the player do, immediate hindsight – should the player have shot or passed the ball, and delayed hindsight given full information regarding the outcome of the decision and execution. The data in this experiment was in the form of positive and negative verbal descriptors of soccer player’s decisions and actions. A series of 16 three-part clips from international soccer games were shown to 200 players with various levels of expertise. The first part showed the lead up to a decision-making situation – should the player pass, hold, dribble, or shoot. The second part showed the actual decision made by the player and the third part of a clip showed the outcome. After each part of the clip the observers were asked to comment on the wisdom of the alternative decision choices from a pre-selected set of descriptors.

The results of the hindsight study on choice of soccer play indicated an increase in the number of positive descriptors (Brilliant, Dynamic, Sensational, Confident, Composed, Ambitious, and Outstanding) when the play turned out to be a success compared with the observations immediately after the decision was known. When the outcome was known to be a failure the reverse trend was observed, there was an increase in the number of negative descriptors (Unconfident, Unambitious, Frantic, Lack Luster and Unremarkable). These descriptors clearly have both execution and cognitive / decision making implications.

Figure 2. A soccer clip – how would you rate the decision of the player with the ball to pass, shoot, dribble or hold?

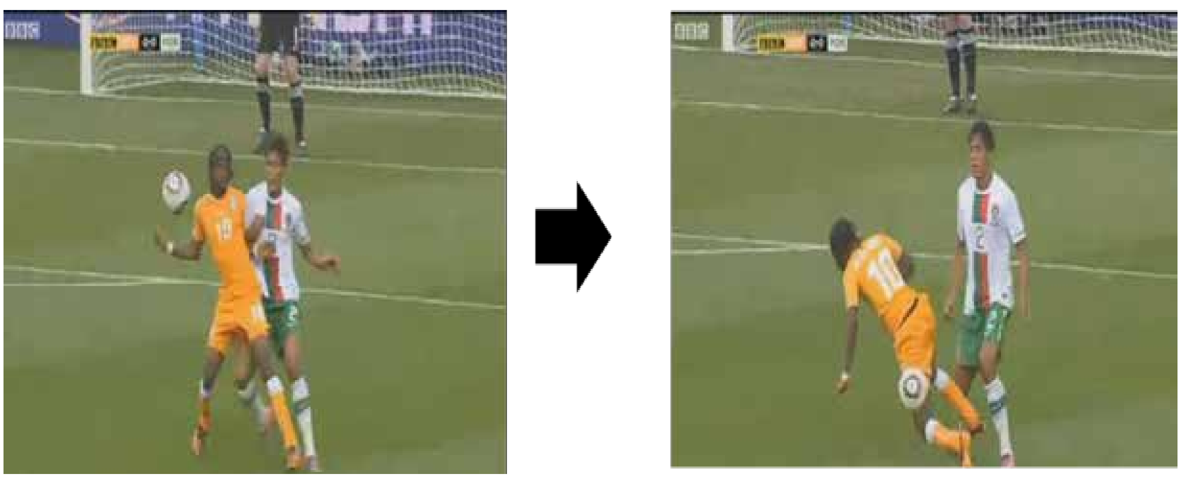
Basketball decision making: The second set of scenarios involved observer judgments of the best decisions from various alternatives (pass, shoot, dribble, hold) when presented with 10 "easy" and 10 "difficult" basketball scenarios in the form of static manikins placed in common game situations (Ng et al 2013). These scenarios involved a sequence of snapshots of players (manikins) in various basketball situations. Observers with various levels of experience were asked to choose among alternative decisions – hold, pass, dribble or shoot. These choices were then compared with the choices of expert basketball coaches.

In the basketball study experienced players were significantly quicker (average fastest time over all scenarios equaled 1.82 seconds) than novices (average fastest time over all scenarios equaled 2.37 seconds) in making their choices among dribble, hold, pass or shoot. However, there were no significant differences in the accuracy of the choices between novice and experienced players when compared with the coaches' choice of action.

Figure 3. A basketball scenario – should the yellow player pass, shoot, dribble or hold?

Soccer Referees: (Lane, nd; Kranjec, 2010; Mascarenhas, 2002)

The third data set involved soccer referee decision making in real time and slow-motion replays; this investigation compared the relative utility of hindsight by novice and experienced observers. A series of twenty clips were shown to 80 observers with various levels of (self-reported) expertise. After the clip, the observers were asked to choose between foul and no foul and "card" or "no card" – indicating the severity and intention of the offending player. The clips were then replayed in slow motion from a better angle and the observers were invited to reconsider their decisions. The analysis focused on the changes made by novices and experts after the replay.



In the soccer refereeing study, the "correctness" of the decision was based on the actual decision made by the referee in the recorded game. Overall decisions correct answers increased from 68.6% on first real time viewing to 76.8% after the replay. The strong cases (easy decisions) showed 74.3% correct when compared with weak cases (62.0%). Strong cases improved to 83.8% correct and weak cases to 69.9% correct after the replay. Over all incidents (strong and weak cases) "no foul" decisions (71.4% correct) were reported more accurately than "foul" decisions (65.8%). However, "Foul" decisions improved to 78.0% correct after the replay and "No foul" decisions to 75.6%

correct. Self-reported knowledge proficiency was associated with a greater number of correct judgments, especially after the replays.

Soccer Coaching:

A fourth data source was less formal. A soccer coach repeatedly stopped the action during children's practice sessions and asked individual players questions about their "situation awareness", including spatial, temporal, and operational factors, and likely strategic decisions. Naturally, the children did not always like the interruptions, so they had to be imposed sparingly. When children were asked what was going on and what should they do during soccer practice, they were very willing to offer their ideas, or lack thereof. Probing and presentation of spatial, temporal, and operational information by the coach elicited positive responses in most players, but no comprehension in others. Interestingly, many of the strategies offered by the children implied exaggerated perceived execution capabilities.

Discussion

These studies of decision-making behavior and performance indicate some of the complexity when moving from simple reaction time to rapid decision making in games. As seen in the soccer behavior study, descriptions of player behavior and performance go way beyond the easily measurable capabilities of speed, strength, stamina, and skill and imply higher level cognitive capabilities. The basketball study showed that experts are faster than novices at making decisions. Experts are "quick thinkers" - intuitive or impulsive, depending on the outcome. Decisions are complicated by experience and situation awareness. Experts bring greater understanding to the game and so make better decisions under time constraints. Referees can "buy" decision making time by delaying their decision until the play has unfolded. The reported study showed considerable accuracy improvements by the introduction of slow-motion replays, but such a feature may be unacceptable due to its interference with the flow of the game. However its utility has been shown in after the game analyses. The simple implications of these studies are that cognitive capabilities have considerable importance in games and therefore should be addressed in analysis, selection and coaching strategies. The challenges are measurement and implementation. The following are some suggestions for selection and coaching in dynamic games like soccer and basketball.

Coaching methods should be player centric. Verbal instructions (lectures) should be minimal and usually aimed at eliciting a response from players rather than long winded esoteric advice. The "must have" and "more the better" features of a games player will always be important: stamina, strength, speed, and skill; they are essential elements of all games training. Because situation awareness and strategy are or should be collaborative, most activities should be group based (2 on 2, 4 on 4, 8 on 8 and "outnumbered" etc.) Situation awareness – perception, comprehension and prediction – improves with practice, but benefits from reflection. Strategy, as opposed to execution, is a cognitive activity that can be learned through analysis, simulation, experience and reflection. Observation of very young soccer players clearly demonstrates that they have poor situation awareness and are unable to execute strategies other than dribble forward or shoot; they rarely deliberately pass the ball or move to a useful location when they are not playing the ball. Professionals on the other hand plan and execute quite extensive sequences they buy time by keeping possession and moving into space to contribute to the developing offensive or defensive play. They demonstrate good situation awareness and practiced strategic decision making.

The SAGAT (Situation Awareness Global Assessment Technique – Endesly, 1994) method of training and examining pilots, air traffic controllers and members of other teams can be of value in games analysis and coaching. The method involves stopping the action during a simulation or game and asking probing questions about the current spatial, temporal, and operational situation. The approach stimulates thought, mental simulation, and prediction among the participants. It is user centric. It "buys time", like a basketball player holding the ball until a decision becomes clearer or a soccer team keeping possession by passing the ball around until the opportunity for advance occurs.

Collaboration – involving the input from other team members involved in a developing situation leads to "team situation awareness" – an essential precursor to strategic decision making. In soccer or basketball practice or after the game reflection around video recordings, strategic pauses in simulations for analysis and reflection are valuable ways of improving strategy, situation awareness and decision capabilities. The basketball coach's playboard can now be animated with a tablet computer and projected on a large screen for all to see. Rather than showing only Xs, Os and arrows, it can add three-dimensional dynamism to the simulation for the purpose of enhancing collaborative situation awareness and strategic decision making skills.

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Chapter 32

Human Variability, Operations, Design, Forensics: Six Cases

Abstract - Six Forensics Human Factors cases are presented that are typical of many situations where the defendant had no intent to harm the plaintiff and the plaintiff made a, perhaps foreseeable, mistake. There were "human factors" arguments on both sides which delved into the latent hazards associated with the design and operations. In some of the cases the design decision was made for a reasonable purpose but the safety tradeoff was either not considered or simply ignored. These cases highlight the importance of a balance between after the event "ergo cop" mentality and collaborative hardware and operations design interventions.
Key Words: Design, operations, tradeoffs, latent failures, forensics, court decisions

I INTRODUCTION

During litigation, the plaintiff's representative will usually address the technological issues that were the responsibility of the manufacturer followed by the operational issues that may also have been the province of some third party. The defense argument will emphasize the unusual contextual or environmental factors and attempt to discredit the competence of the unfortunate victim. The plaintiff's representative will counter with Ergonomics dogma about design for intended use (users) and foreseeable misuse (misusers); they will then add that products should be resilient in their capability to withstand the effects of unusual contexts and foreseeable operational demands. The defense will point out the difficulty of anticipating and designing safeguards for all possible extreme users, usages and contexts. All of the six cases described below have elements of technological, human, contextual and operational variability and their inevitable interactions. The outcomes of these cases did not always go the way that was expected.

II SIX CASES

A young woman, of average adult female height, but above average weight entered a store to buy cosmetics. As the intended purchase was out of her reach, high on the rear wall of the unit, she stood on the bottom shelf which immediately collapsed, bringing the whole unit on top of her and breaking her leg. Measurements indicated that the item was beyond the reach of more than half of the adult female population. The only shelf was about a foot high and 15 inches deep and the products were hung on hooks connected to the rear wall of the unit. The shelf had a continuous metal edge which looked like a step. There was no warning regarding the lack of structural integrity of the shelf, although the erection manual cautioned people setting up the units not to step on the shelf. The defense expert told the court that the customer behaved in an unusual and unpredictable manner. The plaintiff's expert argued the importance of "foreseeable misuse" being considered in structural design and, failing that, the need for a strong indication that "the shelf was not designed to bear the weight of a person" by the incorporation of a small guard or prominent warnings, that are commonly seen in other similar stores.

In another retail store accident, an older female customer fell down some steps and broke her wrist. The checkout desk in this clothing store was on a platform about three feet above the floor level so that the attendant could monitor the behaviors of the customers. The area in front of the checkout desk was about 15 feet wide and four feet deep and there were 5 steps down to the floor level. There was a handrail at one end of the platform. On the day in question the platform was very crowded, and the lady turned, placed her foot over the edge of the top step and fell. The plaintiff's attorney argued that this type of customer was usual in this store and had no alternative other than climbing the steps to purchase an item.

A middle-aged man walked into a fitness center and the attendant pointed him towards the weight training machines. The customer selected the 4 Way Neck Machine and broke it – his neck not the machine! These machines are often used by football players and some have selectable stops to limit the range of motion, although it is not easy to describe the range(s) of motion of the complex, multi joint cervical spine. The mass of the weight to be moved was greater than the mass of the user's head and it was possible to move the head more quickly than the machine, which would "catch up" with a forceful blow. Apart from the fundamental design flaw in the machine, there were issues of failure to instruct and the absence of warnings. The clinical evidence clearly indicated the association between the activity and the injury.

A farmer drove his pickup into a country garage. He asked for a new tire and said that he would replace the old one when he got back to the farm; he was accustomed to changing tires. After a lot of soap and about 80 psi the tire exploded and broke his arm. He had been trying to put a 15" tire on a $15^{1/2"}$ rim. There were three defendants in this case – the vehicle manufacturer, the tire manufacturer, and the garage owner.

An elderly couple was driving home late at night and the wife reclined the passenger seat to take a nap, while still wearing her seatbelt. The husband also nodded off and drove into the back of an unlit parked truck. The wife "submarined" and became a quadriplegic following the severe damage to her neck. The plaintiff's attorney argued strongly that there should be an interlock to prevent reclining the seat while driving and at least a conspicuous warning to inform the passenger of this dangerous situation. The defense expert pointed out that there was a warning in the owner's manual and that it was practically impossible to warn against all operational failure modes in the front seat of a car, and that "it was clear and obvious" that the seat belt wouldn't work with the seat in the reclined position.

A sixteen-year-old girl lived on a farm where her brothers had created a course around which to ride their three wheeled ATV. The girl went for a ride and attempted to copy her brothers by driving over a large hump of dirt. She leaned backwards and the vehicle flipped and crushed her face. The plaintiff's expert presented evidence regarding the dynamic / operational instability of these vehicles and added arguments about the absence of warnings and recommended training regarding this foreseeable failure mode.

III THEIR DAY IN COURT

These six cases indicate that the plaintiff was "unusual" in some way – young, old, inexperienced, untrained, tired, or behaved in an "unusual" manner – hurried, inattentive, distracted, careless, not cautious, etc. All these variable characteristics and behaviors are usual in a human population and the degree of departure from "average" probably contributed to the accidents to some extent. The key to ergonomics analysis is to recognize this variability; the key to design of both products and operations is to anticipate and accommodate this variability. Situation awareness (Endsley (1995) is a factor in all these cases. SA is constrained by the amount of relevant (and irrelevant) information available, the time available, the experience of the individual, the level of stress at the time of the incident, and various other motivators associated with the action. For example, self or externally imposed time constraints will affect the use of information from operational memory and its application to the perceptual and decision processes.

The young lady who stepped on the shelf to reach a cosmetic product was seriously injured. She was above average weight, but she was representative of height and therefore representative of the intended cosmetics buying population. The item of interest was beyond her reach as demonstrated by the application of anthropometric evidence. There was no warning that the shelf was unsafe and no guard to discourage its use as a step. Did the shelf contravene the "foreseeable misuse" rule? Should the shelf have been constructed to accommodate the weight of a customer – in this case what should have been the load limit? This problem has been addressed in many large retail chains by the placement of guards on the front edge of the bottom shelf and a warning to customers to seek help to access items out of their reach. In this case the argument that the plaintiff was truly representative of the intended user population and exhibited foreseeable (mis)behavior carried the day.

The elderly lady who fell down the steps was only slightly injured. She too was representative of the intended user population – the garments in this shop were intended to be bought by women of all ages. The raised platform was a reasonable security intervention, but there are regulations about accessible handrails. In this case the handrails were at either end of a 15' platform and not accessible in the crowded conditions. Should this operational factor have been considered? Given the notorious perceptual contributions to falls on stairs, should there have been clearer edge markings? A likely contributory factor to this accident was the age of the customer and the cognitive / operational memory / situation awareness decrements that occur with advanced age. Should the designer and operator of the store have recognized this variability of the expected customers? Perhaps this accident could have also happened to a younger person, due to distraction and forgetting. Another twist in this case was that the plaintiff's attorney sought an exorbitant sum because he thought he had a winning case and expert. Although this issue may be beyond the scope of the ergonomics specialist, it probably had a significant bearing on the decision of the court in favor of the defendant.

The fitness center customer really did fracture two cervical vertebrae on the neck machine; the circumstances of the accident and the X-ray evidence clearly showed this to be the case. But the defense expert testified that the damage could not have happened in this way to normal tissue. This type of machine is widely used by football players but did not have range of motion stops so there are certainly operational skills to be taught before using it. Why would an inexperienced person who had just walked into the fitness center for the first time not be trained or cautioned about the dangers of weight training equipment? How does the perception of risk (the range of motion and forces associated with the equipment) apply to this situation? Why didn't the organization's management train and monitor the behaviors of their employees? Could the likelihood of an accident have been reduced by strategic placement of instructions and warnings? The court found in favor of the defense.

This wheel / tire size mismatch issue has arisen on numerous occasions. Should the garage owner have been more careful in matching the wheel and tire? Should old farmers be expected to be aware of the two different wheel sizes? Old farmers know how to put a tire on a truck wheel - just add a bit of soap and a little air and it will seat itself. The level of specific experience of the plaintiff was considered when he bought the wheel This may well have been the failure to perceive the difference in size between two objects that were presented at different times under distracting conditions. Is it possible to add readable labels and warnings of every failure mode on a wheel or tire? Should the farmer have stopped adding air (another perception issue) well before the tire exploded or was he too intent on the task at hand to take notice of the unusual difficulty? What is the responsibility of the wheel and tire manufacturers in guarding against this predictable failure mode? In this case the wheel and tire manufacturers were exonerated of blame. The garage owner on the other hand refused a pre-verdict settlement and when he was found guilty had to pay a substantial fine which resulted in bankruptcy.

The "failure to warn" argument in the case of the reclined seat raises interesting issues of the effectiveness of warnings and the counterproductive issues of a proliferation of warnings. It is not feasible or acceptable to plaster a car with warnings against every possible failure mode. So the car companies select only those prevalent and serious failure modes to receive warnings – the rest go into the owner's manual. Should the designers have addressed the problem with a recliner interlock and radar braking? Should the passenger have recognized the biomechanical problem resulting from reclining the seat? Incidentally, many people including engineers canvassed after this case did not appreciate the hazard. Given that the effectiveness of the seat belt is related to the amount of recline, at what stage of recline would the passenger recognize the problem – another perceptual problem. This case was settled out of court – arguments against a plaintiff in a wheelchair are not good for company image.

The young girl whose face was severely injured when the ATV flipped wanted to copy her two older brothers. She had seen them ride around the yard and over the hump many times. But, due to her lack of training, she did not recognize the problem of her center of gravity moving backwards over the rear axles as she went up the slope. The level of situation awareness in this time constrained activity was probably affected by the ability of the rider to access all relevant information for the task at hand. Most three wheeled ATVs have now been replaced by more stable four wheeled vehicles but even they are notorious for rolling when taken over rough terrain. What does "all terrain" mean? Should the sixteen-year-old or her brothers have perceived the risk? Should there have been formal training by the manufacturer? Should the vehicle have had a warning about this failure mode? This case too was settled out of court

PROBABLE CAUSE - Variability: Our raison d'être and our Achilles heel

The adversarial court system is by its very nature concerned with "probable cause" so it can assign blame, costs and penalties. The aviation industry in the USA also pursues probable cause in accident investigation. But for many years human factors and ergonomics professionals have recognized that there is rarely a single cause (Reason (1990), Holnagel et al, (2006), Weigman and Shappell (2003), Hale and Heijer (2006). The unsafe act itself is the culmination of many contributory factors and various human performance "laws". Human, situational, and temporal variability should always be considered in both accident investigation and design. Is the "probable cause" the same as the "root cause" - the first falling domino - or is it a failure in one element of the set of complex prevention or mitigation defenses? What about "latent" hazards? Human errors occur all the time but mostly we recover and learn from these errors. Thus it is the challenge of the human factors forensics specialist to describe human error and then move on to identifying where, in the complex sea of contributory factors, prevention or mitigation of unwanted outcomes should have been recognized and designed in to the system to obviate the "probable cause".

All accidents are complex and clouded in variability – our raison d'être and our Achilles Heel. On the other hand, the courts want clear and concise descriptions of probable cause and relevant contributory factors. But even ergonomics experts are human and exhibit variability in experience, perception, operational memory, and situation awareness. There is the strong potential for bias given the adversarial context, which can lead to variable weighting of complex items of evidence. We rarely deal with clear cut cases – they are usually settled out of court. Given these operational challenges we should always refer to our code of ethics and *"not allow the adversarial system of jurisprudence to affect the quality or integrity of (our) practice".*

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Chapter 33

Nobody is Normal: Human Factors Measurement and Design Policy
Variability – we can't avoid it

We are surrounded by variability, but this chapter will be limited to the topic of human variability. The empirical observation of variability can, fortunately, be described by probability theory and statistics. These mathematical tools allow us not only to describe human variability, but they also provide the mechanism for making decisions about people and for designing the world in which people exist. Coincidentally, people with no knowledge of these useful tools also deal intuitively with human variability and exploit it. When we speak to a large audience, we use a sound level such that all can hear – "can those in the back hear me?" Conversely, in a crowded room we lower our voices so that only those in the immediate circle can gain the advantage of our insights. Exploiters of variability include the gamblers, the game players, and the politicians. When these people harness the power of probability theory, they get an advantage over those who limit their observations to subjective probability. We – human factors engineers and ergonomists – come armed with these tools – that is why we are useful. Those "Johnny-come-latelys" who limit their observations in a reactive way, solely to the "voice of the customer," are doomed to an eternity of feedback control or tampering (Deming, 1989.)

Probability

Variability comes in all sorts of shapes and sizes. Evans, Hastings, and Peacock (2000) describe some 40 statistical distributions, many of which can be brought to bear on the analysis of human variability. One distribution – the Normal Distribution or "bell curve"– stands out as the most widely applied tool. Many people blame Gauss for developing this theory, but the real culprit was the father of probability – a Frenchman named de Moivre, in 1773. Gauss simply used the ideas to explain how the universe works.

Those who are hazy on the subject should go and take a statistics class – you cannot understand human factors engineering or ergonomics if you do not understand probability and statistics! In case I have offended someone I should hasten to add that you cannot understand the application of human factors engineering if you do not understand the domain in which you are practicing – Deming calls this "profound knowledge." Best practices in Ergonomics / Human Factors involve teams of HFE and domain specialists.

Correlation

The example given above – the heights of people – is the unfortunate example that almost everyone knows about. They know that a 5th percentile person is taller than 5% of the population and go on to extrapolate that they are also stronger, have better eyesight and are more intelligent than 5% of the population. What gobbledygook! But do not laugh – the clothing industry has been making such assumptions for years about the various shapes and sizes of people. And they sometimes get away with the assumption. Why? Because many human variables are correlated – that is taller people are usually heavier and have longer legs than smaller people. The problem with this correlation thing is that we need another pot full of statistics to describe it, again based on that pervasive Normal Distribution. Suffice it to say that correlation may be perfect and positive, perfect, and negative and all shades in between. When we measure people, stature (height) is highly correlated with leg length, but less correlated with back length, girth or weight or strength or stamina or memory or vison or age or political party. You get the idea.

We can measure people on thousands of dimensions that are positively or negatively correlated. These similarities and differences have genetic and environmental causes. What is particularly striking about genetic factors is that we have more similarities than differences as a race. We are not like apes or aphids or apples. Most people can sleep on a standard size bed, eat a standard size big burger, read the standard font on a newspaper, drive a standard car or carry a standard size suitcase. One size fits all? Well it depends how precise you want to be or how important it is that the glass slipper fits only one princess. Given our genetic underpinnings, opportunity and practice allow us to adapt to our environment. Expertise is determined by dedicated practice. Unfortunately, age and disease fight our attempts to exaggerate our differences. But to get back to the central thesis of this article, subjective and objective measurement of people can be made on thousands of dimensions and, given sufficient resolution of our measures, we can articulate substantial variability on each dimension. Furthermore, these measures are not necessarily correlated.

Say we are a 95th percentile height, 70th percentile weight, 80th percentile strength, 90th percentile stamina, 30th percentile dexterity, 50th percentile sociability, 40th percentile at swimming, 10th percentile at singing and so on. What is the probability that we will find someone else just like us? Fat chance. But with all this genetic stuff pushing through we are likely to be more like our parents on many dimensions than our overseas pen pals.

By now we have established convincingly that people are not alike. We have explained why these differences occur and how probability and statistics can be used to describe the variability. No two persons are alike ergo nobody can be Normal.

Design

Now to the challenges of design to accommodate this variability. The challenge hit me between the eyes (almost literally) when I contributed the ergonomics input to the design of the Hong Kong Mass Transit Railway. Assuming that 2 million people have ridden the train each day over the past twenty years I feel that I have contributed substantially to the comfort, convenience and safety of a lot of people – I leave it to the reader to do the arithmetic. One challenge was a decision regarding the height of a horizontal grab rail to be used by passengers as they moved up and down the train. Of course, we should take the comfortable upward reach of the 5th percentile Chinese female (98% of the Hong Kong population is Chinese and their stature, due to genetic and dietary factors is less than Westerners or Northern Chinese.) So, I arrived at a number that hit a fiftieth percentile male on the chin or thereabouts. I had discovered the ergonomics challenge of conflicting criteria! Compromise! The reader is invited to travel to Hong Kong to assess the utility of the final design decision.

The reader is referred to the diagram earlier in this article, specifically to the value of X. Suppose our job is to design the instructions related to income tax forms. We hope that most citizens will be able to read and understand them. Question: citizens must be members of the human race, can tax lawyers be citizens? So, the well-intentioned advisor to the IRS persuades the government to make a law that the instructions must be written at an 8th grade reading level – we will assume that this X represents the 5th percentile tax paying adult. This is a pretty difficult task because the cognitive content of the tax laws is determined by these tax lawyers and the instructions only represent the interface. So, the result is that 50% of the tax paying public make use of a professional service. Great interface? Do not blame the interface – it is the system designed by tax lawyers itself that discriminates.

Conflicting criteria

Now for an example of conflicting criteria. Suppose we work as an ergonomist for one of those parcel distribution companies. Our job is to answer the question: how many (few) young, strong, students does it take to move N parcels, with an average weight of P pounds from A to B in an ideally designed "ergonomic" (I hate that word) workplace, in order to fulfill the company's promise of next day delivery? One more thing: without hurting these young, strong students. Fortunately, we have a wealth of industrial engineering knowledge and the NIOSH lift equation. If we pay our workers enough money, they will work hard and we can set the value of X – the work rate - very high. Another way of looking at it is that we can call x the materials handling capability of the population and we can set the X selection screen to say the 75th percentile parcel handling capability – young strong. Looking at it from the safety perspective we know that as the demands on the body increase there will be two outcomes – first we will get a training effect – the bodies will become stronger but not younger. The second effect of increasing the demands is that a greater proportion of the population will break. The NIOSH Lift equation lift index is a surrogate for the probability of breaking. (I do not want to get into a lengthy discussion of how good a surrogate it is – it's probably as good as a test of reading level in the tax form example.) So, back to the design question. We have done our best at work place design; we have controlled the mean parcel weight by economic and physical restrictions; we have selected our worker population perhaps with the help of the union; we are left with the design dimension (X) of parcels per person per hour over a ten hour day. Our conflicting criteria are productivity and safety – both having probabilistic underpinnings. Set X high and we get great productivity and a high incidence of injuries and vice versa. What are we to do? Well we are not alone – this question has been debated in the highest circles in the land and was resolved at least temporarily by a 5 to 4 vote in the US Supreme Court. Productivity rules OK! Ergonomics is junk science. (But by the way do not hurt anyone.)

Ergonomics, variability and policy

These two examples – tax instructions and parcel handling rate – highlight the fundamental separation of human factors engineering and policy. The human factors engineer can measure human capabilities and limitations on thousands of dimensions. It is up to the policy makers – management, government, and union negotiators etc. to draw the lines in the sand. It is just like traffic speed limits and blood alcohol levels. We are working on a probabilistic continuum that is based on human characteristics, behavior, and performance measures. So where does this leave our sacred 5th percentile female or even our 95% confidence limits. These are policy concepts; they are human factors dogma; they are convenient; they are useful; they may be used as the basis of rules; rules are meant to be broken, laws are meant to be interpreted, or negotiated. Human factors engineers are good at measuring, they should also help management and the legislature with the evidence of human variability that is the basis of policy. Nobody is Normal. People vary. Ergonomists by whatever name have job security because of it. But human variability is our Achilles heel.

Chapter 34

Drillis and Contini Revisited

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ABSTRACT

Anthropometry has been the bedrock of ergonomics and human factors since the formalization of these fields of study some 70 years ago. There are various measurement conventions and many data bases (ISO, SAE, WHO, CDC). Perhaps the most comprehensive text on the subject is that by Pheasant and Haslegrave (2006). The methods used for workplace design involve convenient, usually boney, landmarks such as the acromion or patella. On occasion, soft tissues are included, especially for widths and girths. Perhaps the most highly developed application is for “occupant packaging” in automobile design (Roe, 1993). Contemporary methods include wand based pointers and whole body scanning. Contini and Drillis (1963) and Pheasant (1982) hypothesized that any of these measures could be predicted with sufficient accuracy from a single measure of stature. Their results have been widely published and applied. The purpose of this paper is to revisit these findings by analyzing the correlations among many measures from data obtained in various recent anthropometric surveys. A more detailed approach used multiple regression and structural equation modeling to improve the reliability of prediction. As expected the dimensions that had the highest associations were limb segment lengths. Width and girth measures were inter-correlated and more associated with weight than stature. Head, foot and hand measures were not highly correlated with other measures. Whereas the Drillis and Contini ratios were found to be sufficient for many practical purposes, the addition of weight as a predictor provided greater accuracy.

1. INTRODUCTION

Anthropometry has been the bedrock of ergonomics and human factors since the formalization of these fields of study some 70 years ago. Usually the term anthropometry is limited to the static measurement of human body segment dimensions, such as stature, popliteal height, reach or shoulder width. There are various measurement conventions and many data bases (ISO, SAE, WHO, CDC) . Perhaps the most comprehensive text on the subject is that by Pheasant and Haslegrave (2006). The methods used for workplace design involve convenient, usually boney, landmarks such as the acromion or patella. On occasion, soft tissues are included, especially for widths and girths. Perhaps the most highly developed application is for “occupant packaging” in automobile design (Roe, 1993). Also, NASA scientists routinely collect data from astronaut candidates for use in space suit and other equipment designs (Rajulu, 2009). A slightly different set of landmarks is used by the physical education community. The anthropomorphic modeling community uses joint centers of rotation as reference points for the development of avatars.

A formal description of body shape was developed by Sheldon (1940), who used scales of endomorphy, ectomorphy and mesomorphy to describe the relative degrees of fatness, lengthiness, and muscularity. Skin fold measurements, underwater weighing and electrical resistance methods were later added to describe body composition. Contemporary methods of wand based landmark identification tools and whole body scanning can provide complete descriptions of body or segmental size and shape – such as heads, hands and feet for specific equipment and clothing design purposes (ISO, 2010, Harrison and Robinette, 2002).

Contini and Drillis (1963) and Pheasant (1982) hypothesized that any of these measures could be predicted with sufficient accuracy from a single measure of stature (Figure 1). Their results have been widely published and applied.

The Drillis and Contini tables refer to segment ratios based on joint centers. This approach begs the question of what is “sufficient accuracy”? Parents have their unshod children on their birthdays “stand up straight” with their back to the door jamb, then with the aid of a book placed on the child’s head, make a pencil mark to record the annual growth. Similar methods may be used in the evening and the morning to measure overnight “growth” in adults. Astronauts play the same game, although here the stakes are higher if micro gravity exposure results in their not being able to fit into the reentry or emergency evacuation suit. A pragmatic strategy by the space agencies is to reject very tall and very small candidates for selection to the prestigious astronaut corps; corpulence is usually not an issue among these highly driven individuals. Another major source of inaccuracy in the collection of population data is due to the universal use of convenient samples; even the most elaborate, expensive national surveys may fail this basic scientific assumption and test of random sampling. But this is the lot of most if not all ergonomics research.

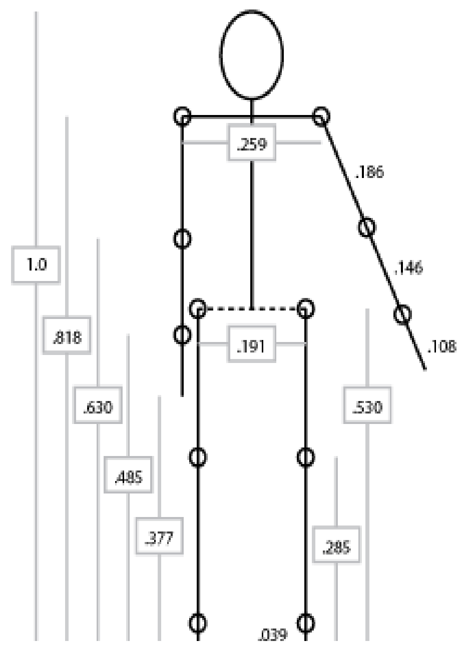

Figure 1 The Drillis and Contini (1966) model modified by Penn State University Open Lab (http://www.openlab.psu.edu/tools/proportionality_constants.php)

Although the technology and methodology of anthropometry has advanced considerably, in practice product designers employ much less precise measures and use many other criteria in their designs. For example, mass transit seat designers must address not only sitting comfort but also the ease of moving into and out of a seat during short journeys. Automobile designers (Roe, 1993) accommodate occupant size and shape variability by including adjustable seats, steering wheels and sometimes pedals into their designs. Fortunately, our customers – the equipment designers - rarely complain about our lack of precision. A ballpark number, based on tradition, will often suffice. Does it really matter whether we accommodate the 5th or 10th or even the 20th percentile lower leg length in transportation, auditorium, or public restaurant seating? Around the world travelers may offer a more critical analysis of seat design, especially if they come from some Eastern countries where ethnic anthropometric differences are observed. Usually door head clearances are a little more generous – their dimensions are based more on tradition and industry norms than precise anthropometry. Clothing and shoe manufacturers base their initial dimensions on tradition and adjust their batch production based more on sales than sizing; contemporary “big and tall” shops make proportional adjustments; short people can often use the children’s or teen-age section. Aftermarket tailored adjustments sometimes resolve the design or purchase error. The clothing market and the forces of fashion are generally somewhat forgiving of small anthropometric errors in design.

One shortcoming of the "Drillis and Contini" segmental proportions method is that the correlations between stature and segment lengths are generally more reliable than those between stature and width or girth (Table 3); these latter measures are more highly correlated with body weight or a single measure of abdominal girth, albeit with problems of precise definition and implementation. Furthermore, measures of heads, feet and hands appear to be less related to stature or width. It is also likely that there are gender and ethnic differences in body segment proportions.

The purpose of this paper is to revisit the findings of Drillis and Contini (1966), Roebuck et al (1975) and Pheasant and Hazelgrave (2006) by analyzing the correlations among many measures from data obtained in recent anthropometric surveys of Singaporean residents. The results of these analyses will be applied to the development of a minimal set of measures from which sufficiently reliable proportional predictions of other measures can be made.

2 METHODS

Three anthropometric surveys were conducted in Singapore. Hartono and Tan, (2010), using conventional anthropometry calipers, recorded 42 dimensions, using standard procedures (Table 1) from 194 male and 99 female Singaporeans and 156 male and 67 female Indonesians. Tong Xin et al, using a purpose made measurement rig, very precise skin markings and 3 repeated observations for each of 43 dimensions on each subject, surveyed 57 male Singaporeans and 56 females. These totals were after the elimination of subject records for missing and clearly spurious data, due to either measurement or recording error. The methods of rejection were by observation of the skewness and variance of the raw data. The third survey involved the use of a simple tape measure in a class exercise in which the class members surveyed 8 dimensions of family and friends with considerably less precision. This rapid exercise resulted in more than 600 Singaporean and Chinese subjects after, as expected, the rejection of at least 10% of the measures for missing data or clearly spurious observations.

Table 1 ISO sources for anthropometry procedures

ISO (7250-!:2006 Basic human body measurements for technological design – Part 1: Body measurement definitions and landmarks.
ISO/TR 7250-2 2010 Basic human body measurement for technological design – Part 2: Statistical summaries of body measurements from individual ISO populations.

Both the traditional and contemporary methods of anthropometry strive for accuracy by applying precise, calibrated equipment and procedures (Roebuck et al, 1975). But even these efforts sometimes fail in the hands of inexperienced investigators, and both within and between observers errors abound. What exactly is "shoulder width?" Other errors are introduced by the subject sampling procedures, especially regarding gender, ethnicity, nationality, and age.

3 DATA Analysis

The data analysis first consisted of the construction of a correlation matrix relating all measures obtained from the three surveys with each other. These Pearson Product Moment Correlation Coefficients were tested using the Students T test and grouped according to high, medium and low significant correlations. A second analysis used the structural equation modeling to extract significant multiple predictor variables.

4 Results

The results in Tables 2, 3 and 4 show a section of the raw data, correlations and correlation coefficient significance levels respectively.

Table 2 Typical raw data from the UniSIM data set

Subject No	Age	Neck Circumference	Shoulder Circumference	Waist Circumference	Hip Circumference	Weight (Kg)	Stature	Shoulder Height	Overhead Reach
1	39	37.7	111.3	82.5	95.2	70.0	161.9	132.1	201.8
2	31	37.1	105.1	70.3	87.0	53.3	165.5	132.9	206.2
3	45	37.6	109.9	90.7	98.1	70.4	175.0	140.6	220.0
4	26	34.4	99.7	66.4	85.4	52.4	169.0	132.9	207.9
5	33	38.9	114.0	94.3	105.0	80.9	172.3	141.2	215.3
6	27	34.6	103.1	85.5	93.4	58.7	169.5	137.7	212.2
7	38	37.9	106.6	90.0	97.5	71.4	176.3	141.7	222.0
8	37	42.8	124.9	108.1	108.2	97.6	176.0	143.9	225.0
9	48	41.5	119.9	98.1	101.5	80.8	171.4	136.2	212.1
10	30	36.7	111.5	88.1	91.8	65.7	171.1	136.5	217.1

Table 3 Typical correlation coefficients between segments

	Age	Neck Circumference	Shoulder Circumference	Waist Circumference	Hip Circumference	Weight (Kg)	Stature	Shoulder Height	Overhead Reach
Age	1.00	0.43	0.23	0.48	0.15	0.21	-0.23	-0.16	-0.17
Neck Circumference	0.43	1.00	0.79	0.83	0.68	0.82	0.00	0.09	0.06
Shoulder Circumference	0.23	0.79	1.00	0.76	0.78	0.88	0.12	0.20	0.16
Waist Circumference	0.48	0.83	0.76	1.00	0.83	0.87	0.00	0.10	0.06
Hip Circumference	0.15	0.68	0.78	0.83	1.00	0.90	0.16	0.25	0.20
Weight (Kg)	0.21	0.82	0.88	0.87	0.90	1.00	0.26	0.36	0.31
Stature	-0.23	0.00	0.12	0.00	0.16	0.26	1.00	0.96	0.95
Shoulder Height	-0.16	0.09	0.20	0.10	0.25	0.36	0.96	1.00	0.94
Overhead Reach	-0.17	0.06	0.16	0.06	0.20	0.31	0.95	0.94	1.00

Table 4 Typical Students T tests for the significance of the Correlation Coefficient

Dimension	Age	Neck Circumference	Shoulder Circumference	Waist Circumference	Hip Circumference	Weight (Kg)	Stature	Shoulder Height	Overhead Reach
Age		2.202	0.812	2.944	0.464	0.729	-1.635	-1.211	0.400
Neck Circumference	2.202		9.209	9.447	6.636	10.097	0.723	1.187	0.390
Shoulder Circumference	0.812	9.209		7.709	9.061	14.107	1.523	1.964	0.960
Waist Circumference	2.944	9.447	7.709		9.714	10.873	0.449	1.038	1.147
Hip Circumference	0.464	6.636	9.061	9.714		14.649	1.635	2.213	1.486
Weight (Kg)	0.729	10.097	14.107	10.873	14.649		2.381	2.976	1.526
Stature	-1.635	0.723	1.523	0.449	1.635	2.381		21.879	2.813
Shoulder Height	-1.211	1.187	1.964	1.038	2.213	2.976	21.879		2.930
Overhead Reach	0.400	0.390	0.960	1.147	1.486	1.526	2.813	2.930	

Table 5 and 6 show the means and standard deviations of anthropometric measures from the UniSIM (Tong Xin, 2011) data, the correlations with weight and stature, and the ratios with weight and stature for males and females, respectively. The highlighted correlations are significant at the P< .05 level.

Table 5 Male Data showing segment means and standard deviations, and correlations and ratios with Stature and Weight; the highlighted values are statistically significant based on the Student's T test.

	Avg	SD	Weight Corr	Stature Corr	Weight Ratio	Stature Ratio
Age	**30.89**	**6.24**	**0.21**	**-0.23**	**0.45**	**0.18**
Neck Circumference	**37.17**	**2.92**	**0.82**	**0.00**	**0.54**	**0.22**
Shoulder Circ	**112.60**	**7.76**	**0.88**	**0.12**	**1.65**	**0.66**
Waist Circ	**84.02**	**10.16**	**0.87**	**0.00**	**1.22**	**0.49**
Hip Circumference	**96.81**	**7.15**	**0.90**	**0.16**	**1.42**	**0.56**
Weight (Kg)	**69.28**	**14.96**	**1.00**	**0.26**	**1.00**	**0.40**
Stature	**171.73**	**7.27**	**0.26**	**1.00**	**2.53**	**1.00**
Shoulder Height	**139.11**	**6.89**	**0.36**	**0.96**	**2.05**	**0.81**
Overhead Reach	**215.05**	**12.99**	**0.31**	**0.95**	**3.17**	**1.25**
Span	**172.89**	**9.93**	**0.30**	**0.86**	**2.55**	**1.01**
Shoulder to Elbow	**34.56**	**2.08**	**0.37**	**0.79**	**0.51**	**0.20**
Chest Breadth	**31.35**	**3.34**	**0.81**	**0.11**	**0.46**	**0.18**
Chest Depth	**20.06**	**2.98**	**0.83**	**0.01**	**0.29**	**0.12**
Sitting Waist Depth	**21.60**	**2.75**	**0.80**	**-0.03**	**0.31**	**0.13**
Shoulder Breadth	**45.92**	**2.69**	**0.77**	**0.22**	**0.67**	**0.27**
Biacromial Breadth	**40.23**	**1.35**	**0.30**	**0.34**	**0.59**	**0.23**

Forearm To Forearm	**47.21**	**5.87**	**0.91**	**0.10**	**0.69**	**0.28**
Head Length	**19.05**	**0.94**	**0.64**	**0.06**	**0.28**	**0.11**
Head Breadth	**16.12**	**0.35**	**0.22**	**0.21**	**0.24**	**0.09**
Head Circumference	**57.79**	**1.66**	**0.59**	**0.24**	**0.85**	**0.34**
Hand Length	**18.79**	**1.04**	**0.33**	**0.53**	**0.28**	**0.11**
Hand Breadth	**8.08**	**0.42**	**0.68**	**0.34**	**0.12**	**0.05**
Wrist Circumference	**16.59**	**0.71**	**0.80**	**0.16**	**0.24**	**0.10**
Buttock To Popliteal	**45.75**	**3.25**	**0.43**	**0.63**	**0.67**	**0.27**
Buttock To Knee	**58.78**	**3.32**	**0.45**	**0.71**	**0.86**	**0.34**
Elbow To Fingertip	**46.13**	**2.67**	**0.30**	**0.77**	**0.68**	**0.27**
Forward Reach	**83.62**	**5.48**	**0.43**	**0.75**	**1.23**	**0.49**
Sitting Eye Height	**78.86**	**2.99**	**0.31**	**0.78**	**1.16**	**0.46**
Shoulder Height	**58.98**	**3.29**	**0.35**	**0.67**	**0.87**	**0.34**
Elbow Rest Height	**25.47**	**3.43**	**0.15**	**0.12**	**0.37**	**0.15**
Thigh Clearance	**14.99**	**1.34**	**0.61**	**-0.02**	**0.22**	**0.09**
Sitting Knee Height	**52.66**	**2.64**	**0.30**	**0.73**	**0.78**	**0.31**
Popliteal Height	**40.67**	**1.71**	**0.03**	**0.72**	**0.60**	**0.24**
Sitting Height	**91.24**	**2.95**	**0.26**	**0.83**	**1.34**	**0.53**
Overhead Reach	**134.81**	**6.97**	**0.23**	**0.84**	**1.99**	**0.78**
Sitting Hip Breadth	**36.46**	**3.66**	**0.87**	**0.13**	**0.53**	**0.21**
Foot Length	**25.44**	**1.35**	**0.35**	**0.67**	**0.37**	**0.15**
Ankle Height	**6.98**	**0.31**	**0.15**	**0.35**	**0.10**	**0.04**
Heel Breadth	**5.86**	**0.38**	**0.55**	**0.23**	**0.09**	**0.03**
Ball Of Foot Width	**9.75**	**0.41**	**0.61**	**0.06**	**0.14**	**0.06**
Foot Circumference	**24.28**	**1.06**	**0.47**	**0.01**	**0.36**	**0.14**
BMI	**23.52**	**4.56**	**0.88**	**-0.22**	**0.34**	**0.14**

Tables 7 and 8 present summaries of the correlations and ratios with weight and stature respectively from the UniSIM data (Tong Xin (2011).

Table 7 Summary of rank ordered significant mean correlations and ratios with weight for males and females

Female	Mean Ratio with Weight	Correlation	Male	Mean Ratio with Weight	Correlation
Shoulder Circumference	1.81	0.86	Shoulder Circumference	1.65	0.88
Hip Circumference	1.73	0.87	Hip Circumference	1.42	0.90
Waist Circumference	1.35	0.80	Waist Circumference	1.22	0.87
Shoulder Breadth	0.75	0.84	Forearm To Forearm	0.69	0.91
Forearm To Forearm	0.75	0.83	Shoulder Breadth	0.67	0.77
Sitting Hip Breadth	0.67	0.85	Neck Circumference	0.54	0.82
Neck Circumference	0.59	0.76	Sitting Hip Breadth	0.53	0.87
Chest Breadth	0.50	0.75	Chest Breadth	0.46	0.81
BMI	0.39	0.83	BMI	0.34	0.88
Sitting Waist Depth	0.35	0.68	Sitting Waist Depth	0.31	0.80
Chest Depth	0.34	0.76	Chest Depth	0.29	0.83
Wrist Circumference	0.27	0.75	Wrist Circumference	0.24	0.80
Thigh Clearance	0.25	0.69	Thigh Clearance	0.22	0.61

Table 8 Summary of rank ordered significant mean correlations and ratios with stature for males and females

Female	Mean Ratio with Stature	Correlation	Male	Mean Ratio with Stature	Correlation
Overhead Reach	1.24	0.94	Overhead Reach	1.25	0.95
Span	0.99	0.75	Span	1.01	0.86
Shoulder Height	0.81	0.94	Shoulder Height	0.81	0.96
Sitting Overhead Reach	0.78	0.92	Sitting Overhead Reach	0.78	0.84
Sitting Height	0.54	0.82	Sitting Height	0.53	0.83
Forward Reach	0.48	0.69	Forward Reach	0.49	0.75
Sitting Eye Height	0.46	0.78	Sitting Eye Height	0.46	0.78
Sitting Buttock To Knee Length	0.35	0.66	Sitting Shoulder Height	0.34	0.67
Sitting Shoulder Height	0.35	0.66	Sitting Buttock To Knee Length	0.34	0.71
Sitting Knee Height	0.30	0.55	Sitting Knee Height	0.31	0.73
Sitting Buttock To Popliteal Length	0.27	0.66	Elbow To Fingertip	0.27	0.77
Elbow To Fingertip	0.26	0.70	Sitting Buttock To Popliteal Length	0.27	0.63
Sitting Popliteal Height	0.24	0.68	Sitting Popliteal Height	0.24	0.72
Shoulder to Elbow Length	0.20	0.75	Shoulder to Elbow Length	0.20	0.79

It is noted that the dimensions that had the highest associations with stature were limb segment lengths. Limb lengths were more highly correlated with stature and (standing) shoulder height than was sitting height. Width and girth measures were inter-correlated and more associated with weight than stature. Head measures were not highly correlated with other measures nor were hand and foot measures. These associations also showed differences between the sexes. There were not enough data to draw reliable conclusions regarding the differences or similarities among subjects of different ethnic backgrounds. Whereas the Drillis and Contini (1966) ratios were found to be sufficient for many practical purposes, the addition of a weight or girth measure plus more sophisticated statistical methods provides greater predictive capability. The results of the Tan et al (2010) study and the large, less rigorous class survey provided similar results regarding correlations and proportions.

5 Discussion

Scientists and practitioners are often found to diverge in their pursuit of accuracy and practicality. The science and practice of human factors, ergonomics and anthropometry are no exception. Researchers strive for accuracy and spend money and time developing equipment and procedures that more accurately describe their subject of interest. Such processes are essential ingredients of science. Practitioners, on the other hand, depending on the situation, use rapid access to sufficiently accurate data and procedures, often through look up tables, then round the values to convenient whole numbers. Next, they consider other aspects and constraints of the applied situation and design accordingly. Designers and engineers who develop products for the mass market prefer round the numbers and rely on human variability and versatility to correct for residual "errors." What really is the practical difference between a fifth percentile reach and a tenth percentile reach, especially when the operator can move his or her feet? This issue was highlighted in a recent court case related to a collapsed store shelf after a shopper had used the bottom shelf as a step to reach a product. How high should the seat be in a mass transit train given relatively short journey times and the associated acts of sitting down and getting up easily? One also may recall the sticks provided for Soyuz cosmonauts to manipulate their controls, the aftermarket extensions for some automobile controls or the devices developed for wheelchair users to reach the elevator buttons. Also, even if we do get the anthropometry "right" for one sub task, what about compromises between reach and fit? What about frequency of use and importance?

It is usual for practicing ergonomists and designers to use anthropometric data developed by specialists. These data are likely to be based on reliable measurements using standard procedures. The ISO TC 159/SC3 committee (ISO, 2012) is the principal source for methods, data and applications of anthropometry. Despite the reliability of these data and ergonomics methods, engineers, and designers, perhaps because of the lack of availability of trained ergonomists, are more likely to use simpler methods. Larger organizations make use of anthropometric modeling methods, but these again are more effectively used in the hands of skilled ergonomists. Contemporary integrated anthropometric and cognitive models such as MIDAS (NASA, 2008) take the sophistication of human modeling to another dimension. However, the methods of Drillis and Contini, albeit amplified by adding in weight as a predictor of width and girth measures, are sufficient for many practical purposes.

6 Conclusions

The correlations and ratios described in this study advance the model offered by Drillis and Contini (1966) and Roebuck et al (1975) by adding weight as the main predictor of width and girth measures. For some measures, shoulder height was found to be a marginally better predictor than stature. In depth data analysis, using structural equation modeling looked at multiple predictor variables. Greater refinement of this study is possible by adding in more predictor variables but for practical purposes the simple measures of stature and weight should suffice. Some of the apparent discrepancies in this study may be due to differences between the segmental reference points used by Drillis and Contini (1966) and those currently used in anthropometry studies (Table 1). An ergonomics practitioner who comprehends the many challenges of human and situational variability in design may use this practical extension of the Drillis and Contini (1966) model to estimate most other dimensions of size and shape (Tables, 5, 6, 7, 8). The possibility of differences among populations of different ethnic origins needs to be addressed by controlled sampling of these cohorts.

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Chapter 35

Human Factors Contributions to ISS Productivity

Human Factors has a spectrum of ultimate purposes – Effectiveness, Efficiency (Productivity), Safety, Health, Comfort, Convenience, Motivation etc. Another view is that Human Factors interventions create the conditions whereby human activities (behavior) are influenced to improve performance and reduce the likelihood of error. In some instances, there may be conflicts between these multiple purposes – the classical speed – accuracy tradeoff is one example. A second example is where increased productivity may compromise safety and long-term health. Human Factors can provide the evidence related to these many effects, but the decisions regarding choice of intervention, risk and tradeoffs will always be a management or operator (crew member) decision.

The interventions in ISS and STS design and operations, outlined below, have been identified by the NASA Space Human Factors Community as being likely to have crew member productivity implications. Quantification of their possible effects is difficult and will only be improved by implementing formal activity monitoring processes, which, ironically, may be counterproductive and viewed as intrusive. However, if this exercise is to have any credibility beyond the subjective level, some minimal form of activity monitoring will be required.

Time saving estimates are offered associated with each suggested intervention. These estimates are initial guesses and can be improved by consensus estimates involving operations and crew personnel, followed by a serious attempt to measure temporal resources. It will be noted that the cumulative effect of these improvements could result in up to a 100% increase in crew time availability.

There are three major challenges for space operations in general and ISS operations regarding crew member activity scheduling. The first is the absence of reliable evidence regarding the time needed to complete generic tasks in the microgravity environment. The second is inaccurate estimation of the time needed to carry out tasks in the ISS environment. The third is the absence of a sophisticated activity scheduling approach that allows a high degree of crew autonomy to amalgamate information regarding activity time estimates, resource requirements and knowledge of local conditions. These operational challenges must be addressed in parallel with the following interventions that are likely to have productivity implications.

There is a need for caution in the pursuit of productivity. Where planned activities encroach on crewmember temporal autonomy there may be a tendency for cumulative dissatisfaction – especially as mission durations increase. A second matter is that inefficiencies and slack sometimes provide for the needed relaxation by crewmembers, which will have a beneficial effect over the long term. It has long been known in manufacturing industry that the blinkered pursuit of productivity may have both quality and human health and satisfaction implications over the long term.

1. Procedure design

The procedures on the ISS are notoriously cumbersome as indicated both by comparison with human factors guidelines and by the voiced experiences of the crew members. On occasion, failure to adhere to the letter of a procedure can result in errors but it is reported that over time crew members commonly take shortcuts. The procedure itself may only reflect underlying equipment design shortcomings from the usability viewpoint. Consequently, it may be necessary to address procedure design in conjunction with equipment design. (see #6 below). However, in general it is usually easier to make procedure interventions than hardware changes.

It is recommended that a human factors team be formed to review all ISS procedures and make suggestions for improvements using well defined guidelines. This project will also involve procedure usability testing and evaluation as well as earth and ISS validation.

It is estimated that improved procedure design could make a 50% difference in the time and accuracy of procedure use.

2. Stowage and interior volume management

An increasing challenge with the ISS is the management of stowage of equipment, materials, tools, and trash. Anecdotal evidence suggests that the time taken to locate, and extract needed items is a constant cause of frustration among crew members and may on occasion add considerable time to some tasks. These delays may be cumulative and lead to resource utilization conflicts and the failure to complete low priority tasks.

A second interior volume control problem is that there is no sophisticated system for spatio-temporal management. Thus, equipment interferences occur due to inappropriate scheduling. Anecdotal reports have identified the exercise equipment as being a source of spatio-temporal conflicts.

These conflicts become more important where there is limited opportunity for rescheduling when the problem arises. The solution to this problem is the development of a spatio temporal modeling / scheduling process based on the interior volume control groundwork that has been carried out in the JSC Human Factors department. (see also #8 below) Such facilities are widely used in manufacturing and transportation industries.

It is estimated that a sophisticated spatio-temporal modeling approach could reduce the time wasted by conflicts by up to 20%.

3. Communications facilities

A major part of the crew members activity involves communication with colleagues, ground control and the various ISS systems, including caution and warning signals. Debrief information suggests that interruptions and the associated translations are very time consuming. Also, the communications interfaces often require significant translation to reach them.

The solution is clearly a mobile communications facility or at least multiple or transportable terminals so that both formal communications with mission control, inter crew member communications and information regarding system caution and warning can be available at any location in the ISS without need for translation. The proliferation of ground-based cell phones, wireless LANs and portable terminals (PDAs) attests to the attractiveness of such technology.

It is recommended that a thorough analysis of communication needs on the ISS be instituted, followed by a systematic introduction of portable communications technology. It is estimated that such interventions will increase communications efficiencies by 50%.

4. Labeling

Stowage of materials, equipment, tools, procedures, and trash makes use of generic containers, that can only be differentiated by labeling or direct inspection of the container contents. This latter approach faces serious problems in micro gravity as container contents may float about. One strategy to reduce this problem is using transparent containers – a strategy that has been used in most kitchens and workshops since the invention of clear plastic.

A second strategy is to control stowage of products more carefully through a contemporary inventory management system. Retail stores and warehouses have faced these challenges successfully, even before the introduction of barcoding. A requirement of such an approach is the disciplined adherence to the housekeeping principles that every astronaut's mother taught them.

The third opportunity is through an improvement to the payload and ISS labeling systems that address container content, location, application, and schedule information. Such a "spring cleaning" of the ISS will have long term benefits that could lead to a 50% reduction in the efficiency of item identification and collection for use.

5. **Computer interface design**

Debrief information indicates that crewmembers have difficulty changing between the multiple payload and ISS system computer interfaces, because of lack of commonality. The enormous penetration of earth-bound computer technology into education, commerce, transportation, recreation, heath care and so on, among all ages and levels of technical sophistication of users attests to the opportunities in interface design.

It is recommended that a human computer interface task force be set up to review all the ISS and mission control systems and make recommendations for communization.

It is anticipated that improvements in these interfaces could both reduce errors and greatly reduce training and operation times. An achievable target of 50% is anticipated.

6. **Equipment improvements.**

This issue was addressed in the procedure, stowage, labeling and computer interface design sections. The physical design, layout and user interfaces of equipment are fundamental to workplace efficiency. Unfortunately, much of the equipment on the ISS is well established, and up mass restrictions prohibit wholesale equipment changes. However, many small modifications and replacements, based on crew member debriefs could be instituted. Examples cited to date include portable lights, vacuum cleaners, small item tethers and fasteners.

The cumulative effect of these minor modifications could result in productivity improvements with specific items of up to 50%.

7. **Automation**

The introduction of automation into agriculture, manufacturing, commerce, retail and other industries has greatly increased labor and white-collar productivity in the Western world over the past century. These improvements have been both systematic and piecemeal. A thorough review of ISS crewmember activities will identify many opportunities for automation – including materials management, system and environmental monitoring, scientific procedures and so on. The micro gravity environment is unique and will certainly impose restrictions on automation, as also will upmass and interior volume constraints.

It is recommended that a task force be set up to systematically review all ISS activities and recommend opportunities for automation. The productivity value of automation is considerable, although account must be taken of the increased human monitoring trouble shooting and maintenance demands. Thus, the achievable productivity increases where automation is feasible vary between 50% and 100%. It should also be noted that automation may be expensive, thus the capital costs of change must be evaluated alongside the operational savings.

There are important reservations regarding automation. Whereas crew members may be changed every 6 months or so, major equipment will be expected to last for the duration of the useful life of the ISS, unless major overhauls are contemplated. These issues must be addressed by a sophisticated process of reliability-based maintenance, which will minimize the reactive maintenance, and repair demands on crew time as the ISS systems deteriorate over time. Failure to address this issue will inevitably lead to a shorter useful life of the ISS, reduced productivity and perhaps catastrophic failure.

8. **Crewmember activity scheduling**

This issue was addressed to some extent in the introduction and is the subject of an ongoing "tiger team" effort at JSC, involving the program office, mission operations, the crew office, flight medicine and human factors. The first pre-requisite of a crewmember activity scheduling effort is to obtain reliable data on "actual times" for comparison with estimated times and to for the basis of an analytic scheduling approach. The next step is to develop reliable estimates for generic activities in microgravity. Manufacturing industry has successfully applied approaches such as MTM for many years to better estimate complex activity times from predetermined elemental times.

Over the past three decades manufacturing industry has made use of computer based scheduling and discrete event simulation tools to investigate and plan resource constrained activities, that are much more complex than the ISS.

Although the current scheduling devices – the OOS, the OSTPV and the Task List - do provide some degree of time management of this relatively complex resource constrained system, these devices are not sophisticated and they currently rely on inadequate "actual time" data. They do not address such intrinsic human characteristics as individual variability, learning and fatigue. The whole ISS operation is in a learning mode and will improve its operational management as time goes by. However, it is suggested that the use of sophisticated operations management tools will greatly enhance crewmember activity efficiencies.

It must be noted that these scheduling approaches, if used improperly, can lead to a reduction in crew member autonomy, which will in turn have deleterious effects. The ideal system should have open access and allow the crew members to make sensible and optimal decisions about resource allocation (including the time resource). It is estimated that the time savings by better resource scheduling could produce a 50% improvement in certain activities.

9. Training

The space program has always placed a high priority on astronaut selection and meticulous training. With short missions, where every second is closely orchestrated and monitored this approach has had enormous success. However, with long duration missions and the increased and increasing complexity of the ISS, including its international nature, over-reliance on training is likely to be inefficient. Automation and human centered equipment and procedure design can greatly reduce the training demands. Also the provision of just in time training and job aids will allow crew members to focus on strategic matters rather than the detailed operational isues.

If the ISS is seen as a prototype for extended duration exploration class missions, it is essential that the reliance on up front training will have to be reduced. Given a fixed task challenge – whether physical or cognitive – there is considerable variability (as much as tenfold) in human performance. This variability is due to individual differences, which may be addressed by task assignment, and training

There have been several Human Factors NRA projects over the past few years that have addressed the "readiness to perform" and "just in time training" issues. It is recommended that a task force be set up to systematically review the current approach to training and recommend alternatives.

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10. Habitability

There is considerable evidence that the general environment has a great effect on human behavior and performance. Individuals can perform well for short periods under extreme conditions, but their abilities inevitably decline over the long term. The space program is in a transition phase between the sterling efforts of the first-generation astronauts and the time when almost anyone can survive and thrive in space for extended durations.

Such an ideal will only be achieved if the conditions of living approach those of earth-based ones in terms of habitability. The important habitability issues include spatial and environmental factors (heat, light, noise, vibration, air, water, and radiation protection). They also include the efficiency with which operational and personal tasks (sleep, exercise, hygiene, recreation) are performed and the objects in the environment are managed. Finally, they include those personal issues of health, privacy, collaboration, communication and organizational structure that can override the more basic functional and environmental issues.

Over the past year the concept and tools related to an Index of Habitability have been developed. It is recommended that greater efforts be made along these lines to objectively measure, define and study the effects of "habitability". Such measures could be the basis of future designs and ISS modification prioritization.

11. Remote control task displays

Various EVA and docking tasks are performed under degraded and / or remote viewing conditions. The traditional countermeasure for these tasks, because of their critical nature, is a very high focus on training and where appropriate multiple levels of operator redundancy. The typical operational intervention is to slow the task down – both to reduce the inertial elements of the task and to provide the operator with sufficient time to make control adjustments. Ironically, many of these operators, due to their training as pilots of fast airplanes, are very accustomed to both heads up and instrument maneuvers at high speed.

The human factors approach to such extreme challenges is to reduce the task demands. This is accomplished by automation, where appropriate, providing good or enhanced direct viewing, adding other non-visual cues, and improving the control and display physical and informational characteristics. The human factors literature is full of examples of where interventions of this nature have improved the accuracy, safety and speed of complex tasks. These examples are found in air and surface vehicles, drilling operations, power plants and manufacturing industry.

The ISS and the STS remote control tasks face many challenges of degraded visual information. The vary variable ambient and task lighting environment compounds the problem. It is recommended that a human factors review of these tasks be undertaken and steps taken to improve the direct viewing options, displays and controls as well as implementing automatic control elements where appropriate. It is anticipated that such interventions could cut the time taken for many of these complex tasks in half, while not compromising accuracy and safety.

12. Restraints

Debrief evidence often cites inconvenient restraints as a barrier to stability and mobility in micro gravity. A frequent comment is that the handrails are used as foot restraints, that crew members often used convenient surfaces to wedge themselves against and that they use any available protrusion as a mobility aid. Crewmembers often complain of calluses on the tops of their feet. On the other hand, there is anecdotal evidence that the STS RMS restraints have proved to be very convenient for extended duration tasks.

A project is underway in the Space Human Factors Branch to systematically evaluate the ISS restraint systems and to develop improved designs. It is recommended that this project is accelerated in collaboration with the crew office and the design center with the object of systematically overhauling the ISS stability and mobility aids.

It is anticipated that such interventions could improve the productivity of translation tasks by up to 50% and greatly improve the comfort of tasks that involve controlled static postures.

Chapter 36

Sensible ~~Shoes~~ Chairs

Nigel Corlett, Brian Peacock, Rani Lueder

This article addresses the relationships between functional anatomy and chair design and usage. Some myths are uncovered, and some opportunities identified.

Orthotics

An orthotic device is made of rigid or semi rigid material that is intended to support the body in a fixed posture. Typically, orthotics are used to support bones and their adjacent joints while a fracture is healing. Similar devices are used to support joints and their adjacent bones following ligament damage. A third use of orthotic devices is to correct chronic deformities, such as scoliosis, or wayward teeth. A final form orthotic is a temporary device used to support the body in a convenient posture for the purpose of rest or some activity such as drawing. High-heeled shoes have aesthetic purposes, but most users will readily admit that such devices are best used on a temporary basis. The dentist’s chair is also best used for limited durations.

Chairs are simply orthotic devices that have functional purposes, such as the reduction of the static muscular fatigue of standing and holding the body in a posture conducive to work, such as eating, driving, or looking at a screen.

Sitting

Sitting, when compared with standing, classically involves the knees and the hips being flexed to ninety degrees. Furthermore, the lumbar spine, which in standing assumes a lordotic (concave) shape, flexes in sitting to a straight or slightly convex shape. This occurs as the pelvic girdle rocks backward on the ischial tuberosities, thus further extending the hip joint. Given this basic posture, volition, aided by individual differences, gravity, and chair features, produces a wide range of variation, including asymmetries.

One common variant (slumping) involves some straightening of the knees, extension of the hips, further backward rotation of the pelvis and flexion of the lumbar spine. Corpulence, or overindulgence, sometimes induces this variant. A second factor, particularly where the knees are extended as in car driving, is the stretching of the hamstring muscles, which span both the hip and knee joints. Where there is low friction between the sitter and the seat then gravity may become a dominant force that further increases the slump.

The addition of “lumbar support” to counter this action is in fact counterproductive. Because the lumbar spine is vertical or even convex, all that happens is that the whole body is pushed forward on the seat.

Seats

The basic seat (stool) has a horizontal surface at a height slightly less than the distance between the head of the fibula (hamstrings tendons) and the floor plus the thickness of the heel. The depth of the seat pan is less than the distance between a vertical line tangential to the spine and the back of the calf and greater than the line tangential to the spine and a vertical line through the ischial tuberosities. Traditional teachings cite pressure on the soft tissues behind the knee and interference with circulation as the reason for these dimensional constraints.

The primary function of a seat is to take the weight off the legs and transfer it to the ischial tuberosities. A stool fulfills this purpose very well and many industrial workers, children and bar frequenters find this mode of sitting perfectly acceptable. However, the use of a stool requires activity by the trunk muscles to maintain the line of gravity over the ischial tuberosities in order to attain a static sitting posture. This static equilibrium is often aided by the interaction between the hands or elbows with the surrounding workplace. The lack of lateral support by a stool is also conducive to frequent movements.

The addition of a backrest to a stool to form a chair becomes essential when the feet are involved in forceful movements as in car driving. The backrest also allows the line of gravity of the trunk to move backwards somewhat, and because the postural base is then effectively enlarged it reduces the need for muscle activity, particularly that of the trunk flexors and extensors, to maintain a static upright posture.

A key feature of seat design that is often ignored is sometimes referred to as the “butt pocket.” This is a gap between the rear edge of the seat pan and the lower edge of the back rest that obviates pressure on the sacrum which can further increase the tendency to slump. Absence of this feature as in some airline seats may be a cause of discomfort.

Conventional wisdom in seat design provides for a lumbar support with vertical adjustment to account for individual differences in spinal length. As the affluence of the sitter increases the backrest increases both vertically and laterally to provide support all over the back and shoulders. Rests behind the neck and head are sometimes designed for comfort, as in airlines, but in motor vehicles their primary function is as a restraint to counter the whiplash effect of sudden decelerations or accelerations.

A common feature in seat pan design is the provision of contouring to provide “lateral support” – preventing lateral rotation and splaying of the hips. In some seats a horse’s saddle is mimicked to provide support on the medial surfaces of the thighs. It is debatable whether such support is useful, although some designers and customers rave about it.

Sitting

All the features described above presume that sitting is a somewhat static function and this may be true among people who work for long hours at computers or in vehicle control. In practice however a normal response to static postures is movement - both to relieve the pressure in particular areas and to allow muscle and joint movement. Such fidgeting is particularly noticeable among children but is also common among all sitters, albeit with less frequency and amplitude when compared with a young child. The stimuli for such movements is often compression of soft tissues that have been compromised by the well-meaning efforts of the seat designers to provide support (restraint) wherever possible. Astute seat designers should recognize that sitting is a dynamic activity and should therefore provide a balance between support and features conducive to postural change, including gross changes between sitting and standing. Some outgoing presenters at conferences may be observed to encourage their audiences to “Get up and stretch” before being sent back to sleep by the oratory – an operational solution.

Miserere Seats

Observation of the choir stalls in churches over the past few hundred years shows rounded protrusions, situated between two or three feet above the floor. These protrusions allow the chorister to lean back and provide relief from standing, especially during long winded sermons. This concept has also been adopted over the past few decades in the design of (leaning) work seats. Such seats have two key features. First the seat pan is short and may slope downward and second provision must be made to counter the horizontal forces that are an essential component of leaning. Another characteristic of lean sitting is that the postural base is less, due to the knees and hips being flexed to angles less than ninety degrees. This allows the operator greater forward reach with his or her arms, when compared with right angled sitting. The concept is also more conducive to movement to and from the standing position, because the center of mass of the lean sitter is higher.

In 1976 the design of the Hong Kong Mass Transit Railway operator's cab was constrained in two key ways. First the for- aft dimension of the sitting area was to be minimized to provide room for equipment in front and behind the seat and to maximize the availability of standing room in the passenger department. The second constraint that affected seat design was that the operator was required to stand up and get out of the cab at each station to observe video monitors showing the doors at the rear of the train before he actuated the closing mechanism. Typically, this occurred every two minutes although there were some longer sections such as when the train went under the harbor. The seat was therefore designed to be used in the conventional (right angled) sitting position, or when the operator stood up the seat sprang back and the operator could rest back on the very well-padded front edge of the seat pan. The driver could also operate the train from a standing position, although taller operators were compromised visually by a destination board being placed in the upper part of the front window. Observation of operators indicated that they generally preferred the leaning posture.

These lean sitting concepts were further developed by Corlett et al in the 1980s at the University of Nottingham. The key features of this design were a short horizontal seat pan, just sufficient to provide vertical support for the ischial tuberosities and a downward angled front half of the seat pan to allow hip extension (the ischia are below the center of the hip joints), when the seat pan was placed at an adjustable vertical height somewhat greater than that for traditional right angled sitting. This "open" angle of the hips allows forward rotation of the pelvis and a lumbar lordosis closer to that of upright standing. The addition of a lumbar support allows a comfortable posture that both "takes the weight off the feet" and is conducive to easy movement in and out of the "lean sitting" position.

Other Seat Features

Observation of people in all sorts of postures, including standing, indicates a propensity to provide some support for the upper limbs. For example, standers often, apparently involuntarily, fold their arms, put their hands in their pockets, entwine their thumbs in their belt or braces. Children seated at the dinner table, when mother is not watching, are frequently observed to rest their elbows on the table. Draftsmen habitually rest their forearms on their desks. Seat designers have picked up on these natural habits and add arm rests of various shapes and sizes to their seats. An innovative design in a contemporary seat is a chest rest. Seat materials also provide a great opportunity for added value, including cushioning, some friction and thermal comfort.

Perhaps the most important feature of seats is adjustability to account for the variability of sizes, shapes and activities of seat users. The ranges of adjustability or the setting of fixed reach / fit features can be derived from conventional anthropometric data, together with a little geometry. Some seat designers may however be inaccurate in their understanding of user perceptions of seat adjustability. Kirk et al (1968) addressed this challenge by carrying out a psychophysical assessment of the perception of seat surface height. They concluded that the sensitivity (JND) of sitters to seat height differences was of the order of a quarter of an inch.

Conclusion

Whereas this article is not intended to negate the undoubtedly attractive features of a well-padded settee in front of a television, it is aimed at correcting some of the misunderstandings that have given rise to traditional (right angled) design of work seats. The concept includes a horizontal support surface for the ischia, allows an open hip angle and lumbar lordosis, is conducive to functional movement of the arms and greatly improves the ease of movement.

Chapter 37

EADES - Employment Analysis and Design for Elderly Singaporeans

Brian Peacock, Chui Yoon Ping, Samuel Low, Liu Shuli, Phang Chun Kai

Abstract

The Ergonomics Analysis and Design for Elderly Singaporeans (EADES) project is the first part of a UniSIM flagship program on Human Factors in Technology Integration. The EADES project includes laboratory data collection regarding physical capabilities and limitations of elderly participants, a survey of attitudes towards the physical challenges of work, a smart technology application for job analysis, and guidelines for ergonomics job design. The results of the laboratory study to date show considerable variation in all age cohorts regarding physical abilities. The implication of these findings is that ergonomics intervention should focus on other (than age) factors in job design.

Introduction

SIM University has funded a major three-year flagship program entitled Human Factors in Technology Integration (HFTI). The mission of this program is to create a Human Factors Center of Expertise to complement the already established and successful Human Factors in Safety degree program. This HFTI program has three main thrusts: Physical Ergonomics – Ergonomics Analysis and Design for Elderly Singaporeans (EADES), Cognitive Ergonomics – Effective Performance in Information Complexity (EPIC), and Macro Ergonomics – Macro Ergonomics approach to Information Technology Evaluation. Presently, the physical ergonomics project is underway, the cognitive ergonomics proposal is in the evaluation stage and the macro ergonomics proposal is in the development stage.

The EADES project has five phases:

1. Objective measurement and analysis of the physical capabilities of a cohort of elderly Singaporeans
2. A Kano inspired survey of the perceptions of elderly employees regarding their jobs
3. An objective analysis of the jobs and workplaces of the participants using a specially developed job analysis application for portable devices
4. A set of design recommendations for workplace and job redesign for elderly workers
5. A training manual for physical ergonomics design for elderly workers

At the present time 80 (out of a planned 100) participants have visited the UniSIM ergonomics laboratory for physical capability measurement and to complete the surveys. More participants will be recruited by site visits with the portable measurement equipment.

The EPIC project will be based on simulations in which subjects of differing levels of experience are faced with varied levels of operational challenges. The subjects will be placed under varying time and outcome reward / stress conditions. The objective of this series of investigations will be to identify common cognitive causes of human error. The intent of this project is to apply novel media to cognitive task analysis for the identification, prediction and prevention of human error in complex control and communication contexts.

The MITE project will adopt the classical macro-ergonomics perspective approaches, that have been used in the past to study complex socio technical systems, to contemporary information technology operations in contexts such as education, social media, e-commerce and so on (Hendrick and Kleiner, 2001). The intent of this project will be to evaluate shortcomings of contemporary large-scale information technologies and offer user centered design guidelines to provide system resilience.

The EADES Project

The physical demands of jobs have been studied for many decades using well validated checklists and analytic devices such as RULA, the Strain Index and the NIOSH Lift Equation. (Stanton et al 2005, Charlton and O'Brien, 2002). These devices may be applied with very little training, but they do not take into account individual operator variability in physical capability due to age, gender and habitual activity. Additionally, those devices do not link directly to intervention guidelines.

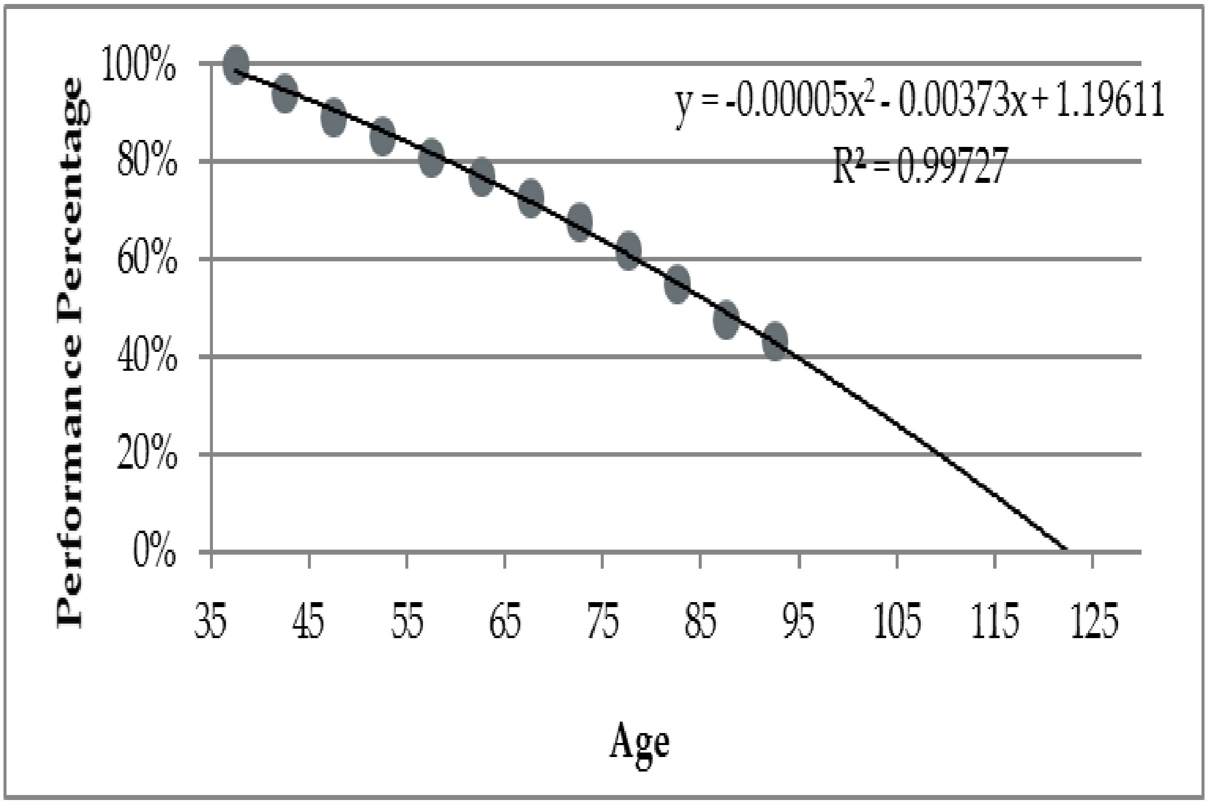

Figure 1 The boundary of aging based on multiple athletic records

A recent study (Ng, Peacock and Tan, 2012) of the boundaries of physical ageing using athletic records indicated a non-linear decline in capabilities from age 35 onward (Figure 1). The physical capability in a wide range of athletic events indicated that a 70-year-old (record holder) was capable of approximately 70% of that of a 35-year-old. All people perform at levels less than that of the record holders and these deficiencies are probably due to individual differences in DNA (inheritance), disinterest, disuse atrophy and disease (injury or illness). These factors may be correlates of age, but not necessarily caused by age *per se.* One purpose of the present study is to identify the relative contribution of age to performance decline. Another purpose is to identify those correlates with age that will benefit from ergonomics intervention.

The Task Assessment Tool

Some ergonomics task assessment tools require significant training to calibrate the judgment of the observer. They also involve somewhat cumbersome and slow data capture, analysis, and reporting processes. The task assessment tool being developed for this project simply requires the assignment of ordinal categories to various job dimensions based on predetermined quantitative cut offs. The tool is deployed as a smart device application which enables real time image recording, data capture, analysis and reporting. The report leads directly to a simulation that allows exploration and evaluation of the effectiveness and efficiency of alternative interventions. Candidate features of this task assessment tool include spatial workplace dimensions and layout, manual materials handling and manipulation task factors, environmental and informational factors. Operational (temporal) factors are assessed in parallel with the other physical factors to identify the relative utility of engineering or administrative interventions.

The EADES Laboratory Phase

Participants are recruited by word of mouth and through advertisements sent to organizations that have "elder friendly" reputations and missions. The sample size is intended to be at least 100 volunteer Singaporeans between the ages of 55 and 75 who are currently employed and have no medical history that might put them at risk during the laboratory procedures. A reference cohort (n = 60) of 20 to 50-year olds carried out the same tests as a class project.

Methods and Results

The following laboratory results were obtained using standardized protocols and trained project students enrolled in the UniSIM Human Factors and Safety program:

Anthropometry:

The following minimal set of measures was taken (Table 1.) Most other anthropometric dimensions can be derived from this basic set using an adaptation of the Drillis and Contini model (Peacock et al, 2012)
.

Female n=43	**Age**	Stature (cm)	Sitting Height	Buttock Popliteal length	Forward Reach	Biacromial	Hip Breadth	Popliteal Height	Weight (kg)
Mean	60.56	160.27	84.70	45.53	79.98	34.95	32.61	38.25	61.67
SD	4.76	8.47	5.44	3.49	4.91	2.90	1.94	3.00	11.31

Male n=37	Age	Stature (cm)	Sitting Height	Buttock Popliteal length	Forward Reach	Biacromial	Hip Breadth	Popliteal Height	Weight (kg) (cm)
Mean	62.24	160.08	85.08	45.80	80.46	35.00	33.94	38.83	64.96
SD	5.75	9.63	5.98	3.14	4.92	3.51	2.37	3.09	11.64

Table 1 Anthropometric measures of a cohort of 80 elderly, working Singaporeans
It should be observed from these results that there are minimal differences between male and female anthropometric measures except for weight, which had a wide variation.

The Minnesota Manual Dexterity Tests:

These two tests require participants to move 60 small round objects between two locations on a board containing an array of 60 holes, either directly using one hand or involving two hands to turn the object. (Table 2)

Female	Placing	Turning	**Male**	Placing	Turning
Average	1.24	1.13	Average	1.15	0.85
SD	0.23	0.30	SD	0.09	0.25

Table 2 Results of the Minnesota Blocks manual dexterity test

Males were faster than females in performing these tasks. There were no age-related effects although there was considerable variability in performance within the 5-year age cohorts.

Strength

Strength tests were conducted using standard protocols for Leg lift, Arm Lift, Grip and Pinch. The gender and age effects are shown in Table 3 and Figure 2

Female	Arm lift	Leg Lift	Hand Grip Left	Hand Grip Right	Pinch Left	Pinch Right
Average	6.72	19.07	14.40	16.02	3.99	4.38
SD	6.25	9.51	4.55	4.92	1.11	1.17

Male	Arm lift	Leg Lift	Hand Grip Left	Hand Grip Right	Pinch Left	Pinch Right
Average	13.94	44.33	25.81	27.32	5.75	6.00
SD	8.32	22.52	8.10	7.85	1.95	2.19

Table 3 Male and female strength for a spectrum of lifting and gripping tests

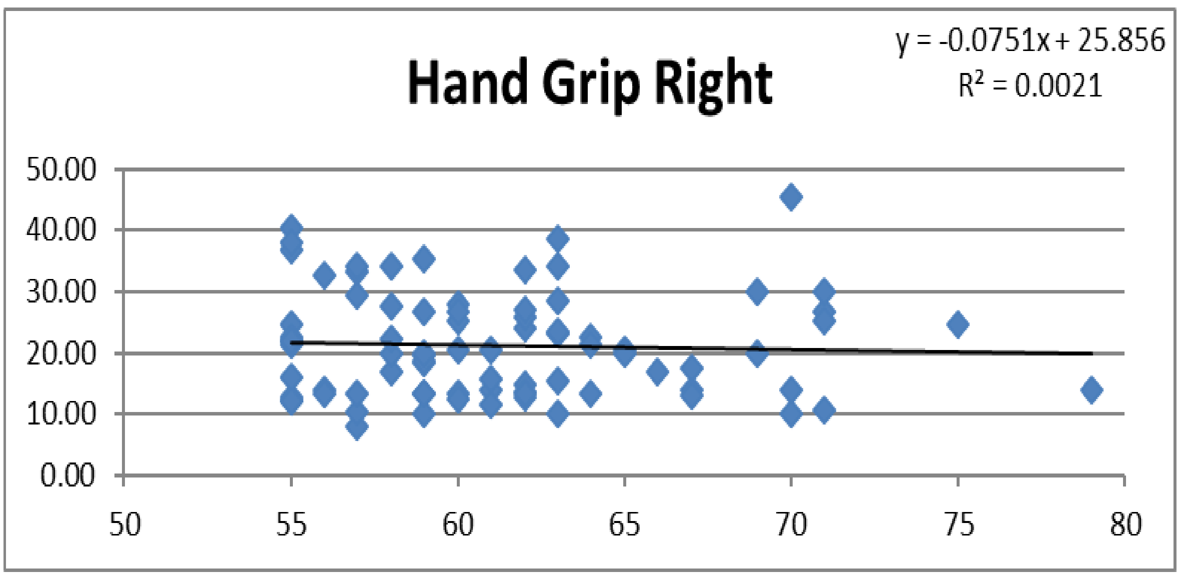

Figure 2 Age effects for the male grip test.

It can be seen that males were stronger than females in all measures but that there was no significant age effect.

Flexibility.

Two standardized tests of flexibility were conducted. The first required the participant to sit on a bench with one leg on the floor and the other stretched out along the bench; they then reached forward as far as possible to touch the bench. The second (back scratch) test required the subjects to attempt to touch their fingers behind their backs with one arm elevated and externally rotated and the other extended and medially rotated.

Female	Back	Arm	Male	Back	Arm
Average	46	-11	Average	53	-13
SD	13	14	SD	10	12

Table 4 Results of Flexibility tests

It can be seen from Table 4 that there were marginally greater scores for males than females; there were no age effects.

Stamina:

The six-minute walk test was used in which participants walked up and down a 30 meter course for six minutes; the total distance walked was recorded.

Female Distance(m)	Male Distance (m)
412.72	444.19
78.67	100.35

Table 5 Results of the Six Minute Walk test for males and females
It may be observed from Table 5 that, on average, males walked further than females, but that there was considerable individual variability. There were no significant age effects.

Speed.

The "Get up and Go" test required subjects to sit on a chair, then standup, walk around a cone three meters away and then return and sit down.

Females Time	Males Time
8.75	9.32
1.23	2.08

Table 6 Results of Male and Female Get up and Go speed test

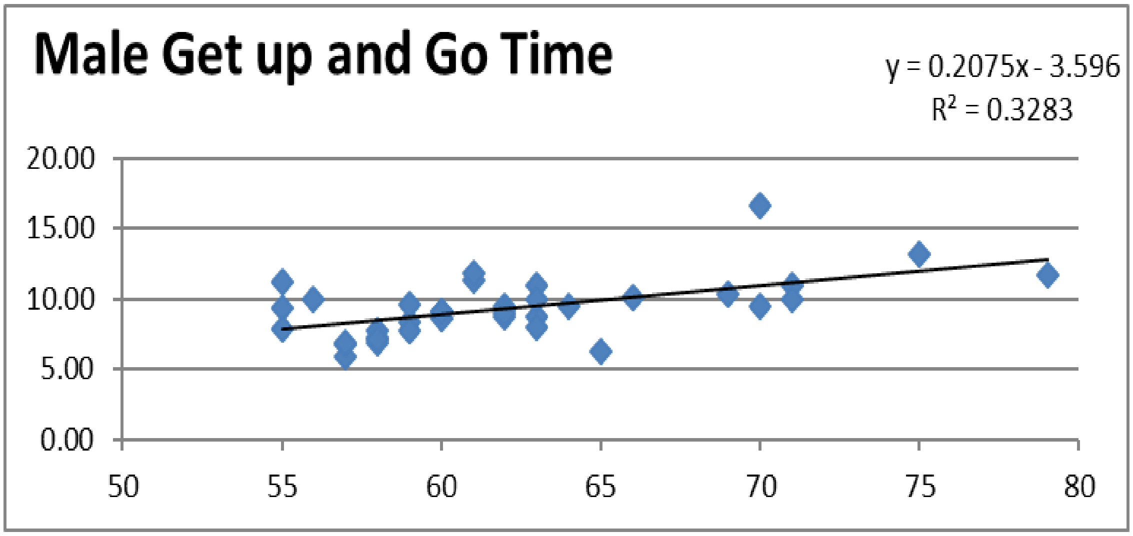

Figure 3 Relationship between age and speed in the (Male) Get up and Go test

It can be seen, from Table 6, that females were marginally faster than males and that there was a significant age effect for males (Figure 3).

Discussion and Conclusions

This is an ongoing project with the first phase of the physical component almost completed. A striking result of the laboratory studies on various physical dimensions is that there are only minimal differences due to gender and age on most dimensions. There are considerable individual differences, presumably due to factors such as dNA, disinterest, disuse atrophy or disease all of which may be correlated with or interact with age. The implications of these findings are that ergonomists and employers should focus on factors other than age *per se* in recruitment, assignment, and job design. Such accommodations should address matches at an individual level on dimensions such as dexterity, strength, flexibility, stamina, and speed.

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Chapter 38

Complexity, Context and Aging

A challenge associated with aging is that of complexity, which may arise from technology design, operations design or context. A confounding factor is that of experience and expertise which facilitate human behavior and performance in the face of complexity. The stress imposed by uncertainty may increase the problem. Examples of the challenges of complexity include attention, comprehension, operational memory, spatial awareness and situation awareness, and their effects on performance. (Peacock B and Chai, K H, “A Fuzzy Model of Knowledge Awareness, Proceedings of IEEE Systems Conference Bali, 2012)

In practical terms these functions may be articulated in the form of questions such as:

“What is going on?”, “How should I perform this procedure?”, “Where am I or where is my destination?", “What should I do?”, “Why should I do it and when should I do it?", “How do I do it?", “What did you just say?” "What information should I recall and use to achieve my objectives?" and so on.

Take the situation of someone shopping in an unfamiliar mall. The location of items of interest is dependent on signposts, maps and labels. It is easy to get lost in a mall. While under stress the hapless shopper may channel his or her focus to the challenge of survival and search for a solution to the detriment of the original reasons for the visit to the mall. Another situation could result from the failure of home technology such as the air conditioner, television or washing machine. To the trained technician the diagnostic pathway is clear - first check the plug and then the circuit breakers, if these are intact then try the appliance switches before reaching for a screwdriver. A more threatening situation could occur when your car stops working during an out of town trip. Do you lift the hood or reach for your cell phone, or just sit and wait for a Good Samaritan? A final situation is how to solve any problem in the world by reaching for your smart phone, if you know what all those funny icons mean.

The description and measurement of complexity may be in information theory terms, subjective difficulty, inquiry behavior analysis or performance accuracy and time. Information, entropy, unpredictability or uncertainty in one dimension can be articulated by

$$H(X) = -\sum_{i=1}^{n} p(x_i) \log_b p(x_i)$$

The more choices you have the greater the entropy

Or for the continuous case

$$h(X) = -\int_{\mathbb{X}} f(x) \log f(x)\, dx.$$

The amount of entropy in two related sources is

$$H(X|Y) = \sum_{i,j} p(x_i, y_j) \log \frac{p(y_j)}{p(x_i, y_j)}$$

That is the combination of the individual source entropies and the degree of overlap

Whereas the maximum entropy associated with multiple sources is

$$H[(X,Y)] \leq H(X) + H(Y).$$

If the sources are independent, then the total entropy is the sum of the individual entropies

The difficulty of applying Information theory to the description and analysis of real world human complexity and uncertainty situations is that there are usually many variables, many interactions and interdependencies and usually much redundancy. Consider the English language. It is possible to jumble up the words in a sentence or omit some of the words and still have perfectly clear communication. However, in games that represent the dilemmas that people face, Information Theory can be a starting place for quantification of difficulty or uncertainty.

Task difficulty is inversely related to experience and causally related to the stress associated with negative or positive outcomes. Time is another contributor to the equation. The more time you have to solve the problem the more likely it is that you will arrive at the correct answer, but with external or self-imposed time stress decisions will be made with less than complete information - you will resort to risky guessing. In general terms, subjective difficulty is equivalent to mental workload and inversely related to situational awareness.

Conceptually:

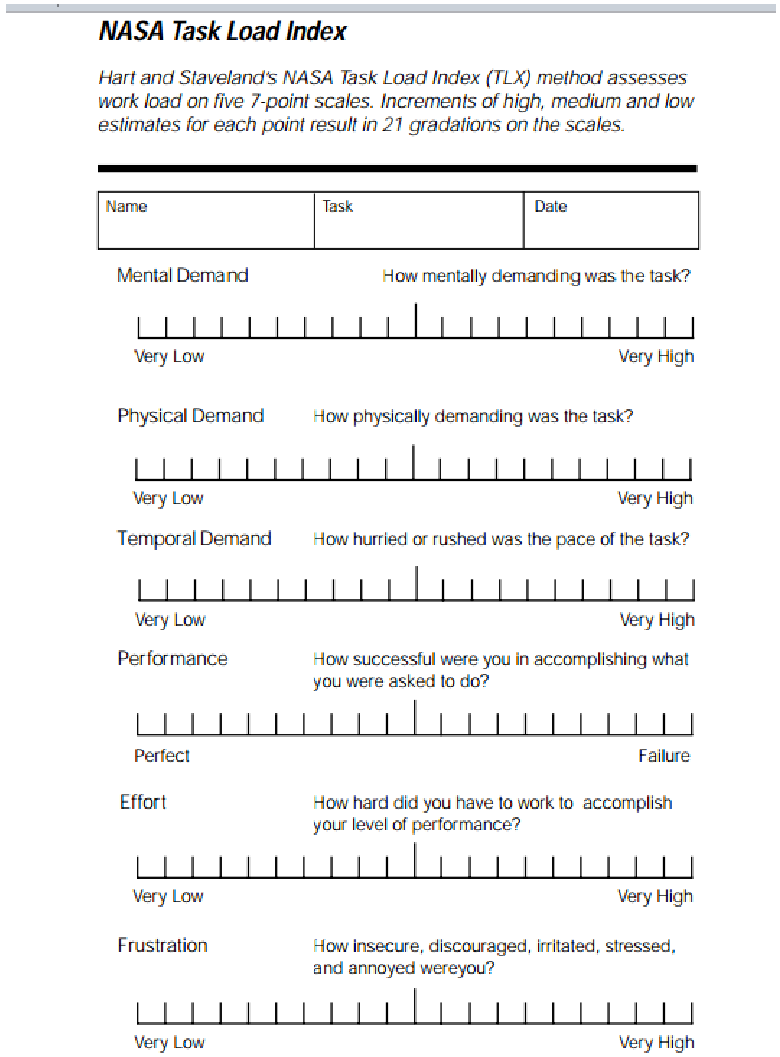
*Mental Workload / Task Difficulty = (Information Content * Stress) / (Time * Experience)*

Also

Awareness, Comprehension, Memory, Performance = 1 / Task Difficulty

Inquiry behavior is affected by uncertainty or lack of situational awareness and procedural knowledge or skill. A novice may become obsessed with a narrow search, whereas an expert will explore various options, both in search for information and use of procedure. One person lost in a shopping mall may go up and down and round and round, another may simply ask someone who works there, or look for the map near the entrance. The do it yourself home appliance mender may take out the screwdriver before checking the fuse. The stranded motorist may start to walk, possibly a bad choice in the desert, whereas an experienced traveler would never leave home without a cell phone or would find some shade and wait for a while.

In complex situations one must resort to Subjective Difficulty using such approaches as the NASA TLX:



NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

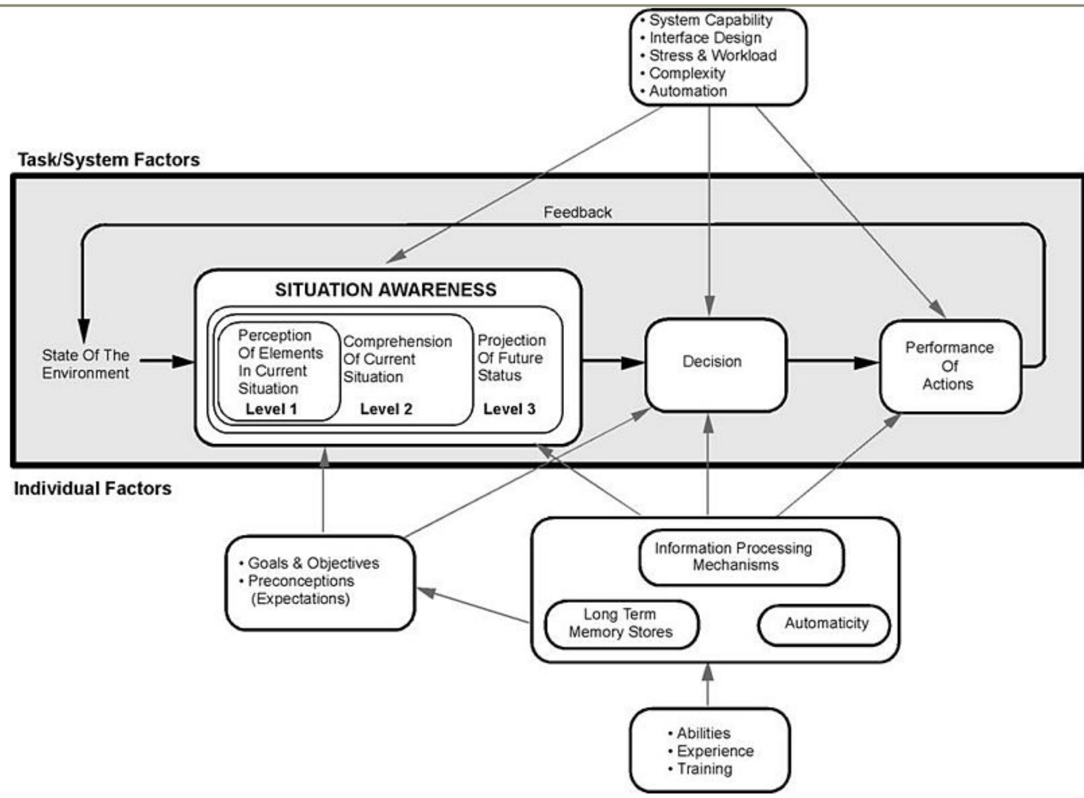
Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

Situation awareness involves the mental activities of perception, understanding and prediction and may be measured in simulated situations by freezing the simulation and asking questions related to the ongoing flow of information, using tools such as SAGAT. Situation awareness fits into a broader information processing concept as shown below



The SAGAT analysis tools involve stopping a simulation and asking pertinent questions about the state of affairs and the likely future outcomes given alternative inputs

Chapter 39

Crutches

Many years ago, I used to teach patients to walk on crutches. First you adjust the length and handle height to make sure that they are taking their weight on their hands and not their axilla. Next you have them put the crutches forward to make a triangle with their weight bearing foot; then they make a little hop, not far enough to put their foot in line with the crutches – that would create an unstable base. After a little while with this shuffle, you get them to swing their foot and hips through in front of the crutches to make another triangle and you are on your way. When the patient has confidence on the level, you teach them how to put the two crutches in one hand, reach down behind for the arm of the chair and sit down. The progression then moves to slopes, steps and stairs, all the while with the therapist having a good grip on the patient's waistband. Finally, when their broken ankle is healed, they throw away the crutches and were glad for the temporary assistance.

Crutches come in many forms, but for the sake of this discussion we will define a crutch as a temporary physical device to help someone deal with a transient physical problem. Where the problem to be dealt with is in the information domain, we use the term facilitator – for such things as instructions, warnings, labels, procedures, maps, reference books and so on. The key concept is that the crutch or facilitator is a temporary device for use until the person has learned to do without it and become self-reliant. Other forms of crutch may be found in medicine, such as painkillers and sleep aids. In the psychosocial domain, crutches, which we will call motivators, take the form of groups and beliefs and a plethora of symbols. People often perform better with the help of others or with some goal or reward in mind. Lean on me.

The downside of crutches is that they can become permanent and that people can become totally dependent. This situation is familiar with power-assisted devices, addictive drugs, some checklists and memory aids, and friends. Sometimes the crutch becomes the main focus. Belonging to a support group can be the purpose and not a means to an end, psychotropic drugs take on a whole life of their own and rituals become more important than the belief itself. In the physical domain the SUV may be used to drive half a mile to the exercise center, even when it is not raining. Sometimes the perceived or actual benefit of a crutch, which greatly enhances someone's capability, becomes indispensable, permanent, and unquestioned.

The astute reader will say, "wow, where is this going?" But there is more, so stay with me for a while. In the beginning man developed tools and the wheel to help him catch or grow food and houses to shelter him from the elements. Next like many animals he developed the family unit to facilitate the nurturing of his progeny. Then he developed castles and weapons and cities and mathematics and language and education and computers and satellite phones and light bulbs and nations and religions and science and engineering and medicine and business and law and social security all in the name of progress. All these developments of society have become permanent, except for the primitive hermit who still lives off the land, happily.

Back on earth we now must wrestle with the definition of crutches, facilitators, and motivators as part of a continuum between temporary and permanent. As a means or an end. Crutches become permanent, or at least semi-permanent parts of our existence when they promise enhancement over a defined time frame. I never learned to touch type, so I still use two fingers, guided by my eyes and these crutches slow down the process.

Chapter 40

Transportation for Older People

Abstract – Transportation is a universal human requirement and as such it has attracted the attention of Human Factors Engineers for many years. This paper will describe ACCESS to transportation in the broadest sense of the word, including physical, cognitive, operational, and ownership ACCESS. The focus will be particularly on the design of transportation systems for the ageing population.

1. INTRODUCTION

People of all ages and abilities regularly use personal or mass transportation, each with many variants. Consequently, transportation has been a prime target for Human Factors and Ergonomics investigators. (Peacock and Karwowski, 1993; Bhise, 2011;Gkikas, 2012).

The design and evaluation of transportation is complex because users, customers and stakeholders have many criteria and constraints. These criteria include effectiveness – does the vehicle move the user from A to B? A second criterion is efficiency – what is the benefit or cost of transportation in terms of time and money and energy? Next comes ease of use – is the transaction (a journey) convenient and comfortable? Finally there is "elegance" – does the means of transportation appeal to the affective expectations of the user? These four requirements may be assessed on a range from complete satisfaction to total dissatisfaction and, because people are fickle, they will change their minds from time to time.

There are constraints to be addressed in addition to the functional and affective requirements. First the transportation process must be safe, in that a failure of the system must not result in harm to the user, the vehicle or the environment. Next the process may need to be secure, in terms of malicious or inadvertent actions of third parties. Third the process must satisfy the constraints imposed by all the stakeholders including designers, manufacturers, users, maintainers, and company shareholders. Finally, the process must be sustainable in that it is reliable under intended conditions and resilient under unexpected and perhaps extreme conditions.

There are many stakeholders associated with the transportation process. There are the employees of the organizations that design, engineer, manufacture and market the vehicles; they need to make a living and a profit. Next there are the organizations that manage the context and operations of transportation – the roadway infrastructure creators, the schedulers, the regulators, the traffic managers, the support service providers and the maintainers. They need to offer facilities and services that perform well under intended demand and unpredicted stresses.

The context of transportation may vary due to unchangeable geographical factors such as the terrain, the weather, the time of day and the population density. Given these complex requirements, constraints, customers, and contexts there is an ongoing need for optimization in design of vehicles, infrastructure and operations. You can't please all the people all the time.

2. THE ACCESS CAR

In 1988 the automobile industry foresaw that a substantial part of their market was growing older. So, a team was assembled to develop the ACCESS Car, designed especially for the older driver. It was realized very early on in this program that this challenge did not just relate to the design of a vehicle but rather to the design of a transportation service. The unique aspect of this program was that it was led by Human Factors specialists. The other team members came from design, engineering, marketing, safety, manufacturing, production and maintenance and included input from the broad technology supplier community, academia, community organizations and transportation planners. After 2 years and hundreds of contributors, one hundred and twenty concepts were developed and demonstrated. The vehicle (service) was to be showcased at the Detroit auto show, but then the market took a dive and this, like many other programs, was canceled. One nail in the coffin came from marketing – *"you can't sell a young man an* *old man's car and old folk don't wish to be told that they are old."* However, because of the outstanding development efforts of the contributors, many of the features and concepts found their way into other vehicles and services. An important realization of the program was that although technology may advance rapidly, the people that use the technology do not change in their capabilities and limitations quite so quickly. One "tongue in cheek" product of the program was a profile of the "ages of carman:"

Age	**Needs and Wants**
Babies	Protection
Children	Restraint
Teenagers	"Wheels"
Twenties	Speed
Thirties	Space for Families
Forties	Style
Fifties	Prestige
Sixties	Convenience
Seventies	Comfort
Eighties	"Pull that license"
Nineties	Wheels

What is clear from this list is that car buyers and users have both functional and emotional requirements. These detailed requirements were solicited through a series of clinics, surveys and interviews, and road and laboratory investigations that generated many predicted and some unexpected results.

A. Physical ACCESS

Drivers must be able to see where they are going. Controls must be within easy reach of all shapes and sizes of drivers and passengers. Wrap around "cockpits" were fashionable – all the vehicle and secondary system controls must be located for quick and easy ACCESS. Cup holders were a must, no one should drive without a non-spill coffee cup at hand! And what about convenient storage for everything from sunglasses to briefcases? A contradictory challenge was that the older drivers and passengers did not like to be confined – they preferred the wide-open bench seat arrangement, which also served as a wide-open storage facility. The "golden triangle" – H (hip) point, Heel point and Hand point – had to be adjustable to suit size differences, postural preferences and mobility limitations. Generally, these occupant packaging variations are met by a six-way adjustable seat with a seat back recliner rather than the available, but expensive, steering wheel and foot pedal adjustments.

Entry and egress presented another challenge. In some clinics aimed at comparing different vehicle types, the older subjects preferred "low rider" pickup trucks because they could get in and out easily as compared with standard sedans where the seats were too low for their reduced agility. However, this same group liked large, high pickups and low cowl sedans, because they could more easily see where they were going. Video analysis of behaviors during entry and egress noted considerable use of the hands as a supplement to their decreased leg power; the steering wheel was a frequent target, but this was not designed to withstand large moments. Seat backs and door frame handles provided other useful mechanical advantages. The entry and egress pathway was also seen to be hindered by high sills and contoured seats. All these requirements were addressed by "occupant packaging" interventions.

One interesting challenge faced by older occupants was that once they got into the vehicle, they could not reach the door to close it. This observation spawned a few different interventions, including door opening detents and extended straps or handles. Once in the car the occupant was faced with the next challenge of reaching their seat belt. This led to the design of an accessible restraint system integrated into the seat, which also brought vehicle assembly advantages as a bonus. A problem faced by smaller, older, more fragile drivers is that they often sat too close to the steering wheel mounted air bag, which could have serious implications in the case of even a small collision. One solution was the addition of deployable pedals, although this turned out to be an aftermarket opportunity. This crash safety problem spawned a major multi university competition to develop an effective passive restraint system. Numerous solutions were presented, including friendly interiors, a deployable dashboard and a deployable air belt. This last device was developed to the stage of crash testing of various deployable bags and belts around the occupant, some of which concepts may be seen in modern vehicles. A notable development addressed side impact protection.

Another unexpected challenge noted among older, smaller drivers was their limited ability to operate the brake pedal with sufficient speed and force. Coplanar pedals were proposed as a partial solution to reduce movement time, but inadvertent actuation was a concern. Around the time of this ACCESS car project there was a major furor about “runaway cars.” One vocal constituency blamed the engine control module, but this was dismissed in favor of the driver error explanation. Usually older drivers who for some reason were disoriented pushed the accelerator pedal instead of the brake and failed to recognize this error – the harder they pressed the faster the vehicle went. This unwanted acceleration issue generated a major investigation involving many older drivers, vehicle types, pedal packages, closed course maneuvers and distractions. The results unequivocally confirmed the driver error explanation. Although the introduction of the brake transmission interlock helped in many common unwanted acceleration scenarios, the problem may never be resolved completely due to the considerable operational advantage of the close proximity of the brake and accelerator.

Storage for items of all sorts and sizes is one of the advantages of the automobile. One contribution of the ACCESS program was the development of a low lift over trunk (boot) for cars. An even better solution is the flat bed trunk found in most minivans today. This issue led to the discussion of the spare wheel, which, when placed horizontally in a trunk well is very difficult to remove. Vertical orientation was seen to help as also were various leveraging devices, and the now popular “mini spare.” However, our survey of older drivers indicated that none of them would ever attempt to change a flat tire. It was suggested that a better solution would be to exchange the spare wheel for a mobile phone!

B. Cognitive ACCESS

At the time of this program the information technology revolution was just beginning to accelerate, and suppliers of new electronic devices were bombarding the vehicle manufacturers with their wares. Entertainment, navigation, and communication systems were beginning to be thrust upon the hapless driver, whose attention and cognitive capabilities did not change to meet the challenge. Older drivers were particularly vulnerable to this data deluge. Simulator studies showed some drivers taking their eyes off the road for more than a minute while fumbling with the buttons on the complicated console. A major simulator study of head up displays showed considerable “cognitive capture.” At the time designers wanted to copy the rich aviation head up display technology, but eventually settled for a minimal number of simple parameter presentations, such as speed and warning lights.

Entertainment and communication were another matter. Designers wished to put screens within easy visual ACCESS for the drivers and then fill them with material not necessarily related to vehicle control. Imagine watching the movie “Top Gun” or watching the World (soccer) Cup while driving along a crowded freeway! The auditory channel provided another information opportunity for designers. Drivers could not only listen to key snippets of sometimes useful information but also talk to their vehicles. At the time of this ACCESS program voice recognition technology was not well developed and this resulted in irate users shouting at their cars to communicate the correct phone number. Talking cars were in vogue, but this platform soon became the medium for irritating repetitions. However, voice commands have now proven their worth in the use of navigation equipment.

At the time of this investigation GPS technology was just beginning to become available and this spawned rudimentary navigation features. Unfortunately, interface designs with too many buttons and deep menus proved to be attractive nuisances and it was suggested that these features should not be used while driving. Recent advances, including voice technology and improved interface design have gone a long way towards removing unnecessary mental workload load during these navigation system interactions.

The contemporary proliferation of mobile technology has drawn the attention of many researchers and regulators. Smart phones are extremely attractive devices for many purposes, including communication (voice and text), navigation, entertainment, and security for older drivers, and attempts to enforce a total ban will not succeed. The intermediate solution of hands-free operation is only minimally effective; the principal culprit is cognitive capture. This saga will continue to be fertile ground for human factors specialists.

One solution to the cognitive overload for drivers is to replace certain vehicle control functions by automation, involving sensing, decision making and vehicle control. The ACCESS car program investigated "NODS and RODS" – near and rear obstacle detection systems. Various sensing technologies were investigated including video, infra red, ultrasound and radar. Nowadays these technologies have an increasing presence in automobile design, but their implementation still leaves opportunities. Should back up devices have both visual and auditory signals; if visual where should the display be placed? Similarly, lane change devices can also employ auditory and visual modalities. Forward looking technology such as infra-red for night driving and radar for headway management are also attractive, but again may tax the cognitive and attention capabilities of drivers if due care is not paid to their implementation.

The natural progression of these technologies is to automate certain driver decision and control responsibilities. The ability of automated (hands, feet and eyes free) systems to "drive" at 150 kph with one meter spacing has been demonstrated. But as with most human factors challenges the ability of the driver to enter and leave such automated systems or deal with emergencies is where full, widespread implementation breaks down. This topic also raises the issue of "trust in automation", a common human factors topic in many domains. In aviation advanced ground proximity warning systems and airplane control automation have been shown to be more reliable than pilots under certain conditions. But the different challenges on surface roads makes such complete automation unlikely in the near future. Another similarity between flying and driving can be seen when all involved vehicle are not fitted with the same advanced technology. In aviation advanced GPS based systems may be better at judging separation than the pilot's eye, but not all airplanes have this technology. Similarly, if a car equipped with hypersensitive radar braking is being followed by a Mack truck some drivers may wish to have alternative automation over-ride options.

C. Safety and Security

A familiar characteristic of older people is their reduced ability to respond to emergencies. This need was met in the ACCESS program by the development of an Emergency Communication System using the new availability of GPS to provide vehicle location information. The concept was a broker – agent system in which the press of a button would connect the driver to a service "broker" who would then dispatch an appropriate service – such as police, ambulance, breakdown, or navigation assistance. The eventual implementation of this system –ONSTAR – reverted to a single call button, leaving the broker to deal with service selection.

Other security features included ACCESS to the vehicle. Microelectronics technology was becoming available to not only open the door, but to configure the vehicle seats, radio, heating and other systems to the driver's preference. The panic switch was a top requirement on the radio frequency key fob. One societal concern is the prevention of incapable drivers getting behind the wheel. This, sometimes temporary lack of capability may be due to sleepiness, prescription or over the counter medication, or alcohol. The research team explored various ways of sensing the driver's capability through target aiming (key in the lock), short term memory tasks and breathalyzer interlocks. The challenges with such interventions are the relative probabilities of false positives and false negatives. To date no totally satisfactory system has been implemented on a large scale. One partial attempt to protect teenagers has been the requirement of a special key to provide ACCESS to the top gears in high performance sports cars.

D. Ownership ACCESS

One probably must sign one's name 27 times to buy, finance, insure, license and maintain the vehicle, having read many pages of small print. Disposal or trade in presents more hurdles and financial pitfalls. The older owner may not have the patience to do this. One solution explored during the ACCESS program was that of rental or leasing, which may offer the convenience and lessen the responsibility of the older owner.

This issue of ownership raised the point of journey type and distance. Older owners may not need to fight with the commuting freeway traffic. All they may wish to do is drive around their neighborhood to the shop, friends, or doctor. This led the ACCESS program to develop concepts for small perhaps rented electric "neighborhood" vehicles. Both older and younger people have affective as well as physical and cognitive dimensions. They may wish to choose a bigger, shinier, faster, more expensive *vehicle with a prestigious nameplate, and defend* vehemently their right to choose. They may like to drive on the freeway at a speed that is half of that of the surrounding traffic. These affective dimensions may be compromised by cognitive limitations and one day their children will have to "throw away the key."

3. PUBLIC TRANSPORT

There are many difficulties for the public transport alternative. First demand varies over the day and overcapacity is inefficient from the supplier's viewpoint. These time issues may be resolved somewhat by those who create demand, such as employers, but they are averse to advice unless that advice is supplemented by an incentive. Second there is the problem of "the last mile" or penetration of the public transport system close to the place of origin and destination. This ACCESS issue may be helped to some extent by feeder systems, such as the minibuses common in all SE Asian cities. Market driven private sector alternatives succeed where there is a void in the public systems. Third there is the challenge of crowding and the aspiration of some to sit in their comfortable, electronics embellished, chauffer driven cars. It is up to the market and government to resolve these challenges.

A study in Hong Kong was aimed at the transportation of the elderly and the disabled. The investigation was related to the problem of ACCESS to the Mass Transit Railway. This study largely relied on the views of transportation experts and focus groups of potential users. The last mile and crowding issues were preeminent. The consensus solutions were segregation and flexibility rather than integration. A communication mediated broker – agent system was designed where a customer called a broker, who connected him or her with an appropriate agent, who had the flexibility and capacity to offer door to door service. A similar concept service for the larger suburbia / private vehicle dominated cities in the West, discussed in the ACCESS program was called "Let me tell you about my grandchildren". In this concept the customers were older people who could not drive and the agents were older, usually retired people who could still drive and who wished to have an opportunity to talk about their grandchildren.

4. CONCLUSIONS

Most large cities pursue the mass transit railway option for most movers. Throughways, fast lanes, bus lanes and bicycle lanes help the segregation solution. Motorcycles pursue the integration solution by filling the gaps in the coarse grain traffic system. The electronics invasion continues apace with opportunities for navigation, communication, entertainment, and vehicle control. Many people learn to cope with these new demands, especially when the Human Factors community has addressed the interfaces. But older people are slow adapters and adopters and they are rapidly becoming a vociferous political majority for a blend of segregation and integration.

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Chapter 41

The Employment of Senior Citizens in Singapore

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ABSTRACT

The employment of senior citizens is a global challenge of major proportions and increasing apace. From the systems ergonomics perspective these challenges can be categorized and measured from physical, cognitive, social, affective, environmental, or economic viewpoints. A series of studies is underway at SIM University, Singapore to evaluate the characteristics, capabilities, limitations, and aspirations of senior citizens aged 55 – 75 with regard to their employment and compare these with a cohort of younger counterparts. The first phase of this project measured physical capabilities including, size and shape, strength, speed, stamina, and motor skills. The results of these studies indicated that, whereas these variables showed some expected associations with age, they also showed exceptionally large individual differences, presumably related to disease, disuse, disinterest, inheritance, and life history. The second phase of the study investigated the perceptions, using a Kano approach (must have, more the better and excitement categories), of older people with regard to their jobs on dimensions such as physical demands, technology demands, economics, relationships (with management, coworkers and customers) and job environment. As predicted economic and relationship issues dominated the results, followed by physical and technology demands. The third phase was an objective approach to the physical and operational job demands using a "Job Physical Activity Sampling" approach. This analysis indicated widely varying sedentary and dynamic job demands. Finally, guidelines are presented regarding employment of elderly people to assure health, safety, and satisfaction. These guidelines are categorized using a consensus-based demand – strain model that addresses spatial, manipulation, environmental, manual materials handling, and operational factors. Participants were also surveyed regarding their perceived fitness for work. The conclusion of the study was that age *per se* is not the main challenge; rather it is the correlates of age, such as disease, that stand in the way of gainful employment.

INTRODUCTION

The employment of senior citizens is a global challenge of major proportions and increasing apace. From the systems ergonomics perspective these challenges can be categorized and measured from physical, cognitive, social, affective, environmental, or economic viewpoints. However, many people and organizations – academics, policy makers, pundits and journalists are showing great interest in this topic that is sometimes described as a grey-haired tsunami. Other more directly interested parties are also jumping on the bandwagon; these include the designers of products and services that may be either needed or wanted by older people. The health care industry is a major benefiter, due to the wide array of diseases and increasing prevalence of illnesses that require costly intervention. There are those metabolic disorders such as obesity, heart disease and diabetes that stem from long term lifestyle choices. Human Factors and Ergonomics has contributions to offer to the physical lifestyle elements of employment, transportation and recreation and the cognitive lifestyle elements of communication, computation, and control, as all these functions present different challenges for elderly people. As in most situations that attract human factors practitioner attention, consideration must also be given to operational, social, and affective issues as these commonly interact with physical and cognitive factors.

The physical, cognitive, and behavioral deterioration associated with aging has been addressed for many decades by the medical, psychology and human factors communities (Anderson and Hussey, 2000.) The approaches to accommodation of the aging population differ widely and include transportation, the cost of health care, employment, family economics, and so on. All of these broader issues are relevant to the ergonomics approach, however the more specific micro ergonomics aims of the present study are to compare the physical capabilities of elderly Singaporeans and their job demands using both objective (laboratory tests and worksite job analysis) and subjective (surveys of perceptions of job demands and personal fitness) methods. The employment of elderly (and other) people may be addressed using the Kano and Maslow models (Kano et al, 1984, Maslow, 1943,). The Kano model has traditionally been used for product and service evaluation (Hartono, 2013.) It articulates three characteristics of a product, service or, in this case, a job. The first is a basic “must have” feature – the product or service must fulfill its basic function; a job must provide minimal levels of remuneration, safety and security – the lower levels of the Maslow hierarchy of human needs. The second Kano level is a one-dimensional factor –the more the better. In the case of a job, remuneration may still be important, but intrinsic content, opportunities for advancement and social interactions would also make a job more attractive. The highest level of the Kano and Maslow models are those features of a job that provide esteem among colleagues, a personal feeling of fulfillment and excitement. The Kano approach suggests that these factors are dynamic – a feature of a product, service or job that is now exciting may become a basic expectation as time passes. In the present investigation attention is paid to individual physical, cognitive (knowledge and experience), operational and social capabilities and expectations.

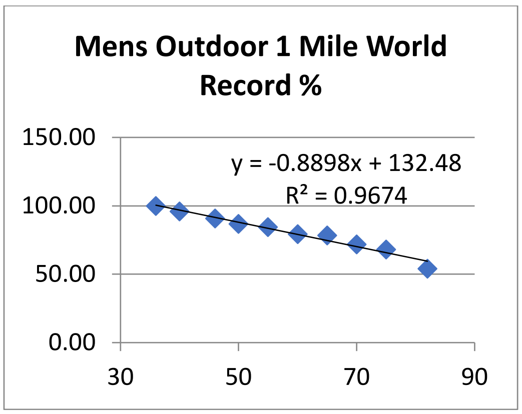
Employment of elderly people is important both from the individual’s viewpoint and that of society at large. In Singapore, as in most developed countries the cost of unemployed older citizens rests with personal savings, the family or social welfare. Much has been said about the inevitable decline in physical, sensory, and cognitive abilities of older people (Jones and Rikli, 2002.) However, as in most areas of ergonomics application, the issue is clouded by considerable individual variability. This variability is due to correlates of age such as disease and disuse on the one hand and experience and engagement on the other. These factors may have genetic underpinnings or simply be a matter of opportunity and motivation. A result of this complexity is that it is difficult to generalize usefully about the employment of elderly people; the focus should rather be on particular limitations, such as vision and hearing, strength, endurance, mobility or aversion to new technology. The classification of “elderly” is also a very fuzzy and sometimes arbitrary concept, and different societies and organizations grapple continually with the establishment of a “retirement age.”

Ergonomics has, for many decades, been applied to the analysis and design of products and work with due regard to human capabilities and limitations. There are numerous publications, education and training courses, analysis tools and standards applicable to various populations, including the elderly (Kroemer et al, 2001, Fisk et al, 2004). However, many of these analyses and tools are esoteric; that is they require expert interpretation and implementation, and do not penetrate into the communities where they are most needed. Also, whereas much is known about the aging process, there are relatively few easy to use and reliable guidelines for product and work designs for the elderly, and particularly for elderly Singaporeans. The application of ergonomics methods to job analysis and design will improve the match between older workers and their job demands. The intended outcome of this work is to increase the number of elderly Singaporeans that are motivated and capable of participating in the workforce by appropriate workplace, equipment, procedures, and job designs.

Kroemer et al (2001) systematically described the elderly as a “special population” and described changes in vision and hearing, strength, stamina, speed, and motor skills. He continued by articulating basic interventions regarding workplace design, tool selection and management of work – rest schedules. Kroemer articulated a broad set of physical and cognitive impairments, described a range of intervention opportunities, and rated these on various criteria such as effectiveness and acceptability for use by the physically impaired. Fisk et al (2004) took a classical human factors approach to the design of products – the things that older people use for work or entertainment. They suggested that *“dexterity and strength change negatively with age. Speed declines. Vision and hearing may be impaired. Older adults are more likely to suffer cognitive decline that may make them slower and more error – prone in mapping their actions to devices.”* They also highlighted the generational differences regarding computer and mobile technology use – older people who do not grow up with the information rich information technology may be slow to catch up, may not explore the many features and functions or may even reject the device altogether because of understanding and usability problems. This Fisk et al perspective is mainly product centered, although there is reference to the mediating effects of context.

Traditional ergonomics dogma deals with human variability by percentile accommodation. This approach may have some merit in such things as one-dimensional anthropometry, but the approach is naïve at best in the context of complex performance accommodation. Likewise, the philosophy of “universal design” (Erlandson, 2008), although laudable, does not acknowledge the reality of individual differences in motivation and ability. The fact that a highly motivated handicapped person may climb Mt Everest does not mean that all similarly handicapped people could or should. The concept of percentile accommodation should be replaced by a human factors' contribution to flexible design, adaptability, adjustability and realistic accommodation.

Peacock et al (2013) investigated the physical boundaries of aging through analysis of age based athletic records obtained from the World Masters Athletics website. The data were from sixteen athletic events including sprinting, hurdles, jumping, throwing and long-distance running. The rational for this approach is that the world record holder for a particular age is unlikely to be hampered by confounding factors of disease, disability, disinterest or disuse; thus the age based (cross sectional) record truly represents the boundary of aging. The decline of this boundary is approximately linear between the ages of 40 and 70 with a rate of around 1% per year; thereafter the rate of decline is greater and a quadratic model provides a slightly better fit. There is a large amount of literature on the decline in physical abilities (strength, speed, stamina and motor skills) with age (Grubb, 1998). The reported declines vary between 0.5 and 2% per year.



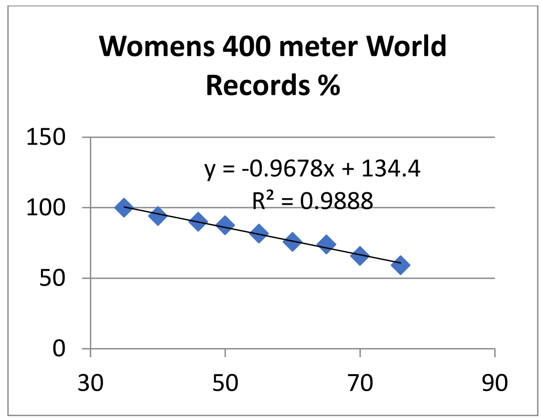


Figure 1: Typical results for world records in athletics using a baseline at age 35. It should be noted that the decline in ability is approximately 1% per year. (World Masters Athletics data)

These observations support the work of Stehl and Yates (2001) who investigated the declining capabilities of physiological subsystems as people aged. This issue of rate of decline is inevitably clouded by individual variability. Cross sectional athletic records represent a boundary; individuals will start out at some percent less than the record and the decline may be more or less, depending on individual or sample selection.

The aim of this present study is to draw on the rich background of ergonomics analysis and accommodation of elderly people to the ongoing challenge of employment of this cohort in Singapore.

METHODS

Phase 1: Subjective Data Collection and Subject Recruitment

The initial approach to a cohort of working adults (N = 83) aged between 55 and 75 was by word of mouth and through community centers. In addition, 58 members of an occupational biomechanics class (aged between 22 and 55) volunteered to participate in the measurement phase. Subjective measures of job demands using a questionnaire was developed as an adaptation of the KANO model to job demands evaluation (Matzler, 2004), the ILO International Classification of Function, the Finnish "Workability Index" and the recent draft Singapore Workplace Health and Safety Ergonomics Programme Guidelines. This screening tool was used to draw an initial subjective picture of working adults and their job demands in Singapore. Volunteer participants were requested to attend a laboratory session (described in Phase 2) to assess their physical capabilities and to allow research team members to visit their place of work to evaluate their job demands (as described in Phase 3). Volunteers were given a letter to their supervisor requesting permission to conduct the job evaluations.

Phase2: Laboratory Data Collection.

A total of 138 subjects (52 Female, 86 Male) participated in the laboratory phase. They were all currently employed. 83 of these subjects were volunteers from the community, the rest were members of a biomechanics class at UniSIM. Participants were introduced to the various pieces of equipment at the different data collection stations and briefed on the tasks that they are required to perform. Participants were then asked to read and sign a consent form and encouraged to ask further questions.

Equipment and Procedures

A custom designed anthropometry rig facilitated the standard measurement of body segments with replications to enhance the reliability of the data. Full grasp, pinch grip and lifting dynamometers were used for strength measurement (Mathiowetz, Kashman et al., 1985). The Minnesota Manual Dexterity Test was used to measure dexterity (Desrosiers, Johanne, et al., 1997). Lower back and hamstring flexibility was measured using the Modified Back-Saver sit-and-reach procedure (Hui and Yuen, 2000).The subject is required to sit with one leg straight along a bench and reaching as far forward horizontally as possible. Shoulder flexibility was measured using a "back scratch" test, in which the subject touches their fingers behind their back with one shoulder laterally rotated and the other medially rotated (Jones and Rikili, 2002). A "get up and go" test was used to measure speed (Podsiadlo and Richardson, 1991); in this test the subject stands up from a chair, walks around another chair placed two meters away and returns to his / her original seated position. Finally, stamina was measured using the 6-minute walk test (American Thoracic Society, 2002) as the distance walked in six minutes up and down a 30 meter course.

Analysis

The data were analyzed using linear regression on age. For convenience of interpretation the data were converted to percentages of the best performance of the subject cohort. It is recognized that the rate of decline will be different for different individuals and that a nonlinear decline is likely, especially noticeable among the older subjects. Another reason for applying these standardization procedures is that the particular test procedure and particular sample will vary from other reported data; hence the most meaningful comparative parameter across many tests and samples is the slope of the linear decline.

Phase 3: Field assessment

The investigator obtained consent from the participant and their manager for a visit to his/her workplace to conduct an analysis of the participant's job. Still photographs and video recordings were taken of the participant at work, again with permission of the participant and company management. It was emphasized that the recordings are confidential and maintained and analyzed by the project team until the completion of the project, and then destroyed.

The following objective and subjective data were then collected:

- Workspaces: access, reach, fit, location, and frequency / importance / sequence of use of materials, equipment, and tools.
- Working postures: temporal patterns of sitting, standing, squatting, bending, twisting, reaching using an activity sampling approach (JPAS) – Job Physical Activity Sampling, developed from the Physical Work Stress Index, (Chen et al, 1989). Particular attention is paid to sedentary work, including habitual postures and opportunities for postural relief
- Working movements: temporal and spatial patterns of walking, climbing, obstacle negotiation etc. using activity sampling.

- Manual materials handling: Characteristics of loads lifted, transferred, held, manipulated, carried, pushed, and pulled, frequencies and shift durations using the NIOSH Lifting Equation approach
- Energy demands: Estimates of daily energy load using activity sampling of postures, movements and activities, and the Borg Scale of subjective energy demands
- Environment: assessment of the visual, auditory, and thermal environment using a checklist.
- Manipulation: description of manipulation tasks with focused attention on postures, loads and frequencies, using the ACGIH Hand Activity Level analysis tool
- Temporal Factors: These factors interact with most of the other factors; they include task cycle, duration, pacing, frequency, and work rest schedules
- Social and Organizational Factors: Assessment of selection, training, and assignment, shift durations, quality and productivity requirements, reporting, autonomy and supervisor, customer and colleague interactions will be obtained by interview and focus group methods.

Surveys

A survey questionnaire was presented to each of the participants, using Survey Monkey, with the following content: Demographics, physical impairments affecting work, personal evaluation of fitness for work and likes and dislikes about their work. Each of the questions invited an ordinal response plus commentary. A second survey was developed to assess the participants' views regarding spatial, materials handling, manipulation, environmental and operational aspects of their work. This survey complemented an objective analysis of these factors using a "job physical activity sampling" approach (JPAS), in which ordinal values were assessed, using direct observation and video records; eleven samples over an hour (every five minutes) were taken as the underlying work was not cyclical. These data points were averaged to assess overall physical workload and successive samples were differenced to assess variability in physical workload.

Phase 4 Job Interventions

After reviewing, evaluating, and discussing the data from the subjective, laboratory and field phases the project team members recommended interventions, if warranted, to improve job outcome quality, productivity, health, safety and satisfaction. These interventions are based on established ergonomics practices for workplace, tool, equipment, task, and job design. The job design approach used the data obtained from the objective job analyses with consensus cut offs, based on the human factors literature, for the spatial, materials handling, manipulation, environmental and operational variables based on the conservative consideration that these subjects would generally be less physically capable than younger cohorts. The recommendations for change, using engineering or operational interventions stemmed directly from these analyses.

RESULTS

Table 1 shows the anthropometric dimensions of the cohort

	Age	Stature	Sitting Height	Buttock-popliteal length	Forward reach	Bi-acromial Width	Hip Width	Popliteal Height	Weight
Female (N=52) Mean (SD)	55.5 (12.5)	154.7 (5.0)	82.5 (3.7)	44.0 (2.5)	76.6 (4.2)	33.4 (2.8)	33.1 (2.9)	36.7 (2.0)	59.3 (11.9)
Male (N=86) Mean (SD)	45.3 (16.6)	170.4 (7.0)	90.1 (4.5)	46.5 (3.6)	82.1 (4.9)	37.9 (2.9)	32.6 (2.0)	40.0 (2.4)	73.5 (12.5)

Table 1: Anthropometric measures (cm, kg)

Figure1 shows the negative relationships between age and stature, and age and weight. Younger participants are generally taller and heavier than their older counterparts. The trend is about .26 cm per year for height and about .29 kg per year for weight. These observations are comparable with previous anthropometric studies of the local population (Peacock et al, 2012, Tan et al, 2009).

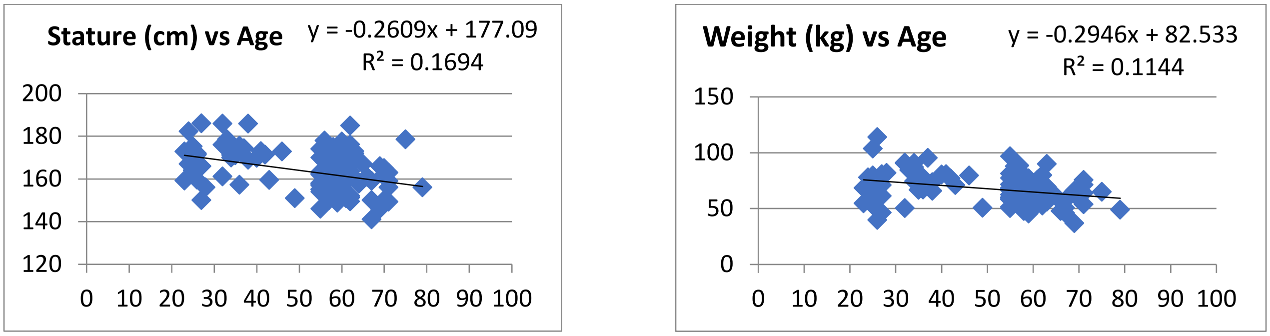


Figure 1: Regression Analysis of Stature and Weight on Age

Figure 2 shows that the deterioration of shoulder mobility with age (3.7%) is much greater than lower back and hip flexibility, however there is considerable variability in these flexibility measures as indicated by the R^2 values. These flexibility issues are expected to have important effects on the ability to carry out physical tasks.

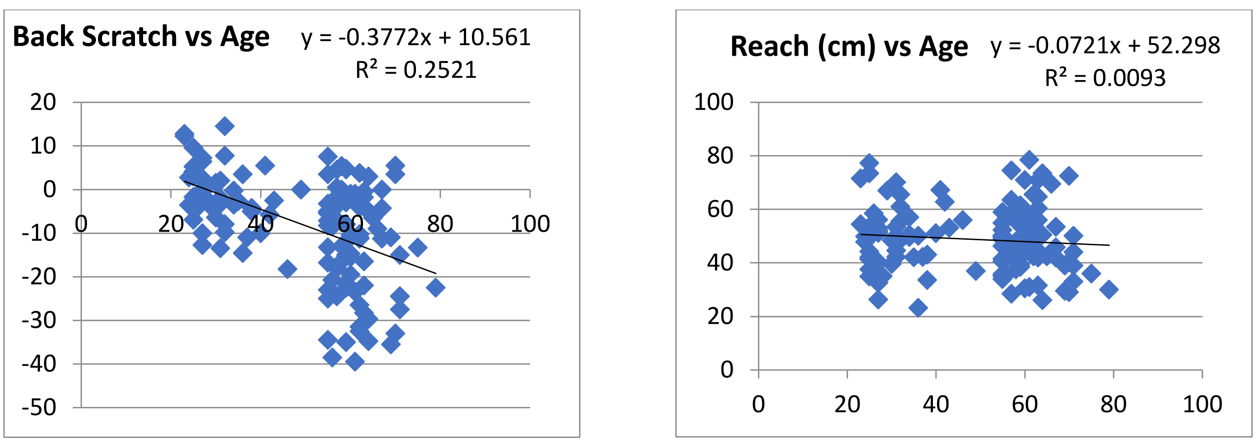


Figure 2, Flexibility as measured by the Back Scratch and Reach tests

Figure 3 shows the relationship between speed and age using the get up and go test in which a seated subject stands up, walks around another chair placed one meter away and then returns to his seat. The performance score reflects the percentage decline in speed and stamina when compared with those of the fastest participants.

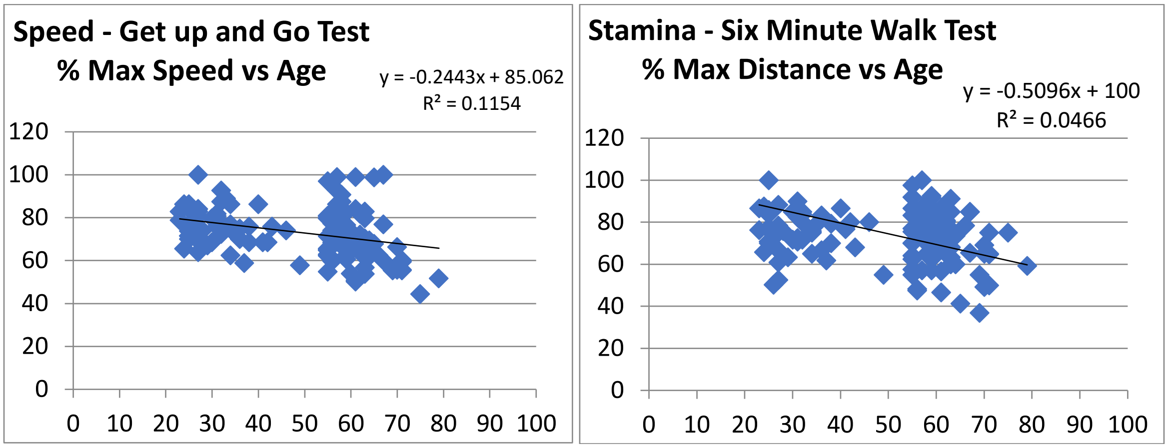


Figure 3: Regression Analysis of % Decline in Speed (Get up and Go test) and Stamina (6 minute walk test) on Age

The dexterity test involved picking and placing a series of blocks – the Minnessota Block test. This standardized test has been widely validated, although care had to be taken to ensure a consistent method among subjects. There were only very small decrements in performance observed.

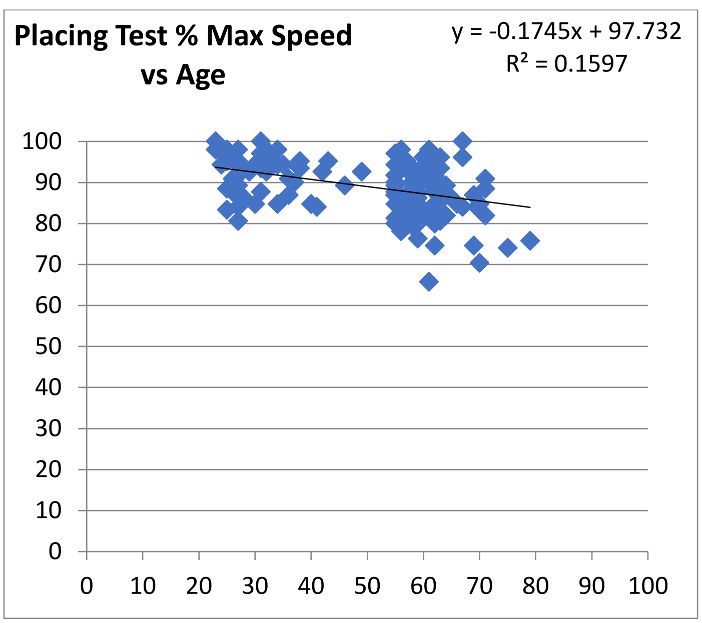


Figure 4: Regression Analysis of % Decline in Placing (dexterity) Test Time on Age

Three strength measures were conducted – a leg lift, a full hand grip and a pinch grip (Figures 5, 6, 7). The grip measures are reported for the preferred hand. The back lift was notable because of the very wide variation in performance – some subjects were only able / prepared to lift a few kilograms. The average age-related decline was about 1.3 % per year.

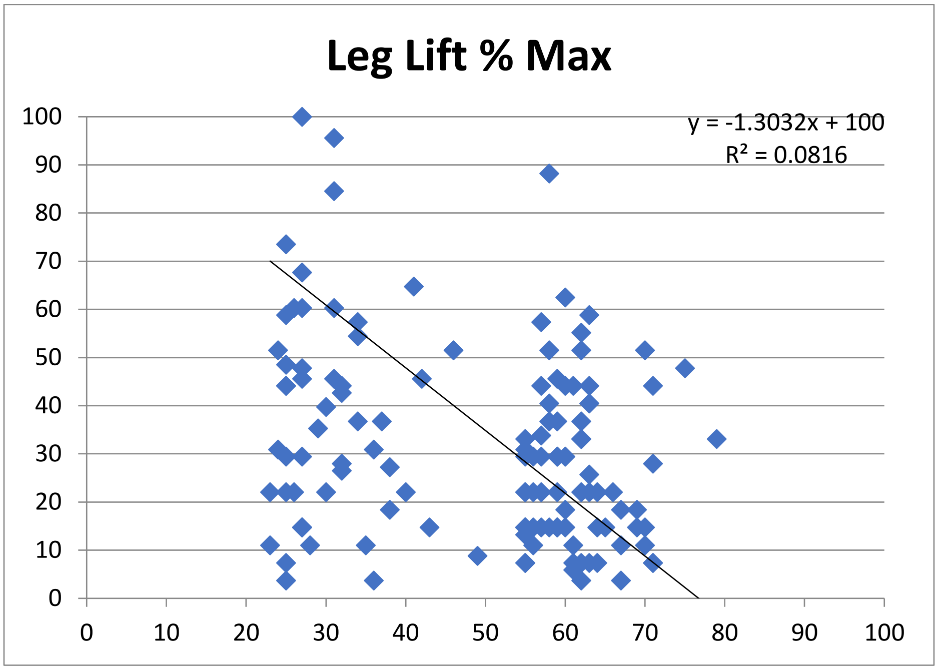
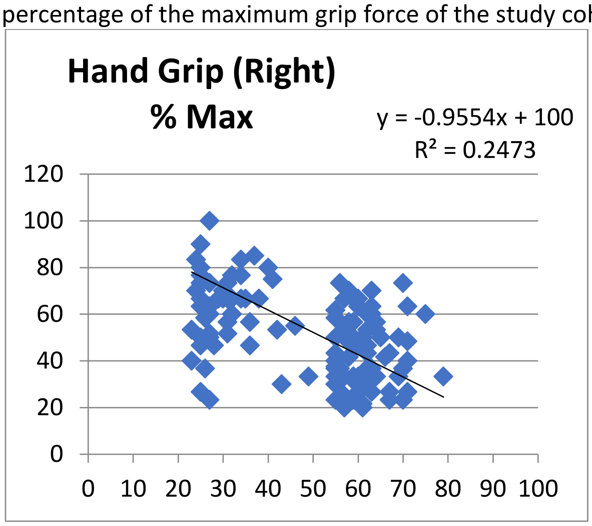


Figure 5: The Association Between Age and a Bent Knee – Straight Back Leg Lift as a Percentage of Maximum

The hand and pinch grip observations are shown as the average of three trials with the left and right hands as a percentage of the maximum grip force of the study cohort. The average annual decline was about 0.9%.



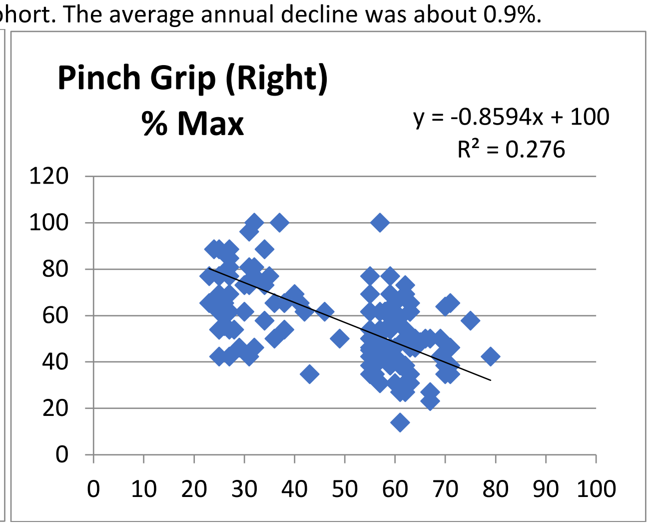


Figure 6: The Relationship Between Age and Hand and Pinch Grip

Fitness for Work Survey

The survey of the subjects' perceived fitness for work was carried out on the same occasions as the laboratory physical measurements were taken. The first set of questions, based on the International Classification of Function (http://www.who.int/classifications/icf/en/), asked whether and to what degree the participants had physical ailments that interfered with their ability to work. A total of 107 subjects, aged 55 – 75, participated in this survey although some subjects did not respond to some questions. Table 2 shows the number of respondents who indicated some degree of limitation. It is seen that the majority of respondents indicated that they had none or mild limitations.

	Severe impairment	Moderate impairment	Mild impairment	No impairment	Total
Seeing	0%	8.41%	45.79%	45.79%	
	0	9	49	49	107
Hearing	0%	6.54%	15.89%	77.57%	
	0	7	17	83	107
Weight management	0%	0.93%	23.36%	75.70%	
	0	1	25	81	107
Cardiovascular system	0%	0%	11.21%	88.79%	
	0	0	12	95	107
Blood Pressure	0%	4.67%	24.30%	71.03%	
	0	5	26	76	107
Respiratory system	0%	1.87%	7.48%	90.65%	
	0	2	8	97	107
Head and neck region	0%	2.80%	19.63%	77.57%	
	0	3	21	83	107
Shoulder region	0%	4.67%	28.04%	67.29%	
	0	5	30	72	107
Upper extremity (arm, hand)	0%	1.87%	18.69%	79.44%	
	0	2	20	85	107
Hip	0%	1.87%	7.48%	90.65%	
	0	2	8	97	107
Lower extremity (leg,foot)	0%	4.67%	34.58%	60.75%	
	0	5	37	65	107
Lower back	0%	1.87%	24.30%	73.83%	
	0	2	26	79	107

Table 2: Participants response to the question "Do you have any physical ailment that interferes with your ability to work?"

Most respondents when asked about physical daily activities indicated that they had no difficulty, although notably climbing stairs and lifting had the greatest numbers of "Mild" or "Moderate" difficulty

	Severe difficulty	Moderate difficulty	Mild difficulty	No difficulty	N.A.	Total
Lifting and carrying objects	0%	6.06%	14.14%	72.73%	7.07%	
	0	6	14	72	7	99
Fine hand use	0%	0%	8.08%	88.89%	3.03%	
	0	0	8	88	3	99
Walking	0%	1.01%	4.04%	93.94%	1.01%	
	0	1	4	93	1	99
Climbing stairs	1.01%	6.06%	24.24%	67.68%	1.01%	
	1	6	24	67	1	99
Transportation (car, bus, train)	0%	1.01%	3.03%	92.93%	3.03%	
	0	1	3	92	3	99

Table 3, Numbers of respondents who indicated some level of difficulty with their current job or daily activities.

Kano evaluation of motivation to work

Table 4 contains counts of synonyms in the open-ended questions “What do you like about your job?” “What aspects of your job are exciting?” and “What do you dislike about your job?” Relationship issues dominated the positive responses and occurred quite frequently in the “dislikes”. Job content and demands were also mentioned frequently along with the indication of ‘keeping active”. As expected, money matters were mentioned quite frequently. Notably many respondents did not offer any “dislikes.”

Likes	**Counts**
Relationship	21
Low job demands	18
Enjoy job scope	17
Keeping active	14
Others	13
Money	11
Excitement	**Counts**
Relationships	27
Task & active	23
Money	16
Others	15
Nil	9

Dislikes	**Counts**
Nil	30
Working Hours	19
Relationships	8
Workload	6
Others	5

Table 4, Counts of synonyms of words associated with the question regarding “likes”, “excitement” and “dislikes”

As expected, the physical capabilities of the employees in this study varied considerably. It should be noted also that this study only applied to working adults and did not account for the changes in employment rates among aging populations, sometimes due to physical / disease limitations, sometimes due to technology and training barriers and sometimes due to socio-economic situation.

DESIGN FOR ELDERLY EMPLOYEES

The general aim of job design is that much of the otherwise qualified cohort should not face unreasonable (physical) barriers. Thus, there are two principles to be addressed – first articulation of the variability among the capabilities and limitations of the target cohort on relevant dimensions and second the policy decisions regarding the level of accommodation. The first principle is addressed by measurement and statistical inference; the second, policy decision, should be made by a consensus of stakeholders, including the employees, managers, and representatives of the regulatory authorities.

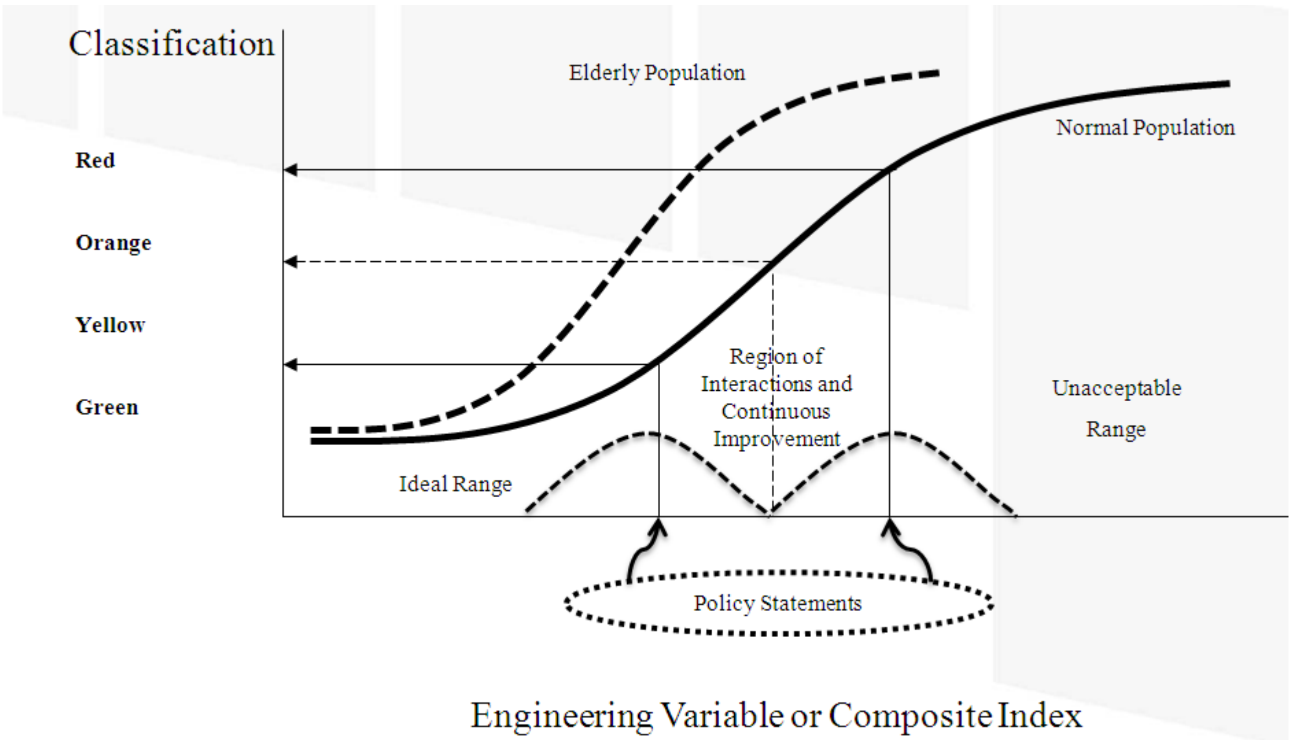


Figure 7: A representation of the relationship between a physical "stressor" and the probability of "strain" in normal and elderly populations

Measurement of human one-dimensional or complex capabilities and limitations may be represented as an ogive (Figure 7) that represents the relationship between a physical (designable) demand, such as lifting, and the percent of people incapable of meeting that demand. The design policy then may be to accept jobs for which more than 90% are capable, implement engineering controls for jobs for which less than say 10% are capable and to institute administrative / operational controls, such as selection and training, restricted work hours or increased staffing levels for the intermediate levels. In most situations context may also play an important part. It should be noted from the upper curve that older people will be capable of coping with lower stress levels. A fuzzy model approach, depicted by the "Normal" variation around the cut off points, may improve the validity of this conceptual model. The analogy of vehicle speed limits is pertinent: 70 km/h may be acceptable on the highway, but 30 km/h is appropriate in a built up area; these standards may change in contexts such as fog or ice or for different kinds of vehicle. The standards do not change formally for drivers of different abilities, although older drivers are often more cautious, and slow down to obtain more information processing time, often to the consternation of younger drivers.

The speed limit analogy is pertinent regarding the process of setting physical job design standards. There are physical, operational, contextual, and human variables to be considered. This leads to a second complication: the responsibility for change on individual dimensions may rest with different stakeholders. Using the example of manual materials handling, such as aviation baggage handling, and the familiar NIOSH lifting guidelines, it may be seen that a product designer or customer may be responsible for the load (the suitcase), a facilities design engineer for the workplace and a supervisor for the work rate. The easiest and most common administrative intervention will be for the supervisor to deal with staffing levels, personnel selection and work rate. On occasion the supervisor and his engineering colleagues may be able to change the workplace, perhaps by installing racks and lifting aids. It may be feasible to change the load by regulation or economic intervention as in the example of airline baggage. Composite indices, such as the NIOSH lifting equation must be decomposed to identify the optimal intervention focus from the space, force, and time domains.

Given these complexities of job design standards a process has been developed to guide the various stakeholders in job analysis and task intervention based on the concepts presented in Figure 8. The independent variable may be any engineering or administrative design variable, or combination of variables. The four dependent ranges are "Red" – engineering controls must be implemented as that variable, even when all other conditions are ideal, is beyond the capability of most of the cohort (elderly Singaporeans); "Orange" – engineering or administrative controls should be implemented such as job aids or increased staffing levels because this stressor will interact with other conditions to create an intolerable situation; "Yellow" – administrative controls, such as increased staffing levels, job rotation or rest breaks should be implemented because this stressor may interact with other conditions to create an intolerable situation; "Green" - the individual stressor is generally tolerable for most of the cohort of elderly Singaporeans, under most operational contexts. A rule of thumb for management intervention could be that all "reds" must be addressed and that no more than three "oranges" or five "yellows" should be permitted. The cut off points for each of the variables should be developed by a consensus of employees, managers, and Human Factors specialists with due reference to the technical literature. The individual variables that are considered for job design or intervention are shown in Table 4. This approach has been implemented in the form of a job intervention application for iPad tablets.

Environmental	**Spatial**	**Manipulation**	**Materials Handling**	**Operations**
Noise	Neck	Upper arm	Lifting	Pacing
Light	Trunk	Lower arm	Carrying	Teams
Temperature	Ramps	Wrist and hand	Pulling/Pushing	Training
Body Vibration	Access	Force	Twisting	Support
Hand Vibration	Reach		Coupling	Participation
Glare	Fit			Acclimatization
Slips and Trips	Orientation			Job cycle
				Shift length
				Static postures

Table 5, Variables addressed in the job analysis and design applications

Conclusions

This investigation of the physical capabilities of elderly (currently employed) Singaporeans indicated that there was generally some deterioration in physical capabilities, but that there was wide individual variation. The age-based rate of decline for the various tests was between 0.2% and 1.5% per year. Analysis of the responses to the subjective survey questions highlighted relationship, activity and financial "likes" with some negative responses to operational and physical issues, including working hours and workload. It should be noted that the "likes" were not necessarily those intrinsic factors articulated by Herzberg (1966). Other less formal findings related to access to the worksite, although most of the subjects who attended the laboratory sessions travelled by public transport, which usually involved at least one overhead pedestrian bridge. Another social issue concerned mobility and job choice; many of the subjects, because of education and training issues had less choice and therefore resorted to local opportunities that were within their physical and experience capabilities. There were some "dislikes" related to physical workload, and one popular elderly cleaner complained that she had to give up her job, because she had to "be on her feet all day." The job intervention and evaluation phases of the project are ongoing.

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Chapter 42

Ergonomics and the Aging Workforce in Singapore

Brian Peacock, Chui Yoon Ping

Ergonomics and Aging

All developing countries are faced with aging populations. These challenges are dealt with by politics, economics, sociology, rhetoric and sometimes by hiding the problems behind closed doors. The ergonomics approach complements and depends on these approaches in that it aspires to use objective analysis of human capabilities and limitations and apply these findings to the design of the physical, informational, operational, social, contextual, technological and esthetic aspects of work.

The outcome of any work situation may be a compromise among effectiveness, efficiency, health and safety and stakeholder satisfaction. The stakeholder may be the individual concerned, a customer, a manager, or a government representative and these may have different expectations. For example, an operator on a production line or in a busy food court must achieve acceptable quality, but the operator must also keep up with the speed of line. If this line speed is too high then the operator may become fatigued, be prone to having accidents or may suffer from cumulative stress. Another problem is that people vary in their characteristics and vulnerabilities.

A traditional view of ergonomics sprung from a simplistic view of anthropometry in that designs were recommended to accommodate 95% of the population on single or multiple spatial dimensions. This philosophy meets with two shortcomings. First when multiple dimensions, including physical, informational, contextual and esthetic are involved, simple ideas of statistical accommodation are complex and usually meaningless. The second challenge to this ergonomics accommodation dogma comes from an offshoot of the ergonomics profession – universal design. The philosophy of this movement is to accommodate everyone concerned, including the elderly and the disabled. The practicality of these concepts is where politics, economics and avoidance come into play. For example, should all computer systems be cognitively accessible to all people? If not, then how far should the designer or system manager go to provide human aided automation? One example is the LTA implementation of longer pedestrian crossing times on demand. How could the massive challenge of overhead pedestrian bridges be dealt with?

Ergonomics Analysis

Ergonomics is based on the basic sciences of anatomy, physiology, psychology, sociology, engineering, and operations management, with due regard to statistics to address the variability inherent in all these domains. It is generally understood that aging is an important contributor to this variability. The challenge for ergonomics is to measure this variability in populations, cohorts, and individuals, and apply appropriate design and accommodation principles. From the physical viewpoint older people generally deteriorate in strength, flexibility, stamina, sensory processes and motor skills. This deterioration is generally linear throughout middle age at about 1% to 5% per year but accelerates in old age (beyond 60 or 70). Again, there is considerable individual variability due to genetic or habitual activities. Sensory capabilities such as vision and hearing also deteriorate, although some degree of personal adaptation is common in the form of spectacles and hearing aids. But more could be done to make information more accessible to those with deteriorating vision and hearing. Contextual interventions of lighting increase and noise reduction can offset this sensory deterioration. Information processing capability also deteriorates, but performance may benefit from strategies based on experience. For example, older people, may "buy time" to search for the best responses. Unfortunately, however, older people may be less flexible in dealing with complexity and uncertainty, resort to habitual responses and disregard possibly relevant information. For example, they may say "I've always done it this way." This lack of flexibility is also evident in operational, social, and affective contexts in that older people may seek familiar, less challenging pathways.

Ergonomics and Design for Aging

The general principle of ergonomics in design for aging is to reduce the demands by providing more time, lower forces and greater amplification and discriminability of sensory sources; there should also be less noise distraction and a reduction of informational complexity. There should be fewer expectations for productivity. From the first principles point of view, accommodation of a large proportion of the population by adjustability in design will facilitate acceptable behavior and performance.

A distinction is often made between white collar and blue-collar workers; in reality this is a continuum as “information workers” may face challenges of too little physical activity and may be susceptible to fatigue due to prolonged static work. Examples include the metabolic illnesses prevalent in white collar workers who spend most of their days tied to a computer. On the other hand, blue collar workers, often limited by strength and stamina capabilities, may also exhibit cognitive failure in safety critical contexts. Examples include driving and manual materials handling. Both white- and blue-collar workers are subject to physical environment challenges, such as thermal, acoustic, and visual stress; they also may be subject to similar operational and social stresses. In Singapore, the thermal environment load is an ever-present hazard for many workers.

One way of addressing these challenges from the political viewpoint is the principle of “seniority” widely used by trade unions in the United States and Europe. This allows individuals with earlier employment dates (but not necessarily greater age) to have a choice of less physically or cognitively demanding jobs. Although seniority is not a direct correlate of age it may be used as a surrogate if age *per se* is deemed to be an unacceptable way of dealing with job choice. An imperfect, general observation is that that age and expertise are correlated. However, as with physical factors, age may be a weak surrogate for expertise, which is dependent on specific experience. Nonetheless, the operational principle of allowing greater choice based on age is preferable to the stereotypical external assignment of more menial task demands. Furthermore, where physical capabilities may be compromised by age, experience may be captured as a mentoring function. These socio-technical principles of human centered design have been shown to enhance both work satisfaction and productivity. Examples include the opportunity for self-paced work, flexible work schedules and part time opportunities.

Summary

In summary, the key to the accommodation of human variability and the predictable deterioration due to aging is through adjustability in design and operations, and choice in physical, informational, contextual, and esthetic aspects of work. A “big picture ergonomics” or socio-technical systems approach must be complemented by micro-ergonomics attention to workplaces, equipment, tools, operations, and environments.

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Chapter 43

Measurement, Models, Medicine and the Ergonomics of Aging

Abstract

This paper considers some of the technical challenges of measurement and modeling of the aging process and some design opportunities based on experience in the automobile industry. Measurement of aging is addressed by assessment of records for well-defined activities, such as athletic events, rather than sample averages. Modeling employs regression methods to describe the aging process and additional effects of sub system deterioration. The design process uses a case study in which some two hundred features, related to physical, cognitive, and psychosocial ACCESS to transportation, were addressed. The data for this study are publicly available from the World Masters Athletes website http://www.world-masters-athletics.org/ and analysis of contemporary vehicles that contain many of the features identified during a two years study of the needs of older drivers.

Measurement and analysis

Measurement and analysis of aging comes in different forms with different levels of reliability, validity, and generalizability. There is no shortage of anecdotal evidence of great feats of old people. At the other end of the spectrum there are voluminous statistics related to morbidity and mortality. In between, the literature contains many reports of surveys and formal performance studies of cohorts of older people. The discussions hover between emphasis of older human capabilities and their limitations.

Modeling

Models of aging typically show an accelerating performance deterioration curve, much like the Weibul equipment wear out curves. Indeed, this is a good model of the human reliability process as affected by aging and associated component deterioration (cancer, arthritis, obesity, neurological deterioration). As with physical systems, human systems are sometimes subject to significant acute incidents (fractures, strokes, heart attacks) that are followed by recovery at varying rates. Parametric performance studies of physical, sensory, and cognitive capabilities commonly make use of the familiar Normal Distribution for comparison purposes. A shortcoming of such studies is that the results may be simple artifacts of the study sample. A second shortcoming is that for one reason or another the data may not be Normally distributed; rather it may be more appropriate to use distributions that have skewness (positive or negative shape parameters) such as the Gamma or Gumbel. The major challenge to modeling is to distinguish between aging per se and the associated sub system failures and deterioration due to injury, illness, or simple disuse.

Medicine

The overt purpose of (geriatric) medicine is to assess, treat and manage those illnesses and acute incidents that are associated with aging, but which are not necessarily a result of aging per se. Typically geriatrics deals with the confluence of multiple, often functionally inter-related disorders – such as osteoarthritis and obesity or diabetes and amputation. The late Charles Sheffield wrote plausible science fiction related to aging and concluded that even an infinite amount of money, spent on medical and engineering interventions, could not prolong life indefinitely, although he did subscribe to the vision of cryogenics. Contemporary medicine for aging populations is dominated by pharmaceutical interventions and organ replacement and is responsible for the prolonging of life through intervention in disease processes. However, physical, mental and social activity in the preventive mode and rehabilitation in the reactive mode remain the essential components, genetics aside, of longevity for most individuals.

Design

The design approach to aging has two facets – engineering and organizational. The engineering philosophy is to replace (automation) or assist human functions. In the case of transportation systems we address ease of entry and egress, accessibility of controls and seat belts and the design of information interfaces, both with the vehicle itself and the outside world, to accommodate the limited sensory, perceptual and cognitive functions of elderly people. Driver communication systems now extend to external support as well as the traditional within vehicle displays. In the broader context, engineering also addresses supplementation devices such as eyeglasses and hearing aids, powered wheelchairs, and kitchen aids. The proliferation of remote-control devices may be a boon for the arthritic but a barrier for the cognitively challenged.

Organizational Design

Organizational design addresses the psychosocial and economic limitations of older people. Social security and Medicare are a start and prescription drug subsidies are essential if older people are to reap the benefits of the research that their tax dollars subsidized. The private sector also sees an organizational opportunity through the construction of comprehensive habitats away from the challenges of roads with18 wheelers. On a smaller scale there are local “agent-broker” transportation systems for the elderly, and organizations such as AARP aggressively sponsor political and functional interventions on behalf of the elderly. At the other end of the spectrum the World and National Senior Games Associations sponsor athletic competitions among older age cohorts. These competitions cover most of the events of the Olympic Games but fall short of some of the recently popular “Extreme Games.” Community organizations, which prefer “senior” to “old”, sponsor many physical and social activities at the local level. In other cultures, the extended family fulfills many of these psychological, social, and economic support roles.

Ergonomics Analysis

So what then is the role of ergonomics in aging? We carry out measurement and analysis, we develop models and we prescribe interventions for individuals and populations. There is merit in formalizing the measurement process, much like the developmental psychologists assess progress at the other end of life. Broad based test batteries, such as the “available motions inventory” have merit as an indicator of functional age. Similar functional, sensory and cognitive tests, such as tests of situation awareness and workload, may also be adapted for older cohorts.

Modeling

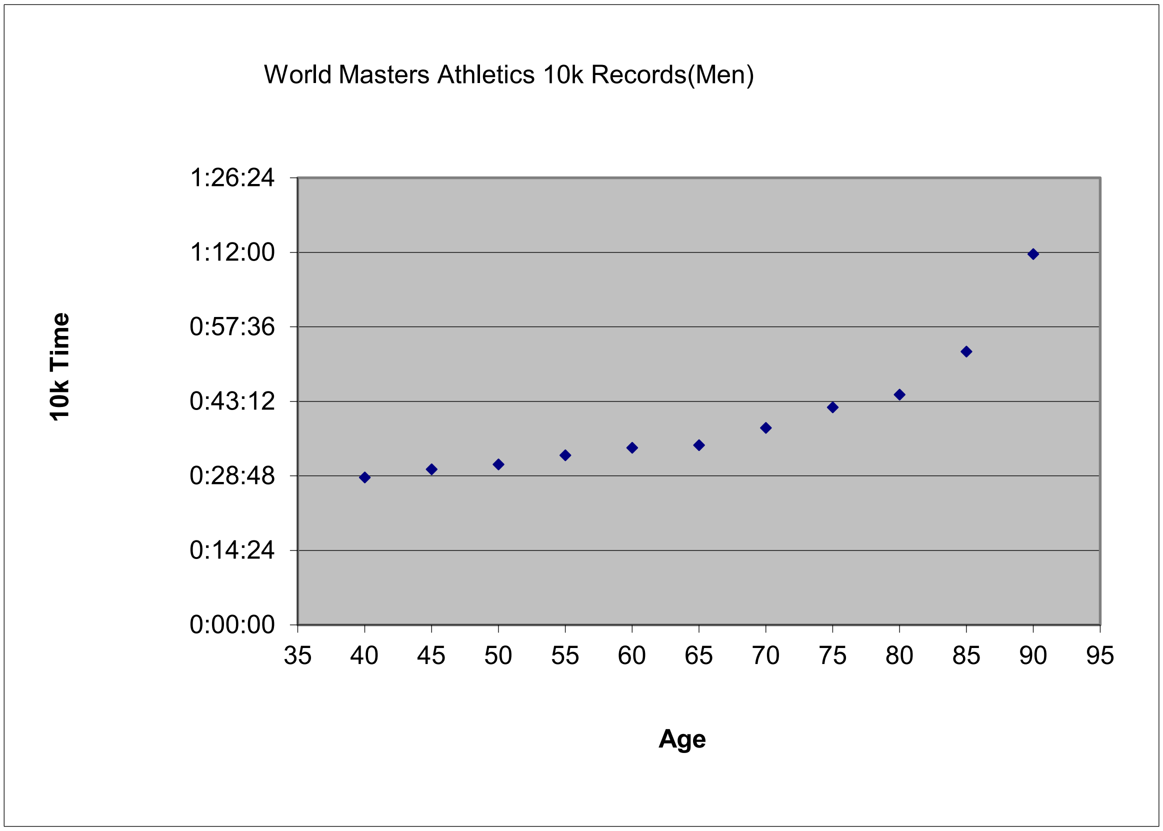
Models of aging lack a “gold (or silver?) standard”. However, the World Masters Athletes http://www.world-masters-athletics.org publishes statistics on a wide variety of track, field and road running events in 5-year age groups between 40 and 90. Many athletic events use these records to create a ratio with actual performance measures as a form of handicapping. Such a broad based physical performance battery, which involves strength, stamina and skill, offers a “pure” model of aging with minimal contamination by illness or lack of motivation. This concept may be usefully applied to other aspects of human functional performance, wherever standardizing task demands can be achieved (chess, scrabble?) The variability associated with such records may be modeled by the Extreme Value (Gumbel) distribution, which reflects their inherent skewness. Regression models may be applied to the general aging variables together with elements related to particular system shortcomings, due to disease or other individual bodily system functional deficiency.

Interventions

Ergonomics intervention may be offered at the population and the personal levels. Such interventions may involve design of hardware, information systems (often software), medication (the usual prerogative of medical “ergonomists”), humanware (selection, training, rehabilitation and assignment) and organizational design. At the population level, the design basis must comprehend the age effect per se, very wide variability and bodily system functional deviations. At the individual level, a rating in comparison with the record will indicate the amount of accommodation (handicap) needed in the design.

Human Performance Data

These concepts will be demonstrated using published data from the World Masters Athletes Organization (formerly WAVA – World Association of Veteran Athletes), experience from a major automobile industry project related to the design of transportation systems for elderly users and experience in the physical rehabilitation of elderly patients. An example of the WMA data for the men's Ten Thousand Kilometers run is shown in the following figure. Note that a quadratic regression provides a good fit to the data.



A Design Case Study

The General Motors ACCESS car program involved studies by many universities, a series of customer clinics with a wide variety of vehicles, and the design and evaluation of some 200 features. The features were classified into physical, informational, and psycho-socio-economic. The entry egress features of interest were related to the design of door openings, including step over and head clearance, seat height and profile, obstructions and the availability of support devices, such as grab handles, seat backs, instrument panels and steering wheels. Similar consideration was given to stowage, for large and small articles, both within the vehicle interior and the trunk. Seat design and seat comfort faced the inevitable discussion of the differences between "comfort" and "discomfort"; on balance however, the older drivers preferred and performed better with firmer seats with less contouring. Access to restraint systems was also a concern with the placement of the seat belts and the fastening mechanisms. Also, the particular fragility / vulnerability of older people to air bags was and remains a concern.

At the informational level there was polarization between the demand of many, usually younger customers for features of all varieties to enhance their driving and peripheral experience, and the requirement of older people for simplicity. Much of this debate revolved around access to a hierarchy of features and interface design. The vehicle system information displays pursued the classical sequence of: tell the driver about the existence of a deviation from normal, indicate the seriousness of the deviation, indicate the source, communicate what should be done to resolve the problem and indicate the urgency. The vehicle operation information display evidence agreed on the visual needs of older people for size and contrast but bounced back and forth between the merits of status ("idiot lights"), analog, digital and representational displays. The special needs of older drivers were addressed by the development of an emergency communication system that at the press of a (large) button connected the driver with assistance for medical, vehicle, navigational and security assistance. This system was a prototype for the commonly available driver communication facilities that involve GPS and agent-broker systems.

The agent-broker concept was also applied to the psycho-social-economic aspects of transportation. Ownership of a vehicle has many challenges – purchase, licensing, insurance, driving, maintenance, repair, disposal etc. The provision of mass, small group and personal transport for elderly people required a high-level systems approach, that started with analysis of journey type. One outcome of this analysis resulted in the development of a neighborhood car concept that required attention to vehicle design, organizational access and journey management. The design implementation of this analysis resulted in the confinement of small electric or hybrid vehicles to largely self-contained neighborhoods, isolated from the 18 wheelers, frantic commuters, and distracted teenagers.

In conclusion, this paper addresses ergonomics approaches to the measurement, modeling and design of systems for the aging population.

Chapter 44

(Less than) Perfect Aging

Ng Yuwen Stella, John Brian Peacock, Tan Kay Chuan

ABSTRACT

Clear articulation of human characteristics, capabilities, behavior, and performance limitations due to aging is confounded by individual differences, which may be very large. In this paper, the authors chose to study athletics records in their research approach to aging as it is not confounded by disease, disuse and disinterest. These age-based data from standardized tests are obtained from the World Masters Athletics organization website.

The records of each 5-year age group are represented as a percentage, with the 35 – 39 year old age group as the baseline. These percentages are then modeled with a parametric function and analyzed for each individual event as well as the event categories (race walks, sprints, distance, marathons and jumps), and with the men's and women's records analyzed separately. Overall, it was observed that the records for jump events declined faster than marathons and distance events, followed by walk and sprint events. Also, for all event categories, women's records declined faster than men's. One-way analysis of variance (ANOVA) is used to study the differences in the events.

This study reports an analysis of age-based athletic records and demonstrates the boundaries of human physical performance as affected by age, without the confounding effects of disease, disuse, and disinterest.

1 INTRODUCTION

With rapidly advancing medical technology and declining birth rates, most industrialized countries are experiencing a demographic shift towards an aging population (Lee 1999; Anderson and Hussey 2000). As such, there is increasing attention in the research of the various aspects of aging. In this study, we focused on the analysis of age-based athletics records to model the boundaries of human physical performance with age.

Human factors and ergonomics specialists constantly face challenges due to variability of individuals, tasks and contexts (Wilson 2000; Salvendy 2006; Pikaar, Koningsveld et al. 2007). As these athletics records are constrained by the design of standardized tests of performance, they reflect the true boundaries of perfect aging. World records are also more empirically stable than sample means and variances as they are, by definition, based on very large sample sizes.

2 LITERATURE REVIEW

Researchers all over the world have been actively studying the effects of age on human physiological functions for many years and the method of using athletics records to infer physical capabilities is not new (Hill 1925; Riegel 1981; Young 1997; Grubb 1998; Baker, Tang et al. 2001; Tanaka and Seals 2003; Baker and Tang 2010). Tanaka and Seals (2003) used running and swimming performances to assess physiological function capacity (PFC) and noticed that PFC "decreased only modestly until age 60–70 years but declined exponentially thereafter". This is consistent with Sehl and Yates (2001) whose study revealed a linear decline in most organ systems of healthy people between the ages 30 – 70 years. However, it is insufficient to study the effects of aging until age 70 years. Compared with the 1980s, the population of people aged 65 and older have increased significantly and it is projected to continue increasing rapidly in all countries (Anderson and Hussey 2000). Thus, there is an increasing need to study the effects of aging beyond age 70 years.

As records for explosive activities like jumping and sprinting peak at an earlier age (Schulz and Curnow 1988), it is expected that they decline more quickly than endurance events such as long distance running. In 2001, Baker and colleagues used an exponential function to model the track running events and a linear function to model the walking and field records of masters athletes published in September 1999. This study revealed that "walking events declined more slowly than the running events, which declined more slowly than the jumping events".

Due to the change in weights of throwing events across the different age groups, there was no standardized way to compare the records across the age groups. Thus, the throwing events were left out of the study in 2001. However, in 2010, Baker and Tang expanded their study to compare the analysis of athletics events done in 2001 with records in swimming, rowing, cycling, triathlon and weightlifting. Thus, they further concluded that "weightlifting showed the fastest and greatest decline" and "rowing showing the least deterioration".

3 HYPOTHESIS

The objective of this research is to develop a model that represents the boundaries of perfect aging. It is hypothesized that there are different rates of decline for different types of events – sprints, distance, marathon, walks and jumps – and the use of percentage performances is an effective way of demonstrating this age-related decline.

4 METHODS

The age-based athletics records used in this study were obtained from the World Masters Athletics records online (WMA 2011) and the age ranges used are 35 – 90 for all men's events and 35 – 85 for women's outdoor events and 35 – 80 for women's indoor events. Performances of each 5-year age group for all events are represented as a percentage of the 35 – 39 year old age group.

$$\text{Performance percentage} = 100\% \times \frac{\text{Performance at each age group}}{\text{Performance of } 35 - 39 \text{ age group}}$$

For timed events, the reciprocal is used (i.e. the performance of the 35 – 39-year-old age group will be used in the numerator to calculate the performance percentage).

$$\text{Performance percentage} = 100\% \times \frac{\text{Performance at } 35 - 39 \text{ age group}}{\text{Performance of each age group}}$$

Tables 4.1, 4.2, 4.3 and 4.4 below show the performance percentages calculated for each event over their respective age ranges. These performance percentages are then used for further analysis.

Table 4.1: Performance percentages for men's outdoor events

	M40	M45	M50	M55	M60	M65	M70	M75	M80	M85	M90
100m	97%	93%	92%	87%	85%	81%	78%	74%	69%	62%	57%
200m	97%	92%	90%	86%	84%	80%	76%	72%	65%	59%	52%
400m	96%	91%	89%	88%	85%	81%	77%	70%	65%	57%	48%
800m	94%	91%	87%	84%	80%	77%	74%	67%	61%	51%	42%
1500m	95%	91%	87%	84%	80%	76%	71%	66%	59%	52%	44%
1 mile	96%	91%	87%	85%	79%	78%	72%	68%	54%	48%	37%
3000m	93%	88%	86%	84%	79%	76%	70%	67%	57%	53%	40%
5000m	94%	90%	87%	83%	80%	78%	70%	67%	59%	52%	41%
10000m	94%	89%	87%	83%	78%	77%	71%	68%	60%	51%	42%
Marathon	94%	89%	87%	83%	78%	77%	71%	68%	60%	51%	42%
High jump	96%	91%	89%	85%	79%	77%	71%	67%	60%	45%	36%

Pole vault	93%	88%	86%	80%	78%	72%	69%	62%	58%	53%	48%
Long jump	97%	87%	81%	78%	69%	65%	56%	51%	47%	38%	24%
Triple jump	90%	86%	80%	75%	71%	64%	61%	57%	51%	44%	38%
3km walk	93%	84%	81%	77%	71%	67%	60%	56%	50%	46%	37%
5km walk	98%	93%	92%	89%	91%	74%	74%	69%	64%	58%	53%
10km walk	94%	89%	88%	83%	82%	74%	71%	67%	63%	56%	53%
20km walk	96%	91%	91%	83%	83%	76%	72%	70%	63%	49%	50%
30km walk	96%	93%	91%	85%	83%	76%	70%	68%	63%	55%	51%
50km walk	100%	91%	91%	85%	85%	74%	73%	63%	62%		

Table 4.2: Performance percentages for women's outdoor events

	W40	*W45*	*W50*	*W55*	*W60*	*W65*	*W70*	*W75*	*W80*	*W85*
100m	97%	95%	92%	81%	78%	76%	73%	68%	58%	54%
200m	97%	92%	85%	80%	77%	75%	70%	64%	54%	48%
400m	94%	90%	88%	82%	76%	74%	66%	59%	50%	38%
800m	98%	95%	86%	82%	75%	72%	65%	60%	52%	39%
1500m	99%	97%	85%	80%	76%	69%	65%	60%	53%	38%
1 mile	98%	89%	86%	79%	74%	68%	63%	54%	48%	39%
3000m	92%	91%	86%	83%	76%	70%	63%	59%	54%	35%
5000m	95%	91%	86%	81%	77%	71%	66%	59%	54%	39%
10000m	98%	96%	87%	84%	80%	74%	66%	62%	53%	36%
Marathon	98%	96%	87%	84%	80%	74%	66%	62%	53%	36%
High jump	96%	95%	84%	82%	72%	68%	62%	56%	49%	34%
Pole vault	89%	88%	80%	77%	73%	68%	65%	58%	53%	47%
Long jump	85%	77%	77%	77%	75%	67%	69%	70%	52%	45%
Triple jump	94%	80%	77%	72%	68%	66%	60%	54%	44%	31%
3km walk	90%	83%	80%	76%	76%	66%	60%	51%	45%	38%
5km walk	90%	86%	87%	79%	78%	74%	67%	58%	57%	44%
10km walk	89%	85%	86%	79%	76%	74%	69%	62%	58%	50%
20km walk	89%	89%	86%	78%	77%	75%	69%	62%	56%	53%
30km walk	91%	90%	81%	75%	74%	72%	64%	53%	41%	

Table 4.3: Performance percentages for men's indoor events

	M40	*M45*	*M50*	*M55*	*M60*	*M65*	*M70*	*M75*	*M80*	*M85*	*M90*
100m	96%	93%	91%	89%	85%	83%	79%	76%	73%	67%	57%
200m	95%	91%	90%	88%	85%	81%	77%	71%	66%	60%	51%
400m	97%	95%	90%	89%	85%	84%	80%	72%	67%	56%	44%
800m	100%	94%	91%	86%	81%	80%	78%	71%	63%	52%	42%
1500m	96%	91%	86%	82%	78%	75%	71%	67%	62%	49%	37%
1 mile	99%	91%	89%	84%	80%	76%	71%	69%	58%	46%	40%
3000m	95%	89%	87%	85%	78%	75%	70%	68%	64%	44%	38%
High jump	91%	89%	87%	80%	75%	70%	69%	61%	59%	52%	47%
Pole vault	91%	87%	80%	77%	69%	63%	55%	50%	47%	41%	31%
Long jump	94%	87%	81%	79%	74%	67%	65%	59%	51%	45%	39%
Triple jump	92%	85%	79%	77%	72%	67%	61%	55%	50%	44%	37%

Table 4.4: Performance percentages for women's indoor events

	W40	*W45*	*W50*	*W55*	*W60*	*W65*	*W70*	*W75*	*W80*
100m	98%	96%	87%	83%	81%	78%	76%	66%	62%
200m	96%	90%	87%	83%	80%	75%	71%	62%	56%
400m	93%	91%	85%	81%	76%	72%	66%	61%	42%
800m	97%	88%	82%	78%	74%	71%	65%	57%	52%
1500m	99%	91%	85%	81%	75%	69%	66%	60%	44%
1 mile	100	98%	93%	90%	80%	77%	68%	59%	44%
3000m	96%	94%	86%	82%	75%	72%	67%	59%	54%
High jump	90%	83%	79%	75%	72%	66%	65%	59%	55%
Pole vault	79%	74%	72%	64%	65%	63%	46%	42%	31%
Long jump	97%	84%	79%	70%	67%	62%	57%	52%	43%
Triple jump	88%	80%	74%	72%	65%	63%	55%	49%	50%

Thereafter, a regression analysis was done to fit the parametric models to each event. In this analysis, events with less than 7 data points (i.e. age range of less than 35 years) are omitted. With these parametric equations, the events are compared individually as well as grouped into the categories – sprint (Outdoor 100m, 200m, 400m, Indoor 60m, 200m, 400m), distance (Outdoor 800m, 1500m, 1 mile, 3000m, 5000m, 10000m, Indoor 800m, 1500m, 1 mile, 3000m), walk (Race walk 3000m, 5000m, 10K, 20K, 30K, 50K), jump (Outdoor and indoor pole vault, high jump, long jump, triple jump).

5 RESULTS

All masters athletics records for all events declined with age and can be adequately modeled with a quadratic function as shown in Figure 5.1 below. Thus, Figure 5.1 illustrates the overall boundary of aging for both men and women combined.

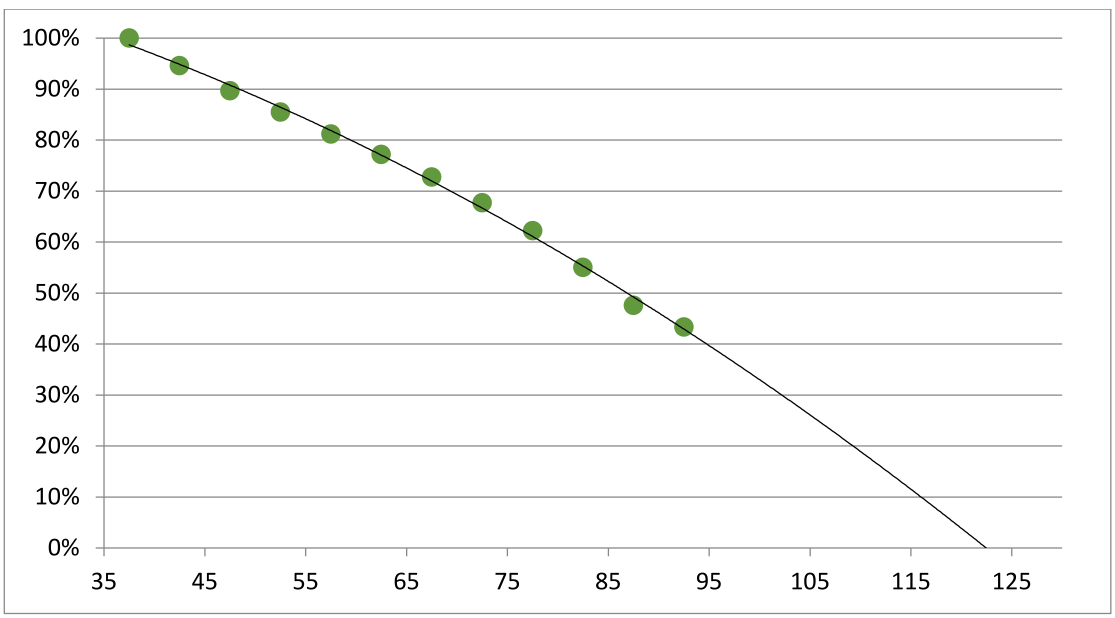


Figure 5.1: Average percentage performance for all men and women events combined

However, there are different rates of decline for different events. Therefore, in our analysis of the effects of aging on athletic performance, we have split the athletics events into 5 categories – jumps, walks, sprints, distance, and marathons. Despite splitting the running events (sprint: 400m and less; distance: above 400m, excluding marathon) with reference to the anaerobic and aerobic energy systems exchange at approximately 90 seconds (Maud and Foster 2006), a one-way ANOVA performed on the individual events within each category showed that there are significant differences within all categories except walks for men, but insignificant differences within all categories except jumps for women.

Table 5.1 below shows the projected age at which the performance percentage goes to zero for each group of events. It is observed that in general, women deteriorate faster than men in all categories and the rate of decline is the fastest for women marathon and the slowest for men marathon.

Table 5.1: Projected intercept for each group of events using parametric model

	Projected intercept (Age)
Women marathon	105.6
Women distance	107.3
Women walk	113.2
Women sprint	114.1
Women jump	117.8
Men sprint	117.9
Men jump	119.8
Men distance	123.5
Men walk	127.2
Men marathon	141.3

Also, with the parametric functions, the rate of decline for each event at all ages can be obtained by solving for the gradient of the respective functions at each required age. In this study, we looked at the rate of decline at the end of each decade within the studied age range. For men's events, pole vault shows the greatest rate of decline at ages 40 and 50 years, followed by the 1 mile run at ages 60, 70 and 80 years. For women's events, pole vault also shows the greatest decline rate at age 40 years; followed by long jump at age 50 years, 50km race walk at ages 60 and 70 years, and 80m hurdles at age 80 years. Table 5.2 below shows the rates of decline at each decade from 40 to 80 years.

Table 5.2: Gradient of respective function at various ages from 40 – 80 years

	40	***50***	***60***	***70***	***80***
Women marathon	-0.0076	-0.0099	-0.0121	-0.0143	-0.0165
Women distance	-0.0063	-0.0088	-0.0113	-0.0138	-0.0163
Women walk	-0.0059	-0.0081	-0.0104	-0.0126	-0.0148
Women sprint	-0.0055	-0.0077	-0.0099	-0.0121	-0.0143
Women jump	-0.0102	-0.0109	-0.0116	-0.0123	-0.0130
Men sprint	-0.0004	-0.0036	-0.0068	-0.0100	-0.0132
Men jump	-0.0092	-0.0100	-0.0107	-0.0114	-0.0122
Men distance	-0.0026	-0.0050	-0.0074	-0.0098	-0.0121
Men walk	-0.0062	-0.0074	-0.0086	-0.0098	-0.0110
Men marathon	-0.0001	-0.0021	-0.0041	-0.0061	-0.0081

The parametric functions for each individual event are shown in Tables 4.5 and 4.6 below. They are ranked from highest to lowest rates of decline at age 40 years (i.e. gradient of each function at x = 40).

Table 4.5: Parametric functions of men's events

Event	*Parametric Equation*	*R^2*	*Age range*	*Data points*
Indoor Pole Vault	$y = 0.0000011x^2 - 0.0121402x + 1.4437133$	0.995	35-90	12
Outdoor Pole Vault	$y = -0.000049x^2 - 0.006662x + 1.317250$	0.991	35-90	12
Outdoor Long Jump	$y = -0.000044x^2 - 0.005303x + 1.220476$	0.984	35-95	13
Outdoor Triple Jump	$y = -0.000048x^2 - 0.004946x + 1.219851$	0.987	35-95	13
Outdoor High Jump	$y = -0.00002x^2 - 0.0071x + 1.2703$	0.997	35-95	13
Indoor Triple Jump	$y = -0.0000517x^2 - 0.0045164x + 1.2050897$	0.986	35-95	13
Indoor High Jump	$y = -0.0000186x^2 - 0.0068358x + 1.2619869$	0.994	35-95	13
Indoor Long Jump	$y = -0.0000635x^2 - 0.0028570x + 1.1706293$	0.988	35-95	13
Race Walk 5000m	$y = -0.0000279x^2 - 0.0047182x + 1.1980052$	0.991	35-90	12
Race Walk 20K	$y = -0.0000413x^2 - 0.0035152x + 1.1919196$	0.995	35-95	13
Race Walk 50K	$y = -0.0000690x^2 - 0.0011812x + 1.1221935$	0.950	35-80	10
Outdoor 1 Mile	$y = -0.0002x^2 + 0.0095x + 0.8303$	0.989	35-95	13
Race Walk 30K	$y = -0.0000647x^2 - 0.0012782x + 1.1471056$	0.967	35-80	10
Race Walk 10K	$y = -0.0000800x^2 + 0.0011247x + 1.0594212$	0.978	35-90	12
Race Walk 3000m	$y = -0.0000755x^2 + 0.0009823x + 1.0726995$	0.971	35-90	12
Indoor 1 Mile	$y = -0.0001143x^2 + 0.0042886x + 0.9893431$	0.983	35-90	12
Indoor 1500m	$y = -0.0001090x^2 + 0.0040524x + 0.9750233$	0.976	35-90	12
Indoor 3000m	$y = -0.0001260x^2 + 0.0061553x + 0.9135185$	0.967	35-90	12
Outdoor 10000m	$y = -0.0001x^2 + 0.0049x + 0.9402$	0.980	35-90	12
Indoor 800m	$y = -0.0001360x^2 + 0.0078026x + 0.8885250$	0.980	35-90	12
Indoor 60m Hurdles	$y = -0.0001152x^2 + 0.0065742x + 0.8768598$	0.974	35-90	12
Outdoor 3000m	$y = -0.0001x^2 + 0.0069x + 0.8803$	0.986	35-95	13
Indoor 400m	$y = -0.0001612x^2 + 0.0118463x + 0.7569069$	0.985	35-90	13
Outdoor 400m	$y = -0.0002x^2 + 0.0152x + 0.6478$	0.985	35-100	14
Indoor 200m	$y = -0.0001624x^2 + 0.0123330x + 0.7216505$	0.973	35-95	13
Outdoor 1500m	$y = -0.0001x^2 + 0.0074x + 0.8804$	0.992	35-100	14
Outdoor 100m	$y = -0.0001x^2 + 0.0075x + 0.8583$	0.988	35-100	14
Outdoor Marathon	$y = -0.0001x^2 + 0.0079x + 0.8812$	0.985	35-90	12
Outdoor 5000m	$y = -0.0001x^2 + 0.0085x + 0.84$	0.983	35-95	13
Outdoor 200m	$y = -0.0001x^2 + 0.0088x + 0.83$	0.987	35-100	14
Outdoor 800m	$y = -0.0001x^2 + 0.0089x + 0.8269$	0.986	35-95	13
Indoor 60m	$y = -0.0001767x^2 + 0.0151579x + 0.6290564$	0.960	35-100	15

Table 4.6: Parametric functions of women's events

Event	*Parametric Equation*	*R2*	*Age range*	*Data points*
Indoor Pole Vault	$y = -0.0000168x^2 - 0.0106383x + 1.3378882$	0.925	35-80	10
Indoor Long Jump	$y = -0.0000347x^2 - 0.0089229x + 1.3725022$	0.983	35-90	12
Indoor Triple Jump	$y = -0.0000138x^2 - 0.0102027x + 1.3525566$	0.966	35-90	12
Indoor High Jump	$y = 0.0000241x^2 - 0.0125235x + 1.3999769$	0.976	35-85	11
Outdoor Long Jump	$y = -0.0000596x^2 - 0.0047878x + 1.2231040$	0.975	35-90	12
Outdoor High Jump	$y = -0.0000133x^2 - 0.0082077x + 1.2912830$	0.989	35-90	12
Outdoor 1 Mile	$y = -0.0000663x^2 - 0.0038284x + 1.2389545$	0.997	35-85	11
Outdoor Pole Vault	$y = -0.0000949x^2 - 0.0012254x + 1.1039898$	0.917	35-80	10
Outdoor Triple Jump	$y = -0.0000766x^2 - 0.0021318x + 1.1449678$	0.986	35-90	12
Outdoor 1500m	$y = -0.0000847x^2 - 0.0013179x + 1.1819422$	0.979	35-85	11
Indoor 1500m	$y = -0.0000954x^2 - 0.0001724x + 1.1430135$	0.981	35-80	10
2000m Steeplechase	$y = -0.0001021x^2 + 0.0005386x + 1.1157328$	0.988	35-75	9
Outdoor Marathon	$y = -0.0001114x^2 + 0.0012838x + 1.1074182$	0.992	35-90	12
Indoor 800m	$y = -0.0000999x^2 + 0.0006635x + 1.0985060$	0.971	35-85	11
Race Walk 20K	$y = -0.0001054x^2 + 0.0011200x + 1.0761853$	0.965	35-80	10
Outdoor 100m	$y = -0.0000587x^2 - 0.0020066x + 1.1605793$	0.986	35-90	12
Outdoor 200m	$y = -0.0000798x^2 - 0.0002551x + 1.1110441$	0.991	35-90	12
Race Walk 10K	$y = -0.0000562x^2 - 0.0020157x + 1.1158256$	0.978	35-90	12
Outdoor 5000m	$y = -0.0001057x^2 + 0.0020447x + 1.0579862$	0.992	35-85	11
Race Walk 3000m	$y = -0.0000780x^2 - 0.0001047x + 1.0758910$	0.977	35-85	11
Outdoor 800m	$y = -0.0001308x^2 + 0.0043630x + 1.0171253$	0.992	35-90	12
Indoor 60m Hurdles	$y = -0.0000897x^2 + 0.0012105x + 1.0619091$	0.973	35-5	9
Race Walk 5000m	$y = -0.0000702x^2 - 0.0002249x + 1.0562635$	0.978	35-90	12
Indoor 60m	$y = -0.0000717x^2 - 0.0000120x + 1.0988357$	0.985	35-90	12
Outdoor 3000m	$y = -0.0001293x^2 + 0.0046588x + 0.9823924$	0.980	35-85	11
Indoor 3000m	$y = -0.0001406x^2 + 0.0056529x + 0.9736177$	0.977	35-85	11
Indoor 200m	$y = -0.0001183x^2 + 0.0044896x + 0.9793282$	0.993	35-90	12
Outdoor 10000m	$y = -0.0001602x^2 + 0.0081437x + 0.9159909$	0.985	35-85	11
Outdoor 400m	$y = -0.0001592x^2 + 0.0082510x + 0.8868137$	0.993	35-90	12
Indoor 400m	$y = -0.0001743x^2 + 0.0096627x + 0.8495953$	0.979	35-85	11
Race Walk 50K	$y = -0.0002479x^2 + 0.0162879x + 0.7680835$	0.887	35-65	7
Indoor 1 Mile	$y = -0.0002343x^2 + 0.0161915x + 0.7316731$	0.994	35-85	11
Outdoor80m Hurdles	$y = -0.0003089x^2 + 0.0257765x + 0.4504762$	0.995	40-80	9

6 DISCUSSION

In this study, a quadratic function was used to model the decline in performance percentage of the athletics records as it is more intuitive to the layperson. Although Stones and Kozma's study (as cited in Baker, Tang et al. (2001)) in 1980 found that an exponential fit was better than power models for running events, our study showed that the quadratic fit also achieves a high coefficient of determination for all of the events. This could be due to the different age range used as Stones and Kozma studied a period of 30 years from ages 40 to 69, while we studied up to the age of 90 in this study. In addition, a quadratic decline of athletics performance fits the quadratic relationship of decrease in muscle area and the number of muscle fibers with increasing age as found by Lexell, Taylor et al. (1988).

On average, the ages at which performance percentage goes to zero for men and women are significantly different ($p < 0.05$) at ages 123.5 years and 111.9 years respectively. This implies that women's athletics performance declines faster than men's. Furthermore, there is also a significant difference between the men's and women's rate of decline for all the event categories except race walks

(p = 0.08) based on the gradient of the quadratic functions over the 40 – 80 years age range. This observation supports the study done by Netz and Argov (1996), which indicated that “women deteriorate more than men in the aging process”.

An analysis of the rates of decline of the 5 categories at each decade from 40 – 80 years showed that there is a significant difference in the rates of decline in the earlier decades (40 – 60 years) but no significant difference at ages 70 and 80 years. This may be due to lower participation rates for athletes aged 70 years and above. The WMA Outdoor Track and Field Championships 2011 showed that the average number of participants in the M80 (W80) category is about 40.2% (21.7%) of the number of participants in the M40 (W40) category for all athletics events (WMA 2011), therefore, leading to a relatively high rate of decline across all events from ages 70 – 85 years.

7 CONCLUSION

In summary, this study has shown that a quadratic function is a good fit in modeling the boundary of perfect aging using athletics records. With these quadratic functions, it was found that there are significant differences between the rates of decline for men and women in sprints, distance, marathons and jumps, but not for walks. There are also significant differences in the rates of decline for the 5 categories from age 40 – 60 years, but the rates of decline among these categories are similar from age 70 – 80 years. As this study has produced the boundary of the human performance using the world records, future research may consider encumbrance factors in the model, so as to develop a more realistic model.

Chapter 45

Shake, Rattle and Roll – Vibration

This article is about mechanical vibrations and their effects on human performance and health.

When I was young my uncle took me on his tractor to plow the cornfields. The ground was rough, and we bounced around a lot on the seat that consisted of a shaped steel platform mounted on a U-shaped steel spring. The rough field also caused the front wheels to transmit the bumps to the steering wheels. When I was allowed to drive, it soon became clear that the immaculately straight furrows would turn into a zigzagging mess. I was certainly not in line to win the plowing championship at the village gymkhana. My performance was degraded by my inability to manage the mechanical vibrations inherent in the task and equipment. Some years later I returned to work on the farm and was given the much less precise task of towing a set of harrows behind the tractor to further break up the soil before planting the corn. The technology had not improved much – I still sat day in day out on a sprung seat, albeit with an old cushion to provide a modicum of damping, and the steering wheel still harmonized with the dancing front wheels. I was a skinny little teenager, which made me more responsive to the bouncing seat, although work on the farm helped a little, particularly as I had to grasp the steering wheel tightly all day to ensure that I followed a straight path up and down the previously plowed field. The price that I paid for these control efforts was very tired and sore hands and arms.

After finishing my undergraduate education in ergonomics, I had a choice between going to graduate school and working for the British aircraft industry, who were very concerned about pilot performance and health as affected by vibrating fixed wing airplanes and helicopters. I chose the former path, but not before I had the opportunity to learn about the substantial fatigue and performance decrements encountered by pilots, who sometimes had difficulty in reading their instruments correctly and in performing target-aiming tasks. To this day piloting small aircraft and helicopters is still hampered by a hostile mechanical vibration environment.

My next formal encounter with vibration was when I was asked to offer my input on ride quality evaluation for transport drivers and passengers. I was particularly concerned with the old busses that wound their ways noisily around the city streets of South East Asia. Back in the 1970's the drivers still had primitive seats and spent long hours navigating the extremely busy streets. At that time researchers in England (Sandover, 1998) and the USA (Jacobson) were developing methods of measuring the mechanical aspects of ride quality and applying their findings to road vehicles, trains, and airplanes. It became immediately clear that only part of the problem was with the vehicle – a lot was to do with the road. Contemporary vehicle manufacturers have come a long way in addressing the transmission pathway for induced vibrations by providing advanced "active" suspensions that can absorb or even actively counter the vibration. Nowadays it is possible to drive high-end vehicles that are smoother than a flying carpet.

The roads are still a problem however, especially in northern climates where the frost, salt, and heavy traffic play havoc with the surfaces. The obvious solution is to repair the roads, but this brings with it another vibration problem in the shape of Jack Hammers and Concrete Breakers. This time the vibration is passed through the hands and arms of the workers and the whole operation is compounded by extremely high noise levels, a common side effect of construction tools. On one occasion in Hong Kong I recorded 120dB in my apartment, some 50 yards from where construction workers were making holes in the rocks on the hillside in order to install concrete cladding to prevent mudslides. Similar percussion tools (chipping hammers) are used to clean flashings from castings in the foundry. The foundry workers stand by the moving belt with these heavy tools and chip away all day in this hot and dusty environment. I once saw an operator, who was doing this casting cleaning job, almost fall over – such was the excitement of this repetitive job that he fell asleep. You may be skeptical, but I came across a similar situation in the forestry industry in New Zealand where workers use chain saws to trim branches off the pine tree trunks, often in very cold and wet conditions. This problem (of sleeping at work) is being addressed by steel toecaps, leather spats, and the incorporation of sensors in clothing, to shut off an errant chain saw.

The best solution to many of these vibration problems is of course automation and great strides have been made in industry, construction and forestry to remove the human operator from the direct pathway of the mechanical vibrations that are inherent in the tasks of "disassembly." A less satisfactory solution is to absorb the vibration in the transmission pathway. Contemporary handheld chipping hammers, chain saws and concrete breakers are designed with damping material to reduce the transmission of vibration to the user. Ironically, some operators have been known to be resistant to such innovations because they interfere with their "feel" for the job and slow down their operations. The next step in the mitigation hierarchy is the use of personal protective equipment in the form of shock absorbing gloves, that both dissipate the forces and channel them away from sensitive structures such as the median nerve as it exits from the carpal tunnel.

Contemporary just in time manufacturing operations gives rise to another vibration problem. Large trucks, with shock absorbing seats, deliver components to the docks of assembly plants where floor space is usually very costly. Stand up fork trucks are used to move the boxes of components from the docks to temporary staging places (supermarkets) from where sit-down fork trucks and tuggers carry the materials to the assembly line. Fork trucks usually have solid tires and very primitive suspensions because of the very high loads that they must carry. Consequently, the vibration from the, often uneven, factory floor or warped dock plates is transmitted to the driver who stands directly above the rear axle. Because of the intrinsic design of these stand up devices, that need to have a small turning circle for their maneuvers, it is difficult to interpose an adequate damping mechanism between the operator and the vehicle and still offer good access to the vehicle controls.

Observation of such operations highlights the most important element of the vibration jigsaw – exposure. The traditional work day is eight or more hours and, for many reasons, job enlargement and rotation to reduce exposure are not feasible or acceptable, especially in organizations where job choice is based on seniority and riding a fork truck is more attractive than working on the assembly line. Also, it is a common observation that self-paced people with quotas to fill or piece-based incentives will hurry to finish a task. This leads to fork trucks being driven too quickly over bumps, which increases the size of the shock, or putting more linear force on the hand tool to finish the job more quickly.

Measurement and analysis of mechanical vibrations has progressed enormously over the past few decades. Triple axis accelerometers can be mounted at strategic sites in the transmission pathways from vehicles and tools to the operator to measure the amplitude and frequency spectrum of the vibrations. There are also dosimeters or clocks that integrate the mechanical and temporal components of operations that involve exposure to vibrations. But this leads to the biggest challenge of all – how to set and enforce standards that will protect workers from the harmful effects of vibration, while attaining an acceptable level of productivity.

The International Standards Organization (ISO 13160) contains some 50 pertinent standards, including
http://www.techstreet.com/cgi-bin/detail?product_id=22795),
the US Navy identifies many pertinent
(http://www.safetycenter.navy.mil/acquisition/vibration/resources.htm)
the American National Standards Institute (http://webstore.ansi.org/ansidocstore/find.asp? - search on 'vibration' for over a hundred standards),
the National Institute of Occupational Safety and Health at http://www.cdc.gov/niosh/handvibra.html describes their current efforts in occupational vibration research and development.

The Occupational Health and Safety Administration (OSHA) as yet has no specific vibration standards although it does cite vibration as an important cause of work related musculoskeletal disorders and addresses the issue through its "General Duty Clause," produced guidelines and standards that limit the exposure of workers to whole body and upper limb vibration. The University of Tennessee has an Institute for the Study of Human Vibration, under the leadership of Donald and Jack Wasserman (http://www.engr.utk.edu/ishv/). All of these standards and guidelines are frequency and amplitude sensitive and provide exposure duration limits.

Although these standards are based on sound physical measurement principles and epidemiological evidence, they face the challenge of most health and safety standards that are developed for application in a context where speed and productivity, either imposed by the company or self-imposed, are of importance. They also must address the ever-present problem of individual differences in operational methods, adaptation, and sensitivity to mechanical stresses. Even though applicable and reliable protective standards do exist there is an enormous challenge of monitoring and enforcing them. For a start measurement and analysis of exposure to vibration requires sophisticated equipment, is technically difficult and relies on sampling repeatedly over time and similar operations and operators to be reliable. Also the adverse health effects of exposure to mechanical vibrations, as with noise and radiation, may take a long time to surface.

The solution of "weeding out the weak" leading to a robust, survivor population will always be attractive to some employers and many employees may be happy to leave jobs for which they are not suited, providing there is not too great an incentive, usually economic and social, or political and philosophical, to stay too long in the offending job. As mentioned earlier, engineering innovation is an attractive solution. Trees can be stripped automatically, although the operator must sit all day in a large, expensive, and not very nimble machine. Some castings can be cleaned automatically, and some casting processes can reduce the amount of flashing. Drivers' seats in trains, busses, planes, and trucks can benefit from vehicle and seat suspensions that make driving a dream, but at a significant cost. Even chain saws and handheld construction and destruction equipment can be fitted with shock absorbing devices. Administrative controls, such as job rotation and enlargement can be used to reduce temporal exposure. In large organizations operators can be monitored for sensitivity to vibration induced illness.

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Chapter 46

The (brief) Anthropology of Work and Play

"And which of you, having a servant plowing or tending sheep, will say to him when he has come in from the field, 'Come at once and sit down to eat'? (Luke 17, 7)

"These last men have worked only one hour, and you have made them equal to us who have borne the burden and heat of the day." (Matthew 20, 12)

Not only did these Biblical employees get paid, perhaps unfairly, for their work, they also got benefits. Nowadays, General Motors gives pensions to more retired employees than working employees, plus health benefits. The automobile industry is a good place to start this story because transportation of people and things represents a substantial portion of what we do but transportation, *per se*, is non value added, except to those who get paid for transporting. Transportation also represents an enormous spectrum of employment opportunities – from managers, lawyers, insurers and advertisers, through engineers, designers and manufacturing and assembly workers, to those involved in mining, petroleum production and agriculture. The car also generates work for road builders, traffic cops, hotel staff, fast food restaurants and emergency room physicians. Nowadays people, in the developed world, spend an inordinate amount of time in cars, trains and planes, just to get to work. The slogan of the American trucking industry is: " If you eat it, wear it or use it, it came on a truck." And all because some lazy prehistoric genius invented the wheel, because he grew tired of running after the game and carrying it home for dinner.

Over the millennia, technology and society have changed considerably but people and work have not changed very much. We continue to look (listen), think (remember) and do (say). Groups of ancients got together to hunt the mammoths while sharing the dangers and the spoils. Nowadays organizations are formed to produce the necessities and niceties of living and to spread the wealth, albeit inconsistently. Homo erectus found a rock to sit on to rest his feet. Homo sapiens found that he needed a computer, the Internet and a cell phone to expand his influence. Homo sedens got fat by sitting and working at computers all day and using the same technology for entertainment all evening. Physical work is necessary to produce the things that society needs, information work is useful to refine that production, but it is play, in its broadest sense, that is essential to satisfy the soul, while the body and brain recuperate. Great technological strides have been made to modulate the form of physical work by the harnessing of power, levers and wheels. Sensing, thinking, calculating, controlling and communicating have also been greatly enhanced by information technology. Play has become more vicarious: instead of dancing around the fire after the feast, we now sit by the fire and watch football; instead of sacrificing a lamb to the sun god, we salve our souls by watching the preacher on television. For the purpose of this article we will consider only three phases of the day – sleeping, working and playing.

The devil of course is in the details; both work and play exhibit enormous variety. The first driver of variety is society and then comes technology. A few thousand years ago populations were small and technology simple. Spears and hoes separated the small groups of hunters and the farmers, although they both used the knife, water and fire for processing. They eventually recognized the merits of enriching the gene pool by interbreeding. As time passed populations grew, cities formed, and technology sprouted to deal with the movement of materials and the management of information. And rock and roll separated the young from the old. Homeland security replaced the village sentry in an attempt to prevent unwanted contamination of the gene pool, by followers of a different drummer. Commercial television replaced the village leader as a guide to behavior.

Measurement

There are jobs, hard jobs and jobs your fathers (and forefathers) used to do. All work has its rewards and much work has significant costs that sometimes outweigh the rewards. Some work is hard on bodies, some on minds and some on souls. Some work provides enormous personal satisfaction, with minimal tangible gain. Other work is boring but lucrative. The relationship between these different rewards and costs of work is not simple – some people, who "work smart, not hard" may get significant financial rewards, others who work physically hard may pay exorbitant costs, but have the satisfaction of substantial personal achievement. A challenge to students of work is to provide a common currency for the description of the context, content and outcome of work, so that valid comparisons may be made.

The multiple purposes of work

There are four principle categories of work purposes or outcomes – effectiveness, efficiency, safety and satisfaction. Effectiveness or quality addresses the expectancies of the customer for the product or service. Efficiency or productivity relates to the consumption of resources, such as time, money, space, equipment, and materials. Safety addresses the prevention of acute or cumulative harm to the people or other resources associated with the carrying out of work. Satisfaction is a uniquely individual outcome or work – one man's meat is another man's poison. additional purposes will include ease of use and esthetic appeal, security and sustainability (reliability and resilience).

Collaboration, slavery, and employment

From the very earliest of times people have formed organizations or collaborative groups to expand the effectiveness, efficiency, safety, and satisfaction associated with work. When these groups are formed there is usually a division of duties and leaders emerge to guide the strategic management of the group. The leaders may be appointed (perhaps self-appointed), selected or elected and sometimes these personnel processes are subject to bias. This bias may not necessarily lead to bad leaders. Indeed, many slaves may be treated very well and have considerable autonomy, except for their opportunity to chose their master.

The line between employment and slavery is very fuzzy in reality although the two conditions of work are distinct politically. In the early days of transportation it was common for groups of slaves to row boats across the sea or move large blocks of stone for the construction of pyramids, castles, churches and factories and be encouraged by physical methods. These slaves typically came from a separate ethnic, geographic or cultural community. In the recent past slave labor became a tradable commodity and shiploads of Africans came to America; to this day employee slaves are forced by their leaders and circumstances to give up their practical rights to choose what they do in the form of work. Golden handcuffs or the promise of better times ahead may be as effective as the whip.

When someone joins the military or the college football team they are typically directed by appointed or selected leaders called sergeants or coaches. When they fail to perform quality work they may be subject to physical or emotional abuse with the intention of making them stronger. In times of war, if a soldier, for very good reasons of personal survival, chooses to opt out, he may be shot. During practice, the deficient footballer may simply be given the symbolic public humiliation of ten pushups or a run around the field. Human deficiencies in the real world of war and sporting competition may be rewarded by career ending public humiliation and untold personal trauma.

It is common in business and industry to use the expression: "I work for" or "who do you work for?" The operational meaning of these expressions is simply a reflection of the appointment or selection of a leader and the symbolic placement of his name in a box on an organization chart. Sometimes appointments and selection of leaders are focused on a subset of the purposes of work – such as productivity – and sometimes these leaders may chose a managerial style that is incompatible with the wishes of the subordinate, especially where that subordinate was not a party to the appointment or selection process. The boss also has a difficult task, because his boss or customers may have expectations that diverge from those of the employee. As in war and football, rule number one in business and industry is that "the boss is always right" and rule number two is that "when the boss is wrong, go to rule number one". The penalty for not understanding these important rules may be career shortening or more subtle modification of the conditions of work.

In government, labor organizations and academia it is common for leaders to be elected by those who they lead. The campaigns leading up to such elections commonly involve promises and quid pro quos. Another characteristic of elections is that the electorate may not be aware of all the facts about the candidates or the implication of decisions made by the successful candidate, once elected. Also, elections are rarely unanimous so that once again as in war, football, industry and business, those that are being lead may not always be happy with their elected leaders. They do have a chance at the next election or even at a recall election, but once again there will usually be a minority of unhappy workers. You can't please all the people all the time, and the context and content of work will always be constrained.

Hertzberg addressed this issue at the individual worker level. He argued strongly that it was the intrinsic content of work that motivated the worker and that the context simply contributed to dissatisfaction. Can a slave be happy picking cotton? Can an automobile assembly worker be happy attaching an exhaust pipe, overhead, to a car every 30 seconds? Can a quarterback be happy if his receivers can't catch or his protectors don't protect? Can a soldier be happy if the war is being lost? Can the voter be happy?

Human variability

Work and play are good indicators of individual differences. In professional sports these differences are documented in great detail and the influence of intangibles, halo effects and pitchfork effects become dominated by objectivity? Play can be measured by wins and losses and by salaries. So can work, but there is enough uncertainty left to create work for students of work and play for the foreseeable future. The outcome of work is measured by effectiveness, efficiency, safety, satisfaction, and their derivations. The human input to work may be physical, informational, or motivational and humans vary enormously on these dimensions.

Demographics of work

Life is divided into three parts – learning, working and smelling the roses. Ideally these activities correlate with the aging process, but the borders are so fuzzy that they may overlap considerably.

Chapter 47

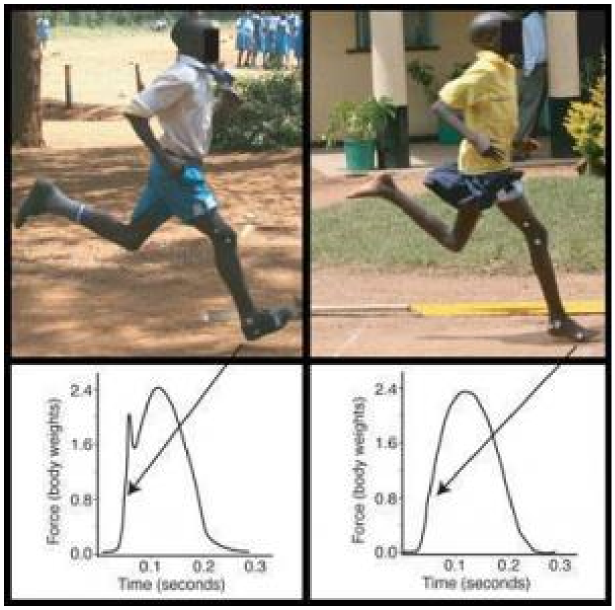
The Art, Science and Practice of Bipedance

Bipedance may be defined as the process of two-legged walking, running, dancing, skipping etc., at some of which I have had a lot of practice. As an art form bipedance spans the full spectrum from the sublime to the ridiculous. For example, the process of race walking, although I do not wish to offend those serious athletes, borders on the ridiculous – perhaps better defined as a hip swaying waddle. The definition of race walking is what causes this ungainly style – part of one foot has to be on the ground at all times, no matter what the speed. As a young man I was taught the rules of polite conversation – do not discuss money, politics or yourself and never talk of others in a disparaging way. In this story I plan to break all those rules, albeit with profound apologies all round. First I must apologize to the race walkers and eat humble pie – I was once passed by a race walker while running a marathon.

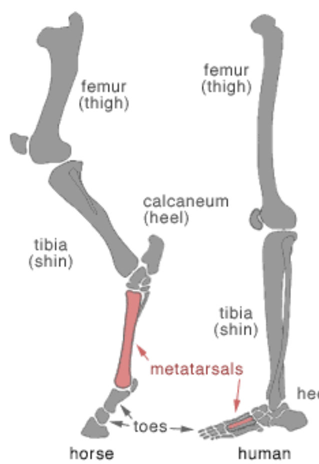
The next broken rule is that I shall frequently discuss my own experiences which I believe are most interesting. For a start I have considerable experience of bipedance having run many marathons. And this is where the problem of definition arises, when is a run not a run, or more precisely, when is a run a walk? I completed the recent Standard Chartered Bank Singapore marathon; I finished about 5000th out of 20,000 starters and 15,000 finishers. But my time was five and a half hours – my worst performance ever by more than an hour. I ran the first 25k at Boston Qualifying pace and then came across this fellow who was tired and walking, so I stopped to accompany him with talk of the trivia common among runners – footwear, friends, family, food and football. We became so engrossed in our conversation that the next 10 kilometers passed in a flash so to speak. We found ourselves surrounded by many other walkers. So we upped and ran the remaining distance to claim our finishers' medals and T shirts. What is notable about these statistics is that marathons are not necessarily running events, nor are they races in the strict sense of the word; they may simply be T shirt collecting rigmaroles. Not that there is anything wrong with this pursuit; 42 klicks is 42 klicks especially in the hot and humid Singapore environment.

Our first topic of conversation was that of running shoes, my newfound colleague was a shoe manufacturer from England who runs monthly marathons to stave off the ageing process. I confessed that I always ran in Garry's and he replied that despite his broad knowledge of the industry, he had never heard of this sort of shoe. I explained that Garry is my long-time running buddy from Michigan who cannot pass a shoe shop without going in to survey, and usually buy, the latest style. He uses these shoes for anywhere from one to a few hundred miles and then passes them on to me, for the next 1000 miles. I must confess that I have not bought a pair of running shoes for more than 20 years and that I probably have enough left to see me through my twilight years. Thank you, Garry, may your shadow never grow less.

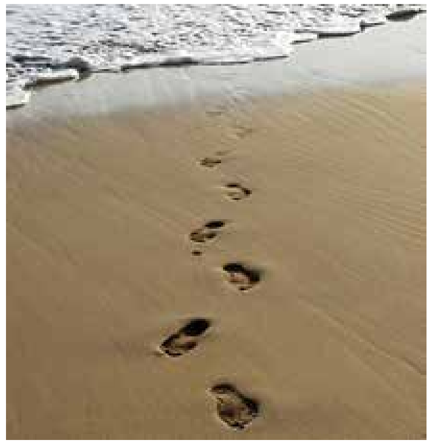
As we walked, we were passed by two bare foot runners, although the roads were hard and often rough. Earlier in the race I was passed by a runner with and artificial leg. These observations led to a discussion of the recent flurry of interest in gait analysis, particularly regarding the mid foot strike pattern. The proponents of this style suggest all sorts of benefits – from faster pace to less musculoskeletal damage. Unfortunately, they do not offer any substantive performance or epidemiological evidence to back up these claims; they simply rely on extrapolation from biomechanical analysis. Furthermore, the studies that I have read to date do not systematically address the confounding factors of running / walking speed, stride length, body parameters such as leg length and weight, and shoe heel height. They also make the unreasonable generalization that their theory (of the superiority of mid foot strike) should apply to all.



Common observation of gait patterns shows that most people walk with a heel strike and that sprinters land on their midfoot. There are variations on these patterns, with some walkers avoiding the heel strike and some, less than accomplished, sprinters landing on their heels. In general, it can be postulated that the strike pattern is related to the speed of bipedance. However, this transition, from heel to midfoot, may not be a continuum. The interested reader may wish to investigate the transitions observed in horses between walking, trotting, cantering, and galloping. The comparative anatomy of horses' heels is a horse of a different color.



Some thirty years ago I developed a gait lab at Dalhousie University as this topic raged in the Canadian sport and rehabilitation communities. Our principal tool was an electro goniometer. Later I graduated to electromyography, force plates and optical systems. Perhaps the best medium for the study of gait patterns, however, is through the observation of footprints in wet sand. This is generally more available and immediately meaningful than force plate – treadmill combinations. The beach is also more fun than the laboratory, and there is no greater pastime than beach running. Perhaps the only shortcoming of this scientific method is the temporary nature of the data which are subject to interference from the incoming tide. The astute scientist will maximize his or her opportunities by starting their day shortly after high tide.



These discussions, controversy and promises of alternate gait patterns have also attracted the attention of running shoe manufacturers. Back in the day it was all about cushioning and support. Great big thick spongy heel materials were guaranteed to save your knees, hips and backs from arthritis. Lateral support enthusiasts and orthotic operators ignored the issue of moments and the beautifully dynamic nature of foot arch mechanisms. Nowadays the minimalist shoe manufacturers propose a gradual transition from thick to thin heels as the runner progresses towards the new theoretically optimal mid foot strike style. The trick here is to buy lots of intermediate heel heighted shoes on your gradual way down to earth. The purpose of this gradual transition can be contrasted with the transition of the stylish weeklong professional lady in her high heeled shoes to the weekend jogger in her also fashionable sneakers. Here there is considerable epidemiological evidence in the form of calf and Achilles tendon strain, and even complete rupture. Did you ever see a lady in high heels try to sprint for the bus with a midfoot strike? A recipe for disaster and probably a missed bus to boot. Parenthetically it can be argued that the high heeled shoe is probably the worst form of orthotic device invented since the chair, but both have their advantages.

A biomechanical analysis of gait indicates that as the foot strikes the ground there are gravity induced bending moments around the ankle, knee and hip. Some of the vertical transmission of force goes through the bones and joints directly, but much of the vertical force is counteracted by eccentric muscle contraction in the ankle, knee and hip extensor muscles. The purist will be quick to tell me that these ankle "extensors" are actually called dorsi and plantar flexors. In lay terms we are talking about the muscles in front of and behind your lower leg. With a heel strike the muscle reaction can be seen (by electromyography) to be first a contraction of your dorsiflexors followed by a strong concentric contraction of your plantar flexors (calf) as the gait cycle progress from heel strike to mid stance and on to toe off. For the mid foot strikers, the plantar flexors first contract eccentrically to absorb the gravity load and then transition to a forceful shortening as you push off. The nature of the stretch reflex can be pursued by those interested in physiological detail. These analyses are simply a matter of mechanics, which are somewhat complicated by the dynamic lateral stability and coordination throughout the gait cycle, which art in motion is only marred by the flat footed, arch dropping, splay footed and pigeon toed runners and walkers that intermingle with those beautiful creatures that surround you in a big race. When you get bored in your next marathon, try foot watching – a captivating pastime.

Bipedance is like flying – it involves lift and drag and consumes fuel. The drag – horizontal resistance to movement is related to the surface area and the square of the velocity:

$F_D = \frac{1}{2}\, p\, v^2 C_D A$

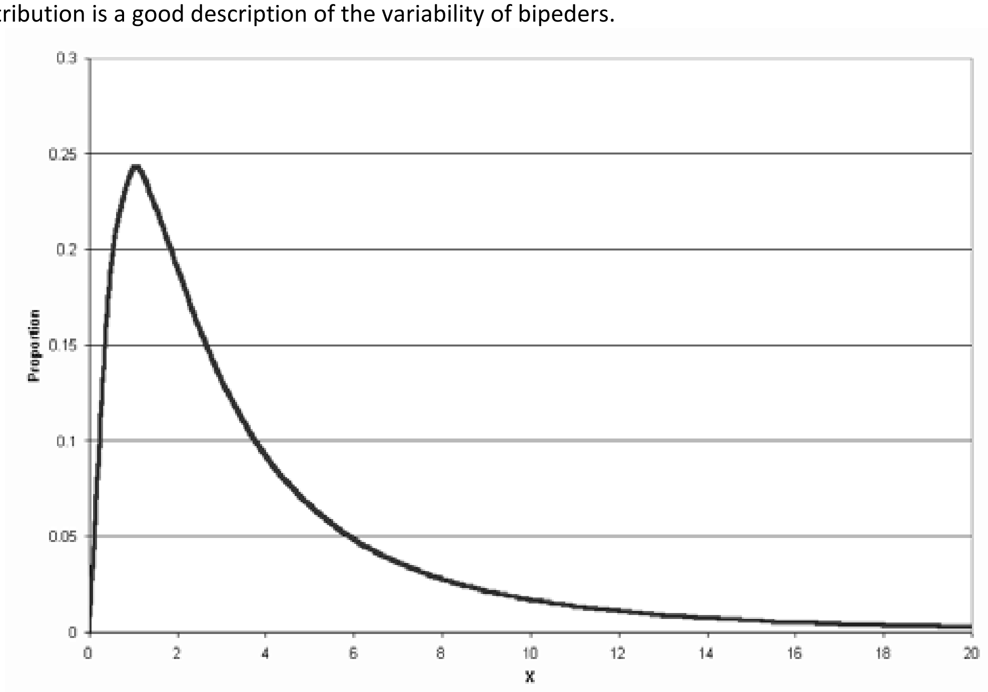
where

F_D is the force of drag, which is the force component in the direction of the flow velocity
p is the density of the fluid / air
v is the velocity of the object relative to the fluid / air
A is the reference area and
C_D is the drag coefficient related to the object's geometry and taking into account both friction and form components

However, as we do not run very fast this kind of drag is not very important, except when the wind blows in our face. Swimmers on the other hand obsess about synthetic swimsuit interplay with the viscous water. Also, the enthusiast may want to discuss the terminal velocity of a skydiver (120mph) where the drag balances the gravitational force. If you are really keen on this drag thing consider the reentry of the Space Shuttle into the earth's atmosphere, but don't touch the Shuttle's nose with your bare hands. Another horizontal component of (frictional) resistance to movement is when our foot hits the pavement. Try running on ice and you will see what I mean. It may be argued that this component is related to the duration of the stance phase and so midfoot strike might reduce this wasted energy. The second greater amount of wasted energy in running is due to vertical motion. The weight of your running shoes may be a minor issue over the duration of a marathon, but nowhere near as much as the weight of that extra load around your midriff which is due to too little running and too much eating. Astronauts, who have been known to run around the earth in about an hour and a half, use artificial gravity in the form of bungee straps to keep their feet on the ground, figuratively speaking. I have a few friends and family members who are ultra marathoners. In fact my niece's son is one of the very best at this endeavor; it must be in the genes! These fools need to conserve energy by running efficiently; they also need a fair dose of insanity / masochism to put their bodies through this extended period of suffering. Ultra marathoners are often heel striking shufflers – very little vertical motion of their feet and bodies. I also have a friend who is a mid foot striking elite female marathoner, poetry in motion. The difficult question here is the relative vertical component of energy consumption between heel and mid foot strikers.

The third form of bipedance is dance, which comes in many forms. Notably we have the tap variety which amplifies the heel and toe strike for acoustic effect. As speed of strike is of the essence, large vertical motions of the shoes are minimized. Next come the ballet dancers with their toe intensive "En pointe." This is the pinnacle of the art of bipedance. But is it "natural and safe?" This is a biomechanical topic for another day. Jazz dance and rock and roll come next – these are art of a different form requiring more energy and an awful lot of mid foot striking. Skipping is another fascinating form of bipedance. The biomechanical and physiological issues with these dance forms are the repeated accelerations and decelerations and changes of direction. Now this is a take home question – *if you dance or skip in a small space for the same time duration as it takes you to run a marathon and with the same number of steps, do you consume less, more or the same amount of energy?*

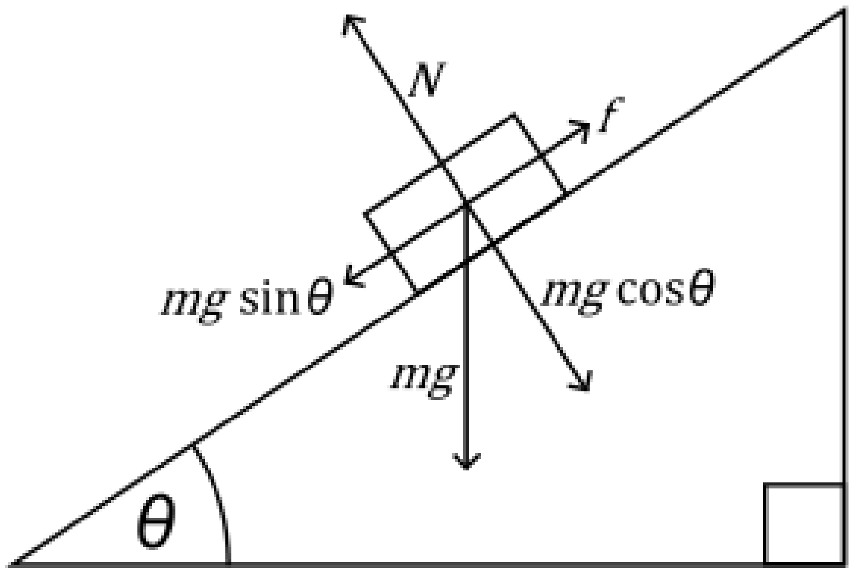
Speed is another thing. Technically we are talking about velocity, in that our direction is especially important in races. Fast marathon runners run 26 miles in 2 hours – 13 miles an hour; fast sprinters run 100 meters in 10 seconds – about 20 miles per hour; average walkers amble at 2 – 4 miles per hour. Skippers don't go anywhere, dancers (including the ballet variety) keep coming and going and twisting and turning. Stair climbers may do around 1 mile per hour horizontally. Perhaps the log Normal Distribution is a good description of the variability of bipeders.



What about efficiency you may well ask. What is efficiency? I would suggest that it is horizontal movement divided by vertical movement. Support for this point of view may be found by looking at bicyclists, bladers and skaters; cyclists have very little vertical movement of the bulk of their weight, whereas bladers and skaters don't require as much vertical movement as even shufflers. Cross country skiers love to glide, but uphill telemarkers plod painfully. Others suggest that efficiency is all about the duration of the stance phase – the duration of the gait cycle (heel strike to heel strike) divided by the time between heel (or mid foot) strike and toe off. Sprinters, with this definition, are efficient, but long-distance shufflers may be more efficient in the long run. Sprinters burn more Calories per minute than walkers. But what about Calories per mile? Heavy guys burn more Calories (per) than light guys.

Back to the issue of midfoot and heel strike in bipedance. People differ, and this must not be ignored. If we run up hill we usually contact the ground with our midfoot, whereas downhill running sees our heels strike first. These observations have kinematic causes (the amount of dorsi flexion in our ankles is less than that of plantar flexion) – try running downhill with a mid-foot strike and you will probably experience the effects of a resultant force of your center of mass getting ahead of your support base.

Similarly running up hill with a heel strike could well result in a back of head strike instead of a nose strike. The results of these experiments may be partially supported by a similar experiment during your Thursday morning assault of the stadium steps. Be careful, the Institutional Review Board does not like to deal with broken experimental subjects.



Armed with all this experimental biomechanical evidence we should now address the more insidious issues of habit and epidemiology. You can tell an old runner when you see one, but you can't tell him much. Old habits die hard. Can we or should we attempt to change our habitual gait patterns? Is it feasible to carry out a sufficient and reliable investigation of the transition from heel to mid foot strike behavior and the (long term) epidemiological outcomes? Meanwhile the issue will be treated as an opportunity for shoe salesmen and coaches. I think that the answers to this controversy may be found by beach running and foot watching in your next marathon.

Chapter 48

Grading

Today I again joined the College grading discussion and was dismayed to hear the perennial arguments that the grades in one class were different from those in another and that there were too many “A”s here and too many “F”s there.

The implicit assumption, as indicated by the discussion, is that the average and spread of marks from one class should be like those of other classes. In fact, this assumption has its basis in both tradition and Statistical reasoning – the difference between two groups can only be validly assessed by a calibrated common tool. In the situation at hand there is no common tool; classes have different content, teachers, and examinations. Consequently, classes should be considered to be similar in their mark distributions as there is no valid proof that they are different – only the biased opinions of the lecturers and managers.

We attempt to address this problem up front by management of lecturers, class content, tests and their grading rubrics. We spend an inordinate amount of time and effort micromanaging the marks. Despite these efforts we always end up with discrepancies that are dealt with after the event by moderation processes and heated debates and accusations. This tampering may even create a worse situation. There is a better way:

- We should continue to manage the desired equivalence of classes up front by management of lecturers, tests, and rubrics. In practice, however this will never alone achieve the desired numerical and alphabetic course equivalence result.

- We should continue to have committee oversight to deal with major discrepancies, but we can avoid the heated discussions and improve the grading process by inserting one of various alternative procedures.

    - The simplest way is to perform a straightforward linear transformation of all sets of marks so that they end up with the same distribution parameters (mean and standard deviation). We should then assign letter grades either around rigid numbers (40, 45, 50 etc.) or around natural empirical breaks which usually occur in sets of marks, and which are unaffected by a linear transformation. In practice we do this informally by not allowing “38s and 39s”.

        - This post hoc process, sometimes erroneously called Normalization or colloquially called “curving”, has its critics who argue that examinations and grading should rely on the professional judgment of the professor, and that only gross discrepancies should be dealt with by an oversight committee.

    - An alternative post hoc process is to have a set of “fuzzy” buckets for the assignment of letter grades. With this process, only the individual professor needs to see the numerical grades – either from continuous assessment or the final examination. After all these numbers are only an intermediate means to an end – a letter grade. This can be done by **ranking** the class members based on their total (continuous assessment + final examination) marks and assigning letter grades. Inspection of the raw numbers may be used to look for natural breaks. The following “fuzzy bucket” guidelines could apply:

Grade	%	% Range			
A+	5	0 – 10			
A	5	0 – 10	Min 10	Av 20	Max 25
A-	10	5 – 15			
B+	20	15 – 25			
B	20	15 – 25	Min 50	Av 60	Max 70
B-	20	15 – 25			
C+	10	5 – 15			
C	5	0 – 10	Min 10	Av 20	Max 25
F	5	0 – 10			

Chapter 49

An alternative approach to teaching ergonomics by Scenario Analysis

Study Scope

The ergonomics researcher, professional or practitioner is often faced with complex situations and has to decide on an approach to the problem including consideration of:

1. What are the important problems? What are the purposes of the investigation?
    a. Are there problems of system effectiveness?
    b. Are there efficiency, productivity, or cost implications?
    c. Are there health and safety problems? What are the probabilities of “human error or failure”? What are the implications or consequences of system failure? Are the effects acute or long term?
    d. Are there issues of human preference? Opinion?
    e. Are there individual and social issues involved?
2. What data or evidence is needed?
    a. Do accurate, reliable, and valid data / evidence already exist?
    b. Are there any existing design guidelines or standards that are not being applied?
    c. Can data be obtained by simple observation or questioning of those involved?
    d. Should a formal survey or observational approach be used?
    e. Can physical mockups, modeling or simulation be used?
    f. Can the investigation be carried out in the laboratory? In a simulator, or in the field?
    g. Is a formal controlled experiment needed? What about sample selection and size? What about experimental design? What about confounding? What about subject selection?
    h. Is there need for a multi-pronged approach to the collection of evidence?
    i. How long will it take to collect the data? How much will data collection cost?
    j. What equipment and methods should be used?
    k. Are there any human subject and institutional review board issues with your proposed approach?
3. Which measurement and analysis tools should be used?
    a. What tools should be used to collect, process and analyze the data?
    b. Are the approaches validated and calibrated?
    c. Is significance of differences or associations important?
4. What designs or changes are indicated?
    a. Do the suggested designs or changes include hardware, software, or operations?
    b. Are user selection and training needed?
    c. Will facilitators help? – Instructions, warnings, labels, checklists, procedures, tutorials, augmented reality?
    d. Will the changes require careful implementation, persuasion and monitoring?
5. How should the changes be justified and communicated?
    a. What effects will the changes be expected to have?
    b. How long will it be before the changes have a detectable / useful effect?
6. How should the effects of human variability be assessed and communicated?
    a. To whom should the results be presented?
    b. How should the results of the investigation be communicated? – Presentation, report, process requirements, system design specifications, guidelines, standards.
    c. How should graphs, tables, diagrams, photographs, statistics, verbal arguments, demonstrations be used?
    d. Are the results of the investigation suitable for publication in academic, professional or trade literature? Are the results proprietary? Could the results be used in court cases?
7. How should the effects of the changes be evaluated?

a. Is there a plan for monitoring the implementation and effects of the changes?
b. Will these evaluations be specific to the particular situation or will they have general applications?

Possible study scenarios

The reader is invited to address each of these aspects of an investigation with regard to the following scenarios.

1. The observations of air traffic control and the communications from the pilot of a small airplane indicated that he was acting irrationally shortly before the plane crashed. The pilot was relatively inexperienced and was not trained to fly at night over open water using his instruments. You have been asked to comment on the possibility that hypoxia was a leading factor in the accident. Describe how you would prepare for your presentation to the board of enquiry, which may include members not familiar with physiology?

2. You are SCUBA diving at a depth of about 90 feet in relatively warm water in the Caribbean. You notice that a relatively inexperienced pair of divers appear to be in difficulties and are repeatedly looking at their pressure and depth gauges and dive computer. Given that you have a PADI instructors certification how would you assess the possible causes of the problem and what information would you seek and what advice / instructions would you give? What are the implications of alternative responses to the problem? How would you evaluate alternative equipment designs and training to prevent such incidents?

3. You are a newly hired ergonomist in a large gas and oil company that produces, transports, stores, processes and distributes products under pressure. You have been given the task of reviewing the instrumentation used throughout the processes to reduce the probability of human error by the process controllers. How would you use your knowledge of the gas laws (Charles Law, Boyles Law etc.) to recommend changes in display design? What help would you seek from experienced chemical engineers?

4. You have been asked by a university vice president for facilities to advise on the seating design for a new basketball stadium donated by a rich alumnus. How would you address the challenge of human variability in your recommendations? What criteria would you use in the evaluation of alternative designs? What recommendations would you give and how would you justify them?

5. You have been asked to design a seat for a new fork truck, which is to be used to move materials in and out of trucks parked at the loading bay, to temporary storage areas and then to sites of operations throughout a large manufacturing plant. How would you address this task and evaluate the appropriateness of alternative designs?

6. You have been engaged by a commuter airline to investigate the numerous complaints about seats. How would you approach your task? An approach proposed by the CEO is to provide adjustable seating and to charge a premium for people who take up more space. How would you implement this approach?

7. A major league baseball club is planning to address the challenge of soaring salaries by opening its batting cages for the general public to pay to participate in a new game – hitting baseballs for distance with different implements and different ball speeds – from 0 to 100 mph. What factors would affect the distances achieved? How would you design an investigation to evaluate the effects of equipment design, ball speed and individual differences?

8. A major league football club is interested in alternative biomechanical strategies for their defensive linemen. They have engaged you to develop a computer based model of the locations, directions and sizes of the forces involved, including issues of friction, but excluding holding and tripping. How would you go about this task?

9. OSHA has engaged you as a consultant to evaluate and modify the NIOSH lift equation for application to single lifts. Their objective is to account for all possible factors associated with acute injuries to people in the warehousing and construction industries. What biomechanical factors would you consider important? How would you develop a model of injury likelihood? How would you validate this model empirically?

10. You have been engaged to investigate an epidemic of bad backs in a large data processing facility. The union leadership has offered the opinion that all the desks and chairs should be replaced by adjustable units, based on a numerical fitting matrix. The union membership would rather just have the adjustable chairs. Management is prepared to pay for either new chairs or new desks, but not both. How would you approach this problem? How would you plan an evaluation of the effects of the changes? How would you justify your findings to the scientific community?

11. A nonunion precision, labor intensive manufacturing facility is being pressured to reduce costs and increase productivity, while maintaining its historic high-quality standards. The management approach is to introduce a team structure along typical Japanese line. What would you expect to be the long-term outcome of this situation? How would you monitor the effects of the changes?

12. A colleague with a business school background has asked you to explain the Hawthorn effect to a professional seminar for accountants. You may expect that they had all taken an organizational behavior class. How would you communicate to your audience that the causal factors for individual and group behavior may not necessarily be related to their organizational design strategies?

13. When you get into a rental car you have various expectancies regarding the locations and direction of operation of the secondary controls such as climate control, entertainment systems, seats, and windows. These expectancies are based on basic spatial relationships and your experience with other vehicles and control operations. How would you address the designers of future cars, the marketing departments, and their managers regarding the importance, or otherwise of standardized control locations and operations? What kind of arguments against your ideas do you expect to face? How would you deal with these arguments?

14. When you want to increase the flow of water from a tap you turn it counterclockwise. When you want to increase the volume of your radio you turn it clockwise. How would you investigate and design an electronic interface for the control of the temperature of a shower (assuming that you could be sure that you would not electrocute the subjects during your usability trials?)

15. One difficult job for an astronaut is the control of a six-degree of freedom robotic arm. This involves the use of two controls – one for pitch, yaw, and roll and the other for the three translation axes. The astronaut also makes use of multiple cameras, with similar controls, but which, because some are mounted on the arm and some are on fixed stations, provide different views of the scene at different times of an operation. How would you apply your knowledge of expectancy and compatibility to the design of controls and training methods?

16. Foundry workers are required to clean out hot furnaces. Time is of the essence as the costs of shutting down and starting up the furnaces in terms of productivity are extremely high. Consequently, management would like to get the maintenance operators into the furnaces as quickly as possible after shutting down. Describe your approach to data collection, analysis, and intervention, including personal protective equipment and administrative controls. How would you explain heat stress to the workers and managers?

17. You have been engaged by the Army to acclimatize the infantry for very physically demanding work in a desert war zone. How would you assess the effects of alternative and complementary intervention approaches?

18. You have been engaged by a local school board in Texas to investigate the dangers of starting aggressive football training on July the first. How would you assess the physiological effects of alternative training, monitoring and intervention strategies?

19. You have been asked by the government to develop easy to use rules for manual materials handling in large hardware stores that can be easily implemented assessed and understood, like traffic control rules. How would you research the background to this task? How would you quantify, implement, enforce, and evaluate the rules?

20. The biggest challenge to ergonomists is human variability. Individuals vary on many dimensions and most tasks involve many human attributes. How can you justify simple 5percentile type rules? What other forms of rules could be developed and applied so that most of the population could be productive and safe in their work?

21. Many ergonomics situations involve tradeoffs between productivity and safety. These issues are notoriously contentious. How would you develop and implement a rule based approach to the challenges of baggage handling at airports or in nursing homes.

22. You have been engaged by the Department of Homeland Security to design the jobs of inspectors who must screen thousands of people a day with the challenge of identifying a few terrorists. The Department is increasingly sensitive to the problems of false accusations. Given that all physical avenues (lighting, image enhancement, training, etc.) to improved detection have been exhausted, what organizational strategies could be applied to improve inspector performance?

23. Car driving is becoming increasingly complex with fast speeds, traffic congestion, complex vehicle features and increasing numbers of non-driving tasks led by the ubiquitous cell phone. Given that driver performance is related to distraction levels but that the effects of distraction are situationally specific and often of little importance how would you use laboratory, simulator, and field methods to develop guidelines for driver attentional management?

24. You have been asked by a major wine producing company to plan an evaluation of wine tasting methods in a task that compares home produced wines with imported wines. The plan is to have large groups of volunteers assemble on Friday evenings for three-hour wine tasting sessions. Given that wine can be assessed by sight, smell and taste you are expected to distinguish between the roles of these senses and the possible interaction effects. You are also required to produce and evaluate criteria for measuring individual differences in wine tasting behavior and performance. Finally, you are expected to assess the likely order effect in performance and time into session, assuming of course that designated drivers accompany all participants.

25. People come in all shapes and sizes and clothes manufacturers address these challenges by discrete sizing systems, sometimes with a little bit of adjustability. Fine tuning is carried out on the sewing machine and if all else fails sartorial license rules. Given the advent of whole body scanning techniques there is a wealth of new information that could be brought to bear on clothing design. Devise a field fitting method for men’s suits using whole body scanning and while you wait sizing and adjustability.

26. Common experience demonstrates that individuals familiar to the observer can be recognized under limited lighting and exposure duration conditions, especially if movement information is added to shape and size. Identify a set of features that are likely contributors to this shape recognition task and develop a laboratory experiment and computer-based method to test your hypotheses.

27. Sheldon developed an easy to understand method of somatotyping that has become less popular in modern times. Devise an experiment involving both anthropometric measurement and subjective perception to evaluate Sheldon's model.

28. Contemporary advertisers highlight key features and associations of products, such as cars, to inflate customer's general impression of the product. A challenge to such processes is that the products do not differ a great deal objectively on these dimensions. Devise a field experiment to investigate the halo effect in car purchase behavior.

29. Multiple choice or "objective" tests are used widely in education and professional certification examinations. However, many educators still consider that essay type or problem solving answers tell more about the student's analytic and communication capabilities. Devise an experiment to test the reliability of both forms of examination.

30. The interview has been shown on many occasions to be an unreliable method of personnel selection. However, most managers still place considerable weight on their own judgment capabilities during interviews. Devise an experiment to evaluate the reliability or otherwise of individual and panel interview processes.

31. The methods of psychophysics are generally applied to assess the abilities of individuals to make judgments on single physical dimensions such as size, weight or color. The results of these experiments are usually reported in terms of "just noticeable differences" that are detected on 50 percent of trials. Devise an experiment to establish the relationship between a physical dimension and a standard and the proportion of

32. You have been asked to advise a retail chain on the perception by customers of package size and perceived value. How would you apply psychophysical methods to this task?

33. Psychophysically derived differences do not always estimate operationally significant differences. You have been asked by a fast food retailer to address the perceived hamburger size issue, with a view to cost cutting on the amount of meat used. Develop a field experiment to detect customer judgment of hamburger size.

34. Use a psychophysical experiment to assess the perception of speed – baseballs, cars, trains, airplanes, hand movement, running, walking etc.

35. Carry out a simple experiment to measure human errors (and human variability) in the recall of digit and letter strings of different lengths. Repeat the experiment with mixed lists and grouped sequences, including meaningful and nonsense syllables.

36. Write down at least 50 codes associated with person or product description. Investigate how these codes are processed.

37. You have been asked by the State Department of Transportation to revolutionize the way in which people, vehicles and licenses are coded. How would you investigate the current problems of errors and productivity? What new designs would you suggest? How would you implement and evaluate the new designs?

38. Everybody knows about learning curves, but very few people actually quantify their own learning curves. Devise an easy to use process to measure and predict changes in performance over time in booking a flight on the web, knitting, running or walking one mile, throwing darts, reading etc.

39. You have been hired by an automobile manufacturing company to investigate how many cycles it takes to get a new car line moving at a rate of one car an hour to 60 cars an hour. How would you go about this task? What about quality?

40. Murphy's law states that if anything can be done to cause a catastrophe then someone will do that thing. Research the web for the Darwin Awards and explain why these priceless individuals did obey Murphy's Law.

41. You have been engaged by the Office of Homeland Efficiency to investigate why airline flights are held up because of bizarre human behavior. How would you collect appropriate data on these relatively infrequent events? What changes would you suggest recognizing that you must not interfere unduly with the obedient majority?

42. You have been engaged by a cell phone company to investigate all possible failure modes of the system that are due to inappropriate human behavior. How would you investigate these problems?

43. You have decided to go into the wall and ceiling papering business, as you believe that there are a lot of surfaces out there waiting to help you make your fortune. You have estimated that one casual helper can paper three 20 * 15 * 10 rooms (3000 ft^2) in an 8 hour day, and that you should charge by the square foot ($0.10 plus materials) and not by the hour. Unfortunately, on day one you only manage to finish one room. How would you investigate the physiological causes of this low productivity? How would you revise your estimating procedure in order to make $1,000,000 per year, always assuming that you stayed competitive?

44. You wish to describe and demonstrate local muscle fatigue and recovery to a class of unruly high school students, noting that different muscle types fatigue at different rates. Devise a demonstration that involves the whole class and results in data that can be used for a peer-reviewed publication. How would you account for individual differences? What methods would you use? What experimental design would you employ? How would you address the order effect?

45. You have been engaged to investigate why the productivity of some employees in a parcel handling center stays constant over the 12-hour shifts while that of others declines significantly. How would you investigate the effects of general physiological fatigue. What changes in work design would you make given that no new equipment could be purchased?

Chapter 50

Authentic Assessment: One Page Reporting

Introduction

It is ironical that this discussion of one-page reporting should take the form of many pages of written material. Consequently, a summary of this discussion is offered in the appendix as a one page report. Assessment has three main purposes; the first is feedback to the student and teacher in order to confirm their understanding or generate further explanation of the problem at hand. The second purpose is grading, to either confirm an absolute level of understanding – criterion based grading, or describe the attainment of the student relative to the rest of the class or a wider cohort of students – norm-based grading. A third, implicit or explicit, purpose of grading is prediction of future performance. According to Ashford-Rowe (2013), an authentic assessment will need to meet the following criteria:

1. Does the assessment challenge the student?
2. Is a performance or product required as a final assessment?
3. Does the assessment require a transfer of learning?
4. Does the assessment require metacognition?
5. Is fidelity required in the assessment?
6. Does the assessment involve discussion and feedback?
7. Is the product of assessment recognized by the stakeholders as being authentic?
8. Does the assessment involve collaboration among students?

In traditional measurement terms these criteria may be described as precision, accuracy, reliability and validity. Another semantic breakdown of the process describes landmark, route and survey knowledge in complex task understanding, with survey knowledge implying a higher level of metacognition (Oman,). The Bloom taxonomy (Bloom, 1956) and its extensions, widely used in education circles offers a hierarchy of knowledge states from literal retention to the demonstration of creativity. A fifth classification, often used in the literature on expertise is the knowledge, rule and skills based behaviors of operators controlling complex systems (Rasmussen, 1983). One difference of the Ashford Rowe characterization is that it includes qualitatively different criteria, such as feedback, collaboration, and stakeholder involvement.

A review of Question Theory (Graesser, Lauer and Peacock, 1992) indicates that a question, depending on its wording, may elicit different forms of response. Assessment in education covers the full spectrum of question types and expected responses, from the cryptic Yes / No and multiple-choice forms, through short answer and calculations to long essays. The context of the assessment may be in the form of a final examination or part of a continuous assessment process. Questions embedded within a lecture may also be of value in assessing individual and class understanding and providing an indication that further elaboration of an item may be needed (Peacock, 1982). In medicine and skilled trades' apprenticeships the *viva-voce* examination is the norm in which the expert uses questioning to explore the breadth and depth of the student's (apprentice's) knowledge and skills. In flight training the instructor or examiner observes the student pilot's behavior and poses real time constrained questions. A research question - the research hypothesis – will require an extended dialog including an introduction, a description of the investigation methods, the results, a discussion and conclusions. The research paper will also be expected to include references to complement the hypothesis, methods and conclusions. Theses, dissertations, and reports will usually contain much greater detail.

Before moving on to more details it is pertinent to discuss the issue of plagiarism. A tongue in cheek definition of plagiarism is that it means stealing from someone, whereas research is stealing from many. Professional practice relies on multiple sources. Education is by definition plagiarism; people learn from others. Teaching and learning specialists will be quick to point out that the process of learning involves a creative contribution by the student in the amalgamation of multiple sources and concepts to establish a personal understanding. In the present context – authentic assessment through one page reporting – especially in this electronic age, it is unthinkable that the student should not make full use of available sources. The only constraint is that the student should acknowledge his or her sources.

One Page Reports

The discussion so far has briefly explored the many purposes, contexts and processes of assessment to offer a context for one-page reporting as a versatile and authentic assessment mechanism. The one-page report is solicited by a question which indicates its purpose, scope and to some extent format. The important rule is that the response should be limited to one page. However, especially in the context of e-Reporting there may be the opportunity for links to supporting information or more detailed explanation. A second rule of one-page reporting is that it should contain a title, an author(s), a date and a contextual reference, such as the class code. There are no more rules and the authors are encouraged to make creative use of text, diagrams, tables, charts, pictures etc. to tell a story – the answer to a question.

In the educational context, one-page reports can be used for many purposes and take many forms. They can be homework that is graded as part of a continuous assessment process. They may be individual, or group based. They may be used to report progress in an ongoing project, such as a Capstone project. They can be used as a final examination answer; in this case the student will (quickly) make notes on the left-hand page and then create his or her OPR on the right-hand page. In the world outside education, communication must be concise and be consequential. Managers and managers' managers do not have the time or need to read the detail, they expect integrity, clarity and accuracy; they also expect the report to have consequence – it will lead to some decision or action.

Referring back to the "authentic assessment" discussion there are some guidelines for the creation and assessment of one-page reports:

- Complete: The report should be effective and comprehensive in answering the question
- Concise: The report should be efficient in the use of words and other media
- Creative: The report should make full use of multiple media
- Catching: The report should be attractive
- Collaborative: Reports may be individual, but preferably involve collaboration
- Clear: The report should be uncluttered and elicit intended search patterns
- Challenging: The question and report should have substance
- Consequence: The report should indicate some conclusion, decision or action
- Clarification: The report should include links or references to supporting evidence
- Copacetic: The reporting and grading method must be acceptable to all concerned

Accuracy, reliability and validity in grading have their challenges. Multiple choice, yes / no and short answer formats tend to be more accurate and reliable (repeatable) than other forms although item analysis is needed to remove inconsistencies. Longer answers, although more searching, open the door to semantic misconceptions and judgmental bias among the graders. Scenario based questions may be useful to explore the transfer of theoretical knowledge to an applied context. Grading rubrics may be of value in guiding the examiner towards greater consistency, but most examiners will reserve the right to interpret and judge alternatively presented responses.

One page reporting is a very flexible medium and so assessment needs to be equally flexible, while retaining sufficient precision, resolution, accuracy, reliability, resilience and validity. A generic rubric is to assess the report on breadth, depth and presentation, using five point scales and verbal anchors. A holistic approach is to subjectively sort the reports by paired comparisons, into 3 to 5 groups. For homework purposes a criterion based method may be applied to sort the reports into two or three groups (fail, sufficient, outstanding). Where greater fidelity is required, content criteria need to be specified and ordinal marks assigned. For example, a report on an experiment may need an introduction, background, hypothesis, method, results, discussion, conclusions and references, each scored on say three-point scales. Project update reports may include purpose, recent activities, barriers, and planned activities.

Readability is a perennial problem in grading and one-page reports can lead to the temptation to include too much detail. One way of ensuring readability is to require a minimal font size, say 10 or 12. However with electronic reporting it is possible to enlarge the reading area. Also, with electronic reporting, hyperlinks to supporting material are easily created. Twitter and other social media have shown the power of eye-catching tweets and more substantive links. For many years newspapers have used headlines, summaries and greater detail if needed; newspapers have also shown the value of multiple formats. Academia also makes use of titles, key words, abstracts, full text and appendices. One-page reporting, especially in the electronic form should make use of all these strategies.

Posters

The poster medium has become a familiar sight at academic conferences and within academic organizations for reporting on Capstone projects. In some circles, the poster is viewed as inferior to a full twenty-minute presentation. The poster is often the first experience in publication for a graduate student. Various full paper and abstract proceedings are published in both hard copy and electronic form. The poster, which is simply a larger version of a one-page report, is widely recognized as a more effective two-way communication device than the presentation. Observation of the posters at academic conferences shows enormous artistic creativity and very varied levels of detail. It is common for poster presentations to be supplemented by take away one-page reports. Some conferences use a brief presentation (5 minutes) to direct the audience to the posters for more detailed small group discussion. The one-page report in a class may be seen as a steppingstone towards poster presentations.

Experience with one-page reporting

One page reporting was used widely in a major multinational manufacturing company. There was no need for long winded academic explanation and justification. The practicing engineer was required to report the results of his or her analysis, investigations or experiments and communicate the results and implications to management in a regular program meeting. Typically, the one-page report was complemented by a presentation and supplemented by details where needed. On occasion, the one-page report was an amalgam of key slides from the presentation. The reports were easily filed and searchable and provided a historical record of the evidence behind program decisions. The process was regarded as generally effective and efficient.

Space Human Factors Projects

The NASA space human factors organization provided major funding for internal scientists, academics, and technical subcontractors. These projects usually lasted one or more years and reported to NASA scientist site visits or at annual conferences. Other reporting was through papers to technical society conferences. A routine quarterly process of one-page reporting that summarized progress, barriers and plans greatly helped with program management.

Recent experience with one-page reports

Over the past few years one-page reports and posters have been used in a variety of courses, including: System Safety, Socio Technical Systems, Human Factors in Engineering Design, Industrial Engineering Techniques, Discrete Event Simulation, and Aerospace Human Factors and Occupational Biomechanics. To date there have been a few hundred reports presented, with very wide variation in format, but generally sufficient or outstanding content and presentation. Typically, a group based one page report is required after each of the classes on a topic related to the content of that class. Apart from the requirement for a Title, Names, Course and Date, the students may use any format they wish to construct the report, which is presented in both hard and soft copy format. The final group-based poster presentations are usually an expansion of one or more of the homework reports. Evaluation of these reports is by a combination of the lecturer and peer grading, using a template that indicates ordinal assessment of breadth, depth, and presentation. Comparison of lecturer and peer grades shows a high level of correlation.

Discussion

One-page reporting meets the criteria for Authentic Assessment to varied extent:

1. Complete: The report should be effective and comprehensive in answering the question
   a. By imposing content guidelines, the one-page reports generally cover the required content
2. Concise: The report should be efficient in the use of words and other media
   a. The reports are generally, by definition, concise; some groups attempt to put too much detail into the reports but improve with practice.
3. Creative: The report should make full use of multiple media
   a. The evidence shows great creativity; often within a group there is a student with an artistic flair and the others chip in with content
4. Catching: The report should be attractive
   a. With practice the students make increasing use of color, pictures, diagrams, charts, data, and varied font sizes
5. Collaborative: Reports may be individual, but preferably involve the many advantages of collaboration
   a. Students are given a choice of group size, up to five or six. A few students prefer to work alone, but these reports are generally inferior. Perhaps this is not a reflection on individual work, rather a reflection on some individuals who chose to work alone. Most student groups welcome the opportunity to collaborate
6. Clear: The report should be uncluttered and elicit intended search patterns
   a. The reports vary considerably in their clarity; some use very small font size and simply dump detailed, rather than summarized data tables into the reports. Feedback and practice is needed
7. Challenging: The question and report should have substance
   a. Generally speaking, each class for which a report is required covers a well-defined technical area. Student groups offer different levels of understanding as articulated by Bloom. It is important to use the Bloom Taxonomy in articulating the questions to be addressed by the OPRs
8. Consequence: The report should indicate some conclusion, decision or action
   a. To date experience with class OPRs is that they generally tend to be retrospective rather than offer creative approaches to real world problems (questions). Here again there is an opportunity to improve the question wording.
9. Clarification: The report should include links or references to supporting evidence
   a. Some reports make no references, some only to Wikipedia and some offer extensive electronic and journal / textbook / class notes references. Guidance here may be warranted
10. Copacetic: The reporting and grading method must be acceptable to all concerned
    a. An opportunity is given to the students to offer their reflections on the method of one-page reporting. Some are widely supportive based on their creative efforts; others complain that the reports are time consuming and that group collaboration is logistically challenging.

Conclusions

Education is about motivation, explanation, participation and examination. The group based one-page reporting method for homework and project progress has been shown to have merit in both these areas. The OPR is a natural forerunner and training opportunity for the final project poster. Future developments of the OPR as a medium for “explanation” beyond the material presented in class and the textbook could be explored. As an assessment tool various OPR grading rubrics of various levels of detail may be proposed. At the poster level, peer assessment is shown to be a reliable method by comparison with lecturer evaluation. OPRs for project update and discussion save considerable time in meetings. The use of the OPR medium for final examinations merits more investigation.

1. Peacock, B (1982)"The Feedback Classroom," Proceedings of the Annual Conference of the American Society for Engineering Education, Texas A&M University
2. Graesser, Lauer and Peacock (1992) ‘Questions and Information Systems”, Lawrence Erlbaum

Chapter 51

Human Factors Scenario Based Examination Questions

1. Introduction

The old Chinese proverb: "Tell me and I'll forget; show me and I may remember; involve me and I'll understand" is incomplete. It is appropriate to add "test me and you'll know that I understand" to complete the educational process of evaluation, assignment of credit, certification and licensing. There are various descriptions of human knowledge and abilities that may be assessed during or after a period of instruction or learning as in a college course. First, Bloom described a hierarchy of cognitive abilities: Knowledge, Comprehension, Application, Analysis, Synthesis and Evaluation, later the ability to Create was added to this list. Reason described knowledge, rule, and skill based behavior as a progression from novice to expert. A third classification (Hanchana) of human abilities is cognitive (knowledge), affective (emotional, attitude) and psychomotor (physical skills). Specific application of these concepts to the development of tests usually involves the use of key words, many of which are found in articles about the Bloom taxonomy.

2. Scope

In the context of a general human factors course it is appropriate to teach and test a broad spectrum of knowledge, to require students to apply this knowledge, and to use their acquired knowledge in the processes of analysis, synthesis, evaluation and creativity. The broad scope of human factors or ergonomics is articulated clearly in the Edwards SHEL model. The "liveware" element of this model includes physical (anthropometry, biomechanics, physiology, motor skills), informational (sensory processes, attention, perception, memory, and various aspects of cognition, communication and control.) Next it is appropriate to address contextual factors such as the physical, operational and social environment that may be amenable to mitigation if not design. Finally, in the applied context of human factors, it is appropriate to address the design of technology (hardware and software) and processes (the interactions between people and technology,) to match the human physical and information handling capabilities and limitations described earlier. Extensions of human factors into the affective domain require that designed systems and processes should be likeable and motivating.

3. Approach to scenario-based examination questions

a. These questions usually address the higher levels of cognitive skills
   i. Apply, Analyze, Evaluate, Develop
   ii. They also reflect the lower levels of Knowledge and Comprehension / Understanding
   iii. Design and Create are usually assessed outside the examination room
b. Read the questions
c. If there is a choice, select those questions with which you feel most comfortable.
d. Check the time available and allocate an appropriate amount of time to each question: no answer no marks!
e. Underline or circle key words:
   i. Verbs – what you must do
   ii. Nouns – the context, what you must produce
   iii. Tools - the identified HF process
f. Develop a concept map (mind map), list or other framework of your answer
   i. Use the blank left-hand sheet in the answer book
   ii. This is not a formal part of your answer, but the examiner may be impressed by your systematic approach to the problem

iii. Use this framework to structure your answer

g. Check that you have chosen the best questions to answer
h. Respond to every key word in the question
i. Compile your answer
j. Read your answer
k. Modify or amplify where necessary
l. Leave time at the end of the exam to reread your answers and correct / modify where necessary
m. For example if your exam has 10 short questions to be answered in 2 hours, you should allocate 10 minutes to a preliminary read through (120 – 10 = 110), 2 minutes planning your answers (110 – 2 X 10 = 90), 8 minutes for each answer (90 – 8 X 10 = 10) leaving10 minutes at the end to check your answers. Of course there will be some variability, but not too much, remember no answer no marks!

4. **Given this background the following scenario-based examination questions, which address scope, breadth and depth, will be analyzed and discussed:**

a. Physical Ergonomics

i. Anthropometry and workplace design

1. *Describe how you would obtain and apply anthropometric and operational data to design and evaluate an auditorium to seat 100 students.*
    a. *Data collection*
    b. *Data analysis*
    c. *Design approach*
    d. *Design evaluation*
2. *Repeat for a computer workstation, supermarket checkout, bus driver's cockpit*

ii. Biomechanics and manual materials handling

1. *Analyze epidemiological and incident report evidence as a basis for the redesign of an airport baggage handling process*
    a. *Injury reports*
    b. *Incident reports*
    c. *Process design*
    d. *Stage manual handling activities (Passenger, check in clerk, baggage handler)*
    e. *Physical layout(s), equipment, handling aids*
    f. *Motions and moments analysis*
    g. *Design recommendations*
2. *Repeat for UPS / FedEx driver, Park / garden maintenance worker*

iii. Physiology and job design

1. *What methods would you use to assess and manage the physiological stress of a waitress in a busy restaurant that serves meals from 6 am to midnight?*
    a. *List the methods:*
        i. *Physiological: oxygen consumption, heart rate, body temperature*
            1. *Discuss process, and ease of use*
        ii. *Reported stress (Borg scale)*

iii. *Incident reports*
iv. *Interviews and focus groups*
v. *Diaries*
vi. *Shift schedules*
vii. *Rest breaks*
viii. *Job rotations*

b. *Repeat for security guard, nurse, professional athlete*

iv. Psycho-Motor Skills

1. *You have been asked to manage the line balance of an electronics equipment production line, given a high turnover of operators. Discuss what steps you would take to measure the individual task elements, group them into feasible, balanced tasks, assign tasks according to motor skill ability and redesign the product to facilitate assembly.*
    a. *Operations flow / sequence chart*
    b. *Micro motional analysis*
    c. *Element grouping*
    d. *Individual skills assessment*
    e. *Job cycle design*
    f. *Task assignment*
    g. *Training, job rotation and job enlargement implementation*
    h. *Product and process evaluation to redesign assembly tasks– target size, postures and motions, forces, visual conditions, error checking and error proofing*
2. *Repeat for food preparation employees, drivers*
3.

b. Information Ergonomics

i. Sensory factors

1. *Many tasks such as reading instructions, fine assembly and inspection work or complex tasks such as driving depend on good visual performance which is facilitated by good lighting. Describe how visual acuity is affected by individual differences and lighting conditions. Describe how visual acuity and lighting can be measured. How would you design a facility for hand phone repair?*
    a. *Eye anatomy and function*
    b. *Visual acuity measurement*
    c. *Lighting and acuity*
    d. *Lighting environment design*
        i. *General and local task lighting*
        ii. *Glare factors*
        iii. *Color factors*
    e. *Work station design, including postures and lighting*
        i. *Vision aids*
    f. *Selection and job design*
        i. *Knowledge and visual capability*
        ii. *Rest pauses*
2. *Repeat for proofreader, driver, classroom, lighting*

ii. *Attention*

1. *You have been asked to investigate and evaluate the performance of security guards in a shopping mall. Describe how you would measure behavior, performance and vigilance decrement. How would you redesign the job to raise the level and increase the sustainability of performance?*
    a. *Task analysis*
    b. *Behavior measurement*
    c. *Performance measurement*
    d. *Vigilance decrement measurement*
    e. *Reliability*
    f. *Resilience under abnormal conditions*
    g. *Design, including technology, operations and training.*

iii. *Repeat the exercise for customs and immigration officers, drivers, pilots, air traffic controllers, process controllers*

iv. Perception

1. *Our perception and understanding of the meaning of information presented to us through our eyes or ears requires that that information is matched with some more or less sophisticated template, set or framework. As we gain familiarity with the information source, form and content our perceptual capabilities increase, and our understanding improves. So perception and understanding require a coincidence of external information and an internal framework. Where mismatches occur, we may see or hear what we expect to see or hear, which may lead to perceptual errors or illusions.*
    a. *Describe the challenges of a conversation in a foreign language*
    b. *How does redundancy improve perception and understanding?*
    c. *When we look at a mathematical model how do we visualize the physical realization of that model?*
    d. *When we see the face of a person in a crowd how do we recognize it as belonging to a friend or acquaintance? Why do we sometimes make recognition mistakes?*
    e. *When we read or listen to complex instructions, such as how to go to a location in a strange town or campus, how to operate the ATM, how to taxi back to the ramp in a strange airport, how to make a meal or how to assemble new piece of furniture, why do we make mistakes?*
    f. *What are illusions? Describe some examples of illusions.*
    g. *Suggest ways in which misperceptions can be prevented:*
        i. *By improving the perceptual set or eliciting the correct set by preamble*
        ii. *By improving the message content*
        iii. *By adding redundancy*

v. Cognitive factors

1. *Driving a car, flying an airplane and cooking a meal all require continuous attention to changes in the operational environment, recall of procedural knowledge, ongoing operational memory and situation awareness, decision making, control and communication inputs, and outcome monitoring and evaluation. Describe the operational and cognitive demands required to make a meal. Analyze the opportunities for error. Identify the cognitive resource(s) responsible for the errors. Suggest ways of preventing errors, detecting errors, and mitigating the effects of errors.*
    a. *Describe operational sequence*
    b. *Describe cognitive demands*
    c. *Analyze error possibilities*
    d. *Identify cognitive resource basis for the error*
    e. *Suggest ways of preventing errors by materials, equipment, or process design*
    f. *Suggest ways of detecting errors and intervening to reduce the effect of error (mitigation)*
2. *Repeat for driving, flying, crane operation, exam script grading*

vi. Memory

1. *Operational memory requires the retention of pertinent facts and procedures as a task is conducted. The capacity of operational memory is limited. Irrelevant information is discarded. Relevant information may be retained by rehearsal. Failure of operational memory is often due to interference from competing sources or overload. Analyze your use of operational memory for a series of your daily tasks.*
    a. *Identify the information sources*
    b. *Estimate the duration of retention*
    c. *Describe competing / interference sources*
    d. *Specify the required outcome*
    e. *Analyze the causes of forgetting*
    f. *Design memory aids for each task*
2. *Repeat for a call center / help desk operator, shopping*

vii. Situation awareness

1. *Situation awareness is a necessary human capacity (and limitation) in flying an airplane, controlling an electricity generating plant or playing a game of football. The key components of situation awareness are perception, comprehension, and prediction.*
    a. *Analyze a familiar sequence of events in a football (or similar) game.*
    b. *Identify the human resources needed to achieve and maintain situation awareness.*
    c. *Discuss the possible cognitive causes for lost situation awareness and the implications of this performance failure.*
    d. *Suggest ways of improving situation awareness by*
        i. *Operator behavior*
        ii. *Task design*

viii. Communications

1. *Communication is a key activity in most human activities. Communications may be between people or between people and technology. Communications may fail due to semantic or physical encoding, transmission, physical or semantic decoding, memory, lost information, added information or noise. Consider the context of an air traffic controller and a pilot or a restaurant client, waitress and a cook. Describe the nature of communications involved in approaching and landing at an airport or ordering and delivering a meal. Identify the opportunities for error, and their implications. Describe mitigation procedures when errors occur. Design a process to prevent errors in.*
    a. *ATC – Pilot communication*
    b. *Ordering at a restaurant*

ix. Control

1. *Manual control operations involve inputs, external conditions, system outputs, time lags and feedback. Improved performance may be due to anticipation of external force effects, rule-based adaptation to outputs or learning based modulation of inputs based on memory. Consider four scenarios*
    a. *Controlling room temperature by altering the amount of heating / cooling, or by setting a desired temperature and relying on automatic control.*
    b. *Driving a car or bicycle and keeping within the white lines in a road with many bends*
    c. *Landing an airplane by controlling heading, altitude and speed through adjustments to pitch, power, rudder and flaps*
    d. *Playing Angry Birds by manipulating trajectory and force*
    e. *Describe the control elements of these tasks, the opportunity for error, mitigation of error effects and design of equipment or procedures to prevent error.*

c. Affective ergonomics

i. Motivation

1. *The motivation to carry out an activity is related to the payoff associated with success or failure in terms of effectiveness, efficiency, ease of use, emotional appeal, safety security, satisfaction and sustainability. There are always tradeoffs among the importance, likelihood and desirability of these outcomes. Often affective considerations dominate other outcomes. Consider the following scenarios:*
    a. *Going to the gym or out for a run every day. The activity may be uncomfortable, even painful, the time may be inconvenient, the immediate rewards may appear negative,*

but you know that the long-term outcome is better shape, enhanced fitness and greater self-esteem.

b. *Going to a restaurant and ordering an exotic and expensive meal or to a food stall and ordering simple chicken and rice. Both meals may have equivalent nutritional value but will vary considerably in cost.*

c. *Buying an expensive gold Rolex or a $2 watch from a sidewalk stall. Both will tell the time accurately.*

d. *Studying for a boring Human Factors exam or going out to the cinema with your friends.*

e. *Discuss the informational and affective factors, and their weighting, that contribute to your decision in each of these cases*

ii. Attitude

1. *The attitude to work may differ among company owners, who profit from high quality inexpensive products or services, and employees who get a fixed wage irrespective of deviations in quality and productivity. Discuss ways in which the attitudes of employees to work can be changed.*
2. *The attitude of students to a course is related to course content, course difficulty, quantity of work, the delivery methods (lecture, seminar, eProcess or laboratory), the characteristics and behaviors of the lecturer and the perceived value of a grade in the course in the context of an educational program. Discuss ways in which students' attitudes are affected and may be changed.*
3. *How are your attitudes to a service from a waiter, bank teller, shop assistant, taxi driver affected by their behaviors over and above the functional delivery of the service?*

d. Decision making

i. *Decision making is an element of all human behavior and usually affects task performance. Decisions are made out of habit (rule based behavior), evaluation of the costs (effort, money etc.), consideration of all the consequences (negative or positive benefits), the likelihood of the outcomes given alternative decisions, and the opportunities to reverse or tolerate erroneous decisions. Consider the following decision scenarios*

1. *Should you walk, ride your bicycle, take the bus or drive your car to work?*
2. *Should you gamble or invest your savings if you know that the long run probability of losing is greater than that of winning?*
3. *Should you drive faster than the posted speed limit if you know the likelihood of getting caught is remote and the penalty for getting caught is minimal?*
4. *How are your decisions affected by the packaging and esthetic design of a product over and above the products function and reliability?*

e. Contextual factors
   i. Physical Environment
      1. Heat
         a. *The thermal environment has a substantial effect on human comfort, behavior, performance, health and safety. Extremes of temperature can be fatal. Sub extreme temperatures are modulated by behaviors such as choice of clothing or physical activity, or physiological responses such as change in heart rate, cutaneous blood flow, shivering etc. These responses are dependent on the consumption of sufficient fluids and nutrients. A certain degree of acclimatization occurs in these physiological processes. External responses include shelter from radiant heat, fans to increase convective heat loss and heating and air conditioning to control temperature and humidity. Totally controlled microenvironments may be observed in astronaut suits.*
            i. *Describe how you would measure the thermal environment*
            ii. *Describe how you would observe the physiological responses to changes in the thermal environment.*
            iii. *Outline the design of a thermal environment protection program for outdoor workers in Singapore*
      2. Light
         a. *Light is essential for visual performance. However the visual system is very adaptable to variations in lighting. Consider the contexts of recognition of color-coded electrical wires, driving in the dark, reading labels and instructions on a medicine bottle or the placement of a computer monitor in an office.*
            i. *Describe the major structures of the eye and their functions*
            ii. *How would you measure visual acuity?*
            iii. *How would you measure color discrimination defects?*
            iv. *What are the effects of glare?*
            v. *What is adaptation?*
            vi. *What is accommodation?*
            vii. *Develop guidelines for lighting in a computer repair shop.*

      3. Noise
         a. *Sound may be defined as an acoustic signal generated at a source and received at the ear. Often these signals are meaningful and useful. However on other occasions they may be classified as noise – perhaps meaningful but contextually not useful. The ratio of signal to noise determines the effectiveness of a communication channel.*

Excessive sound levels cause temporary or permanent hearing damage. Consider the following scenarios:

i. *A conversation in a busy restaurant*
ii. *An emergency vehicle in busy traffic*
iii. *Listening to music during a lecture*
iv. *Communication between Air Traffic Control and a Pilot in the context of ambient airport / airplane noise and static (white noise)*
v. *Working in a bottle processing or metal fabrication factory*

b. *How would you measure sound frequency and intensity?*
c. *How would you measure hearing ability?*
d. *What is the effect of aging on hearing?*
e. *How would you protect workers from excessive noise in a factory?*
f. *What are the essential elements of a hearing conservation program?*

4. Vibration and acceleration

a. *Mechanical vibrations can be harmful to anatomical structures and may interfere with performance and comfort. The vulnerability of anatomical structures is related to their size / mass and the frequency / intensity of the imposed vibrations. Accelerations may be described as sudden changes in velocity of an object or person. A jerk is a change in acceleration. Consider the following scenarios:*

i. *A bus or fork truck driver spends 10 hours a day driving a vehicle and being subject to "whole body vibration" through the seat (or feet if he is standing)*
ii. *A forestry worker operates a chain saw all day*
iii. *A foundry worker operates a chipping hammer to clean the flashings off castings*
iv. *A construction worker operates a tampering machine all day long to compress asphalt repairs*
v. *A manufacturing employee uses a power drill or screwdriver all day while fastening components together*
vi. *A passenger on a bus fell and was severely injured when the bus departed from the stop erratically*

b. Answer the following questions

i. *How would you measure vibration?*
ii. *How would you measure the effects of vibration on people?*
iii. *How would you develop a guideline for the protection of workers from vibration transmitted from tools and vehicles*
iv. *How would you prevent accidents due to jerks on public transport?*

ii. Operational context

1. Time factors

   a. *Time is an inevitable contributor to all human experience. Time factors include the time to react to a signal, the time to complete a task, the time spent at work, the time to travel to work or abroad. The time of day and night when you are awake or asleep. How old you are, and so on.*
   b. *What factors affect your response time to a signal such as a traffic light?*
   c. *How long can you sit in a chair without moving?*
   d. *What are your usual waking / sleeping habits?*
   e. *Why do you feel fatigued after a period of physical (mental) activity?*
   f. *How long does it take to decide between two (or more) alternative choices or actions?*
   g. *How long can you focus on a boring lecture?*
   h. *How long should the shift be for an aviation security officer?*
   i. *Describe another 100 ways in which time affects your life*

2. Autonomy

   a. *Many jobs such as those on a production line or in a call center do not allow the operator any discretion regarding his or her activities. The job cycle is precisely analyzed and prescribed. In other jobs external incidents dictate individual responses and actions. Some people have considerable autonomy regarding their activities although they are usually constrained by some required deliverables. Consider the following scenarios:*
      i. *A pilot is landing an airplane, he can't stop. How does he manage information, action and time?*
      ii. *A shop attendant or bank teller waits for the customer request before offering a response, usually from a rule-based set of alternatives. How is his / her behavior affected by pressures for productivity and customer service?*
      iii. *How should a student manage his / her time between studying, projects, recreation, and relaxation?*
      iv. *How should a person on a paced production line respond to a damaged tool or faulty materials?*

iii. Social Context

1. Team behavior

   a. *A team is a collection of people with a common purpose that is usually achieved by cooperation. People normally work in teams of varying levels of structure. Team work normally requires communication, collaboration and situational leadership. Consider the following scenarios:*

i. *Air Traffic Control and pilots must operate as a team to navigate through congested airspace and land safely.*
ii. *City car drivers must collaborate to avoid collisions.*
iii. *A sports team assigns different role to different players at different times with the purpose of optimizing resources and winning the game.*
iv. *A surgical team consists of a surgeon, assistant surgeon, scrub nurse, anesthetist and a patient. At various times different team members take leadership and decision roles, although the surgeon (or patient) may have the final say.*
v. *A project team in a university course may have assigned responsibilities, leadership roles and a requirement to collaborate in brainstorming for report / poster design ideas.*

b. *Respond to the following questions:*
   i. *How would you measure team behavior?*
   ii. *How would you improve team efficiency by allocation of duties?*
   iii. *How are difficult decisions made?*

2. Crew resource management
   a. *Crew resource management is a formalized way of managing team-based activities with appropriate situational allocation of responsibilities. The concept of "resource" goes beyond the team members to include all the technological support facilities, such as maps, instruction books, computer simulations and so on. Develop concept maps to describe the human and technological resources in the following situations, show the key communication links:*
      i. *Emergency approach and landing of an airplane*
      ii. *A search and rescue operation for a missing scuba diver*
      iii. *A food court*
      iv. *A study team*

f. Technology Design
   i. Mechanical aides
      1. *The development of the lever, wheel and pulley greatly expanded human abilities to perform mechanical work. The addition of mechanical power - internal combustion engine, steam and electrical- added another order of magnitude. Nuclear and solar energy add different opportunities and challenges. These inventions also produced control, efficiency, safety, security, and sustainability questions.*
         a. *Sketch a lever, wheel, and pulley, indicate the magnitudes and directions of the forces*

b. *Compare the advantages and disadvantages of motor vehicles*
c. *What are the costs and benefits of walking or riding on a bicycle, or in a car, bus, or airplane?*
d. *Discuss the issue of Inertia in crane design and operation*
e. *Compare the advantages and disadvantages of manual and powered small tools*

ii. Sensory Aides

1. *Immediate sensory aids include spectacles and hearing aids, however sensor technologies such as X Ray, radar, sonar, ultrasound, electrical conduction, electron microscope etc vastly expanded the human ability to observe detail and at a great distance. The addition of computers to store, analyze and respond to the information from sensors and telecommunications to transfer this information are the foundations of automation and robotics. As with mechanical aids, the development of sensory aids brought questions related to efficiency, safety, and security.*
    a. *List and describe the functions of as many sensing aids as you can*
    b. *Discuss the safety and security issues that these technologies bring*

iii. Information aides

1. *Writing greatly extended the human ability to store information; the invention of the printing press expanded our abilities to communicate large amounts of information. The computer, telecommunications and recently the Internet, smart phones and tablets created another giant leap in information communication and analysis. But these devices bring significant challenges.*
    a. *Discuss the challenges of privacy created by contemporary information systems*
    b. *Discuss the challenges of system safety and security that a large information system failure would cause*
    c. *Develop a system to safeguard the information that you need for your job*
    d. *Should we use open or closed book exams? Explain your answer.*

iv. Interfaces

1. Displays
    a. *Sensor technology uses displays to keep humans in the control loop. The clock tells us the time, a GPS display tells us where we are, a speedometer tells us how fast we are going, the tape measure and weighing scales tell us about our size and shape; road signs tell us where to go and the labels on the box tells us what is inside. Now the computer can translate, analyze, reduce, and display any kind of information a meaningful form on a screen we can carry with us. Computers can also display integrated, representational, synthetic, and predictive information. The*

next generation of displays will go straight to our brains and bypass our eyes and ears. Display technology has been the cornerstone of Human Factors and Ergonomics in the attempt to present the right information at the right time. HCI (Human Computer Interaction) is a major industry.

b. *Make a list of as many computer based and non-computer based displays you can think of*
c. *Discuss the relevance of precision, accuracy, and utility / pertinence of these displays.*
d. *Examine what we would do without these displays*
e. *Describe some criteria for display evaluation*
f. *Describe the human challenges of too much information, and noise.*

2. Controls
   a. *Controls allow us to communicate information to some external system. Handlebars and steering wheels control our direction. Switches turn the lights on, knobs and sliders turn the music up. Mice allow us to point, click and move a cursor on our computer screen. Key boards add enormous versatility to our abilities to send messages. As controls become more powerful the implications of a click of the mouse can be monumental.*
   b. *Discuss the issue of control display relationships*
   c. *What is a population direction of motion stereotype?*
   d. *Discuss the importance of the "back" button on a computer keyboard.*
   e. *What should be the diameter of a steering wheel?*
   f. *How big should a button be on a smart phone?*
   g. *What are the advantages and disadvantages of "word anticipation" software?*

v. Facilitators: Instructions, labels, warnings, procedures
   1. *Typical facilitators include labels, warnings, instructions and procedures. A facilitator is a temporary device that allows us to understand how to interact with a system; with practice we can throw away the facilitator. Because the possible users of a system may range from the novice to the expert it is not wise to throw away the facilitator. Without facilitators the chance of an inappropriate human action is greater. Analyze the following scenarios:*
      a. *You arrive at the curb with the intention of crossing the street and avoiding the traffic. How useful are the traffic lights?*
      b. *You arrive at the store and find that all the commodities are packaged. How useful are the labels?*
      c. *You buy a "some assembly required" product. Should you throw away the instructions?*
      d. *You come across a man in the street having a heart attack. Somebody passes you an AED device. What should you do?*

e. *How is color used to differentiate Danger, Warning, Caution and Information signs?*

f. *What information should be contained in the label on a medicine bottle?*

vi Process Design

2. Time / operational factors
3. Production lines
    a. *Production lines offer a considerable improvement in productivity over traditional craft work, by having a sequence of well-defined tasks carried out by highly trained (in a limited set of activities) operators. However paced production lines imply repetitive work that may be physically harmful and mentally numbing.*
        i. *How would you assess a production line?*
        ii. *How would you develop a production line?*
        iii. *What are Work Related Cumulative Trauma Disorders?*
        iv. *What can be done to reduce repetition stress?*
4. *Shift work*
    a. *Shift work interferes with your Circadian Rhythms which are driven by Zeitgebers. This disruption is compounded by sleep loss. Adaptation occurs after a few days / weeks. Short term effects are interference with mood and performance and frequent changes can have serious domestic, social and health effects in the long term.*
        i. *Make a list of occupations that involve shift work*
        ii. *What are circadian rhythms?*
        iii. *How can they be measured?*
        iv. *Why are one-week rotations the worst schedule?*
        v. *Compare long and short rotation schedules.*
5. Time stress
    a. *Time stress in physical work produces physical fatigue. Time stress in cognitive work reduces our ability to obtain and process information, time stress reduces situation awareness. In both cases the result may be "system failure" due to overload. Experts (physical and cognitive) can handle time stress better than novices. Optimal levels of stress produce optimal levels of performance. (Yerkes Dodson Law)*
        i. *Describe some jobs that produce physical time stress*
        ii. *Describe some jobs that produce cognitive time stress*
        iii. *Describe technological and operational interventions for time stress.*

g. Human Factors Processes:

   i. All the questions above may be addressed by Human Factors or Ergonomics specialist at any stage of the life cycle of HFE, from basic research to accident investigation. The profession has tools applicable to each of these stages.

   ii. Research (methods)

      1. *HFE research involves the development and testing of general statements (laws) about human characteristics, capabilities, limitations, attitudes, behaviors and performance. The methods ideally involve "representative samples" of the target population, appropriate instruments, controlled experiments and statistical analysis of the data. Some brilliant examples of research products are the Weber Fechner Law, The Hick Hyman Law, Fitts Law, The Yerkes Dodson Law, The Drillis and Contini proportions and the NIOSH Lift Equation.*

      2. *List some more examples of laws that have been generated by Human Factors and Ergonomics researchers*

   iii. Applied research

      1. *It is often argued that Human Factors and Ergonomics is (not are) an applied science. The difference between basic and applied science is that the former aspires to be general whereas the latter usually applies to a limited population in a constrained context. For example, the research question "How do drivers behave when approaching traffic lights" is a specific subset of general behavior. Often applied HFE research takes place in field settings, such as the road, shop or in front of a computer.*

         a. *Identify applied HFE research topics in the areas of: workplace design, manual materials handling, airplane landing, consumer behavior, attention and vigilance, warnings design, team collaboration etc.*

   iv. Simulation

      1. *Simulation is usually much less expensive and much more flexible that research in real conditions. The caveat is that of validity. For example the certification of the Airbus A380 depended on a demonstration of emergency evacuation. This demonstration was a very elaborate event. Taking four years to plan, costing millions of dollars to implement and causing injuries to some of the subjects. The demonstration only dealt with one configuration of door availability. An alternative approach is discrete event simulation which can explore many configurations and many variations of passenger behavior in just a few seconds. Of course the simulation model must be valid.*

         a. *Describe other uses of simulation in HFE applied research*

   v. Design

      1. *HFE is an applied subject that usually investigates the relationships between human behavior and technological designs. The purpose of HFE is to offer advice, based on good evidence to technology designers. Without technology there would be no need for HFE. Argue the case that Technology Design needs HFE*

vi. Evaluation

1. *HFE often arrives on the scene after the technology has been developed and is on the market or about to be launched. The HFE practitioner walks in and "calls the designer's baby ugly." No wonder we are not always a popular profession. Ideally the HFE should work with the designer, engineer, manufacturing, marketing and where appropriate the regulatory bodies to ensure the product launched has an HFE stamp. This process however will require that the HFE practitioner is timely in his advice – "come back in six months when I have completed my experiments" - will not go down well. On occasion HFE practitioners get to manage the design process and sometimes wishes he were back on the other side of the table.*
2. *Identify a range of consumer products and services; evaluate them for effectiveness, efficiency, ease of use, elegance, safety, security, satisfaction and sustainability.*

vii. Ergonomics Toolkit

1. *The profession over the past few decades has developed a wide range of tools and techniques that are aimed at collecting reliable evidence and offering useful advice. These tools vary from sophisticated simulators to checklists and ethnographic observations. Describe and evaluate tools for each of the following areas of human factors and ergonomics:*
   a. *Physical*
   b. *Sensory*
   c. *Cognitive*
   d. *Social*
   e. *Behavioral*
   f. *Affective*
   g. *Environmental*
   h. *Temporal*
   i. *Performance assessment*

h. Big Picture Ergonomics

i. Complexity: People, Technology, Operations, Contexts
1. *Describe the Edwards SHEL model*
2. *Rearticulate the SHEL model*

ii. Integration: Interfaces, interactions, interdependencies, interruptions
1. *Expand the Edwards SHEL model*

iii. Use: Utility, Users (misusers), Usage (misusage), Utilization, Usability, User error
1. *Apply the 6 Us and 2Ms to a kitchen appliance, a smart phone, an ATM, and a college course in Human Factors*

iv. Scope: Physical, Sensory, Cognitive, Social, Affective, Contextual (Environmental and operational)
1. *When someone comes to a job, he brings all these features which constantly interact. Describe your own job regarding these categories*

v. Lifecycle: Research, Applied Research, Analysis, Simulation, Design, Evaluation Investigation (Errors and Accidents)

1. *Consider the life cycles of a car, an airport, a shopping center, Singapore, or a meal. Describe the opportunities for different forms of Human Factors involvement*

vi. Stakeholders: Management, Design, Engineering, Production, Use, Maintenance, Disposal
   1. *Consider the different stakeholders in the life cycle of a taxi, a smart phone, or a university. What are their requirements? What are the tradeoffs?*

vii. Voice of the customer: Must have, More the better, Excitement
   1. *How would you determine the different requirements of a customer for a product such as a TV set or a chair, or a service such as a hairdresser or waiter?*

viii. Objectives: Requirements, Guidelines, Specifications
   1. *Requirements are functional – verbs qualified by adverbs. Specifications are physical – nouns qualified by adjectives. Requirements can be validated; specifications can be verified. Describe the requirements and specifications for a home, a chair, a mouse, a coffee cup*

ix. Outcomes: E4S4: Effectiveness, Efficiency, Ease of use, Esthetics, Safety, Security, Satisfaction, Sustainability (reliability and resilience), Tradeoffs
   1. *Describe the multiple outcomes and tradeoffs of a university, bus service, examination, pair of shoes*

x. Analysis: Outcomes, Operations, Decisions, Interventions, Mitigations
   1. *Systems and process present many opportunities for data capture. Consider a recreation center, a theme park, an IT system, a fast food restaurant, a political campaign or an examination question. Analyze the system or process from multiple viewpoints.*

xi. Error: Incident and Accident reporting
   1. *How should we collect data about aviation accidents and incidents, consumer products, hotel services?*

xii. Continuous Improvement
   1. *The world never stops, what is exciting today will be expected tomorrow. Continuous improvement is a control process, it needs feedback. Discuss how a manufacturing process or a bus service can "continually improve"*

Chapter 52

Answering Exam Questions

1. Read through all the questions
2. Choose order of answering and calculate time to allot to each question
    a. E.g. 4 questions in two hours
        i. allot 20 – 25 minutes each
        ii. leave remaining time to read through and add to / amend your answers
3. Underline key points in the question
4. Do not just start writing otherwise your answer will be unorganized, unstructured, unbalanced and maybe unintelligible
5. Sketch your answer framework at the top of the page
    a. Make sure all the key points from the question are covered
    b. Add your own key points for your answer
6. In your answer do not just make lists or regurgitate your notes
7. A paragraph should have four sentences (approximately)
    a. Introduction to the topic
    b. Method of measurement / approach
    c. Description of evidence / data
    d. Discussion and conclusion
8. Balance your responses to each of the key points
9. Keep your eye on the clock and leave time for all the questions
10. Read through your answers and correct if necessary

Chapter 53

A Full Time Undergraduate Program in Human Factors / Ergonomics

1. Definition
    a. Human Factors (Ergonomics) is the scientific study of human characteristics, capabilities and limitations applied to the design and evaluation of products, systems, processes and contexts.
2. Scope
    a. Physical, Sensory, Cognitive, Social and Affective human characteristics, capabilities and limitations
    b. Technological, operational, contextual and temporal demands on human behavior and performance
    c. Research, Analysis, Simulation, Design, Evaluation and Investigation methods
3. Prerequisites (or preliminary courses) – Year 0
    a. Mathematics
    b. Physics
    c. Chemistry
    d. Human Biology
    e. Psychology
4. Foundation courses – Year 1 – Traditional didactic methods
    a. Human factors and system design
    b. Anatomy
    c. Physiology
    d. Sensory processes
    e. Human information processing
    f. Human emotion
    g. Mechanics
    h. Probability and Statistics
5. Methods Courses – Year 2 – Packaged practical units
    a. Investigation design and data analysis
    b. Product, interface and interaction design
    c. Information technology design and evaluation
    d. Anthropometry and workplace design
    e. Occupational biomechanics
    f. Work physiology and fatigue management
    g. Industrial hygiene methods
    h. Environmental design and mitigation practices
    i. Sensory motor skills and control performance
    j. Cognitive behavior and performance measurement
    k. Socio technical systems analysis and design
    l. Affective design and evaluation
    m. Systems safety and risk analysis methods
    n. Simulation and prototype methods
    o. Surveys, focus groups and user clinic methods
    p. Experimental design
6. Applications Courses – Year 3 – Problem based learning
    a. Product and process evaluation
    b. Accident investigation
    c. Safety management
    d. Behavior based safety
    e. Ground transportation
    f. Aviation
    g. Manufacturing
    h. Process industry

i. Primary industries
j. Office industries
k. Service industry
l. Management processes and operations design
m. Information technology
n. Multivariate statistics and data mining

7. Professional practice courses – Year 4
    a. Laboratory methods project
    b. Product design project
    c. Product / process evaluation project
    d. Accident investigation project

Chapter 54

One Page Reports and Posters: Tools for Collaborative Learning

Introduction

Education is about motivation, knowledge transfer and assessment. It is an active process of teaching, learning and testing. These activities always involve students and often require teachers. Because availability of information on the Internet is far beyond individual teacher's and textbook's knowledge, the teacher's role has changed from information source to tour guide. Even the process of examination can be preset, but many hidden dangers lurk in this department regarding reliability and validity. These educational activities take place in many contexts and through many media, and now e-Learning is in its ascendency.

One-page reports and posters are robust tools that can address all these activities effectively and efficiently. These processes are active, creative and student centered. The methods are not new; indeed, poster presentations are common in most academic conferences and one-page reports have been used in many academic disciplines and business organizations. However, as a focused strategy for collaborative learning these processes merit special attention, formal evaluation and refinement followed by strategic implementation as part of the educational process.

One Page Reports

"Toyota Motor Manufacturing expects all employees to write **one-page reports** whenever possible, using graphics as much as possible" (Carnes, 1997). The same expectation was experienced by the author in General Motors from the early 1990s. One-page reports and posters are succinct, creative, informative and compelling communications. They may represent individual or group efforts. Whereas some organizations provide detailed content requirements, formatting guidelines and templates, probably the most useful requirements should be a title, name(s), context and date, the rest should be left to the student(s), who should be given free rein to use creative verbiage, color, pictures, charts, graphs, references etc. Other guidelines, in a research context, may include such conventional frameworks as introduction, background, literature survey, methods, results, discussion, conclusions and references. In product development the sections could include purpose, process, product, and evaluation. The now wide availability of material, including images, on the Internet should be exploited to the fullest extent possible, with a requirement that sources, and copyrights should be acknowledged. It should be expected that plagiarism spotting utilities such as "Turnitin" will identify high percentages; the only crime here is if due credit is not given to the original authors.

The role of these one-page reports and posters in collaborative learning is to ensure group based, product focused, analytic, and creative discussion. Group size flexibility may be allowed with groups ranging from one to five or six; some students may have logistic challenges that get in the way of collaboration or simply prefer to work alone. However, with contemporary communications such as Internet chat rooms and other social media, collaboration is rarely a barrier. The product focus and time deadlines do require social issues of situational leadership and contributions of individual responsibilities and skills; these are all part of the educational process.

The use of one page reports and posters in full time and part time education generally requires a one page report in the form of focused group homework every week and the presentation of a more elaborate poster, perhaps an extension of one of the reports, at the end of the course. The reports and posters may be presented either in hard copy or electronic forms, or both; they may use any utility, such as Microsoft Word, PowerPoint, a Spreadsheet or more specific software, all of which allow multiple forms of verbal, numeric and graphical communication. Above all, one-page reports should tell a clear, concise, cohesive, comprehensive and compelling story.

One Page Reports and Posters

"A picture is worth a thousand words," (Arthur Brisbane, 1911). Traditional text is sequential, as we learn to read, we develop semantic frameworks which are retained and updated as the material is read. On occasion, we supplement our vulnerable memories by back tracking to earlier sections of the prose. Pictures on the other hand are non-sequential, or rather the sequence of information acquisition is not necessarily dictated by any rules of order; instead the picture creator uses emphases to attract attention and then encourages a search throughout the picture for detail to complete the story. The observer of a picture can use any search strategy and can backtrack easily.

One-page reports and posters are pictures, albeit containing text and other media that require some sequential perception to enable comprehension. The artists who create these devices have a wide range of tools, much richer than words alone. One particularly powerful tool that can serve to link the various elements of the picture is the "concept map", sometimes called a "mind map". This tool comes in various forms. It may be hierarchical. Often the links between spatial elements on the map have grammatical forms – the "investigator" of this "problem" collected "data" using this "instrument, " which was analyzed by these "methods" and resulted in these "conclusions". From each node (noun) in the concept map the reviewer may be drawn to greater detail in the small print or to a picture or chart which tell a detailed story. Of course, this level of analysis of a poster or one-page report will usually be implicit, although some students have formally used concept mapping frameworks to create their masterpiece.

Assessment

Academia has developed many forms of evaluation over the centuries, from viva – voce examinations, through multiple choice, short answer, problem solving, scenario based questions, and extensive reports, theses, dissertations and refereed publications. These devices vary widely in their reliability and validity, depending on their usage. It is increasingly common to develop rubrics to guide, or even dictate evaluation which include a set of criteria and multiple ordinal levels of performance in each criterion. A challenge, especially with very detailed criteria and large class sizes is bias due to "the halo effect" (Peacock, 2002, Cooper, 1981). The reviewer may be particularly influenced by a one feature of the report and grade all other criteria accordingly. Another problem of bias is a general shift up or down for a set of reports or drift one way or another over a series of evaluations. Frequent calibration by reference to the rubric is a time consuming and thus neglected activity. A widely held response to evaluator calibration is strict training in the use of a particular rubric, and sometimes a trend towards increase in the complexity of the rubric. But even this approach is vulnerable to the effects of the essential subjectivity of the human grading process, and the always present time pressure.

Alternative approaches to grading and feedback, especially in the context of these one-page reports and posters, includes the use of a panel of judges and peer grading, using simple rubrics; delegating particular criteria to different evaluators may also be an option. Such approaches comprehend subjectivity and bias and the statistical value of replication will inevitably produce a more reliable result. There are familiar precedents to panel based grading in art, science and business, such as music, gymnastics, the job interview, professional certification, promotion systems, grant proposal evaluation and university program accreditation; they all use a set of, sometimes weighted, criteria that are evaluated on some, usually ordinal, scale by one or a group of variably qualified and experienced judges, who invariably exhibit human behaviors of subjectivity and bias. One way of dealing with variable spread and skewness in the results from small panels is to eliminate the top and bottom scores and average the rest. The peer grading approach, especially with large groups, can also solicit verbal comments on individual reports or posters, which when extracted and grouped can produce informative feedback. These comments may be classified according to the Kano model of "must have", "the more the better" and the "excitement" factor, perhaps using both positive and negative assessments. Where panel, peer and individual teacher approaches are used then attention must be paid to the weighting of these contributions to the final score; a 30:20:50 ratio has been used recently and accepted as being fair.

Where individuals evaluate reports, even with clear rubrics, there will still be variability in the level and scale of the set of numbers or letter grades that emanate from the process. Sometimes there will be too may "As", sometimes too many "Fs". These results are not necessarily due to incompetent graders;

rather they are more likely due to normal subjectivity and bias; on occasion this bias may be extreme, due to prejudice or even maliciously motivated. It should be noted that the spread (standard deviation) of scores on an individual criterion has more effect on the final amalgamated total score or rank than the average criterion score and the prescribed criterion weighting. The most appropriate statistical solution to this problem of an unwanted shift or spread is to superimpose a linear transformation to the individual criterion scores. An alternative approach is to reduce all the criterion data to ranked scores and then assign a predefined quantity to each grade level. In practice such interventions may not be deemed necessary or even considered valid. If a qualified, and assumed unbiased, judge, using a validated rubric calls the grade an “A” then an “A” it should be. This assumption is the norm in most teacher graded reports.

Prior to this recent exploration of one-page reports and posters the author had quite extensive experience with these media in large scale automobile manufacturing industry and in space research project monitoring. Recent experience with this process of one-page reports and a final course project poster has covered ten classes at two universities in Industrial Engineering, Human Factors, Occupational Biomechanics, System Safety and Aerospace Human Factors. The average size of these classes was about 50 and the average number of groups per class about 12; the choice to carry out individual projects did occur, but not very frequently; chosen group sizes of two, three and four were the norm.

A few technical problems were experienced: some students couldn’t understand the meaning of “1” and attempted to present multiple page dissertations; other groups, in their enthusiasm for detail, used unreadable font size; a common error was to omit references for the clearly downloaded images, charts and even verbiage. Groups quickly became more creative with color, font and layout as the courses progressed and avoided the earlier technical shortcomings.

Grading of these one-page homework reports presented the most serious problem. The simple grading rubric had three equally weighted criteria – breadth, depth and presentation, each scored on a five (six) point scale – from “Fantastic” to “Absent”; creation of verbal anchors for these scales is a fine art. A single one page report generally represented only 3% - 5% of the final grade. The quality of the submissions of most groups resulted in full marks generally being awarded. This observation attested to the motivational value of this continuous assessment item. However, this criterion based, non-discriminative grading of group submissions delegated the role of norm-based evaluation of individuals to later assessment components.

The Posters

The final group-based posters were presented on the last day of class, each poster representing 20% - 30% of the overall course grade, the final examination contributing 50% to 70% depending on the class. The posters were placed horizontally around the class and each class member rated (using a simple rubric) each poster (including their own) on score sheets that only contained a numerical (ID) reference. A comments column was provided for the solicitation of verbal supplements to the numeric score. After this peer grading process class members were asked to provide reflections on the back of the score sheet regarding course content, format and one-page report and poster continuous assessment process. An alternative format was explored in which groups gave a short 10-minute presentation on their topic, either directly via the poster or with the aid of projected slides or a lap top presentation. Although the oral presentation medium has its advocates it was replaced in later classes by questions and answers from peers and the teacher. A second round of grading involved the teacher, academic colleagues, and teaching assistants. In general, only 5 to 10 minutes was required per poster. Whereas student groups had generally received full marks for their one-page reports, there was greater discrimination between the posters, although generally speaking they received high marks. An alternative panel evaluation approach for the posters, borrowing from psychophysics, can use paired comparisons and the movement and grouping of items around the board room table to establish ranked rather than numeric scores. This process can use collaboration (rather than independence) among the panel of judges. Such processes are particularly effective in reaching consensus regarding the top and bottom (fail) submissions.

Score amalgamation was through a straightforward spreadsheet tool that assigned the pre-defined weights to the peers, teacher, and colleagues / teaching assistants. The final course grade can follow a standardization / linear transformation process to bring them within an expected range. The calculation of rankings for criteria also helps to remove the numerical score biases. One outcome of the panel approach to poster evaluation was that there was generally a high correlation among the different judges, regarding poster quality. Where substantial discrepancies occurred, panel discussions were used to resolve the problem. The opportunity to offer reflections on the course and one-page report and poster process generally produced very positive comments. Another informal observation was of the obvious pride shown by the group members as they presented their creative posters. Furthermore, rather than shelf storage of traditional reports, the one-page reports and posters are conveniently displayed in circulation areas to inform, educate and impress other students and visitors.

Discussion

The underlying driver of this process is that it is student centered, group based and creative. It is inherently motivational with a defined product (the one-page report or process), a deadline, the encouragement of creativity, explicitly collaborative and a contribution to the course grade. The process enhances knowledge acquisition by reference to the class material, search for other sources, particularly the extremely rich Internet and consolidation into a concise communication. One-page reports and posters are amenable to criterion based or norm-based assessment, using rubrics, peers and panels of judges. The one-page reports offer practice in the medium before the final poster development. Rather than factually based quizzes and other continuous assessment devices these one-page reports and posters must involve discussion, creative communication design and joint responsibility. The individual student contributions to the group products were raised as a concern. This can be resolved by within group peer review, but such approaches are likely to be divisive, even if anonymous. The counter to this relative contribution criticism is that discrimination between individuals will invariably occur with the final examinations. At a higher level, most students will have to contribute to group projects in their later employment, hence this training in collaborative learning will contribute another skill for their success in industry.

Chapter 55

The Writing is on the Screen for the Lecture and Examination

Back in the days of the Greek philosophers such as Aristotle, Plato, Euclid and Socrates, the great thinkers gathered around them eager groups of students and communicated their thoughts with minimal use of complementary technology. Moving forward, the religious leaders used more strategic pyramid processes, through their cohorts of disciples, to spread their word widely. They also made good use of technology in the form of writings, such as those found in the Old and New Testaments and Koran. As populations grew and education became more formalized the teacher – classroom model boomed because of its efficiencies and control. A teacher could guarantee the attention of his or her students for hours at a time although recognition of the vigilance decrement resulted in rotations of topics throughout the day. Another form of control – of "quality" - was achieved by the introduction of examinations. These tests generally had the primary purpose of verifying that the student had remembered literally what had been taught. Enterprising teachers would seek to validate the learning by having students answer questions that involved both deductive and inductive reasoning and by conducting applied projects. Only the teachers down the educational line and the eventual employers were in a position to really validate the effectiveness of this efficient "lecture and examine" educational process.

The invention of the printing press gave birth first to the reference book and library and then to the textbook and on to the formalization of homework. These developments also started the obsolescence of the lecture and examination. The teacher could become even more effective and efficient; the students didn't need to attend class or pay attention in class, as long as they weren't disruptive towards those who didn't know how to study outside the classroom. Despite the possibility that students could now study successfully outside the classroom the lecture persisted for many years. It also gave birth to other formal educational media such as the seminar, laboratory and study group. Even the textbooks were adapted to support these more effective learning media. The textbooks also began to include tests of one kind or another with answers in the back. The writing was now on the wall for the lecture, but the teacher was resilient and continued to prosper. Anyway, someone has to write the textbooks.

The examination also adapted and squeezed away from the teacher. Professional societies developed certification and governments developed licensing. Other organizations even developed accreditation as a way of controlling the quality of educational establishments. Industrial, military and business organizations developed aptitude testing in a variety of guises. The well written resume and personal performance at an interview became the keys to success.
If the first nails in the twin coffins of the lecture and examination were the printing press and textbook, the final nails were surely the computer, internet, Wikipedia, and mobile personal devices. Information is now available any place any time. There is no reason why anyone cannot learn anything, anywhere. But people vary; many are not sufficiently disciplined to learn alone or not honest or capable enough to be responsible for their own examination. Most also need guidance to select wisely from the ocean of information and misinformation at their fingertips; they also need help in interpretation of the material. So, the teacher is still needed; but there is still the challenge of efficiency – teachers cannot provide one on one interpretive service to all their charges.

So the teacher must have disciples, in the form of tutors and make use of focused groups – "wherever two or three are gathered together…" they will most likely converge on some level of agreement, perhaps even "the truth." Of course, we still have to ascertain whether or not individuals have understood the truth in order that they can reflect their status in their resumes. Information technology is up to this task too. First a near infinite number of questions and problems can be organized on the Internet, and satellites, cell towers, ocean floor cables and broadband wireless cities can reach around the world. We even have biometric technology to check the authenticity of the examinee and after the event software to provide a measure of plagiarism, although this is a can of worms that contradicts the whole purpose of education – to learn from others, which is far more effective and efficient than discovering everything ourselves from scratch.

So, the writing is on the screen for the lecture and the traditional examination, but not for the teacher and examiner.

Chapter 56

The Demise of the Lecture

The Educational Institution

The Educational Institution, like all organizations may be categorized by analysis of its structures, processes, and outcomes. The structures include bricks and mortar, dollars, and people. The processes include lectures, research, and quality management. The outcomes are assessed by research publications, examinations, and the employment of graduates. SIM University is unique in its focus on adult learners, the reliance on professionals rather than academics and the imposition of a stringent quality management process.

The Lecture

For more than 2000 years the lecture has been the preferred medium for the transfer of knowledge from an expert to a group of students. There are two driving forces behind this time honored medium. First there is the matter of effectiveness or quality – the expert is selected because of his / her knowledge and the proven ability to communicate that knowledge. The second force is that of efficiency or economy. A professor can deliver the same message to a handful or even to hundreds of students in the same amount of time.

The invention of the printing press was the first nail in the coffin of the lecture. A textbook can deliver the same message to thousands of students. For many decades the professor and the textbook have complemented each other to better transfer the desired material. The library and laboratory have developed as key supplements to the educational process. The recent final blow to the concept of the lecture is the growth of the Internet. The Internet has more information than any individual professor or textbook on any subject, available at the fingertips of the student.

Because the Internet is so rich in pertinent information and so clouded with irrelevant and sometimes unreliable or even untrue information, there is still the need to guide the student along a path that society delegates to the educational institutions. But there are many methods of guidance and the classical lecture may be the least effective.

Outcome Assessment

The examination, in its many forms, has accompanied the lecture over these many years and society demands that some form of measurement be applied to evaluate the knowledge and capability of the graduate as a predictor of future actions, such as future courses, the conference of certificates of competence and eventually professional practice or employment.

Examinations have two basic purposes: verification and validation. Verification simply measures whether the student has absorbed the information and can regurgitate it on the examination script or in a viva voce setting. Validation reflects the ability of the student to use and apply the information in a way similar to the higher levels of cognition described by Bloom.

These two forms of outcome measurement – of knowledge and interpretation / application - have taxed the ingenuity of educators, administrators, and employers for many years. The sheer efficiency and objectivity of the multiple-choice format has dominated the process over the past few decades. However, confirmation of the higher levels of understanding is needed to validate the effectiveness and quality of the learning process. These methods include problem solving questions, albeit with standard answer templates, and the far less efficient viva voce examination. Integrated Capstone courses and theses of one form or another are used to explore the ability of the student to extend the knowledge given in lectures and courses beyond the sum of the individual parts.

An Educational Hypothesis – "The Lecture is Moribund"

SIM University has made great steps forward in the management of quality and efficiency of the educational process for adult students. Courses and examinations are prepared and delivered through the media of textbooks, course notes, lectures, laboratories and examinations of one kind or another. Some courses may be developed by one person and delivered by another. These developers and deliverers are often experienced professionals rather than career academics.

SIM University is now in a unique position to evaluate and perhaps preside over the demise of the traditional lecture. Of course, the lecture must be replaced by some more effective and efficient form. This ideal form is supported by the Chinese proverb:

"Tell me and I'll forget; show me and I may remember; involve me and I'll understand."

All hypotheses, including this one, need testing by formal scientifically controlled experimentation methods if they are to be converted into acceptable policies and procedures.

A Proposed Experiment in Education

A selection of University courses should be split and delivered in one of four alternative ways:

1. The present method, including the 6*3-hour lecture, by an expert
2. The replacement of the lecture component by a seminar, using teaching assistants
3. The replacement of the lecture component by well defined, but unsupervised, small group projects based on the course material
    a. A variation on this alternative would be individual projects
    b. Another variation would include direct or Internet based access to a professor or teaching assistant
4. Ideally, from the experimental point of view, the fourth alternative would remove the lecture component without any replacement.

The materials presented to all the participants would include the course textbooks, the course notes and some Internet reference sites.

The assignment of students to groups would have to be randomized and care would have to be taken to observe the behaviors of the different experimental groups regarding their use of alternative sources, such as Internet forums and chat rooms.
All participants would be evaluated by the same examining methods and double blind methods would be applied to avoid evaluation biases.

Summary

The lecture is an obsolete concept; its demise was initiated by the textbook and finalized by the Internet. Greater effectiveness and efficiency in education can be achieved by carefully managed alternative methods. Before such methods are implemented on a significant scale, they need to be subject to rigorous scientific evaluation, not just the opinion of educational "experts."

Chapter 57

Manual Job Analysis Screening Tool (MJAST)

Operations, Spatial, Manipulation, Manual Materials Handling, Environment, Other Tools

Operational Factors

Job pacing

Self	Machine

Team structures

Yes	No

Technical support

Yes	No

Participatory processes

Yes	No

Technical support

Yes	No

Training, Acclimatization

Yes	No

Special Populations ?

Yes	No

Repetition (per minute)

1	2	5

Duration (% Job cycle)

1	2	5

Comments

Spatial Factors

Neck(Chaffin" and Kilbom ***et a/)***
□Twisting □Side bending

10	20	>20 or <0

Trunk (RULA)
□Twisting □Side bending

seated			
0°	20°	60°	

Legs (are they supported)

Yes	No

Task surface orientation

Front	Top	Left Right	Under Back

Access (Code on accessibility 2013)

1.8m	1.5m	0.9m

Ramps (UK building regulations)

3°	4°	5°

Reach (EADES +tongxin data)

700	750	800

Fit (health and safety uk)

$15m^3$	$13m^3$	$11m^3$

Volume of room

Comments

Manipulation

Upper arm(RULA)
elevated shoulder
□abducted
(increase one level)
□leaning □weight of arm supported (decrease one level)

-20-20°	45°	90°

Lower arm (Grandjean** and Tichauer)

60-100°	0-60° or >100°	+Midline

□ across midline

Wrist (Tichauer'".)

□ mid range of twist (+1)
□ end range (+2)

0°	±15°	+Twist

Force

1	2	5

Repetition

1	2	5

Shift Duration

1	4	8

Comments

Manual Materials Handling

Lifting (NIOSH)
raw weight / FM = effective weight

[illegible]	[illegible]	[illegible]

Carrying (SNOOK)

14	16	19

Pushing OR Pulling (SNOOK)

17	20	24

Twisting (NIOSH)

[illegible]	[illegible]	[illegible]

Coupling (NIOSH)

Good	Fair	Poor	None

Comments

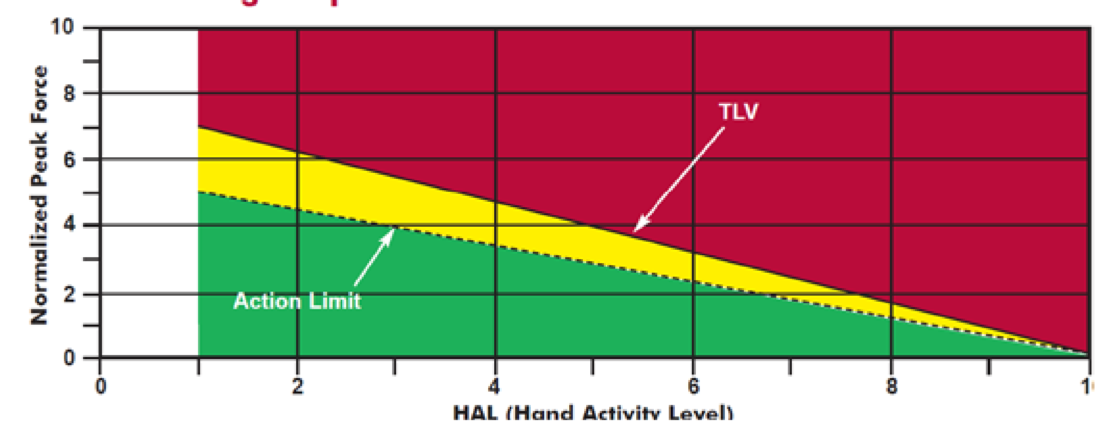
Environment

Factor				
Noise (MOM) 30 min sampling for 8 hour shift	83	84	85	
Light (IESNA) measured 76 cm above the floor	1000	500	200	
Glare	No glare	Reflected Glare	Direct Light bulb Glare	Direct Sunlight Glare
Temperature (ACGIH, 2008)(MOM)	28	30	32	
Acceleration	0.5	0.7	0.9	
Slips, trips and falls	Yes	No		

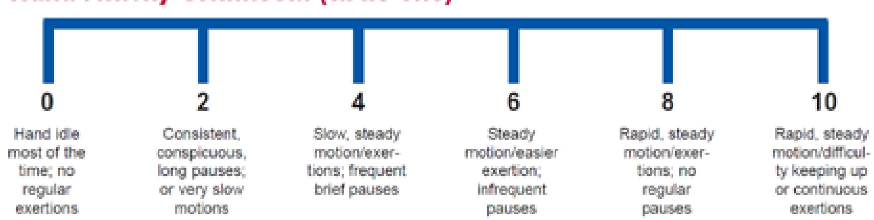
Comments Alternative Screening Tools

Comments

HAL TLV Scoring Graph



Hand Activity Continuum (circle one)



Borg CR-10 Scoring

Rating	0	1	2	3	4	5	6	7	8	9	10	•
Average Score												

Chapter 58

Ergonomics Task Analysis Tools

Introduction

The following ergonomics analysis tools consist of a series of Yes / No screening question (Level I analysis) followed by questions on specific topics (Level II analysis) and a series of more detailed analytic tools (Level III analysis)

The Initial Screening (Level I) checklist consists of trigger values that indicate to the analyst where more detailed investigations are warranted. The trigger values in and of themselves do not necessarily indicate the existence of a potential ease of use, effectiveness, efficiency, elegance, safety, security, satisfaction, and sustainability (Reliability and resilience) problem. Depending on the pattern of responses to the screening questions the analyst will be directed to one or more Level II question sets.

The Level II questions are generally objective and univariate. That is they each deal with one dimension or variable. The objective measures are linked by consensus judgment to a 4-point scale that indicates the level of strain or performance difficulty imposed by that variable. Again, high ratings of individual questions may not necessarily indicate a high probability of strain or performance decrement. However, where combinations of high values occur among related variables there may be an indication for a Level III analysis, based on the objective inputs to the answers to the Level II questions.

Level II Analysis consists of the following question sets:

1. General product characteristics
2. Product quality
3. Containers
4. Product assembly forces
5. Hand tools
6. Manual materials handling
7. Workplace layout
8. Movement / energy consumption
9. Manipulation
10. Exposure

The Level III analytic tools consist of worksheets or computer-based methods which amalgamate the combined effects of different stressors. The result of the Level III (and Level II) analyses will generally take the form of an index of stress that can be related to epidemiological, productivity, product quality or job satisfaction evidence.

Ergonomics Screening Checklist (Level I)

Each question should be answered Yes, No or Not applicable. If the answer to any question is "Yes" the analyst should move to a Level II analysis.

1. Process outcomes
    1.1. Ease of use
    1.2. Effectiveness - Product Quality
        1.2.1. Is the operator responsible for checking the quality of his work or that of others?
        1.2.2. Is task completion / quality feedback clear and unambiguous?
        1.2.3. Is there sufficient visual access and lighting for the inspection task?
                1.2.3.1.1.1. Level II analysis – Product Quality
    1.3. Efficiency – Productivity

1.4. Elegance
1.5. Safety
1.6. Security
1.7. Satisfaction
1.8. Sustainability
    1.8.1. Reliability
    1.8.2. Resilience
2. Subsystem characteristics
    2.1. General Product characteristics
        2.1.1. Does the component / sub assembly weigh more than 5 kg?
        2.1.2. Does the part have any dimension greater than 50 cms?
        2.1.3. Does the part have sharp edges or corners?
        2.1.4. Does the part have multiple options or fasteners?
            2.1.4.1. Level II analysis – General product characteristics
    2.2. Containers
        2.2.1. Does the container have a dimension greater than 50 cms?
        2.2.2. Does the full container weigh more than 5kg?
            2.2.2.1. Level II analysis – Posture, Manual Materials Handling, Containers, Energy
    2.3. Product assembly forces
        2.3.1. Does a threaded fastener have a torque rating greater than 30Nm?
        2.3.2. Does a press fastener require a hand force greater than 10 N?
        2.3.3. Does the fastener have to be attached with the finger or thumb?
            2.3.3.1.1.1. Level II analysis – Product assembly forces
    2.4. Hand tools
        2.4.1. Will a hand tool be used routinely?
            2.4.1.1.1.1. Level II analysis – Hand tools, Product assembly forces
    2.5. Manual materials handling
        2.5.1. Are the parts / container greater that 5kg?
        2.5.2. Are the parts / container located outside the "box"
            2.5.2.1. Between 50 and 150 vertical, 75 horizontal and +/- 50 laterally from the midline
                2.5.2.1.1. Level II analysis: workplace, Manual materials handling, Containers
    2.6. Workplace layout
        2.6.1. Are parts presented to the operator and the work confined to "the box'?
            2.6.1.1. Between 50 and 150 vertical, 75 horizontal and +/- 50 laterally from the midline
        2.6.2. Are there obstructions to the movement of the operator, parts or tools?
            2.6.2.1. Level II analysis: Workplace design
    2.7. Movement / energy consumption
        2.7.1. Does the operator have to walk more than 10 m/min on a regular basis?
        2.7.2. Does the operator have to climb up or down steps or ramps?
        2.7.3. Does the operator have to lift, hold, pull, push or carry heavy objects?
            2.7.3.1. Level II analysis – Movement, energy expenditure
    2.8. Manipulation
        2.8.1. Is the line rate greater than 30 per hour?
        2.8.2. Is the same or similar task carried out more than 5 times in a minute?
        2.8.3. Does the operator have to work above shoulder height?
        2.8.4. Does the task involve the forceful use of fingers or thumbs?
            2.8.4.1. Level II analysis – Manipulation, Product assembly forces, and hand tools
    2.9. Exposure
        2.9.1. Is the line rate faster than on vehicle or part per minute?
        2.9.2. Does the task contain more than 5 repetitions per minute?

2.9.3. Does the operator work on the same job for more than 2 hours per day?

3. Level III Ergonomics Analysis
   3.1. NIOSH lifting equation
      3.1.1. Horizontal distance
      3.1.2. Vertical height at start of lift
      3.1.3. Vertical height at end of lift
      3.1.4. Lift frequency
      3.1.5. Degree of asymmetry
      3.1.6. Hand / object coupling
   3.2. Energy Guidelines
      3.2.1. Horizontal distance walked
      3.2.2. Vertical distance climber (ramp or stairs)
      3.2.3. Weight of objects lifted or carried
      3.2.4. Amount of pulling / pushing
      3.2.5. Heavy hand / arm work
      3.2.6. Upper Limb Stress Index
      3.2.7. Type of hand / object interface
      3.2.8. Upper limb joint postures, ranges and speed of motion
      3.2.9. Within cycle duration of force exertion
      3.2.10. Repetition of same or similar task within a job cycle
      3.2.11. Cycle duration / line rate
      3.2.12. Rotation or shift duration
   3.3. Thermal Stress Index
      3.3.1. Air temperature
      3.3.2. Radiant temperature
      3.3.3. Relative humidity
      3.3.4. Air movement
      3.3.5. Type of task
      3.3.6. Type of clothing
   3.4. Noise and Vibration
      3.4.1. Interference with function
         3.4.1.1. Communication
         3.4.1.2. Manipulation
      3.4.2. Interference with health and safety
         3.4.2.1. Frequency / Intensity spectrum
   3.5. Vision and Lighting
      3.5.1. Natural / artificial light
      3.5.2. Light levels
      3.5.3. Glare sources
      3.5.4. Task visual requirements
         3.5.4.1. Target size and movement
      3.5.5. Vision aiding equipment
         3.5.5.1. Microscopes
            3.5.5.1.1. Postures
      3.5.6. Color vision requirements
   3.6. Quality Stress Index
      3.6.1. Number of distinct tasks to be performed
      3.6.2. Clarity of task standards and completion feedback
      3.6.3. Rate of decision making

- 3.6.4. Visual access
- 3.6.5. Motor control / balance difficulty
- 3.6.6. Availability of auditory or tacto kinesthetic signals

3.7. Equipment operation index
- 3.7.1. Number of displays
- 3.7.2. Number of controls
- 3.7.3. Types of displays
- 3.7.4. Annunciators
- 3.7.5. Accessibility

3.8. Exposure Index
- 3.8.1. Job cycle duration
- 3.8.2. Duration of high-level muscular activity in any body segment
- 3.8.3. Number of repetitions of same or similar activity within a job cycle
- 3.8.4. Number of job cycles per hour
- 3.8.5. Number of hours per rotation or shift
- 3.8.6. Number of rotations per shift
- 3.8.7. Shift duration and schedule
- 3.8.8. Number and duration of rest and recovery pauses

3.9. General Product Characteristics
- 3.9.1. Weight
- 3.9.2. Size
- 3.9.3. Handling Surfaces
- 3.9.4. Number of fasteners
- 3.9.5. Fastener support
- 3.9.6. Options

3.10. Product Quality
- 3.10.1. Damaged part history
- 3.10.2. Signal complexity
- 3.10.3. Number of signals
- 3.10.4. Controls and displays
- 3.10.5. Lighting
- 3.10.6. Glare

3.11. Containers
- 3.11.1. Height
- 3.11.2. Width
- 3.11.3. Depth
- 3.11.4. Weight empty
- 3.11.5. Weight full
- 3.11.6. Handle diameter
- 3.11.7. Handle width
- 3.11.8. Dunnage weight
- 3.11.9. Access

3.12. Product assembly forces
- 3.12.1. Torque (In line)
- 3.12.2. Torque (Pistol Grip)
- 3.12.3. Torque (Right angle)
- 3.12.4. Finger push force
- 3.12.5. Palm push force
- 3.12.6. Arm push / pull forces
- 3.12.7. Vibration

- 3.13. Hand tools
  - 3.13.1. Handle diameter
  - 3.13.2. Handle length
  - 3.13.3. Triggers
  - 3.13.4. Weight
  - 3.13.5. Balance
  - 3.13.6. Vibration
  - 3.13.7. Torque (In line)
  - 3.13.8. Torque (Pistol grip)
  - 3.13.9. Torque (Right angle)
  - 3.13.10. Linear force
- 3.14. Manual materials handling
  - 3.14.1. Part / container weight
  - 3.14.2. Part / container size
  - 3.14.3. Surfaces, hand coupling
  - 3.14.4. Holding, gripping
  - 3.14.5. One hand lifting
  - 3.14.6. Horizontal reaches
  - 3.14.7. Vertical reaches
  - 3.14.8. Vertical distance
  - 3.14.9. Asymmetry
- 3.15. Workplace layout
  - 3.15.1. General access
  - 3.15.2. Clearances
  - 3.15.3. Manual access
  - 3.15.4. Visual access
  - 3.15.5. Working surface
  - 3.15.6. Horizontal reaches
  - 3.15.7. Vertical reaches
  - 3.15.8. Equipment lateral location
- 3.16. Movement / energy consumption
  - 3.16.1. Base posture
  - 3.16.2. Walking
  - 3.16.3. Climbing
  - 3.16.4. Lifting / lowering
  - 3.16.5. Carrying load
  - 3.16.6. Carrying distance
  - 3.16.7. Stationary pulling pushing
  - 3.16.8. One handed lifting
  - 3.16.9. Ambient temperature
  - 3.16.10. Humidity
- 3.17. Manipulation
  - 3.17.1. Part / container weight
  - 3.17.2. Interface / grip
  - 3.17.3. Carrying distance
  - 3.17.4. 3-D movement
  - 3.17.5. Reorientation
  - 3.17.6. Pushing / pulling
  - 3.17.7. Placement
- 3.18. Social / Organizational Factors

3.18.1. Machine pacing
3.18.2. Task cycle duration
3.18.3. Job rotation / enlargement
3.18.4. Vertical job enlargement

3.19. Quality, productivity, safety, management, training, selection

3.19.1. Selection, training, rewards
3.19.2. Quality, productivity, safety climate
3.19.3. Shift work
3.19.4. Work rest schedule
3.19.5. Facilities
3.19.6. Food
3.19.7. Hygiene
3.19.8. Transportation
3.19.9. Medical

Chapter 59

HFAPPS

Brian Peacock

with

Phang Kun Chai, Zhou Chen, Jorene Chai, Sim Jing Hui, Chan Jing Hua, Wong Daquan, Ng Yuwen

Introduction

The development of smart technology, including smart phones and tablets has progressed apace. This hardware and operating system development has spawned an avalanche of applications for entertainment, information, measurement, and education. Already there are many apps in the field of human factors and related domains. Photographic, video and audio records are basic utilities. It is now convenient, using a smart phone application, to measure light and perform vision testing, measure sound, and carry out an audiometric test and measure acceleration and vibration to assess the safety of public transport. In the physical ergonomics domain, there are apps for workplace posture analysis, manual materials handling assessment and energy expenditure. In the cognitive area there are many perception, memory, and decision-making apps. Also, electronic games like Sudoku, chess, checkers and many others measure applied aspects of human cognition. There are also numerous entertainment-oriented games that test memory, strategy, motor skill, decision making, judgment, and so on. Even Angry Birds can be a perceptual, cognitive, and motor challenge!

A key feature of most of these apps is their capacity for performance feedback. However, more useful features, from the HFE perspective, are progressive difficulty, data storage and data analysis based on demographic or contextual variables. The main advantage of these apps, many of which are free, is their enormous reach into the community, their ease of use and entertainment value. A shortcoming is sometimes their lack of formal evaluation and validation when compared with many traditional laboratory devices. Ironically, another shortcoming is their proliferation and ease of use; which apps should a teacher or researcher choose to use?

The app development process

A smart device application (app for short) is like any other product in terms of its development and life cycle. First there is the identification of a functional need; next come exploration, customer requirements definitions and concept development, evaluation, selection and refinement. The “manufacturing” (software development) process starts with architectural design, subsystem / module structures and detailed specifications. Next comes the hard part – coding. This requires knowledge and experience in Java for the Android Platform and iOS and developer registration for Apple apps. The app development process progresses iteratively through verification related to the specifications and validation testing based on the earlier articulated customer requirements. As with any design process from meals to cars to space vehicles there are many constraints along the way. Time is usually a critical constraint; this leads to a Darwinian process of survival of the strong and extinction of the weak. Good designs are customer driven, often modular and amenable to rapid modification following field exposure. Like many design processes – from cars to university courses – experience may bring flexibility or stagnation. Some professors have used the same notes for decades and some car companies are awfully slow to adapt to foreign ingenuity and competition. The app world is extremely fast, sometimes this requires substantial manpower and customer choice makes the business hazardous.

The National University of Singapore Human Factors app development experience

Like most university programs, the National University of Singapore Industrial and Systems Engineering Department requires undergraduates to carry out individual Final Year Projects. Over the past two years seven students have opted to embark on app development for their FYPs. This decision was a leap of faith on their part because none of them had training in software development; they had to learn Java from scratch. These students however are both intelligent and resilient. They were highly motivated and burned the midnight oil. They had their ups and downs. They collaborated with each other and sought out friends in the Computer Science department when necessary.

The requirements for the apps were that they must be functionally correct and error free, the interface must be quick and easy to use with minimal support material, the appearance and functionality must be esthetically pleasing, recorded data should be fed back to the user with reference to previous sessions and cohort performance, personal identifiers should be secure and the experience and derived data must be useful and satisfying to all stakeholders, including subjects, researchers, teachers and software developers and maintainers. They developed the following Human Factors apps:

Jorene Chai Jorene@gmail.com focused on the iterative app development process with customer input throughout. She used the familiar medium of playing card arrangements to create apps to investigate Memory, Grammatical Reasoning and Complex decision making.

Phang Chun Kai chunkai.phang@nus.edu.sg addressed the processes associated with rapid decision making, including simple and choice reaction time, anticipation and warning, compatibility, operational memory and the psychological refractory period. He used the simple media of colored circles to present stimuli and response targets.

Zhou Chen zhouchen@nus.edu,sg developed an app to investigate cognitive deterioration associated with aging, although the device can apply to any cohort. He used the medium of pictures of pairs of hands to assess spatial reasoning, spatial memory, grammatical reasoning, and reaction time (scissors, paper, stone game)
Chan Jing Hua Gabriel.chan@nus.edu.sg created a generic approach to ergonomics checklists. This app allows the identification of up to 10 quantitative univariate criteria and then uses an expert consensus approach to separate high, medium, and low cutoff points for each criterion. A second expert consensus approach is used to assign decision frequencies based on counts of scores on individual criteria. The evaluation is then applied to the product or task of interest and the frequencies of Reds, Oranges, Yellows and Greens are used to indicate the importance or utility of engineering controls, administrative controls or continued monitoring of the process.

Wong Daquan u0905642@nus.edu.sg developed an app to teach Discrete Probability Distributions, including the Binomial, Pascal, Poisson, Geometric and Hypergeometric distributions. All these distributions have use for research and application regarding human characteristics, behavior, performance, and attitudes. The app manages the input of observations, parameter estimation and goodness of fit tests for a chosen distribution. User / student interest is generated by choice of topic, animation, and sounds.

Sim Jing Hui jerry.sim@nus.edu.sg is in the process of developing an app to demonstrate and investigate Fitts, Hicks and de Jong's Laws following an Excel based tool developed as a class project.

Ng Yuwen, Stella (a PhD student) Yuwen@Nus.edu.sg developed an app to present manikin representations of various basketball scenarios and response selections (hold, pass, dribble, shoot). Response times and errors (as judged by experienced coaches) are used to evaluate the choices made by subjects with different levels of experience with the purpose of identifying players with good "situational awareness" and promise.

Evaluation and Reflections

A feature of all these application developments was up front "voice of the customer" assessment and evaluation of the final product by a convenient sample of faculty, friends, and student colleagues. The evaluation criteria – utility, functionality, reliability, design for maintenance and upgrading, usability, appearance, data collection, analysis, and security – were generally well met. Initially it was planned to use a high-level app development tool – the MIT / Google app Inventor, but this tool proved to be too restrictive, so Java became the medium of choice. It should be noted at this point that these Industrial and Systems Engineering students, who had no prior experience with Java or iOS programming, developed of the order of 3000 lines of code for each application. Many references from the academic, technical, and commercial literature were obtained and are available on request. Most of the students plan on continuing the development process after graduation. All the participants found this to be a challenging but worthwhile and memorable process. Please feel free to contact the individual developer for more information.

Chapter 60

EPIC: Effective Performance in Information Complexity

Brian Peacock Chui Yoon Ping

1.0 Outline

Human error is usually due to a failure to deal with cognitive complexity in a timely manner and, given unaccommodating conditions, may lead to an accident with physical consequences. This project aims to assess the effectiveness, efficiency and safety of human behavior and performance in the face of information complexity, especially under time constraints. The approach will be through the simulation of complex scenarios, such as time constrained and hazardous operations in transportation, sport and construction, in order to quantify the information and knowledge demands on individuals and groups, and identify the factors leading to system success or failure. The validation phase of the project will address human performance in real world complex situations. This project proposal is part of the Human Factors in Technology Integration program.

1.0 Introduction and Background

The topic of Human Information Processing has been addressed for many years by Human Factors researchers. Cognitive science is now a massive activity throughout the human factors, psychology and computer science domains. One general finding is that expertise is the ability of trained individuals to handle more information and complex situations more effectively than novices[,2]. Another observation is that "naturalistic decision making" infers the selective attention to and weighting of available information in order to make more efficient decisions[3,4].

The demands on human information processing are time dependent – they require focused attention, effective memory, and perceptive prediction. The stress imposed by input or outcome uncertainty may exacerbate the problem. Examples of the challenges of complexity include operational, spatial, temporal, procedural, and situational awareness, and their effects on performance. A model that represents the complexity of "fuzzy knowledge awareness" is shown below (Figure 1). This model integrates traditional models of human information processing, situation awareness and control in a context of distraction and noise. Whereas the model suggests Operational Memory as the central processing resource, it should be noted that operational failure may be due to failure of any of the contributing functions, which are all at best probabilistic.

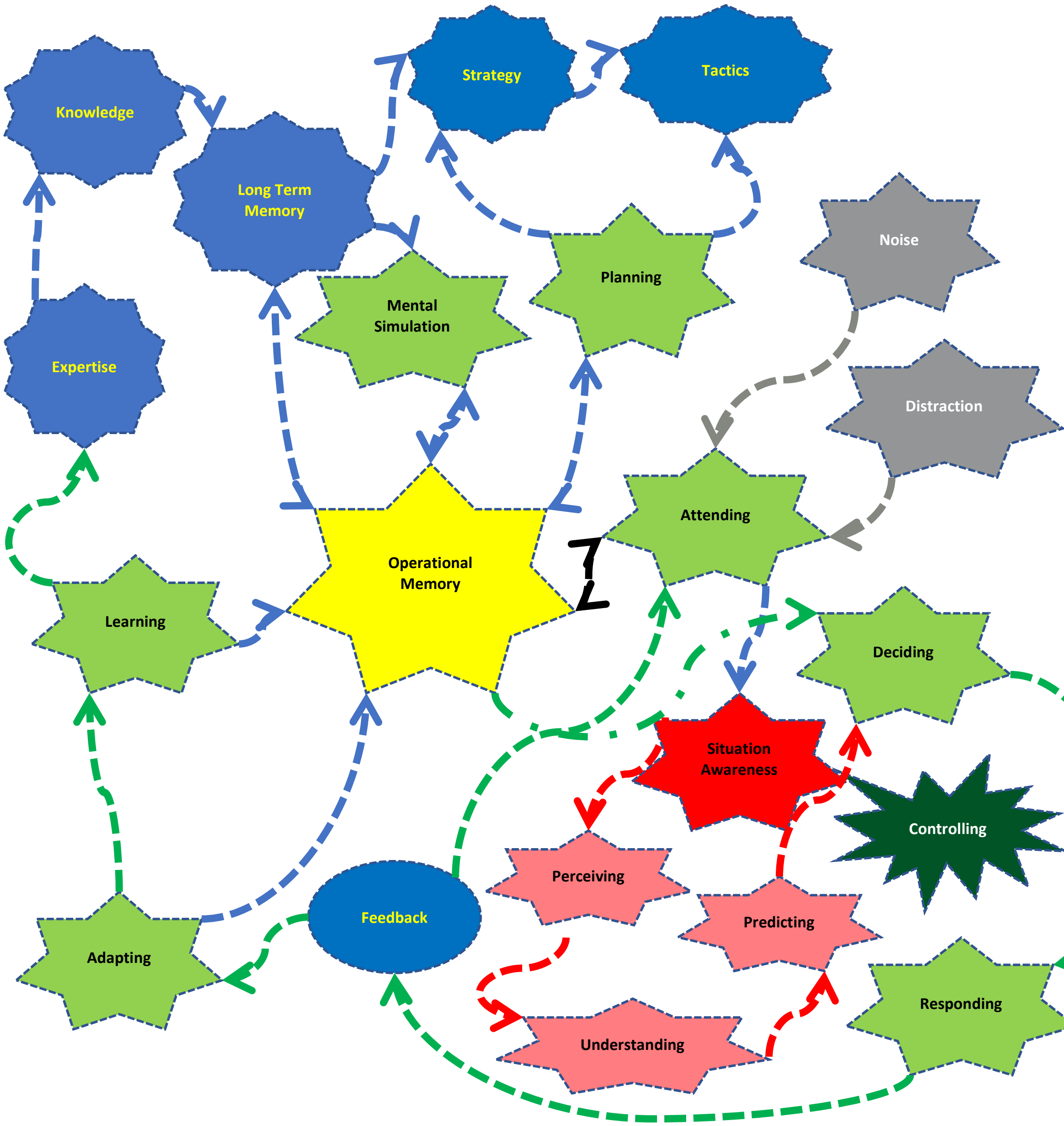


Figure 1: A Fuzzy Model of Knowledge Awareness[5]

14.2 Applications

15. An analysis of near collisions of LNG tanker vessels was carried out using Fault Tree Analysis to identify the "performance shaping factors" leading to unsafe behaviors [8]. This problem of human and contextual difficulty was addressed again recently in a study of the geometry of near midair collisions which again demonstrated cognitive lapses in judgment of separation.[7] In both cases the cognitive failures of situation awareness (perception, comprehension, prediction[11]) were exacerbated by degraded contextual information. A cognitive challenge in these situations lies in the need for prediction in order to account for speed and inertial factors in the vehicles. A similar study is planned to examine near misses in ship navigation, especially in the congested waterways around Singapore.

16. A series of (NUS) student projects has been conducted into decision making behavior in team sports. Games such as football and basketball are characterized by frequent "errors" in which

ball possession changes sides. These studies identified some advantage of "buying time" to process the dynamically changing situations. Greater experience of players and referees contributed to better decisions.

17. The construction industry is extremely hazardous, because of the heights, the many slip and trip hazards on the working surfaces and the wide variety of loads and tools. In 2012, there 26 fatal injuries in the construction sector, particularly involving formwork, a fatal injury rate of 5.9 per 100K workers. The top three types of injuries occurring at the workplace over the last two years are fall from height, slips, trips and falls and crushed by moving objects. Many of these accidents are the result of failed attention and situation awareness, but others are caused by safety procedure lapses and violations. In this and the earlier contexts the involved individual does not intend to make an error, rather he or she usually fails to apply all the available information to the situation because of attention or processing time constraints. Human error aside, a second aspect of these accidents is due to predisposing causes such as the mechanical hazard and the expertise of the operator and supervisor. These predisposing causes may also have human behavior and performance contributions.

    The construction industry may offer an amenable opportunity to study human safety behavior in a simulation context, in the form of a virtual reality "cave". Collaboration with WSHI and MAJ will be pursued to explore the development of virtual reality for the purpose of training and certification in the construction industry.

18. A familiar scenario faced by everyone from time to time is the comprehension of instructions, procedures, and warning. These "facilitators" [13] are characterized by varied length, technical jargon, and presentation format. Furthermore, these devices may be needed under conditions of time and outcome stress and in the hands of both novices and experts. In the transportation and construction industry contexts, the strategic use of facilitators may be used to enhance the situation awareness of operators.

19. The UniSIM SST SIMVA project is an ongoing "edutainment" activity that presents aerospace students with various flight missions using the multiplayer feature of Microsoft Flight Simulator. This activity presents the opportunity to study the effects of spreading mental workload, in aviation, navigation and communication assignments, among team members to explore the concepts of situation awareness and crew resource management. One advantage of this activity related to the current project proposal is the opportunistic capture of data from large cohorts of motivated students with a reliable time stamp of developing situations and operator inputs.

Despite the considerable research knowledge regarding human cognition and the application of models and tools such as Information and Question Theory[12], Bayesian and Naturalistic DecisionMaking[3, 4], the real world is inundated with failures, errors and inefficiencies due to technology and process complexity, contextual interference, inadequately designed interfaces, inexperience and time constraints. The intent of this project, "Effective Performance in Information Complexity", is to explore simulated and real world scenarios that are characterized by complexity, time constraints, outcome stress and varying levels of expertise in order to identify opportunities for both training and technology to prevent error and improve performance. Specifically, the following conceptual model of human performance will be explored:

Human Performance deteriorates as Task Difficulty increases
*Task Difficulty = (Information Content * Stress) / (Time * Experience)*

The components of this model – information, stress, time and experience – and the performance outcomes are amenable to experimental manipulation, especially in a sophisticated simulation context, such as flight simulation or a virtual reality cave. Available information may be varied by manipulating the number of sources and level of detail. Stress can be manipulated by the imposition of scoring penalties. Actual safety stress, although a key component may not be acceptable; however retrospective analysis using SA technologies may be informative. Expertise can be assessed by performance calibration and amount of practice in an experimental task. The critical factor of time can be controlled by external task pacing. One key factor in human information processing is the contribution of expectancy and anticipation based on previous experience. These variables can be controlled experimentally by varying the probabilities of occurrence of information items. As in most human factors investigations time and error are the principal outcome variables, although subjective and physiological (e.g. eye movements, heart rate) measures can be used to supplement the performance measures. The somewhat distinct human information processing functions as shown in Figure 1 may be isolated by task design manipulation in which emphasis is placed on attention, operational memory and decision making.

1.0 Methods

1.1 Preliminary Phase

Ethnographic, Interview and Focus Group methods will be used to explore human error and safety in aviation, shipping, construction, and sports. These exploratory studies, together with more extensive literature review are expected to shed light on the nature of cognitive error and the effects of context, time constraints, stress, and expertise on error avoidance. A second opportunity early in this project will be to explore the use of technologies such as predictive displays[14.] This preliminary phase will also research the availability of technological aids and facilitators to enhance human performance under information, time and outcome stress and reduce the likelihood of human error.

1.2 Simulation Phase

This project will develop simulations of scenarios with controlled levels of Information, Outcome stress and Time available and apply these scenarios to subjects with varying levels of expertise (and age). Alternative task aids – facilitators – will be used to assist comprehension and aid retention, prediction, and decisions. The platforms for these investigations will include the following activities which are conducive to manipulation in terms of complexity / task difficulty and measurement of performance time and accuracy. This collection of simulation projects all address the same human factors problem – decision making under time constraints with varied outcome stress, expertise, and task difficulty. The first part of this simulation phase will be to explore the construction and aviation domains and media to evaluate feasibility and utility of the concepts and approach:

Basic Information processing tasks, such as simple and choice reaction time, and variably spaced (paced) stimuli will be presented though the medium of a tablet-based application to assess the relationship between complexity and performance. The platforms for these studies were developed by 6 NUS FYP students.

1.3 Facilitator Comprehension – Instructions and procedures of varying complexity will be presented with varying time constraints and payoffs (rewards and deductions). The subjects' responses to probing questions will be assessed regarding time and accuracy. These facilitators will be drawn from the construction industry domain. A collaborative project involving the development of a virtual reality cave will be pursued. This simulation could take the form of a computer game in which rewards for the accomplishment of hazardous tasks and penalties for failure are modulated by facilitators with different design attributes.

1.4 SIM Virtual Airspace (SIMVA) will be used to present controllers (as individuals or in teams) with Aviation, Navigation and Communication tasks of measured complexity and time constraints. This project will benefit from the approach used in eight recent UniSIM SST Aerospace Capstone Projects

1.5 A simulator representing the control of large ships will be developed to explore the abilities of participants to predict future states given alternative closure scenarios. It is expected that this project will be part of a major NUS Institute of Maritime Studies project on maritime safety.

1.6 Sports scenarios involving complex decisions will be presented to players and officials with varying levels of expertise to explore their use of available information under time constraints. This will be in collaboration with an ongoing NUS PhD project and a continuation of four NUS FYP projects. A paper related to this topic: "Kneejerk: Intuition, Cognition and Hindsight Bias" - was published recently"[6]

Validation Phase

The validation phase of the project will identify tasks like those in the first and simulation phases that are accessible to observation and measurement. Where appropriate, technological, and operational interventions to reduce the likelihood of human error will be recommended for discussion and evaluation.

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Chapter 61

A Fuzzy Model of Knowledge Awareness

Brian Peacock, Chai Kah Hin

ABSTRACT

Situation Awareness is a highly successful concept that has built on traditional Human Factors models of information processing, mental workload, working memory and expertise. However, these models do not capture the essential plasticity, variability, flexibility and vulnerability of real-world human in the loop control and communication systems. A more encompassing concept is Knowledge Awareness that through memory, with the help of technology, feeds situation awareness and offers greater insights into human control and communication performance. In particular, the Fuzzy Awareness concepts proposed in this paper allow the investigator to describe the human, system, contextual, operational, and temporal variability effects that occur in such contexts as process control, business, military operations, and management. These concepts have been subject to preliminary testing using retrospective commentary by experts and novices in control processes. However, the ready availability of game and simulation technology will enable a much more perceptive analysis of the concepts of Fuzzy Awareness

INTRODUCTION

Every year, organizations lose billions of dollars in productivity as the result of inefficient and ineffective searches for information. Individuals rack their memories for the correct procedures, names or meanings. Groups of people share their individual knowledge to make difficult design or business decisions. Doctors consult their clinical evidence and test results for diagnostic and patient management procedures. Nuclear plant technicians monitor and control their equipment to control their operations efficiently and safely. Every day we scour our e-mails, disc drives and the Internet for key items of information. Our computers help somewhat with intelligent search utilities. These activities take place in a sea of data, information, and knowledge. The human factors community describes these situations with models, flow charts and measurement tools related to concepts such as human information processing, cognition, control theory, communication, mental workload, situation awareness, working memory, naturalistic decision making, team behavior and crew resource management. These conceptual models are generally depicted as well-defined structures, processes and outcomes (Donabedian, 2005) to aid the researcher, practitioner and students to better appreciate and carry out their intellectual pursuits.

> *Consider the scenario involving a novice trainee pilot and his experienced instructor who have been out for a flight to practice maneuvers with their stick, rudder and throttle and are returning to their home airport. All the necessary information for a safe landing is available to both of them. There is a view of the airport in the distance, a busy highway below and a large mountain to the right. The flight instruments show their attitude, heading, altitude and speed. They have an aeronautical chart that offers a great deal of information about the airport and its features, facilities, and procedures. Their radios are available for them to contact the air traffic control tower for information about wind, operational runways and approach. Their ground school training has offered a wide collection of procedures and checklists necessary for a successful return. More advanced students have available at their fingertips a technology-based alphabet soup containing ingredients such as IFR, ILS, DME, VOR, GPS, AWAS and Synthetic Vision. Left alone with all this available information the novice would make many mistakes. On the other hand, the expert instructor has extensive knowledge and situational awareness and knows how, where, when and why to obtain pertinent information and apply it to the process of safe landing. The differences between the two pilots are in aptitude, training, and expertise. But what if the airport has no tower, the engine, flight instruments or radios malfunction, the pilot brought the wrong chart or checklist, there is a low cloud base, a family of coyotes is walking up the runway, the landing is at an unfamiliar airport, there is a substantial crosswind, or the student is on his or her first solo cross country flight? (Peacock and Northam, 2006)*

BACKGROUND and LITERATURE

Knowledge Awareness

This scenario illustrates some differences between data, information and knowledge. Data are the unsorted and unstructured reflections of our environment available for our use, if we know where and how. Information is the meaning contained in these data that is categorized and communicated for our use. Knowledge is how to integrate the information in the active management of our decisions and actions. An extension of these concepts in terms of team behavior is described as the process of Crew Resource Management (CRM.) Other models of human control performance include the concepts of Knowledge, Rule and Skill based behaviors (Rasmussen, 1983) and the use of Landmark, Route and Survey levels of knowledge (Oman, 2003). A final concept is that of complex and emergent systems that require nonlinear, probabilistic extrapolation from the available information. The observations regarding naturalistic decision making indicates that these human centered processes occur is a sea of variability, probability, bias, and vulnerability (Zsambok, C.E. and Klein, 1997).

A review of the literature found that knowledge awareness (KA), though mentioned or implied by a number of authors (Chai and Gregory, 2000, Hansen et al, 2005) and clearly obvious in the presence of experts, is undeveloped and poorly studied in the field of knowledge management (KM). These authors argue that prior to the transfer of knowledge (communication), one first has to search for and become aware of the knowledge. Leckie et al. (1996) proposed a dynamic, cyclical model, where the awareness of information sources, relevance and importance guided the seeking of information, which in turn fed back to awareness. These insights are useful in developing a dynamic framework for Knowledge Awareness.

Situation Awareness

The concept of Situation Awareness (SA) has had enormous success in describing and analyzing the behavior and performance of individuals and groups in the control of complex systems, as in aviation and medicine. Situation awareness (SA), as defined by Endsley (1995) involves perception, understanding and prediction (Figure 1). Its relevance extends to many applications, ranging from railroad operations (Roth *et al.*, 2006) to Internet shopping malls (Lee *et al.*, 2003). According to Endsley (1995, p. 36),

"Situation Awareness is the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future."

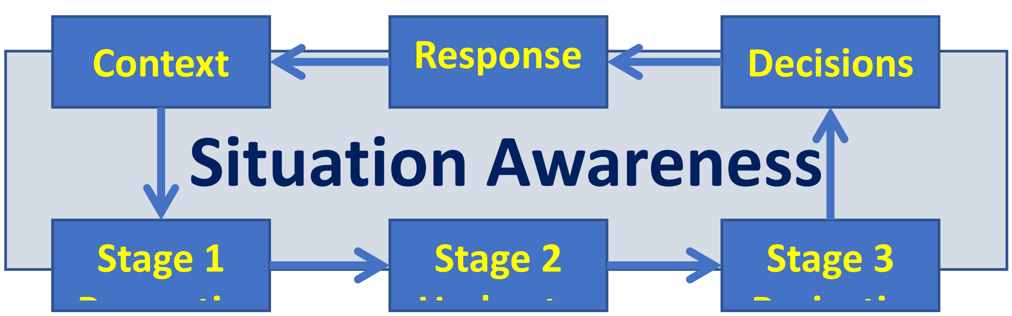

Figure 1 A model of Situation Awareness (after Endsley (1995)

Measurement of "situation awareness" can employ various tools (Gawron, 2008) – retrospective description of what went on during a transaction (SART), assessment of the current state of affairs by freezing a simulation in mid-stream and asking the operator searching questions about their perceptions, understanding and predictions about the developing situation (SAGAT), and real time commentary on what is happening (Verbal Protocol Technique). This last technique has the disadvantage that the conscious articulation of the available information and ongoing processes may interfere with the operators' control behavior and performance. The former two methods (SART and SAGAT) may be inaccurate due to "wishful thinking" and "hindsight bias." The NASA Task Load Index is a retrospective analysis of the stress imposed on the individual or group as they carry out their tasks, again vulnerable to hindsight bias.

Verbal Protocol Analysis has been used for many years to try to explain how control operators make decisions. However, there are often discrepancies between what an operator intends to do, recalls as having done, and what he or she actually did. The rationalization may be related to the outcome of a decision or action. One has only to read the accounts of participants in or spectators of sports contests after the event and compare these with objective analyses of the activities to recognize the universal presence of hindsight bias in human perceptions.

Human Information Processing Models

Human Information Processing and Mental Workload have been central concepts in Human Factors Engineering / Ergonomics for many decades. A concept commonly used to describe the process is that of Human Cognitive Resource Theory (Wickens, 1984, cited in Sanders and McCormick, 1993, Wickens and McCarley, 2007), which identifies the capacities and limitations of information processing resources such as sensing, attention, perception, operational memory, decision management and effectors management. Bloom (1956) offered a perceptive description of various cognition levels that are parallel to the development of expertise that is widely used in cognitive and educational psychology teachings

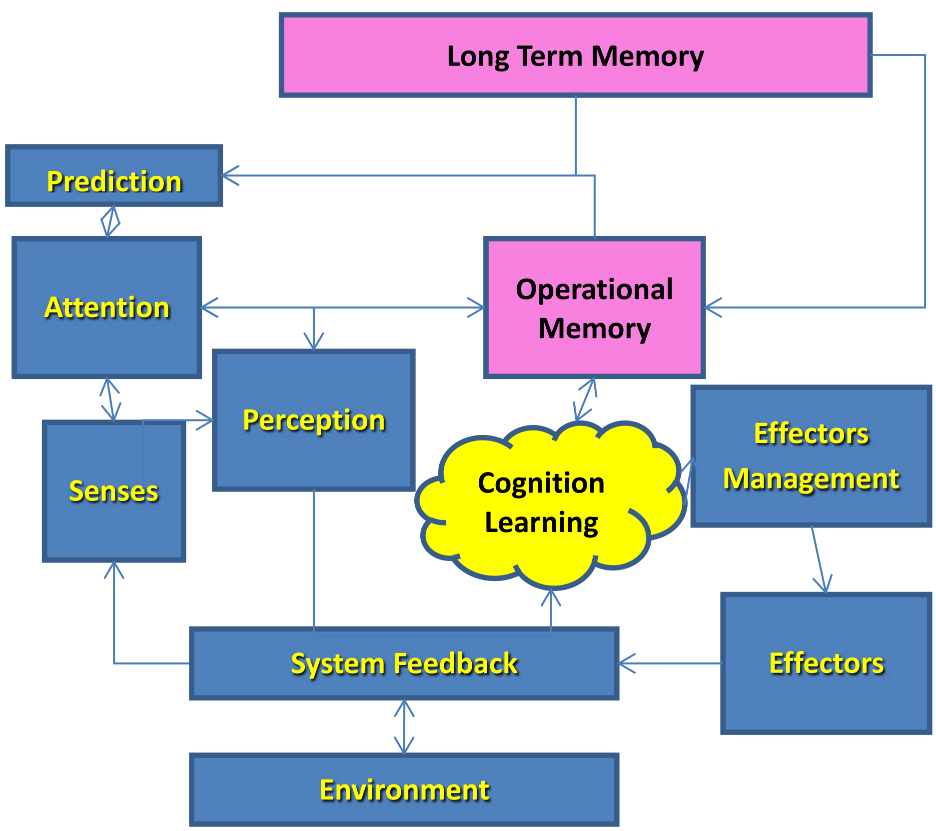

Figure 2 A traditional resource based model of Human Information Processing and control

Memory

In summarizing the theories behind SA, Endsley (2000) highlighted the key roles of working memory and long-term memory. Citing the work of multiple authors Endsley explained that working memory was necessary in the successful integration, comparison, and projection of information. Gugerty & Tirre (2000) claimed that Working Memory "is the central bottleneck in information processing and its capacity varies considerably across individuals. Thus, SA is expected to be limited by working memory capacity".

Endsley (2000) portrayed long term memory as a superset of working memory. If working memory is the set of actively handled memories, long-term memory represented all the possible memories that can be activated. A variation of this perspective was offered by Sarter and Woods (1991 cited in Endsley, 2000, p. 15) who "emphasized the importance of information that can be activated from long-term memory to support limited working memory." Therefore, failures of the memory or retrieval processes will result in difficulties accessing information to support the development of SA. Operational, working or short-term memory is notoriously limited in the amount of information it can hold. The classic work by Miller – "The Magic Number 7 Plus or Minus Two" refers to the capacity of short-term memory for distinct "chunks" of information (Miller, 1956, Baddeley, 1992). One difficulty with this theory lies in the content of a "chunk". With time, rehearsal, consolidation and learning a chunk can contain more and more "bits" of information. For example, one can accurately recall one's telephone, identity number or long computer password, a sequence of instructions for baking a cake or driving to work, but not a set of random digits of the same length or objective information content. Similarly, one can recall in a timely way complex procedures and access complex mental models of operational scenarios in any domain. A Working Memory assessment tool – Operational Memory Involvement Recording Chart may be used to assess and predict human performance as limited by content and interference in the dynamic information processing operation. (Peacock 1972)

OMIRC	Proactive Support (+) Interference (-)	Item Information Content	Retroactive Support (+) Interference (-)	Response Information Content
Sensory Modality	Visual Auditory Tactile (-2) (-1) (0) (+1) (+2)	Visual Auditory Tactile	Visual Auditory Tactile (-2) (-1) (0) (+1) (+2)	Manual Verbal (-2) (-1) (0) (+1) (+2)
Form	Symbolic Spatial (-2) (-1) (0) (+1) (+2)	Symbolic Spatial	Symbolic Spatial (-2) (-1) (0) (+1) (+2)	Symbolic Spatial (-2) (-1) (0) (+1) (+2)
Literal / Semantic Content	Support Neutral Interference (-2) (-1) (0) (+1) (+2)	Familiarity Consolidation Rehearsal Novelty Fuzziness (-2) (-1) (0) (+1) (+2)	Support Neutral Interference (-2) (-1) (0) (+1) (+2)	Support Neutral Interference (-2) (-1) (0) (+1) (+2)
Information Content	High Medium Low (-2) (-1) (0) (+1) (+2)	High Medium Low (-2) (-1) (0) (+1) (+2)	High Medium Low (-2) (-1) (0) (+1) (+2)	Precise Medium Coarse (-2) (-1) (0) (+1) (+2)
Temporal Relationship	Seconds Minutes Hours (-2) (-1) (0) (+1) (+2)	Total Score Forget Recall	Seconds Minutes Hours (-2) (-1) (0) (+1) (+2)	Seconds Minutes Hours (-2) (-1) (0) (+1) (+2)

Figure 5, Memory Involvement Recording Chart

FUZZY AWARENESS MODEL CONCEPTS

A shortcoming of these traditional models is that they do not always capture the complexities, variability and susceptibilities of the processes involved. Consequently, two fuzzy models of Knowledge Awareness and Operational Memory are proposed that capture the essential plasticity of the concepts. These models are living concepts that can and should be manipulated, modified, and extended to better describe how complex Knowledge Management happens. The models are deliberately plastic, perhaps like a neural network. The purpose of the models is to identify Situation Awareness as part of a greater concept of Knowledge Awareness and control. The central foci of the models are Operational Memory and Attention which serve as dynamic links between the noisy outside world and the often-fuzzy knowledge available to an individual or operational team engaged in some complex control process. One important observation is that operational memory is not necessarily conscious; indeed rapid intuitive decisions may be made without apparent conscious control. This topic is addressed extensively by the popular writer Malcolm Gladwell in his book “Blink” (Gladwell, 2007). A significant cohort of Human Factors researchers currently communicate extensively through the “High Velocity Human Factors” Internet Technical Group. Topics of interest include the apparently intuitive decisions and actions of sports players, military and police, vehicle and process controllers and business and investment analysts.

The model of memory depicted in Figure 4 reflects various forms of memory described in the cognitive psychology literature. The model described here depicts these forms as dynamic, fuzzy concepts that interact to serve the processes of knowledge and situation awareness and operations management.

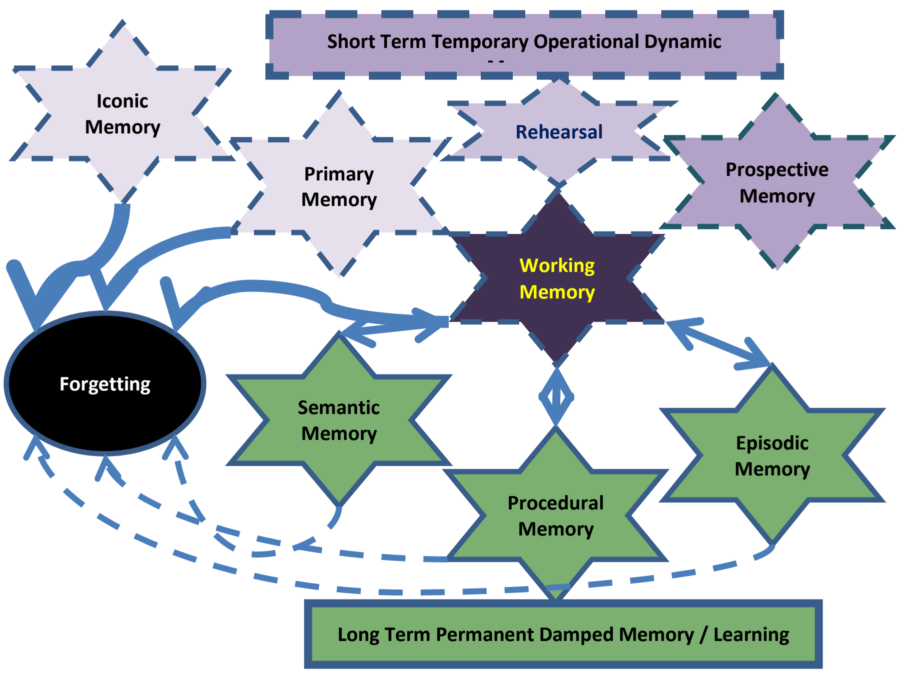

Figure 4 A model linking different (fuzzy) categories of memory

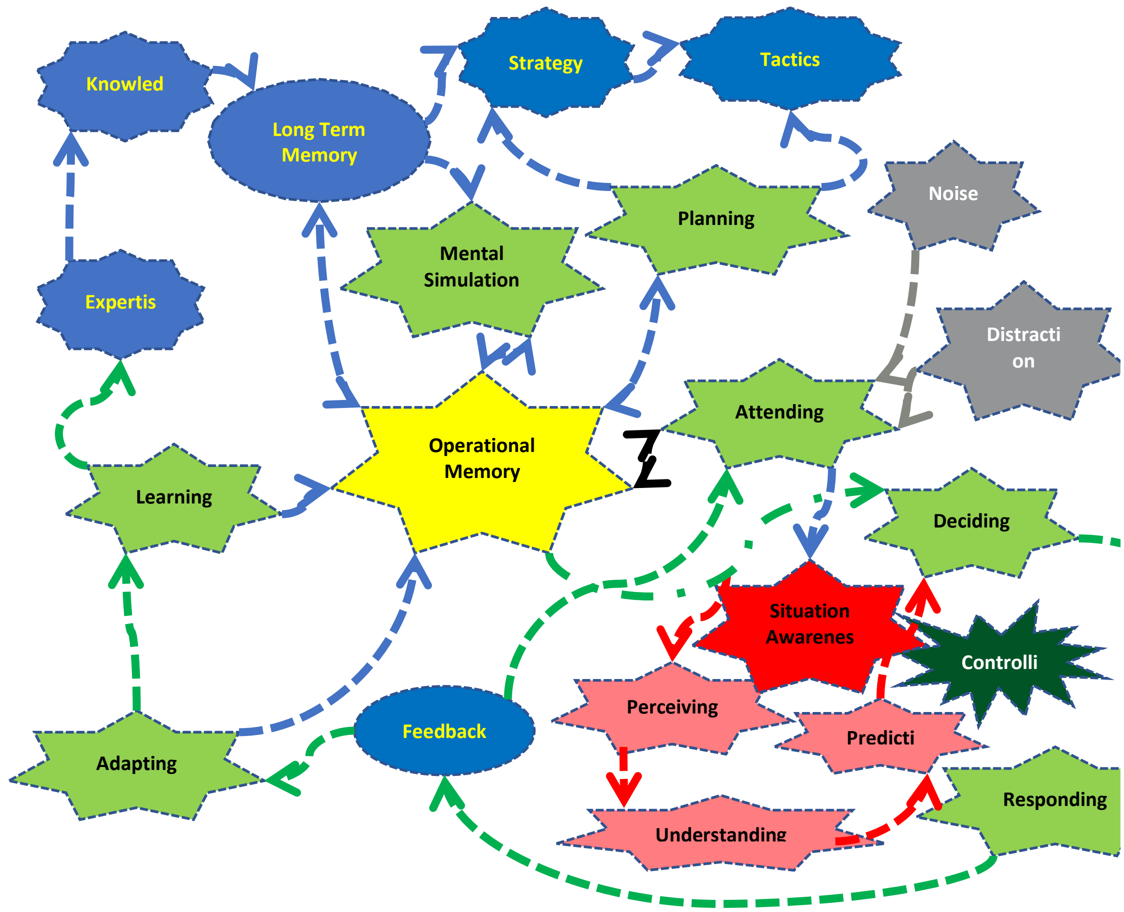

Figure 5 A Fuzzy model of knowledge awareness, memory, situational awareness, and manual control

Some Operational Definitions

- Knowledge awareness is a function of ability, training and expertise. Novices often do not know what they do not know, they may not even know where to look. Experts have the ability to see the big picture (survey knowledge) and fit available information into well-established processes. Experts also may exhibit flexibility in their response to emerging situations.
- Strategic awareness implies that the operator involved has a well-defined purpose. However, this purpose may vary in its precision and tolerance of accuracy, including timeliness.
- Mental simulation first requires a mental model of the unfolding dynamic situation and then adds hypothetical data to evaluate alternative scenario development pathways and outcomes. Again, the validity, effectiveness, reliability and resilience of the mental models are related to expertise and experience.
- Attention requires that the operator focuses on appropriate external or internal sources of information in a timely manner. This process also varies with experience and expertise.
- The first stage of situation awareness implies that the operator has in fact paid attention to relevant information sources and has registered this information into an appropriate "perceptual set."

- The second stage of situation awareness implies that the operator understands the implications of a new item of information and relates this to other information in the developing mental model. The level of understanding is related to expertise (ability and learning)
- The output of this developing mental model implies that the operator can accurately predict the future state or outcome of the situation; the operator may also predict the effects of alternative actions on the future outcomes through mental simulation.
- The next stage of operational management includes decisions, response selection and implementation. This will be dependent on all the previous stages of information processing and succeed or fail because of inappropriate use / weighting of information or execution skill. Risk taking behavior will occur where decisions are made with insufficient or probabilistic information.
- While all this information processing is going on working memory is continually active in recording, storing, manipulating, consolidating relevant, and forgetting non relevant, information. The efficiency of working memory is related to expertise but is particularly vulnerable to interference and modality / resource specific overload.
- Monitoring a developing situation requires selective attention to various sources of information. It is here where external observation of eye movements or verbal commentaries can be applied to assess the appropriateness of the operator's behavior.
- Adaptation occurs generally in rule-based behavior where the operator selects an action from a stored rule set based on feedback from the ongoing situation. Such behavior may fail under emergent conditions where the response rule set may need expansion to deal with novel situations.
- The final stage of cognitive activity is the inevitable learning that takes place following this experience. Learning may be poor where the operator has insufficient knowledge to understand the causes and effects of the developing situation. Consequently, successful human performance will depend on both experience and the establishment of knowledge related to the understanding of the causal chains

A Framework for Knowledge Awareness

An operational definition of KA in this study is adapted from Endsley's definition of SA and written as follows:

Knowledge Awareness is the attention to information in the environment and from memory, the comprehension of its meaning and significance, and the projection of its impact in the dynamic control of a process.

From the definition, it should be clear that Knowledge Awareness goes beyond simple recollection of what knowledge exists and where it lies. It encompasses the ability to mentally register pertinent knowledge, understanding the significance of that knowledge and its relationship to other items of knowledge and the task, and from there, infer or deduce, through mental simulation, the future state of the knowledge environment.

To illustrate this, recall again the flight scenario from the introduction. The knowledge environment refers to the whole set of internal and external knowledge that exists in the flight context and every conceivable relationship these items of knowledge have with each other and with other entities or *activities. KA refers to the pilots' mental model of this reality, and it is from this internal re-creation of the actual knowledge environment that they make their knowledge-based decisions. This can be generalized to any knowledge environment involving any number of individuals.*

Given the dynamic nature of knowledge search, where KA drives search while search outcomes in turn modify awareness in an iterative process, it makes sense to present the state and the process in a dynamic, cyclic relationship. This portrayal is consistent with related models in SA, information seeking and sense making. It is evident from the foregoing that experts have greater knowledge awareness than novices, that groups have more knowledge awareness than individuals and that technology can be designed to enhance knowledge awareness, decisions, communication and control.

Testing the concepts of Knowledge Awareness

The formal testing of these concepts is through the presentation of scenarios of varying complexity to individuals and groups with different levels of expertise and technological support. Measurement of Knowledge Awareness, Situation Awareness, Decisions and Control Outcomes may be through descriptive or subjective methods (MIRC, SART, SAGAT, Verbal Protocol Technique etc.) and through objective performance measurement. The ready availability of computer-based games, realistic simulations and day to day computer mediated activities in many different domains such as flying, business, literature research etc. are available to study the concepts described in this paper. A preliminary study was completed by Le Van (2006) which clearly identified the characteristics of knowledge awareness using a subjective retrospective questionnaire. Another preliminary study with both subjective and objective measures can be performed by downloading the flight simulator utility in Google Earth and flying prescribed fight paths with varying sources of available information and with subjects of varying levels of expertise. Also various business, adventure, political and military simulation games can be adapted to explore these concepts.

2. CONCLUSIONS

A strong interrelationship was described between Knowledge Awareness, Situation Awareness and Memory. These observations provide impetus to studying the relationship between the constructs. Whereas the concepts of transitive memory (Wegner, 1986) extend the principles of individual memory to the collective memory of groups, the principles of Knowledge Awareness also imply the utility of technology as an important player in the description of real world operations. Contemporary smart phones and portable tablets can even tell us when the next bus will arrive!
For researchers, the proposed framework for KA lays the foundation for subsequent research and highlights the need to take into account the development of KA as a prior stage to situation awareness, decision and communication, which in turn is essential for control. Finally, the differences between perceived, subjective, and actual performance are a reminder to researchers of how different perspectives can yield quite different measures that are equally valid. For KM practitioners, the study highlights the importance of enhancing KA as part of a larger KM strategy. It also points out the need to look beyond information systems to encouraging social interaction to enhance KA in an organization. Contemporary social and professional networking utilities facilitate such sharing.

This study being exploratory in nature, uncovered many potential areas for future study. The first possibility would be to delve deeper into identifying and measuring the factors influencing KA including expertise and working memory. Teasing out the various aspects of team behavior and Crew Resource Management or using more robust measurement techniques may yield further insights. The fuzzy models of working memory and knowledge and situation awareness in control and communication can be validated through interviews with novices and experts or through objective empirical research using selections from the vast array of computer simulations of real-world knowledge intensive situations.

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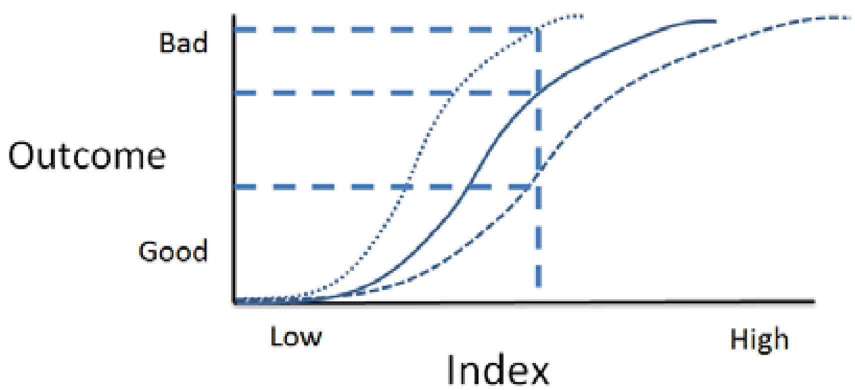
Chapter 62

Workability Index – Research and Development

1. **Overview**

   a. A "workability index" is a single composite measure of the multiple factors associated with a job, including the workplace, physical environment, equipment, material, pacing, other operational details and the capability of a particular individual. In general an index has the following form:



   b. The three curves represent the relationship between the Index and the Outcome for average, robust and vulnerable (perhaps elderly) workers. The dashed lines indicate that a cut-off point on the Index will have different Outcomes for different populations. The "Outcome" may also have qualitatively different and perhaps contradictory meanings, such as productivity or safety.

   c. Workability Indices take into account physical factors, such as spatial arrangements, strength, stamina, speed and skill, environmental factors such as heat, cold, noise and vibration, informational factors such as vision, hearing, memory and situational awareness, and operational / temporal factors such as static posture duration, job pacing, job cycle duration and work shift duration. These factors can be assessed individually and the measures combined to produce a "Workability Index" that reflects the physical, cognitive, environmental, social and temporal demands of a job.

   d. Three examples (there are numerous others such as OWAS, HAL, The Strain Index etc.) of widely validated occupational health and safety "Indices" are: the NIOSH Lift Index, RULA and the Snook / Liberty Mutual Psychophysical Tables for manual materials handling. The first two do not formally address the issue of different populations, whereas the Snook Tables are presented as a "percentage of the population who are capable of safely performing a particular task." These tools were all developed in the West and may not be an accurate reflection of the capabilities and limitations of Singaporean workers. The Finnish "Workability Index" is a clinical tool that addresses both work demands and individual factors, including disease. Similarly, the International Classification of Function (World Health Organization) is individual centered; it describes both specific body system function and the capabilities of an individual to perform "acts of daily living."

   e. These "Indices" vary considerably in their complexity and scope, although in trained hands they have been shown to be effective measures of the relationship between work demands and populations of workers. They also may be time consuming to apply.

One way of addressing these "efficiency" factors is to have a hierarchy of screening, analytic and in depth investigation tools. This "triage" in the emergency room sense makes efficient use of the time and expertise of health and safety professionals, with different training levels.

f. One lesson learned from the NIOSH Lift Index is that the single index needs to be decomposed into its constituent parts in order to identify and rectify the job if necessary. This is because different engineers have responsibility for different components of the task, such as load (Product Engineer), spatial (Manufacturing Engineer) and temporal (Industrial / Production Engineer) factors. The NIOSH Lift Equation is a "Discounting Equation" with a set of multipliers, each taking a value between 0 and 1. Thus the intervention strategy first addresses "the low hanging fruit" and directs the intervention to the appropriate engineering specialist. One way of addressing this link between analysis and intervention strategy is to use job profiling graphs and matrices or polar graphs. Such communication tools have been used widely in such diverse areas as company financial performance and physical rehabilitation.

g. Another approach (widely used throughout General Motors for the past two decades) is to assign a "common currency" outcome metric to many qualitatively different job stressors, such a load, location, force, frequency and duration. These common currency outcomes are amalgamated to produce an Index of Workability but decomposed into their original dimensions to drive interventions. Also the Physical Work Strain Index uses an activity sampling approach that aspires to determine a balance between high static and high dynamic physical workloads. Some publications by the principal investigator that describe these approaches in more detail include:
   i. A Discounting Model for Task Design, Applied Ergonomics Conference, IIE, 2005, Orlando, Florida
   ii. Rule Based Ergonomics, Ergonomics in Design Vol. 12, No. 4, 2004
   Habitability Measurement in Space Vehicles and Earth Analogs, Chapter 74 in Stanton et al Handbook of Human Factors and Ergonomics Methods CRC press,
   iii. Measurement in Manufacturing Ergonomics, Chapter 8 in Handbook of Human Factors Testing and Evaluation, Charlton and O'Brien, Lawrence Erlbaum, 2002
   iv. (with Jen Gwo Chen and Hwa S Jung) "A Fuzzy Sets Modeling Approach for Ergonomic Workload Stress Analysis", International Journal of Industrial Ergonomics 13, 189 – 216, 1994
   v. (with J. G. Chen and R. E. Schlegel) "An Observational Technique for Physical Work Stress Analysis", International Journal of Industrial Ergonomics, No.3 (1989)

h. This proposal involves the adaptation or development of a Workability Index and Job Profile for application in Singapore (SWIJP), with particular reference to vulnerable populations, including the elderly worker. The principles and operational format of internationally validated tools will form the basis of the SWJIP development. It is likely also that enhancements could be made to include greater attention to the temporal dimension of static and dynamic work demands. The parameters will be subject to validation for local use in a wide variety of workplaces – from construction through logistics to the office.

2. Proposed Plan of Study / Time Line

Item	Description of work	Duration
1	Survey of workability indices and job profiles around the world. Identification of elements and processes to include in the proposed toolset.	Three months
2	Design of a measurement, analysis and communication instrument for Singapore. (SWIJP) Pre-testing the instrument.	Two months
3	Development of training material to accompany the SWIJP	Two months
3	Field testing and validating the SWIJP instrument.	Three months
4	Modifications and final changes to the SWIJP instrument.	Two months

3. Background – The Older Worker (Singapore)

a. Work is a tangible way in which individuals can contribute to society. It is also a means by which individuals can receive financial rewards and personal fulfillment. A complication of this symbiotic relationship is the wide variability among individual's knowledge, experience, capabilities, limitations and aspirations on the one hand and the enormous variation in employment opportunities on the other. The matching of opportunities with individual capabilities and interests presents complex technical and organizational challenges. A particular challenge for employment is the process of aging.

b. The following chart (Figure 1) shows the number of persons in each 5 year age group for the years 2000 and 2010. This "age pyramid" shows clearly that the Singapore population is ageing. Singapore's situation in this regard is not unique. The same observations are made in Europe, North America and Japan. The primary causes of these changes are the birth rate and the contributions of public health and medical interventions to prevent and treat otherwise fatal diseases.

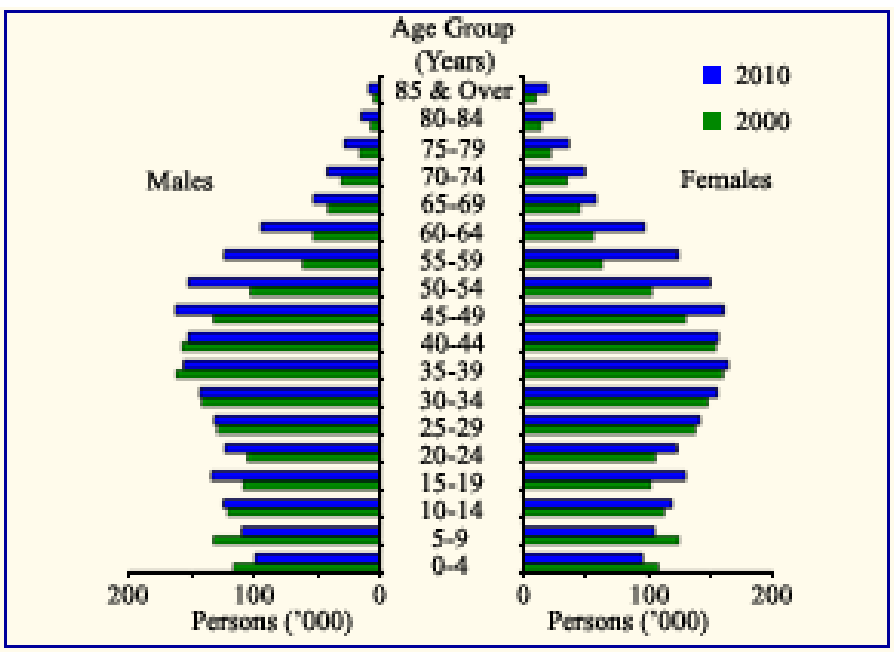


Figure 1 Singapore age pyramid
(Source: from www.singstat.gov)

c. Figure 2 shows that the participation of Singaporeans in the workforce is also “aging”. The decline in numbers begins to increase significantly after the age of 55 compared with a turning point at 50 in 1999. There are also many more people working after the age of 70. Minister Mentor Lee is quoted as saying that “there should be no retirement age for workers”. The philosophy behind this statement is that not only will the working capacity of Singaporeans be increased, but also that individuals will remain healthier and happier due to the stimulation associated with work. It should be noted that there is an alternative point of view. Some older people, who are less intrinsically motivated by their employment, look forward to a phase in life when they can “smell the roses” and spend quality time with their grandchildren and hobbies. They argue that this is a reward for a lifetime’s contribution to society. The key to these alternative viewpoints is the fundamental fact that all people, including elderly people, differ in their interests and aspirations.

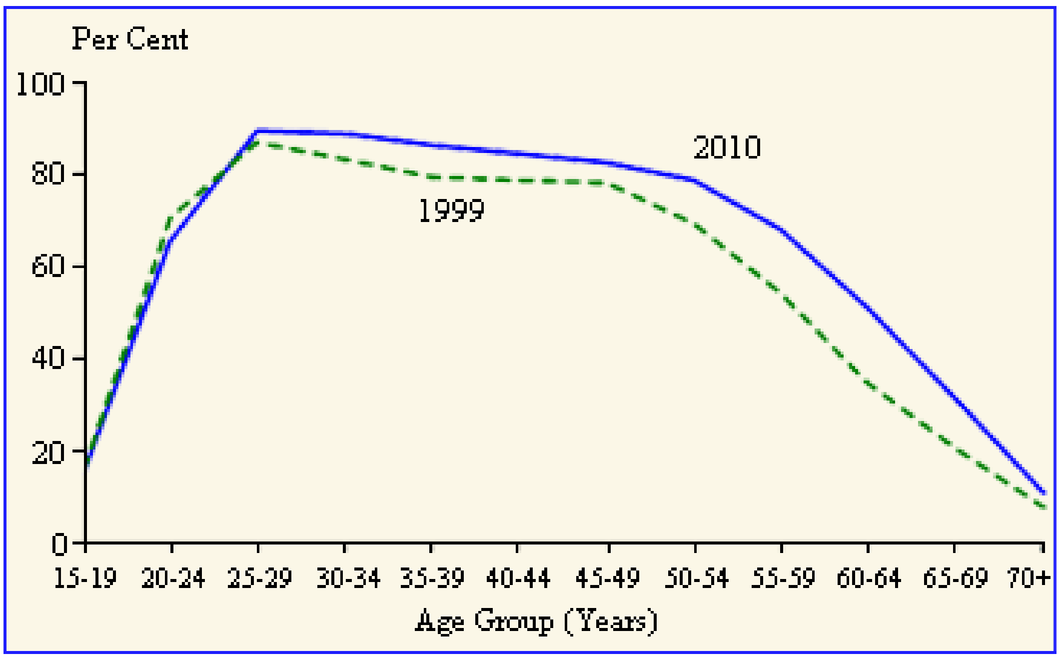


Figure 2 Participation in the workforce
(Source: [http://www.singstat.gov.sg/stats/charts/popn-area.html)](http://www.singstat.gov.sg/stats/charts/popn-area.html)

d. More importantly, one implication of the changes in the age pyramid is shown in Figure 3. This shows a dramatic decrease in the ratio of the population above and below the age of 65. This fact, together with the increasing trend for both husband and wife to pursue careers, for personal fulfillment, social or financial reasons, results in an increasing likelihood that unemployed elderly people will remain at home alone, or need attention from a domestic servant.

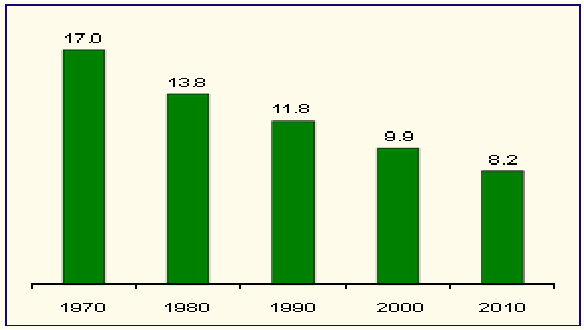


Figure 3 Old Age Support Ratio - Number of Residents Aged 15-64 Years per Elderly (>65)Resident *(Source: http://www.singstat.gov.sg/stats/charts/popn-area.html#popnC)*

e. The challenges that these trends present are the provision of opportunities for an increasing number of elderly people to find personally, socially and financially fulfilling work. One contribution to the resolution of this challenge is the application of ergonomics to the analysis and design of equipment, workplaces and jobs that match the capabilities and limitations of this cohort.

6. Factors associated with aging

There are wide individual differences among older people that have genetic, medical and life style underpinnings. These factors may not be due to ageing *per se*, rather they may simply be associated with ageing. Either way the "solution" to the ageing issue may be to address these associated or "confounding" factors:

a. Disease Aging in general and with particular body systems is affected by genetic factors. There are genetic markers for many diseases. This early available information can be used to intervene in the disease process and thus prevent or reduce the effects of this disease as a person ages. One strategy to increase the "active longevity" of ageing people is regular and enhanced medical attention. Disease processes affecting vital functions such as circulation, vision, cognition etc. can have considerable effect on the "aging process" of other human functions. Medical intervention through drugs, replacement parts such as joints, dental, vision and hearing devices or rehabilitation may offset some disease factors associated with ageing.

b. Lifestyle Diet, exercise, cognitive and social activity affect the rate of decline of human capabilities. This decline can therefore be slowed significantly by lifestyle intervention among ageing people. For example poor diets and low levels of physical activity give rise to obesity, which in turn leads to metabolic disorders, such as diabetes. As employment is a significant element of "lifestyle" the design of jobs that are historically sedentary in nature should be addressed to include a greater opportunity for routine physical activity and social interaction. This philosophy may contradict short term objectives of productivity, but over the long term will maintain the physical and motivational capabilities of employees.

c. Training and Experience Specific experience with equipment, tasks or contexts will offset the age based decline in cognitive abilities. Routine specific job related training will be appropriate to facilitate the capabilities of older people as they interact with new technology or contexts

d. Generational effect Older people may have difficulty with contemporary technology, not due to ageing *per se*, but rather due to their exposure to such technology or to their perceptions regarding the need for the technology. Again the routine inclusion of ongoing training with contemporary technology in the workplace will go a long way towards offsetting this generational effect.

e. **Motivation** Individuals vary considerably in their motivation to work and participate in physical, cognitive and social activities. The intrinsic nature and context of these activities will generate positive or negative effects on motivation. In the workplace, it is the responsibility of employers / supervisors to consider these issues in the monitoring of individual behavior and performance, and the design of jobs.

f. **Support** The declines associated with ageing can be offset by family, employment and community support structures. If society and employers wish to prolong the active employment of individuals then there will be a need for support structures and processes that address such things as transportation, counseling, health care, continuing education etc.

g. **Economic factors** Some older people need to work to provide for their basic life needs of shelter and sustenance. An important responsibility of society, employers and families is therefore the mitigation of economic stressors among ageing people. The principle of "social security" of course has political ramifications. However an active rather than passive process of support can go a long way towards maintaining the contributions to society by people as they age.

h. **Affect** Older people are like all other people in their affective behaviors. They often express opinions and make decisions based on "likeability" rather than objectivity or function. However the affective behavior of older people differs from younger people in that they favor familiarity rather than novelty. Their opinions become entrenched, their behaviors more rigid and their performance abilities less flexible. When faced with challenging situations older people may revert to over learned, but situationally inappropriate behaviors. These characteristics of older people are a natural learned result of activities that have been repeated many times. Tasks and situations that take older people out of their "comfort zone" may cause stress and performance failures.

i. **Job Design** As people age the decline in physical, mental and social abilities is inevitable, although the rate of decline may be mitigated by the interventions discussed earlier. One other mitigation approach is to reduce the demands on older people by such strategies as reducing the length of their work day, the amount of work done over a certain time or other job responsibilities. The socialist slogan articulated by Karl Marx (1875): "From each according to his ability, to each according to his need", is in fact a truism. People do vary in ability and contribution and capitalist societies do protect the weak, for humanitarian and long term economic reasons. In the context of the ageing workforce these issues need sophisticated consideration.

j. **Ergonomics Analysis and Design** The primary contributions of ergonomics are the design of workplaces, equipment, contexts and tasks to accommodate these age related changes. Necessary precursors of design are incisive and reliable analysis and domain knowledge. The ergonomics community is trained in the use of many physical, sensory, cognitive, behavioral, performance and affect measurement tools. Also there are many standard principles and rules that can be applied to design for ageing populations. The success of ergonomics interventions is also dependent on substantial domain knowledge. This knowledge can be obtained firsthand or more commonly by working with individuals that are well versed in the context of interest. These principles of "participation" and harnessing the "voice of the customer" are essential ingredients of the ergonomics analysis and design process.

k. All these factors present opportunities to explain and address the declines associated with ageing. In practice the most successful approach to ageing should involve in depth consideration these factors.

7. The International Classification of Function Disability and Health (ICF)

a. The International classification of function is primarily a medical tool, developed to complement the International Classification of Disease. However, the principles and methods that comprise the ICF may be used or adapted to evaluate the effects of aging on task performance.

b. The ICF is structured around the following broad components:
   i. Body functions and structure
   ii. Activities (related to tasks and actions by an individual) and participation (involvement in a life situation)
   iii. Additional information on severity and environmental factors

c. ICF is described as the complex interaction between the health of an individual and his or her context. This description clearly links the knowledge and practice of ergonomics to the purposes of the ICF:

Functioning and disability are viewed as a complex interaction between the health condition of the individual and the contextual factors of the environment as well as personal factors. The picture produced by this combination of factors and dimensions is of "the person in his or her world". The classification treats these dimensions as interactive and dynamic rather than linear or static. It allows for an assessment of the degree of disability, although it is not a measurement instrument. It is applicable to all people, whatever their health condition. The language of the ICF is neutral as to etiology, placing the emphasis on function rather than condition or disease. It also is carefully designed to be relevant across cultures as well as age groups and genders, making it highly appropriate for heterogeneous populations."

From:
http://en.wikipedia.org/wiki/International_Classification_of_Functioning,_Disability_and_Health

d. Whereas the usual focus of the ICF relates to people who are incapacitated for reasons of disease, the approach is relevant to all levels and causes of incapacity, particularly as related to an individual's interaction with his or her context. Both the normal deterioration associated with aging and the concomitant health issues make the ICF a pertinent tool for consideration of the functioning of older people at work. The ICF is generally completed by a team of analysts, each with a different perspective on the unique individual / context interaction. Whereas the team members often have a medical bias, there is no reason why a similar approach with operational team members should not be applied to the unique problem of ageing individuals. The results of this analysis can be used to guide ergonomics interventions.
An outline of the ICF can be found through the following link:

http://www.who.int/classifications/icf/training/icfchecklist.pdf

Ergonomics intervention opportunities

Ergonomics interventions may be developed from the following first principles:

a. Space The management of spatial factors must address two extremes. First because of mobility and physiological limitations movement distances should be reduced: these will involve interventions to reduce such things as the distance of walking, climbing, lifting carrying, pulling pushing etc. The Liberty Mutual (Snook) Tables provide guidelines for such activities that identify the proportion of the (adult) population capable of completing tasks of this nature with defined parameters. These tables were developed for the North American adult population so there will be a need to either transform the data to fit the Singaporean elderly population or carry out a substantial local research project to accommodate Singaporeans.

b. Skills The second spatial intervention principle is based on perceptual and motor skill requirements and involves the size and contrasts of fonts, objects and targets. In general the sensory – motor skills of older people are less than those of their younger counterparts. These deficiencies may be compensated for by allowing a greater amount of time for task completion. However a more appropriate intervention is to increase the contrasts and size of targets, such as boxes on forms or buttons on web pages. Other size and skills related design issues are associated with gross body movements. Older people, being less agile will generally require more space to carry out these movements. Other sensory motor skill declines are associated with balance. Tasks should be designed to avoid or mitigate the effects of loss of balance, by not requiring the negotiation of steps or stairs or by providing convenient hand rails.

c. Strength Older people generally have a decline in strength; this requires a reduction in the forces or moments necessary to perform materials handling or manipulation tasks. Analysis of materials handling tasks can be carried out using the NIOSH lift equation, the Liberty Mutual Tables and various other ergonomics analysis tools, such as RULA. Interpretation of the results of such analyses for the strength characteristics of the Singapore population can be carried out by reducing the derived index cut off point.

d. Speed Older people are generally slower than younger people in the time it takes for task completion, despite similar amounts of "effort." Thus it is necessary to make allowances in job content and pacing.

e. Stamina Older people generally have reduced ability to perform physical work over time (Stamina) because of decreased cardiac, respiratory and muscular capacities. The rate of decline may be offset to some extent by physical training, but usually the decline is increased by diseases associated with disuse and abuse, such as heart conditions and osteo arthritis. In work terms this involves the reduction of distances and loads or an increased time to accomplish materials handling or walking tasks. There are numerous performance measures of individual fitness, but these are not usually used in the ergonomics and work design context. Tools that can be used include estimates of the caloric demands of jobs or subjective estimates of physical stress, such as the Borg scale.

f. Intensity Intensity is a characteristic of size, brightness, loudness, force etc. Such variables are generally perceived in the context of "noise" or distracting background information. Older people require greater signal to noise ratios in the presentation of visual, audible, touch, taste, smell and force information. The distracting effects of noise also require greater concentration / effort on the task at hand; older people find background "noise" especially irritating. Tasks designed for older people should seek to minimize distractions such as audible noise or peripheral activity / movement.

g. Information The information content of tasks in terms of understanding, decision difficulty or memory needs to be reduced to offset the decline in these capabilities associated with ageing. However such declines can be offset by experience and practice. Older people may require longer times and more practice to acquire specific information handling and control skills. As with physical tasks the remedy for information intensive tasks is a reduction of the task demands imposed on elderly employees.

Older people have difficulty or delays in switching attention; they are particularly attracted to familiar and salient stimuli. Paradoxically they also have a lower tolerance for sustained attention or vigilance. Tasks that require the rapid shifting of attention, such short duration customer relations transactions or process control (e.g. driving) should be designed to provide more time for attention shifts. Tasks that require long periods of focused attention, such as inspection or monitoring tasks should be alternated with less demanding, perhaps more physical tasks.

The ability to deal with complexity and to "multi-task" declines with age. Older people should be given the opportunity to self-pace their tasks and avoid interruptions / distractions. Working or operational memory decline is a notorious characteristic of ageing. Tasks should be designed to limit the demands on working memory or supplemented by the provision of memory aids. Examples include the literal transfer of information such as codes – sequences of numbers, acronyms, abbreviations; these sequences should be kept as short as possible or grouped and replaced by meaningful information wherever feasible. Semantic long-term memory persists and is consolidated with age. Older people perform better with familiar tasks than with high information content tasks. Decision making capabilities also decline especially where decision difficulty is increased. The ergonomics interventions include increasing the ease of decisions by increasing signal to noise ratios or probabilities associated with the correct decision.

h. **Context** The physical, operational and social context of tasks must be managed to reduce their distracting effects on task focus and performance. Older people are less tolerant of extreme or sub extreme physical environments, such as light, heat and noise. For example visual decline requires that greater amounts of lighting are required for fine detail perception.

i. **Time** All the previously mentioned factors (space, force, information, and context) are time dependent. At one extreme it may be necessary to reduce the exposure duration or repetition frequencies; while at the other extreme human functions may be facilitated by providing more time.

j. **Affect** Older people generally prefer the familiar to the novel. This affective characteristic should be addressed by reducing the amount of change associated with any task, function or context. Older people may be hypersensitive to overt changes associated with ageing, such as body shape, strength and stamina and sensory, cognitive, memory and motor abilities. Such sensitivities may create stress, generate over reactive behaviors and exacerbate performance decrements.

k. **Learning and Training** Older adults will respond positively to learning or training opportunities and thus increase their resilience in the face of task stressors. To be successful these learning and training opportunities should be graduated, individually paced and combined with positive feedback of success and clear, non-punitive feedback associated with failure. Generally older people are slower than younger people at learning new procedures and skills. Therefore, the learning process should be addressed in designing products and procedures for use by older people. A particular difficulty is found when older people use products or procedures infrequently. This issue is addressed by improving the memorability of products and procedures by highlighting important features and sequences and removing distractions. A negative effect of learning commonly experienced by older people is that previously acquired stimulus response relationships, including both correct and incorrect relationships persist. Therefore tasks requiring new or changed relationships should be avoided. The “repetition of errors” problem requires more extensive rehabilitation and even then, when an individual is under stress, the old incorrect response may be selected. Part task training, based on previously acquired skills and a global overview of the overall process, should be self-paced and applied with clear positive feedback

l. Combinations Most everyday tasks involve combinations of the stressors described above. The complexity and impact of these combinations should be reduced.

9. Strategies

a. **Research and Development** The phenomenon of aging and mechanisms to reduce the functional implications of ageing have both received considerable attention over the past two decades. There exist in Singapore many opportunities for both basic research into ageing and employment and applied research and development to accommodate the ageing workforce.

b. **New Technology** “Designing for Older Adults”, Fisk et al (2004) describes the challenges faced by older people and design opportunities to assist them in their daily functions. One focus of this book is towards the challenges faced by elderly people with contemporary information technology, such as smart phones, tablets and the internet, and various automated service interfaces, such as banking, ticket purchase. A third exploration opportunity is on-line shopping, which has the advantage of reducing personal journeys, but the disadvantage of non user friendly error correction. Currently older people are reluctant to use this technology – this presents a research opportunity into the general issue of adoption of contemporary technology by older people.

c. **Transportation** The General Motors ACCESS Car program in 1988 – 1989 was focused on the challenges faced by older drivers and interventions that could make their experience more successful. This program had both practical and commercial intentions. This program explored physical, cognitive, medical, behavioral, and social characteristics, capabilities, limitations and aspirations of the elderly car user. Many of the products of this research program have been incorporated in contemporary vehicles. However, the transportation alternatives for older adults merits continued investigation. One strategy that is particularly appropriate for Singapore is to explore the various alternatives to personal and mass transportation through expansion of taxi, small bus and other for hire services. Another local transportation opportunity is in the expansion of small electrically powered personal vehicles.

d. **Employment** A second aspect of the ACCESS program addressed the challenges faced by the older worker in vehicle manufacturing. Auto workers in the USA are represented by a strong and sometimes combative union – the United Auto

Workers (UAW). The cornerstone of unionism is that of seniority where individuals with longer service in the company had first choice of jobs. This policy would often result in "bumping" where more senior employees would replace junior ones in a desirable job (such as fork truck driving around the plant.) Generally speaking seniority is correlated with age, so this policy provided a rational basis for self-selection to protect older workers from the more (perceived) stressful jobs. This principle of self-selection based on age and seniority is relevant in Singapore. However, the precise mechanism requires incisive research, including field research in selected organizations.

e. **Physical Work Design** The physical characteristics, capabilities and limitations (Size, Shape, Strength, Speed, Stamina) of Singaporeans are different from those of their Western counterparts for whom extensive data exist. Furthermore, many of the work analysis and design models that exist are based on this Western data. A major research thrust should be a comprehensive survey of the Singaporean population in areas such as anthropometry, biomechanics and work physiology, with particular reference to age related differences.

f. **Education and Training** Management, unions and employees should receive formal training regarding the processes and effects of aging, and the choice of engineering and administrative interventions. A comprehensive program should be developed to communicate ergonomics principles to management, ergonomics monitors, ergonomics specialists and employees with particular focus on the effects of aging. The material for such education and training programs should be a blend of basic science, human science and mathematics, outcomes associated with appropriate and inappropriate equipment, workplace and job designs, and a collection of ergonomics analysis tools and design guidelines. There is also a shortage of ergonomics practitioners at the Doctorate and Masters levels in Singapore. Specific provisions should be made to support education and research programs in Ergonomics and Safety in Singapore's tertiary education institutions.

g. **Product Design** Older people tend to favor familiar products and functions, and need concrete evidence of the utility of new products before they adopt them. Products for older people should be designed for basic functions without the distraction of unused optional functions. This issue is especially important where errors in product use lead to difficult mitigation or recovery pathways. Such frustrations are behind the reluctance of older people to adopt new products. Products that require manipulation should provide appropriate control and grip surfaces, forces and targets. Examples include smart phone interfaces and the many similar fixed and portable devices such as personal medical products, remote controllers, timepieces, and vehicle controls.

h. **Workplace Design** The spatial, contextual, and operational arrangements of workplaces should accommodate the reach, fit and limited mobility of older adults. Materials, tools, equipment, assists and products should be arranged conveniently at the discretion of the older worker. Workplace design strategies should be considered along with operations design changes and geared towards providing physical variety rather than long duration fixed postures. Examples include the provision of variable height work surfaces and seats along with the operational requirement for postural variety.

i. **Sensory Interface Design** The deterioration of sensory processes, especially vision and hearing, should be addressed by increasing intensity, size, and contrast. An initial strategy for vision is the provision of higher levels of general and task lighting and the avoidance of shadows and reflected glare. A second strategy to accommodate the vision deficits of older people is to design adjustability into task interfaces. An example of such adjustability is the gesture-based zoom function in touch screen devices. Another intervention in hard copy material is to increase the minimum font size and item contrasts. Hearing decline among older workers is a particularly troublesome issue, both for the reliability of communication and the frustration associated with unheard or misinterpreted communications. To some extent this issue can be resolved by "volume control", but a more insidious problem is signal to noise ratio. Older people perform better acoustically when the background noise levels are reduced. Similar sensory declines associated with ageing occur in the other senses, such as touch, taste, and smell. Where these senses are important for task function, the interfaces should provide greater intensity and discrimination levels.

j. **Cognitive Interface Design** The cognitive interface should involve simple compatible relationships, task sequences and feedback. The cognitive interface between people and their tasks is perhaps the greatest challenge associated with aging. Whereas the cognitive interface is improved by experience in familiar tasks, tasks with higher information content and choice are both harder to perform and harder to learn by older people. One consequence is an increased probability of error; another is an increased amount of time taken to perform a given task. Where the task is externally paced this increased time demand may also lead to an increased probability of error. An example of these problems in cognitive interface design is in the familiar task of driving. Older people are slower and less reliable at making key decisions, such as stopping at lights, braking, clearances, and lane changes. Whereas some compensation is possible through slower driving, the individual cannot control the behaviors and speeds of other drivers. The strategy for cognitive task design for older people lies in analysis and design on the one hand and appropriate facilitators and training on the other. The strategic responsibility for these interventions is dependent on detailed cognitive task analysis followed by appropriate equipment, interface, and operations choices. Next supervision is responsible for appropriate training and task assignment. An example of a complex cognitive task can be found in the checkout jobs in grocery and other stores, especially those with a wide variety of products and services. Whereas technology, such as bar codes and readers, goes some way towards the avoidance of errors, employees are continually faced with resolving exceptions, either introduced by the customer or by a change of store policy, such as the introduction of temporary price reductions. A general strategy for addressing the declining cognitive abilities of older people is the provision of less complexity and greater learning time, accompanied by sensitive learning strategies that build on previous knowledge.

k. **Operations Design**. Many functions required of older adults can be achieved effectively and safely if more time is made available. One strategy suited to older adults is to substitute self-paced work for line or team based work. Other strategies can be to assign older adults to trouble shooting tasks that make use of their experience. One phrase that is often used by older employees regarding workplace procedures is "we have always done it this way." On the one hand this may be an appropriate use of experience. On the other hand it may simply be a defense mechanism against change. Operations design is also affected by new technology, such as internet forums, webinars, cloud computing, shared files, social, company and professional networks, apps for personal smart phones and so on. Older employees may be reluctant to adopt such changes or need more time or specialized instruction to facilitate these contemporary business processes.

l. **Job Design** Older people may tire more quickly that younger people thus a useful intervention is to expect less work output and reduce the length of the workday or week. Such a strategy my involve less financial rewards but may offer satisfying and motivating employment. In general, older adults do not respond well to the challenges of shift work or commuting. Opportunities can be explored for shorter, non-rotating shifts that avoid the commuter rush hours. Older people are particularly motivated by task content and success. Tasks should be designed so that procedures and objectives are clear, and feedback provided in a timely and unequivocal manner.

m. **Context Design** The design and maintenance of the physical, operational and social context of the workplace and job should address unwanted "hygiene factors" that serve to demotivate the older adult. Examples of these "hygiene factors" include extreme and fluctuating physical, operational, procedural, supervisory and job compensation stresses. Older adults are more comfortable with predictable contexts and may become uncomfortable with sudden contextual changes that may either threaten their position or procedures.

n. **Assistive Technology** Older workers may function satisfactorily with the help of assistive technology such as aids to mobility, postural support, materials handling, vision, hearing, materials and tool support, manipulation etc. Such aids may have the unwanted effect of increasing task time; however, they will generally reduce the likelihood of physical injury and increase the consistency and quality of physical operations. Cognitive decline may be compensated for by appropriate job aids, such as user-friendly instructions and procedures.

10. A Discounting Model for Physical Work Design

a. The NIOSH lift equation is a "discounting model". The actual physical load is divided by a theoretical maximum load which is multiplied by a series of fractions according to the spatial and temporal conditions of work to produce a "Lift Index". Critics of this model argue that it is invalid in the context of other work stressors not accounted for in the equation. Other critics question the accuracy and precision of the discounting factors. One particular criticism is that the discounting factors are linear, whereas in reality a nonlinear model may be more accurate. Despite these criticisms the method is logical and intuitive and has stood the test of time to emerge as one of the most widely used tools in physical ergonomics.
Peacock B. (2004) A Discounting Model for Task Design, Applied Ergonomics Conference, IIE, Orlando, Florida

b. The principles of this discounting model may be used to assess personal factors, such as age and sex, environmental factors, such as heat, and other factors including physical encumbrance imposed by heavy restrictive clothing, such as a fireman's turnouts or a space suit. Because of human physical capability variability, no single values for the discounting factors will be accurate. Consequently, the model should be used as a guideline for task analysis and design rather than an absolute standard.

c. The model is derived as follows:
   i. A hypothetically maximum possible task for a well-conditioned and trained young male is set as 100%.
   ii. The following discounting factors are then applied:
   iii. Female * 0.7
   iv. Age *(1 - (age – 30)*2/100)
   v. Thermal environment *(1- (^{O}C - 20)*5 / 100)
   vi. Task encumbrance *(1 – (kg*2/100)) (clothing and load)
   vii. Task spatial context *(1-(Distance from hips (cm)* 1/100))
   viii. Horizontal distance factor *(1-(Distance moved (meters)*0.01/100))
   ix. Vertical distance factor *(1-(Vertical distance climbed (meters)*2/100))
   x. Task Intensity *(1-(Exertions per minute*10/100))
   xi. Task Duration Factor *(1-(Shift Length (hours)*5/100))

d. Note that all these discounting factors are linear and the suggested parameters may be subject to debate. Also for each factor the multiplier declines to zero when a maximum stressor level is reached. For a given task some or all the factors may be applied. The NIOSH Lift Equation multipliers may be substituted for the above task factors.

e. **Conclusion** The older employee can make important contributions to the productivity of all industry sectors. Also, the continued employment of older people enhances their independence and reduces the atrophy associated with a reduction of physical, cognitive and social demands. However this continued employment must be intrinsically motivating and appropriately rewarding. Task contexts must also be designed to reduce the unwanted stressors arising from physical and operational environments. Finally job design should be sensitive to the characteristics, capabilities, limitations and aspirations of older people.

11. A Preliminary Workability Index

There exist many validated and incisive ergonomics research, analysis and evaluation tools and standards that vary from simple checklists, through more elaborate worksheets to high level analysis and simulations. This preliminary design of a Singapore Workability Index is derived from extensive experience with many workplace ergonomics tools (see Appendix) This device will be evaluated and improved and adapted for widespread use throughout Singapore manufacturing and service industries.

Chapter 63

The Shopping List

Many years ago when we were first married, we would eat our toast and marmalade on Saturday mornings before going grocery shopping. Over breakfast we would make a shopping list. As we walked from the parking lot, hand in hand carrying our shopping bags as there were no plastic bags back then, we would add to the list mentally. Once in the store we would dart hither and thither filling our shopping basket, as there were no shopping trolleys back then. We ticked off the items on our list and now and then impulsively snatched an attractive product. After a few months of wedded bliss we dispensed with the shopping list and systematically marched up and down every aisle picking out familiar items and again, from time to time, succumbing to those temptations. But as we were young and poor graduate students with a mortgage and a family on the way we would caution our partner for their indiscretions and return the superfluous items to the shelves. Teamwork!

Over the next forty years we became so expert that life's processes became somewhat automated and only major departures from the SOPs would be debated. Then I started to learn how to fly and once again I was inundated with checklists: before start, before takeoff, lost procedures, emergency procedures and so on and so on. The normal procedures were on white cards and the emergency ones on yellow cards, I still have them along with my flight plans and maps. These procedures were called out as we completed our checks and the instructor or co-pilot, in the spirit of system redundancy, would repeat them back. Although some of these steps, unlike a missed grocery item, could have catastrophic consequences if missed, they too became routine as we anticipated excitedly the main event: clear props, clear skies, see the light in his eyes.

Checklists are a subset of a general class of devices called "facilitators." These devices are not part of the execution procedures *per se*; rather they are simply memory aids. Experts can do without their explicit use as their implicit subroutines are cued and executed automatically.

Back in the time of the grocery store checklists, my graduate studies focused on the intricacies of operational memory – that amazing flexible, versatile, but limited cognitive function. Or is it really limited? When we set up well defined laboratory tasks, like remembering random digits, we observe, as did Miller, the magic number 7 plus or minus 2 to be a somewhat robust statement. This magic number also seems to work for more elaborate "chunks" of information. But when we move from numbers to words and procedures we note that our fluid operational memory takes in external cues, pulls templates, data and procedures from our long term stores, and guides us somewhat automatically through extremely complex operations. In this sense our operational memory is not limited, rather it the central processor that manages almost everything we do. In recent years a series of competitions have arisen that demonstrate the phenomenal ability to recall massive sequences of numbers, playing cards and the like by a process of linking.
This central processor is subject to interference which may cause apparent failures in certain tasks when it is distracted by other external or internal data. The bucket analogy explains this apparent limitation – as you pour more water into a limited size bucket some will overflow and perhaps be lost. But the bucket hydrodynamics are not simple. There may be little eddy currents that keep some of the water in place while the rest rushes by. Cognitive psychologists call this rehearsal; it is the mechanism by which we keep important data, procedures and objectives in focus while the other temporary stuff moves on after making its contribution or being ignored. Other phenomena, such as primacy, recency and salience also serve to keep information actively available.

One possible mathematical model to help describe these processes is Bayes Theory. Simply put this theory suggests that if we have a theory, choice or decision, we sequentially sample available data until we converge on a conclusion. Like Miller's Theory, this process can be demonstrated readily under laboratory conditions. One experiment I carried out was the "Baynum Test". I presented digits (or other stimuli) from a defined set such as 1 to 7 or 9 in random sequence and had the subject predict whether the next number would be higher or lower after each presentation. As the probability associated with the decision increased so the subjects converged more quickly on the best decision. A hypothesis was that the greater the operational memory load (the number of preceding digits) the longer it would take to make the decision. This hypothesis was correct up to about half way in the sequence, but after half way those cunning subjects started to "recall" what was to come rather than what had gone, and their responses became quicker and better, based on the objective probability. However, when I experimented with more complex information the subjects became remarkably sub Bayesian. They forgot (or did not use) key items of information and developed bias and weighting towards other items and categories. One conclusion that I came to by controlling the presentation rates, was that temporal "decay" really wasn't a good explanation; rather the active processes of interference and rehearsal were better descriptions of the operational memory function. This conclusion is supported somewhat by the von Restorff effect in which distracting categories in a sequence can interfere with retention of items from the main category.

Shopping lists and aviation checklists are memory aids; we ignore them to our peril. The procedures manuals on the International Space Station are ten inches thick and full of acronyms. When we go to Mars, the books will be terabytes thicker. But fortunately, we have a partner or co-pilot sitting in Mission Control, supported by an army of memory aids, sometimes with the capability of system override if the operator misbehaves. There are real active built in system redundancies. This would be analogous to the grocery store clerk asking, "do you really need that expensive high calorie custard tart?" Perhaps we should automate the grocery shopping process and have the computer-based ordering system make sensible unbiased Bayesian decisions for us.

The main problem with sensible decision making by real people is that information processing takes time and often time is limited. If we fail we are called impulsive, when we succeed we are called intuitive. Because of the time constraints we do not always use our checklists; we also become even more sub Bayesian and select data based on our biases or simply its availability or attractiveness. That "hi cal" cake, although not on the checklist, is both attractive and available. Our obsession with one "train of thought", for example our air speed, to the detriment of another source, say out altitude, can be dangerous. If we have the ball in basketball or soccer, we can hold, dribble, pass, or shoot. Shooting and scoring will make us a hero, but shooting is a low probability option. Our time constrained decisions are based on a biased ratio of the probability of success times the payoff of success divided by the probability of failure times the cost of failure. Operational memory serves these decision-making ratios. Experts make better and quicker decisions because they have better mental models or decision frameworks and make better selections from the available data. They have built in checklists to guide them through the time constrained decision-making processes. In these ball games and airplanes, we have colleagues to help with the attention, memory, and decision processes. "Man on, my ball." "Clear to depart 21 left, clear to depart 21 left."

Another domain that is full of implicit or explicit checklists and guidelines is medicine. Busy doctors check the history, talk to the patient, buy Bayesian time by ordering more tests, or make a sub Bayesian decision based on their experience and intuition. Good doctors mostly get it right. However, an investigation of these processes back in the day of post-doctoral general medical practice research showed that, when presented with sequences of the same signs and symptoms, general practitioners would diverge widely on their diagnoses and treatment selections. They were unquestionably sub-Bayesian. When groups were presented with their collective decisions and allowed to debate the diagnoses and actions, there was generally some convergence, but in-built biases still resulted in alternative choices and rationalizations of approaches. We can add pilots, ball players, process controllers, grocery shoppers and many more to this list of rapid naturalistic decision makers.

The challenge for Human Factors is to break down these applied attention, operational memory and decision processes into their constituent parts and design checklists, procedures, technology and training to make more effective and efficient mouse traps. Contemporary computer simulation technology offers a rich context for controlling information and time in order to study behavior and improve the design of automation and decision aides such as predictive displays. Today's young and not so young people play video games and demonstrate attention, operational memory and rapid decision making under time and information stress all the time.

Simulators for flying, process control, ball games (and perhaps grocery shopping) are readily available. They can make extremely valuable training aides and help in the understanding of attention, operational memory and decision making. We can manipulate the information available, the quality of that information and the time constraints. The results of such investigations will invariably show individual differences in expertise and bias. They will also show that given the same information computers will make more repeatable and quicker decisions, especially when equipped with prediction algorithms and comprehensive checklists. However, this automation utopia will fail because of the human right to be wrong for the right and wrong reasons. I will buy that custard tart, doctors will make the “wrong” medical decision for social reasons, pilots will make the wrong decisions because of over reliance on automation, footballers and basket ballers will make low probability shots and become heroes, astronauts will walk glove in glove on Mars and be so overwhelmed by the experience than they may forget to call home.

The applied human factors challenge is now focused on human computer interaction – HCI. This involves vision and visual aspects of display design. Simple stuff! But more importantly it involves cognition and computation. We must be able to read the words, numbers or icons, but sometimes even this basic font size and contrast requirement is not compatible with old eyes. More importantly we must be able to navigate the menus and choices quickly and effectively and be guided toward the correct decisions and allowed to escape from wrong decisions; the “back” button is a wonderful, but simple, invention. Even more than this the computer must be programmed to make predictions and provide decision guidance; it must have an available and active operational memory to provide the user with context and concise counsel. It must be collaborative, like a co-pilot or shopping partner.

In aviation, intelligent displays can advise the pilot to “pull up, pull up” when the terrain detection system becomes alarmed. The system can even take over control of the airplane, pull up, and then politely hand back the controls; “your controls.” In shopping, a friendly debate about custard tarts will usually, but not always, result in group consensus. In medicine and aviation, crew resource management practices will assure that appropriate decisions are made based on the knowledge and data available to the current situational leader. For example, the anesthetist in surgery may need to suspend the activities of the surgeon when the situation demands. In basketball, a teammate may issue the visual instruction “alleyoop”, when the dynamic situation demands. In aviation, the controller may say “position and hold” to speed up runway traffic. Lane change, headway and parking aids in modern cars can supplement human decision making; light detectors can turn on the headlights. These complex cognitive activities are relevant in time constrained information overload situations. Collaborators and computers can help to calculate “what if” conundrums. Predictive messages and displays can improve on the calculation speed limitations of mere mortals.

In conclusion it is argued that operational memory is central to the acquisition of data and decision frameworks, choices, and execution management. It is further suggested that checklists, explicit, implicit, simple or complex, are essential to the human cognitive processes. Finally, it is recommended that information, time and expertise analysis are central to the human factors contribution to system design and human computer interaction and that these procedures and guidelines should be facilitated by contemporary human in the loop simulation facilities.

Chapter 64

The Law of the Jungle: Multiple Choice Tests

This article is about testing and examinations; it spans the gamut from multiple choices to scenario analysis.

Plants and animals evolve through the process of reproduction. They fail to perpetuate their species, either locally or altogether when, because of an inclement environment or competition with other species for sustenance, they fail. Think of those nasty weeds in your garden. Sometimes, however they adapt by developing features that enable them to succeed in a hostile environment or to prevail in the competition with their enemies. In the higher mammals this competition is fierce, both between and within species. The carnivores prey on the weaker members of the next level down in the food chain. Sometimes males of the same species, vie aggressively for the attentions of members of the fairer sex. Think of the sea lions. Ironically, in the human race, the contemporary hitherto mates often fight to separate. Mostly however people use their wiles to compete for fame and fortune.

But we have advanced apace and now use very formal methods to compete. Even war is controlled by conventions, although sometimes these conventions are subject to situational interpretation. Governments develop laws to protect the weak from exploitation by the strong. Generally, these laws are developed from commandments 6 through 10, but Moses would turn in his grave if he knew of the interpretation of these simple laws in the modern day. In sports we have rules of engagement and complain bitterly when the referee fails to perceive a misdemeanor. It should be noted that just 17 laws govern soccer and it is left to the referee to interpret such things as advantage and intent. Some laws address the behavior of individuals whereas others address that of groups, such as commercial or professional organizations. Often both organizations and individuals can chose those playing fields that are best suited to their physical or intellectual armory. But even here there is plenty of opportunity for survival of the fittest.

During the first quarter of our lives we prepare ourselves, by physical and intellectual training to compete over the next two quarters and spend our last quarter reflecting on where we went wrong, or right. The rules of this hectic race to the top are smattered with fences, which we euphemistically call examinations. These fences are lambasted by the dreamers in the world of education who speak of higher order things like culture and critical thinking; some even believe that one should teach ethics and morality because we didn't listen to Moses or the prophets or our mother. The realists recognize that mastery of a trade – medicine, law, accounting, sometimes engineering and even, some would say, human factors and ergonomics – can be measured by time on the job (experience) and examination. It should be noted that in this respect even the name of the university that one attended was once sufficient to assure a successful career in the professions. The educators fight back and argue that accreditation of an educational establishment is sufficient grounds to justify the future capability of a graduate. But the world in general prefers the licensing or certification of individuals. So we now have the easy to grade multiple-choice question that aims to predict an individual's ability to solve complex problems. We argue that well-constructed multiple-choice tests reflect mastery of a subject. But we sometimes use belt and braces and insert problems to be solved according to some template of correctness. The educational establishments mimic these professional organizations and insert multiple-choice examinations as frequently as possible throughout the semester. In fact, some thirty years ago I developed a feedback classroom (Peacock, 1982) which allowed me to insert questions every five minutes or so during the lecture. It really can be embarrassing when you are faced with the cold fact that half the students have not understood what you just said.

Good multiple-choice questions are difficult to develop. The correct answer is the least of your worries. The more difficult challenge is the creation of distracters that reflect a predictable misconception – such as subtracting rather than adding two numbers.

MCQ Examples

1. Background / question, 4 answers, 1 correct, 3 incorrect for various key reasons.
2. Put most of the descriptive material in the main question not in the answer alternatives
3. Keep the answers approximately the same format and length
4. Design answers to include key factors of understanding / misunderstanding
5. Do not use double negatives
6. Do not use "all / none" of the above
7. Read:
   http://testing.byu.edu/info/handbooks/betteritems.pdf

1. The Grammar of System Design involves the following combined concepts
   a. Activities, verbs, adverbs, validation
   b. Nouns, entities, resources, validation
   c. Adverbs, nouns, specifications, performance requirements
   d. Adjectives, design specifications, verification, validation
2. Concept Maps are
   a. A quantitative method for project planning
   b. A hierarchical method for accident analysis
   c. A flexible method for system structures, processes and outcomes description
   d. A network diagram of alternating activities and queues used to simulate operation resources, logic, and throughput
3. Activity Cycle Diagrams
   a. Include logic, resources, entities, queues, activities and times
   b. Are constructed to give a general view of factors and activities leading up to an accident
   c. Describe the hierarchy of events and interactions leading up to a system failure
   d. A method for the description of system failure modes, likelihoods and consequences
4. Failure Modes and Effects Analyses
   a. Result in an in-depth description of the causal sequences leading up to an accident
   b. Can be either system or function based
   c. Require knowledge of Boolean Algebra to calculate top event probabilities
   d. Are a collection of methods that describe system structures, processes and outcomes
5. Failure Modes and Effects Analyses
   a. Are generic in nature and can be completed without domain knowledge
   b. Are network diagrams for a high-level description of systems and processes
   c. Are only applied in after the event accident analysis
   d. Assess likelihoods and consequences to calculate risk
6. A generic hazard evaluation checklist identifies (among others) the following hazardous element sources.
   a. Acceleration, oxidation, structural failure, pressure
   b. Stress, leakage, temperature, gravity
   c. Environmental, electrical, ecological, energy
   d. Moisture, off gassing, corrosion, carbon monoxide
7. In safety circles MORT stands for
   a. Management oversight and risk tree
   b. Methods, organizations, risks and task analysis
   c. Mortality outcome risk tables
   d. Management of risks and time loss

8. Fault Tree Analysis
    a. Is a systems engineering process that identifies the person at fault for the system failure?
    b. Is a hierarchical process of system failure based on Boolean algebra?
    c. Is an analytical system where the branches converge on the root cause of an accident
    d. Is a cumbersome process that is rarely used in systems engineering?
9. Boolean Algebra
    a. Is a set of equations describing the association between independent and dependent variables?
    b. Is a mathematical process for the amalgamation of event probabilities
    c. Is a hierarchical process based on probability theory?
    d. Is a way of describing the interactions and interdependencies of classifications
10. Risk matrices have
    a. Consequences and likelihoods
    b. Root causes and outcomes
    c. Probabilities and costs
    d. Risks and benefits
11. HFACS stands for
    a. Human Factors Accident Causation Summary
    b. Human Factors Analysis and Classification System
    c. Human Factors Accident Consequence Summary
    d. Human Factors Analysis, Causation and Sustainability
12. HFACS has the following four components
    a. Human Errors, Environmental Factors, Operational Factors, Organization Factors
    b. Causes, Environments, Accidents, Outcomes
    c. Software, Hardware, Environment, Liveware
    d. Unsafe Acts, Unsafe Supervision, Pre-Conditions, Organizational Factors
13. In HFACS, Mistakes and Violations are described as
    a. Sensory, perceptual, cognitive, motor
    b. Skill, decision, perceptual, routine, exceptional
    c. Errors, mishaps, deliberate, accidental
    d. Physical, cognitive, behavioral, performance
14. Ishikawa charts are also known as
    a. The 5 whys
    b. The 5 Ws
    c. Fishbone diagrams
    d. Concept maps
15. Accident rates are the
    a. Frequency of occurrence of an event divided by the number of people exposed
    b. Frequency of occurrence of an event divided by the number of transactions
    c. Incidence divided by prevalence
    d. Mortality divided by morbidity
16. Comparisons and Associations in Statistics are based on
    a. Root mean squares estimates of variance
    b. Analysis of variance and regression analysis
    c. Contingency table analysis
    d. Factor analysis
17. Physical Ergonomics Design Principles include accommodation of
    a. Sensory, metabolic, and cognitive factors
    b. Anthropometry and cognitive task analysis

c. Size, strength, stamina, skill
d. Posture, frequency, repetition, learning, and decision making

18. Extreme, moderate, and minor environmental stress variations cause
    a. Death, serious illness, chronic illness
    b. Interference with behavior and performance
    c. Behavioral insufficiency, performance failure and irritation
    d. Acute performance failure, chronic performance degradation, improved performance
19. What has cognition got to do with accidents?
    a. Accidents have physical, not cognitive causes
    b. Accidents usually have cognitive causes and physical outcomes
    c. Cognitive overload causes physical performance failure
    d. Accidents are caused by situation awareness
20. Organizational system safety is based on
    a. Management commitment and employee participation
    b. An adversarial management – union – government relationship
    c. Compromise with productivity and product quality
    d. Rewards for outcomes rather than process improvement
21. An effective report has the following components
    a. Introduction, background, methods, results, conclusions
    b. Literature survey, statistics, appendices, recommendations
    c. Pictures, graphs, tables, equations
    d. Subjects, equipment, procedures, experimental design
22. The hierarchy of controls in safety practice includes
    a. Process substitution, guarding, warnings, personal protective equipment, training
    b. Elimination, encasement, evasion, employee protection
    c. Feedback control, adaptive control, learning control
    d. Direct control, indirect control, supervisory control
23. Hazards in the workplace should be
    a. Eliminated
    b. Guarded
    c. Warned against
    d. Ignored
24. A control model of human performance has the following elements
    a. Cybernetics, communication, heuristics, disturbing factors
    b. Feedback, feed forward, structures, processes, consequences
    c. Controls, displays, perceptions, actions
    d. Inputs, external factors, process, outcomes, feedback, prediction
25. Energy Trace and Barrier Analysis is
    a. An electrical engineering method for the prevention of short circuits
    b. A human performance analysis method that evaluates the energy costs of physical work
    c. A systems safety tool that identifies where guards should be placed around robots
    d. A systems safety method that analyses the flow of energy and the effectiveness of barriers

Chapter 65

The Mess in the Middle: Individual Differences

This article is about the contrasts between the population-based approach to ergonomics in design and the individual focus of reactive ergonomics. It also addresses the complexity of correlations within and among human characteristics.

Introduction

The classical approach to ergonomics is to identify a design parameter, choose the related human characteristics, measure these characteristics on a sample selected from the expected user population and then choose the design level(s) that accommodate the majority of the users. In anthropometry 101, we measure popliteal height, calculate the fifth percentile, say 15 inches, add a fudge factor for shoes, and then suggest that the seat height should be adjustable over a range of about 6 inches. Next, we throw in seat pan angle, back rests, arm rests, work surfaces, hand and foot controls, force requirements, displays, workplace access, crashworthiness, lighting, vision beyond the immediate workplace, task requirements and so on. These additional design requirements all point to different human capabilities and limitations. In the end popliteal height may be the least of our problems or, in the case of computer operators, truck drivers or airline passengers, it may be the cause of a blood clot and premature death.

The classical approach also pertains to sensory and cognitive activity, as in reading the fine print in the subway or understanding the tax laws paying your electric bill for example – "only click once otherwise you may pay twice" says the notice.

Our design challenges become even murkier when we look at task information content. The example of an airplane pilot will be used, although the discussion could be equally well applied to car drivers, process control operators or web site users. The first principle of flight is that the airplane needs to move forward to create lift. This requires that the engine must be working properly as indicated by the RPM, engine temperature fuel flow, ammeter, and vacuum gauges etc, together with various malfunction annunciators. The astute pilot will learn to appreciate subtle changes in these parameters and perhaps supplement them with information such as the sound of the engine.

The Myth of User Centered Design

User centered design is not a myth – all design is user centered – but human factors engineers do not own the practice, unless of course all designers are considered to be human factors engineers. The following discussion contains an explanation of this paradox together with an articulation of the boundaries of our profession.

All animals take steps to protect themselves from their physical and social environment and extend this defense into offense by physical and operations designs that give them an advantage over their competitors, sometimes through collaboration. Darwin explained the motivation and many of the mechanisms of this competition among and within species. The annual Darwin awards describe some ingenious but failed efforts (by *homo sapiens?)* to gain some advantage, either through engineering or operations design.

The purpose of engineering and operations design is to extend human capabilities; even some small brained primates have been observed to make use of tools, such as nut crackers. The process of design is predictive and should cater for expected use and foreseeable misuse. Use involves sometimes-conflicting criteria such as effectiveness (quality), efficiency (resource utilization), safety, health and satisfaction. Human use sometimes extends satisfaction to the lofty, but nebulous, heights of pleasure. The phases of this process include a mental model of how the engineered device or process will work and how it may fail, together with an assessment of the possible positive or negative outcomes. This stage models the behavior and performance of the resultant design in its context. The second design stage is to create some representative or physical (or electronic) model of the eventual system, commonly in the form of a drawing and some specifications, a computer model or a physical mockup. In many instances an analog will contribute information to the design process. The next stage (unless your designer took a concurrent engineering class (another myth) is to design the manufacturing process. Most of us could design or at least visualize a functional pyramid, but not comprehend the challenges of getting a bunch of reluctant Hebrews to build it. Even if we could design a car and the tools to form the metal and fasten it together, it is left to the operations designer to make this manufacturing process efficiently produce 1000 similar units a day, all with high quality. After all this design has taken place, we have to manage the use of the product or process. This involves making sure that some foolish or incompetent user does not misuse the product and that the product continues to perform reliably over its designed lifetime. Finally, we have to bury the worn-out thing and its batteries in a landfill, or REDUCE, REUSE, RECYCLE.

Where does user centered design fit in? For a start all people are users and by definition will chose and operate some device, such as a chair, car or computer to enhance their capabilities or pleasure. ***The challenge is complexity.*** Whereas most people can visualize the operational use of a particular product, the actual design, manufacture, production or maintenance of most products (including hardware, software and organizationware) is beyond the capabilities of most people *(Norman - The Design of Every Day Things).* In fact, with the exception of a diminishing number of craft industries, most products are actually designed by teams of people, including – inventors, market research, conceptual design, engineering design, manufacturing design, production design, production operations management, marketing, distribution, sales, service and maintenance and operations management. Each of these teams turns specifications into products and hands over to the next phase, unless of course they have heard about concurrent engineering. Concurrent engineering is simply a way of adding constraints into the design process as early as possible. Human factors engineers join in this gig to use their knowledge and tools to anticipate expected use and foreseeable misuse. Human factors engineers, like cost analysts, industrial hygienists, lawyers, doctors and personnel people are rarely responsible for any one of these design activities. But they do have a lot to contribute to each stage, depending on how people interface with the process.

In fact, in large organizations, human factors engineers may not directly help the person responsible for a phase rather they may play the role of advising the advisers. For example, in manufacturing operations, it is the line supervisor who actually manages the operations personnel and he or she in turn is advised by the manufacturing engineer, the safety specialist, the quality guy and the industrial engineer. The human factors engineer is usually at least one step removed. In product design the conceptual designer, marketing specialist and the various engineers and managers collaborate on a product development team, and the human factors specialist has to be very polite when he is invited to the table, often at the behest of the company lawyer. And even then, the contribution of human factors may be only to add color to the warning label that informs the eventual user that use of the product may be acutely life shortening.

This dismal picture paints the human factors engineer as a cosmetic afterthought and puts our aspirations of overseeing user-centered design in perspective. Unfortunately, some models of the human factors process place the human factors engineer as a purveyor of ambiguous requirements, using the excuse of human variability, followed much later in the process as an ergocop with an exaggerated view of self-importance as he or she interprets the vague requirements and signs off on waivers when told to do so by a wise manager. Too often this clumsy process is due to the lack of knowledge of the human factors engineer of the domain in question. In defense of the HFE the acquisition of domain knowledge is not always easy, even after grounding in the local jargon and acronyms. This lack of domain knowledge of the human factors engineer can lead to a lack of credibility, both of the individual and the profession. The excuse that “you may understand the domain, but I understand how people behave and perform” is not good enough.

The challenge to the human factors engineer is of course human and situational variability. It may be easy to design car, navigation system, entertainment system and cell phone interfaces from first principles, focus groups and usability trials and estimate average or even fifth percentile performance levels of the user population. But the reality is that all these come together in the infamous single channel that is narrowed by grandma’s age, grandad’s tipple or some unforgiving traffic light. Even without human factors engineers, designers will design systems that suit many of the people most of the time, occasionally with the help of legislation, a product liability suit or simply product failure in the marketplace. Human factors engineers must learn to deal with their Achilles heel – variability, and not hide behind it in the hope that Lady Luck will be on their side.

There is a better way. Human Factors Engineers should adhere to the following rules:

1. Learn about all of Human Factors – body, mind, and soul; behavior, performance and preference
2. Learn about statistics and investigation design – confounding and significance
3. Learn about your domain or find a friendly expert to run interference for you
4. Know your place as a supporter of the design process, not as an ergocop
5. Recognize that there are many “users” in the design and operations process

Chapter 66

The Science and Art of Guessing

This article is about human decision-making behavior and the attempts by researchers to describe the processes and by practitioners to apply the results of this science to influence the behavior of their clients. In 1763, the Reverend Thomas Bayes articulated a theory of conditional probability that describes convergence in mathematical decision making in the light of multiple sources of evidence (Bayes, 1763).

P(A) = P(A[illegible] P(B|A) * P(A) / P(B), where A is our hypothesis and B is the evidence.

The challenge of course is the calculation or estimation of these probabilities, which is a can of worms. The calculation of probabilities usually depends on data, which itself may be suspect. Often however, as in human decision making, the subjective estimation of probabilities is much more vulnerable to untoward influences, as will be discussed throughout this article. Edwards (1962) compared the theoretically ideal process of decision making as predicted by Bayes Theorem with actual human decisions and found that generally speaking people were sub Baysian, either because of the vulnerability of subjective probability estimation to forgetting or otherwise differential weighting of various sources of evidence. Unfortunately, for me, this reality put a damper on my original dissertation topic that was supposed to explore a Baysian model of human decision making, but fortunately led to a more productive investigation of operational memory and interference (Peacock, 1972)

In 1973 I carried out an investigation with a cohort of general medical practitioners. I presented various items of evidence (associated with common respiratory ailments) sequentially and asked the doctors to converge on their diagnoses as more and more evidence was presented. Big shock! Although most of the doctors converged on the “correct” diagnosis, many of them diverged widely and sought other items of evidence. After we had tabulated all the responses, we applied Bayes Theorem to the process and asked the deviant doctors to explain their reasoning. In some of the exercises the discussions led to the persuasion of the previous majority opinion to more extreme possibilities (probabilities.) This exercise is easily replicated in medicine and many other areas of human decision making. It is instructive both in the processes of human decision making and in understanding the reasoning of experts when confronted with more or less reliable evidence.

Another familiar example of often flawed decision making is in the assignment of grades to students. The professor (expert) has confidence in what evidence reflects the students’ understanding or mastery of the subject matter. First the professor defines a syllabus which constrains the scope of the material of interest. Next, he or she presents lectures and assigns laboratories and other exercises that have been shown in the past to have good pedagogical (pedantic?) merit. Finally, the professor refers to an encyclopedia of assessment rubrics and criteria to evaluate the success of the course (a foregone conclusion until the student evaluations are published) and the relative performance of the students. Unfortunately, evaluation is at best a sampling of the knowledge of the students, as also is the choice of material and presentation processes. In the end the “As”, “Bs”, “Cs”, ”Ds” and “Fs” are presented as a convergent reflection of the multiple weighted sources of evidence and all is well until a knock on the door signals an “appeal” based on creative rationalization or honest criticism. This process and its vulnerabilities are mirrored in the evaluation of art and artistic athletes, the buying of cars and other consumer products, the selection of a mate, job selection and the election of the President of the United States of America.

Another attempt to articulate a theory of decision making that comes closer to reality is that of game theory. This brilliant theory includes not only probabilities, but also the utilities of various possible outcomes, another can of worms. Despite these practical flaws – in the reliability of evidence – game theory is widely applied in economics, warfare, and politics. A derivation of game theory – risk analysis – is widely applied in the safety and space exploration industries. The analyst gathers evidence regarding the probability of one or other outcome, the relative consequences of the different outcomes and the exposure of individuals or “the system” to various failure scenarios. Again the challenge is in the reliability of the evidence.

Guessing

My daughter is a polar bear biologist in Nunavut. She flies around Northern Canada in a helicopter every year, tranquilizes the bears, marks them with a tattoo and pulls a tooth for aging calculations. On returning to the field in subsequent years she counts the number of bears that have been captured previously and uses a extension of the Hypergeometric distribution (N/n = X/x) to estimate population size using a program called "MARK"

http://welcome.warnercnr.colostate.edu/~gwhite/software.html

On return to the headquarters in Igloolik she must explain to the Inuit, who are the traditional shepherds of this endangered mammal, that she estimates the population size, "using science". When translated "estimation" becomes "guessing" which is trumped by "traditional knowledge" in population estimation. The late Kurt Vonnegut in his last book "A man without a country", Seven Stories Press, 2005 also uses the term "guessing" to describe the opinions and decisions of politicians.

Whereas we may be comfortable with the processes of statistical estimation, we may revel in our confidence limits and level of statistical significance, albeit an artifact of sample size, but we should be much less confident in the way in which every day decisions are made.

Time Constraints

Most decisions are made in a context of time constraints. For example, while driving we may not have time to examine the rear-view mirror before hitting the brakes in response to a truck that turns across our path at the traffic lights. Unfortunately, this "catch 22" situation may result in a severe "rear-ender" and a better decision, given more complete information, may have been to swerve in the direction of the oncoming truck. In time constrained situations human decision making is largely affected by "mental workload". A simple view of workload is information divided by time. However, in practice more experienced people can handle more information per unit time than inexperienced people – if you don't believe me try learning to fly an airplane using instruments. Another complication of the workload equation is the weighting of importance of the available items of information. For example, in the case of the previously mentioned truck or a runway incursion the actual response may be dictated by the importance of a single item of overriding information.

Time is also important in less life-threatening decision situations. When preparing a lecture or writing a paper, do we have time to thoroughly review all the pertinent material? Again, experience and item importance weighting may dominate our decisions. When we go into a car dealership to buy a car, are we more influenced by the salesman's patter about styling or speed or handling, or do we do due diligence to the safety reports, fuel economy and interior features? Vonnegut's "guessing" euphemism for appropriate use of appropriate (available) information is again pertinent.

Hicks, Hyman and Fitts showed that the more information we had to process the longer it took to make a decision or movement. These were key predecessors to workload theorists (Wickens). Miller was a little more cautious. He demonstrated that we have operational memory limitations and that we are prone to forget certain items when faced with an overload situation. Early cognitive psychologists also identified information selection strategies of primacy and recency, usually under implicitly time constrained laboratory situations. Decision making that makes use of operational memory for item search, weighting and amalgamation can be shown to be very sensitive to proactive or retroactive interference by items that are situationally dominant (Peacock, 1972). Often time these time constraints may be self-imposed rather than by the external system that we are attempting to control.

The Halo and Pitchfork Effects, and False Consensus

Many human decisions follow the following cognitive pattern – you decide which alternative you like based on a single over weighted dimension and then seek evidence to support that decision, whether positive or negative. The classic personnel selection scenario may be dominated by a nice smile or a university pedigree rather than a duly weighted analysis of the candidates' track records. Nowhere is this halo and pitchfork effect more evident than in the choice of politicians to lead the country. In the recent Democratic party candidate contest between Hilary Clinton and Barak Obama otherwise intelligent people polarized emphatically in their view of who would be the best candidate. They all had access to the same information but chose to emphasize only those items that confirmed their prejudice.

We have all experienced "false consensus" in committee meetings where a particularly vociferous member persuades the rest of the committee to act like lemmings and walk over the cliff. Sometimes hindsight prevails and the bad decision is caught before implementation. Of course, such a mitigation strategy or predesigned escape route is always the sign of a good decision maker. In the decision sciences world one may choose a conservative strategy of least regret rather than the bolder risk of high rewards or high losses. In the practice of safety, we are frequently faced with tradeoffs between costly (in time, materials and money) conservative approaches to protection rather than the riskier corner cutting profitable production route.
Naturalistic Decision Making

Over the past decade the human factors community have been swayed towards a theory of naturalistic decision making (Kline). This theory aspires to describe the real world of fallible decision making in the context of time constraints, information overload, differential item weighting and dominance of data and particular team members. The theory fits well with commonly observed practices of medical and business decision making.

Behavior and Performance

Behavior is the way of getting to a decision or action. Performance is a result of the selected behavior. Guessing or prediction is an essential behavior that in retrospect may or may not lead to acceptable performance. Bailey clearly articulated this distinction in the opening chapter of the first edition of his book on "Human Performance ". He used a scenario of different groups of people participating in a search process. One group used a pedantically systematic approach while the second group was notable for their very unstructured approach. The counter intuitive result of the investigation identified the second group as the best performers in the search task. Prediction, decision making, and guessing are behaviors that are aimed at successful performance. Where due diligence is not applied, lucky or intuitive guessing may win out. But the laws of probability suggest that due diligence will trump guessing in the long run. Of course, we must learn to recognize the difference.

Chapter 67

Predictive Models of Temporal Effects on Human Performance

Brian Peacock
Valerie Rice

1. Purpose

   1.1. The purpose of this research and development project is to deliver a process (index) for the description and prediction of individual and cohort physical performance capabilities as affected by task and context demands over time.

2. Introduction

   2.1. The greatest challenges facing human factors and ergonomics specialists are variability within and among individuals, variability of tasks and variability of contexts. These sources of variability are further compounded by interactions with time (Peacock, 2003). There are many familiar instances of these interactions, including maturation, aging, physical training and local muscular and general performance fatigue. These latter examples are well known to interact with task factors, such as load carried, environmental factors, such as protective clothing and temperature and individual factors, such as age and state of training, and inherited physical characteristics.

   2.2. All these effects are generally monotonic and non linear and may be described by quadratic or exponential models. These monotonic effects are further compounded by rhythmic biological and contextual factors, including circadian rhythms and their associated zeitgebers, such as light and dark cycles. These rhythmic factors are generally modeled by trigonometric (e.g. cosine) functions and have attracted considerable scientific and lay attention under the umbrella term of chronobiology.

   2.3. Classical human factors contrasts between people and mechanical systems have described their relative predispositions to gradual degradation and acute failure. (Fitts, 195-) The reliability of complex mechanical systems is commonly addressed by Weibull analysis. The derived bathtub curve (Hazard function) describes three phases – wear in, steady state and wear out. This analysis is used to predict the probability of failure of critical system components over time or use cycles. A common application of Weibull reliability analysis is in vehicle fleet preventive maintenance. Although human beings generally degrade (e.g. fatigue) gradually, they also exhibit acute subsystem failures, such as broken bones, torn muscles, and heart attacks. These acute failures may interact with gradual biological changes as in the case of stress fractures, muscle cramps and heat exhaustion. In this respect the human systems may be analogous to mechanical systems and thus be represented by the well-developed reliability models.

   2.4. Another characteristic of mechanical and human systems is that they both exhibit positive and negative changes over time. Gears and engines may need to be "worn in" and there is no doubt that appropriate physical training leads to improved physical performance capability and failure resistance. These positive effects are commonly described as learning curves, which are usually monotonic, nonlinear, and asymptotic. This last characteristic of humans – asymptotic learning – was described by De Jong (195?) in the context of fine motor skills. A key finding of this work was that improvement was observed over many years and several million cycles. Similar observations may be made in "stamina" dependent athletic events, where peak performance occurs later (e.g. late twenties) than in the explosive events. A common observation of individual learning and performance is the occurrence of plateaus – periods of no apparent change (or even deterioration) in performance followed by a rapid "step" improvement. Cohort studies however smooth out these steps, which are absorbed statistically into the residual or error variability. Not only may the individual suffer a "bad day", but where that individual is a critical member of a team, the mission may also fail, if there is not appropriate redundancy. Consequently, if a model aspires to be usefully predictive, it is important to address the variability of individual performance as well as the general effects of time, task, and context.

3. Models and Data

3.1. The introduction indicated that the basic models describing human changes over time are relatively simple. Well known polynomial, trigonometric and exponential functions may be used to describe human changes over time. The parameters of these functions will be determined by the task and context of interest. For example, the negative exponential muscle endurance curve will be affected by external load and running speed changes over time will be affected by slope, terrain, clothing, load and temperature. The greater challenge in modeling human performance lies in the amalgamation of the many system components and their interactions, particularly over time. These separately identifiable, but interacting components – task, context, individual and physiological subsystem – will have different parameterization, thus leading to complexity, which is either dealt with by simplifying assumptions or the exploration of novel approaches.

3.2. The traditional approach to modeling is based on statistical averages of data obtained from well-defined tasks and subject samples of various sizes and selection criteria. Sample size and selection criteria both affect the statistical variability associated with the model and hence its apparent predictive capability. But typical small samples and narrow selectivity will inevitably lead to reduced ecological validity of the model and hence its utility. Traditional use of statistical averages, measures of dispersion, confidence intervals and significance fail to address the boundary conditions of system performance.

3.3. An alternative approach is to use records. For example, athletic performance thrives on the use of records whereas average performance is meaningless and usually unobtainable. For example, it is impossible to answer the question: "What is the average time for a person to run a mile or a marathon?" But cohort (e.g. world) record performance is well documented, as also are individual "PRs." These facts are widely exploited in the process of handicapping for competition. For example, the World Association of Veteran Athletes publishes specific age records for many events and scoring in competitions is carried out by computing the ratio of the record to individual performance. For example, if the 10-kilometer world record for a 40-year-old male is 32 minutes and individual runs that distance in 40 minutes then his performance (speed) may be computed as 32/40 = 0.8, or 80%. Similarly, if the record for a 60-year-old is 36 minutes then it indicated that decline in performance capability (speed) due to age over that period is 1- 32/36 = 1 – 0.89 = 0.11 or 11%. An extension of such calculations, for smaller age intervals, can provide the empirical evidence to model the age effect.

3.4. An extension of these concepts may be used to describe and predict cohort and individual performance on tasks in different contexts and on occasions. For example, if the cohort record is equal to say 100% and an individual record 80% then a cohort or individual performance on an occasion, in a context may be observed to be 50% and 20% respectively. A field example could involve the time taken to run a mile (speed) with the baseline being a flat track with no encumbrance and thermal conditions conducive to such an endurance event. The comparative data would be from a similar task (a mile run) but with restrictive clothing, a heavy load in a hot desert. Incidentally, such an approach could also be applicable to the prediction of performance capabilities of astronauts visiting the moon or Mars. The purpose of such an assessment would be to predict the likelihood of task success or the advisability of task redesign.

3.5. A further justification for the use of records (rather than averages) for human performance is that they provide a means of excluding many other complicating (though real) factors. For example, records (both cohort and individual) are unaffected by disuse, disinterest and disease. Also, most records are based on well-defined task design factors and are usually obtained under ideal or controlled contextual (e.g. environmental) conditions. Cohort records are unaffected by individual (dna) differences (there is only one record), and personal records are unique. Finally, in the context of aging studies, records are not censored by death. Records are, by definition, based on very large samples and can be obtained without reference to the mass of data needed to compute traditional statistical parameters, such as the mean and variance.

3.6. The study of records is not new, and it is known that even records exhibit some statistical variability. This variability is conveniently described by the Extreme Value or Gumbel distribution. Consequently, where appropriate, this distribution will be included in performance model development.

4. Methods

4.1. A common dilemma for researchers and developers is the choice between a reductionist or narrowly constrained approach, such as the study of isolated muscle fatigue or cardiac performance and the extrapolation of these findings to complex acts of daily living or working. The classical approach of applied physiologists and psychologists is to develop a test battery that addresses the capabilities and limitations of many contributing systems and predicts performance on many expected (and unexpected) tasks in a spectrum of contexts. In athletics the decathlon, a well-defined test battery, aspires to identify the best all round athlete. The principles of a well-defined, comprehensive test battery and cohort and individual records will be used to obtain data and develop useful predictive models of human performance in multiple tasks and contexts.

4.2. This approach begs the question of how to obtain useful data. The traditional path of developing a new test battery and obtaining performance data is both time and cost prohibitive. Consequently, the approach to be used in this study will be to select batteries of existing tests that are comprehensive for the purpose and contexts intended, and for which there exists data on both cohort and individual record performance. For example, there exists extensive data on performance of military recruits as well as other uniformed services on well-defined and controlled tests. This data has or may be subject to statistical analysis to determine the degree of correlation between test items. Thus, it will be possible to obtain data sets that are “exclusive and exhaustive” or where appropriate to use correlated data sets to test the robustness of the model predictions.

4.3. Task analysis and categorization will be conducted to describe those features of humans that are required for general groups of task - size, weight, arm strength, leg strength, cardio vascular capability, flexibility and motor skill will have differential contributions to different acts of daily living and working. For example, Dryden (197?) developed an approach and associated equipment to describe an “available motions inventory.” Similarly the physical and occupational therapy communities address the effects of subsystem limitations on functional activities. Research will be conducted on performance standards used to differentiate (select) handicapped and able-bodied individuals for certain jobs. Concepts and batteries under the general title of “readiness to perform” testing will be evaluated for their contribution to model development. Similar evidence will also be obtained from military test battery and associated assignments.

4.4. A verification approach to model development (i.e. before the use of military or other uniformed service physical performance data) will be to use published athletic records. Common sources of this data include the World Association of Veteran Athletes, the USA Track and Field Association and the numerous race results obtained from local running club websites and magazines. Also, during the exploration phase of the project, data will be sought on other characteristics of human performance for which records may be obtained, such as vision, hearing, typing and even cognitive performance, such as simultaneous translation and closed captioning. This broad use of records of different types of human performance will help to establish robustness of the approach.

4.5. Other validation efforts will use existing physical performance models of such phenomena as muscle fatigue as developed by Rohmert(196?) and Rose(199?) These models and other evidence based on cohort averages will be compared with the records-based models to detect the scale and form of model and parameter differences.

4.6. Data on human failure will be obtained from published accident statistics. For example, there are extensive data relating age and conditions for road accidents, and similar data will be sought for industrial and household accidents. Of particular interest to the military will be time (e.g. duration of basic training) and age based data related to recruit training during the critical maturation period between ages 18 and 30. Such data will be sought from military sources, such as Operation Aegis.

5. An Index of Performance Expectation

5.1. The amalgamation of separate models to develop a complex index of performance expectation will be addressed through simple (e.g. additive) processes and through more elaborate multivariate statistical methods. The contemporary literature on emergent technologies, including simulation, will be addressed to explore and test composite models, based on alternative amalgamations of the simple functions described earlier. The ultimate intention of this research and development effort will be to produce an Index of Performance Expectation for both cohorts and individuals. Such an index will be useful both in selection and training strategies as well as the prediction of mission success, given expected tasks and contexts.

6. Advantages and Limitations of this Approach

6.1. The use of individual and cohort records rather than sample averages has the advantages that records are more meaningful and much easier to obtain than conventional statistics. A shortcoming is that records describe the upper performance boundary for individuals and cohorts. The lower boundary is always zero; that is failure to accomplish the prescribed task or data censoring. If the cohort upper boundary for a particular test battery is 100 then a discounting approach can be used to estimate the cumulative effects of task, individual and contextual factors.

6.2. A second disadvantage is that there will always remain residual variability that is due to high order interactions, between the individual, task, and context, that cannot be anticipated. However, the records approach will be more robust and probably more conservative in predicting cohort or individual performance than conventional averages and confidence limits which, by definition, include a level of risk in the application of the evidence.

6.3. A third disadvantage lies in the assessment of interactions. For example, if a mountain scaling exercise required functional reach, arm strength, endurance and specific motor skill (experience), the ability of an individual to compensate for a shortcoming in one of these physical attribute components may be underestimated by the model. Such an underestimation would be good – there would be a greater safety margin between the task expectations and actual capabilities. On the other hand, if there was an interaction between arm reach (moment) strength, stamina, and skill degradation then the discounting model approach would overestimate task performance capability.

7. The Technical Approach

7.1. The first step in this project will be the development of concept maps of the problem domain. This step will be accomplished by using the C-map software developed at the Institute for Human and Machine Cognition in Pensacola. This knowledge elicitation tool will be used to explore and refine the data and modeling approach through consultation with experts in the field of human performance and mathematical modeling.

7.2. Although this proposal deliberately does not involve the collection of prospective data under controlled conditions, there will need to be considerable effort spent on obtaining relevant and useful data from reliable sources. This data search effort will be conducted in parallel with model exploration and development. Initially the literature will be searched for individual models that apply to human performance over time, such as learning and fatigue curves and possibly circadian rhythm models from the chronobiology domain.

7.3. Next, the data on human sub-component performance will be assessed for its contribution to the test battery that is relevant to a particular class of tasks of daily living and working which will be established using a conventional task analysis approach.

7.4. The fourth task component will be the development of a simulation test bed for model evaluation. Alternative approaches to this activity will be explored from simple spreadsheet models to the use of more elaborate discrete event simulation and / or fault tree methods.

7.5. Model verification and testing of robustness will be conducted by comparing alternative model components, model formulations and data sets. Comparisons will also be made with established models that are based on conventional statistics.

7.6. Preliminary evaluation of model validity will be based on historical evidence of functional task performance by individuals and cohorts that have been subject to model component tests. Formal validation will require prospective studies in a later project phase.

7.7. It is anticipated that this project will require a staffing level of two full time equivalent researchers for three years. Other costs will include computer facilities, data search and processing support and travel. It is possible that the project would be enhanced by occasional use of consultants in human performance and model building.

8. Personnel

8.1. Dr. Brian Peacock and Dr. Valerie Rice have similar educational backgrounds in the health professions, industrial engineering, and human factors / ergonomics. Dr Peacock has worked in academia, industry, consulting, and government while Dr Rice has spent her career in military research and development. Both principal investigators have good quantitative backgrounds, have published extensively and are familiar with the data, approaches and literature related to this proposal. It will be appropriate to engage the support of junior project personnel with experience in statistical and mathematical modeling, and computer model development.

9. References and Examples

9.1. A preliminary literature review has not produced any material that specifically addresses this challenge by the proposed approach. However, there is an abundance of literature related to temporal modeling of isolated aspects of human performance and on the statistical and mathematical models that are described in this proposal.

9.2. Analysis of data describing human performance variation over long (aging studies) and short (seconds to hours) durations has indicated that simple temporal models (e.g. exponential, polynomial regression) are appropriate for human performance dominated by individual subsystems (strength, endurance). The NIOSH Lift Equation success over the past twenty years has demonstrated that multivariate discounting models are both intuitive and sufficiently accurate for practical purposes, including analysis of the two temporal components – shift duration and lift frequency. Preliminary analysis of composite models where that data are standardized and then added show considerable promise (R^2 = 0.98 for a regression model of composite record data!)

Chapter 68

The Larger Context of Knowledge and Situation Awareness

Chai Kah Hin, Brian Peacock

1. Introduction

Every year, organizations lose billions of dollars in productivity in productivity as the result of inefficient searches for information. Also, To understand the cause of that staggering figure, imagine a typical day at the office of a large multi-national corporation.

Two junior executives, Adam and Zack, were each tasked to prepare a report on a company process. Both of them joined the company together 3 months ago, and had similar job scopes in the same department. While neither of them had directly worked with the individuals involved in that process, Adam knew where to look and was quickly able to acquire the knowledge required for the task. Zack on the other hand, while equally skilled and diligent, had difficulty getting to the right information; he did not know where to start and kept looking in the wrong places. Adam and Zack, two individuals with similar experiences in the company, the same access to corporate information systems, with the same task. Yet one of them was so much more aware than the other was of where to find the knowledge and information he needed. What caused this difference when the externalities were essentially the same? The answer must surely be the differences in their personal attributes.

A second scenario involves a novice trainee pilot (Brian) and his experienced instructor (Sarah). The two have been out for a flight and are returning to their home airport. All the necessary information for a safe landing is available to both of them. There is a view of the airport in the distance, a busy highway below and a large mountain to the right. The flight instruments show their heading, altitude, speed and attitude. They have an aeronautical chart on a clipboard that offers a great deal of information about the airport and its features and facilities. Their radios are available for them to contact the air traffic control tower for information about wind, operational runways and approach. Left alone with all this available information the novice would make many mistakes. On the other hand, the expert instructor has extensive situational awareness and knows how and when to obtain pertinent information and apply it to the process of safe landing. The differences between the two pilots are expertise and knowledge awareness.

Peacock, B and G Northam, (2006) "You've Got to Attend to Everything: Workload and Flying", Ergonomics in Design, Vol. 14, No. 4

These scenarios illustrate the differences between data, information and knowledge. Data are the unsorted and unstructured reflections of our environment, available for our use. Information is the meaning contained in these data that is categorized and communicated for our use. Knowledge is how to use the information in the active management of our decisions and actions. Novices, like Zach and Brian, may have all the necessary information at their fingertips but don't know how to use it. On the other hand, experts like Adam and Sarah, have situation awareness and understand the processes appropriate to predicting and managing the developing scenario. They have knowledge awareness. An extension of these concepts in terms of team behavior is described as the process of Crew Resource Management (CRM.)

A review of the literature found that knowledge awareness (KA), though mentioned or implied by a number of authors (Chai & Gregory, 2000; Hansen *et al.*, 2005; Le Van, 2006), and clearly obvious in the presence of experts, is undeveloped and poorly studied in the field of knowledge management (KM). The first two papers argue that prior to the transfer of knowledge (communication), one first has to search for and become aware of the knowledge. Leckie et al. (1996) proposed a cyclical model of information seeking; where the awareness of information sources and its existence guided the seeking of information, which in turn fed back to awareness. These insights are useful in developing a dynamic framework for KA.

Situation Awareness

The concept of Situation Awareness (SA) has had enormous success in describing and analyzing the behavior and performance of individuals and groups in the control of complex systems, as in aviation and medicine. Situation awareness (SA), as defined by Endsley (1995) involves perception, understanding and prediction (Figure 1). SA finds its roots among military aviators in the First World War (Press, 1986) as a construct for the individual, and has since expanded to include team SA. Its relevance extends beyond military applications, ranging from railroad operations (Roth *et al.*, 2006) to Internet shopping malls (Lee *et al.*, 2003). For the purposes of this paper, Endsley's definition and model of Situation Awareness was selected, as it is described as the "most prominent and widely used definition of SA" (Salmon *et al.*, 2008, p. 299). According to Endsley (1995, p. 36),

> *"Situation Awareness is the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future*

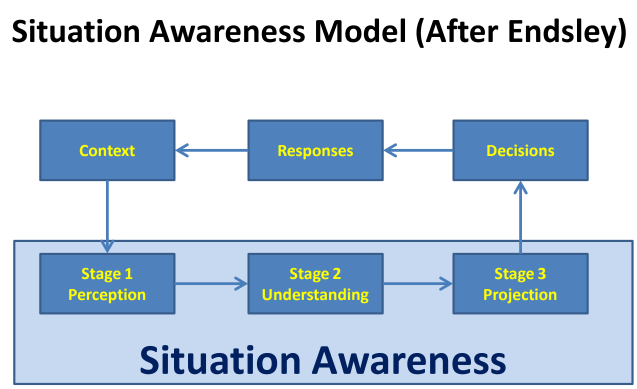


Figure 1 A model of Situation Awareness (after Endsley (1995)

Measurement of "situation awareness" can be by one of three processes – retrospective description of what went on during a transaction (SART), assessment of the current state of affairs by freezing a simulation in mid-stream (SAGAT) and asking the operator searching questions about their perceptions, understanding and predictions about the developing situation, and real time commentary on what is happening (Verbal Protocol Technique). This last technique has the disadvantage that the conscious articulation of the available information and ongoing processes may interfere with the operators' control behavior and performance. The former two methods (SART and SAGAT) may be inaccurate due to "wishful thinking" and hindsight bias."

SART – Situation Awareness Rating Technique

Demand	Instability	Sudden situation changes	1 2 3 4 5 6 7
	Variability	Number of changing variables	1 2 3 4 5 6 7
	Complexity	Situation complexity	1 2 3 4 5 6 7
Supply	Arousal, Concentration	Readiness, expectation	1 2 3 4 5 6 7
	Spare Mental Capacity	Capacity for new variables	1 2 3 4 5 6 7
	Divided Attention	Rate / amount of attention switching	1 2 3 4 5 6 7
Understanding	Information Quantity	Information received and understood	1 2 3 4 5 6 7
	Information Quality	Reliability of information	1 2 3 4 5 6 7
	Familiarity	Experience with similar situations	1 2 3 4 5 6 7

Taylor (1990)
Subjective method
Shows good diagnosticity in Rule and Knowledge based activities

Situation Awareness Global Assessment Technique (SAGAT)

- Requires detailed simulation of complex situation
  - Air Traffic Control, Driving, Process control
  - Alternatively use pencil and paper techniques
- Periodically stop the simulation
  - Ask subject (pre-prepared) key questions
  - Have subjects rate their levels of confidence
  - Record, omissions and other discrepancies
  - Have Subject Matter Experts rate the performance
  - Compile overall performance scores
- High number of random and systematic errors, including blunders indicates low situation awareness
- Provide feedback and suggestions for correcting systematic errors

10

An earlier related model of human behavior and performance is that of "mental workload." This concept may be extended to argue that Knowledge Awareness is the inverse of mental workload in terms of the major factors affecting human or group performance are Information, Time, Experience and Stress. The parameters of this model are necessarily broad and need further breakdown to assess particular situations. Information, in the strict sense of the word, implies all the data that are available, from whatever source, internal or external, to either contribute positively to the situation or to interfere (noise). It is widely demonstrated that the time available limits the amount of information that can be processed / analyzed, however the operator may be voluntarily or involuntarily selective in terms of the information that is used in a particular situation. Experience or expertise also contributes to this selectivity and handling of information and thus may have the effect of reducing mental workload or increasing situation awareness. Stress is a complex phenomenon that affects the way in which information sources are addressed; where the outcome of a decision or action is critical information processing behavior may be influenced.

Mental Workload and Knowledge Awareness

$$\text{Mental Workload} = \frac{\text{Information} \times \text{Stress}}{\text{Time} \times \text{Experience}}$$

$$\text{Knowledge Awareness} = \frac{\text{Time} \times \text{Experience}}{\text{Information} \times \text{Stress}}$$

The NASA Task Load Index is a subjective retrospective assessment of various sources of task stress.

Name	Task	Date

NASA TASK LOADING INDEX

Mental Demand: How mentally demanding was the task?

Very Low — Very High

Physical Demand: How physically demanding was the task?

Very Low — Very High

Temporal Demand: How hurried or rushed was the pace of the task?

Very Low — Very High

Performance: How successful were you in accomplishing what you were asked to do?

Perfect — Failure

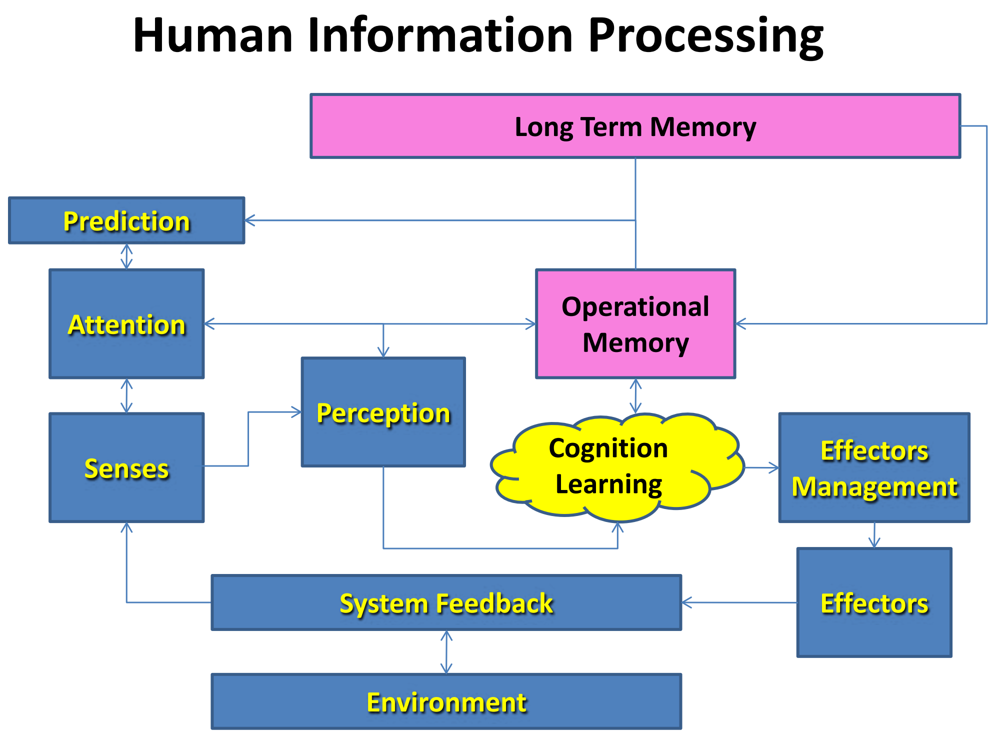
Effort: How hard did you have to work to accomplish your level of performance?

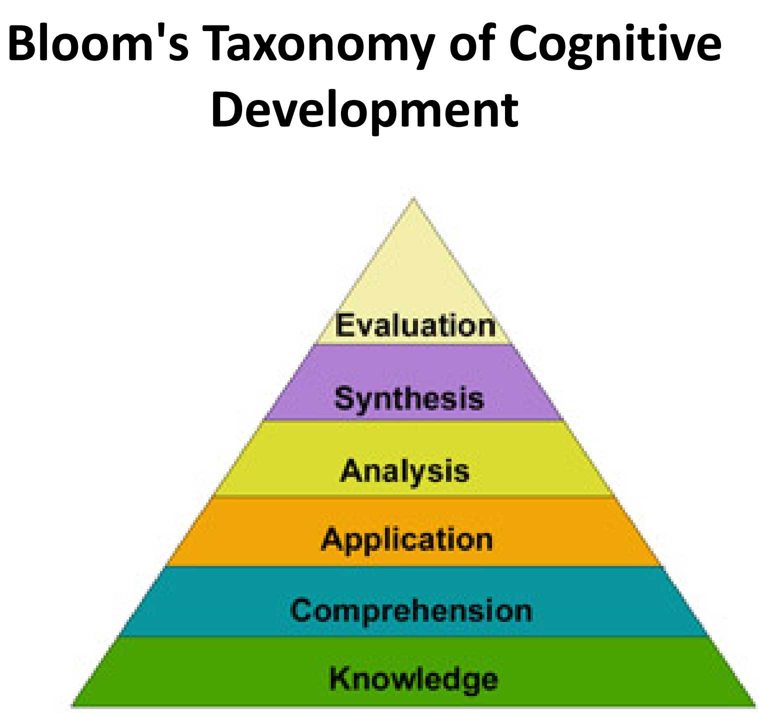
Very Low — Very High

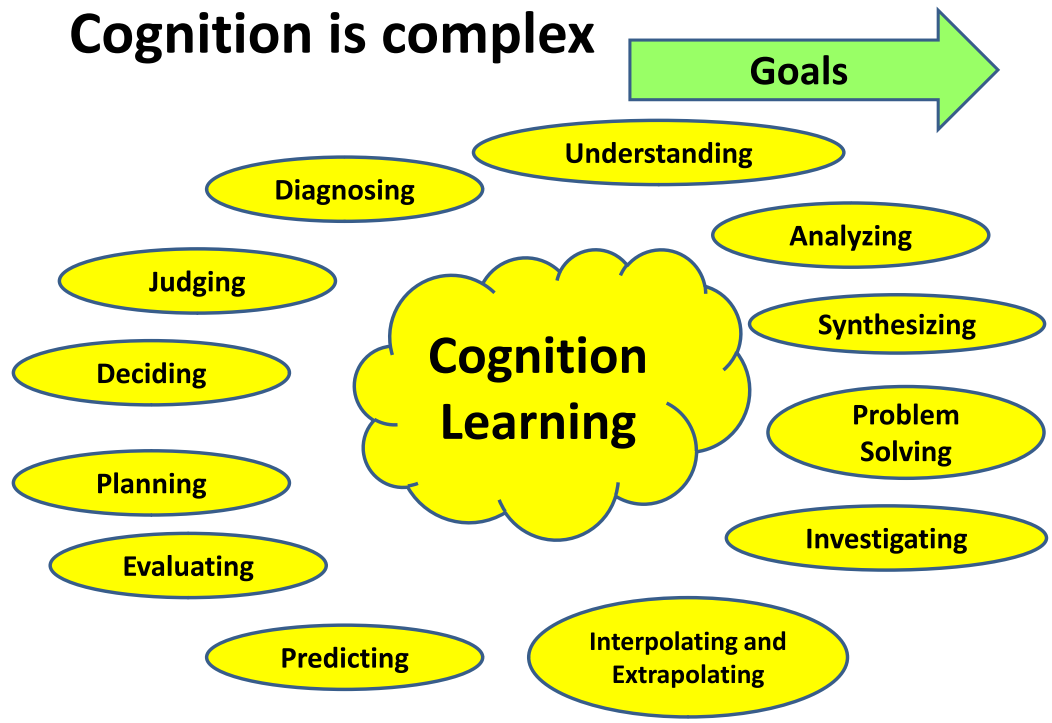
Frustration: How insecure, discouraged, irritated and annoyed were you?

Very Low — Very High

Another derivative of the mental workload concept is that of Human Cognitive Resource Theory (Crossman, Wickens), which identifies the capacities and limitations of information processing resources such as sensing, attention, perception, operational memory, decision management and effectors management. Bloom (194??) offered a perceptive description of various cognition levels that are parallel to the development of expertise. An alternative description of various cognitive processes that may be required to manage a developing situation is given in Figure ()







Memory

In summarizing the theories behind SA, Endsley (2000) highlighted the role of working memory and long-term memory in maintaining SA. Citing the work of multiple authors (Endsley, 1988; Fracker, 1988; Jones & Endsley, 1996; Gugerty & Tirre, 1997; Adams *et al.*, 1995), Endsley (2000) explained that working memory was necessary in the successful integration, comparison and projection of information. Gugerty & Tirre (2000, p. 251) claimed that Working Memory "is the central bottleneck in information processing and its capacity varies considerably across individuals. Thus, SA is expected to be limited by working memory capacity". Peacock (1972) argued that working memory is a

When it came to long-term memory, Endsley (2000) portrayed it as a superset of working memory. If working memory is the set of actively handled memories, long-term memory represented all the possible memories that can be activated. A variation of this perspective was offered by Sarter and Woods (1991 cited in Endsley, 2000, p. 15) who "emphasized the importance of information that can be activated from long-term memory to support limited working memory." Therefore, a weak long-term memory would result in difficulties recalling information to support the development of SA. Adapting these insights to KA, we will see that both factors are applicable.

Imagine again the scenario in the introduction, a strong working memory would allow Adam to consider more information simultaneously, and consequentially identify relationships that Zack could not, giving Adam better KA. To make matters worse, Zack also had poor long-term memory, with the consequence being that he forgot information relevant to the task that he learnt a month ago, lowering his KA. With this short illustration demonstrating how memory influences KA, it was hypothesized that:

H1: Good working memory contributes to higher knowledge awareness.
H2: Good long-term memory contributes to higher knowledge awareness.

A Working Memory assessment tool (Peacock 1972) may be used to assess and predict human performance as limited by content and interference in the dynamic information processing operation.

Operational Memory Involvement Recording Chart

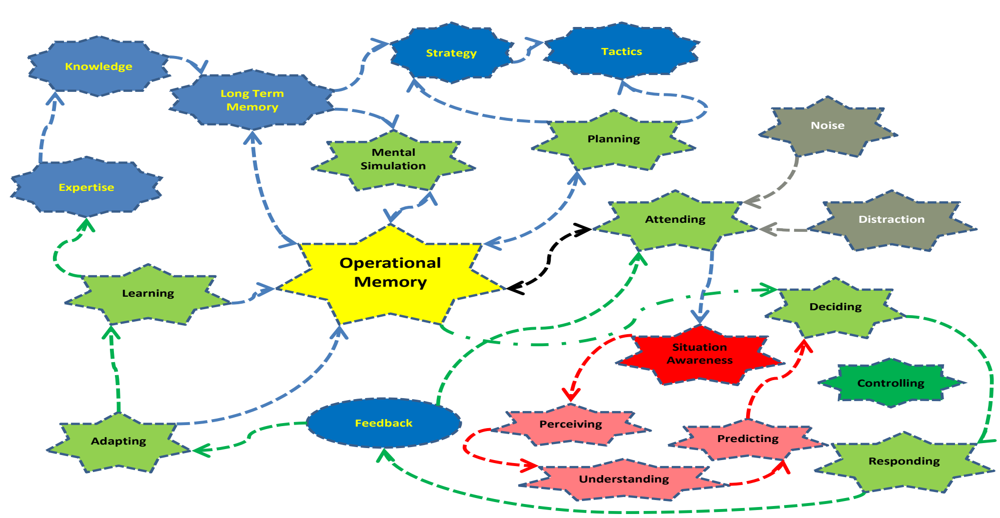
OMIRC	Proactive Support (+) Interference (-)	Item Information Content	Retroactive Support (+) Interference (-)	Response Information Content
Sensory Modality	Visual Auditory Tactile (-2) (-1) (0) (+1) (+2)	Visual Auditory Tactile	Visual Auditory Tactile (-2) (-1) (0) (+1) (+2)	Manual Verbal (-2) (-1) (0) (+1) (+2)
Form	Symbolic Spatial (-2) (-1) (0) (+1) (+2)	Symbolic Spatial	Symbolic Spatial (-2) (-1) (0) (+1) (+2)	Symbolic Spatial (-2) (-1) (0) (+1) (+2)
Literal / Semantic Content	Support Neutral Interference (-2) (-1) (0) (+1) (+2)	Familiarity Consolidation Rehearsal Novelty Fuzziness (-2) (-1) (0) (+1) (+2)	Support Neutral Interference (-2) (-1) (0) (+1) (+2)	Support Neutral Interference (-2) (-1) (0) (+1) (+2)
Information Content	High Medium Low (-2) (-1) (0) (+1) (+2)	High Medium Low (-2) (-1) (0) (+1) (+2)	High Medium Low (-2) (-1) (0) (+1) (+2)	Precise Medium Coarse (-2) (-1) (0) (+1) (+2)
Temporal Relationship	Seconds Minutes Hours (-2) (-1) (0) (+1) (+2)	Total Score Forget Recall	Seconds Minutes Hours (-2) (-1) (0) (+1) (+2)	Seconds Minutes Hours (-2) (-1) (0) (+1) (+2)

Other models of human control performance include the concepts of Knowledge, Rule and Skill based behaviors (Rasmussen) and the use of Landmark, Route and Survey levels of knowledge (Oman). A final concept is that of complex and emergent systems that require nonlinear, probabilistic extrapolation from the available information. Psycho physiological measures such as heart rate, heart rate variability, blink rate, eye fixation analysis, sweating and electroencephalography also have their places in this complex field of study.

The purpose of this paper is to relate these concepts and expand them to produce a more complete model of human behavior and performance supported by a tool that is readily applicable to the assessment of human behavior and performance in complex and emergent situations.

The first concept is that Situation Awareness is the reciprocal of Mental Workload:

A Fuzzy Map of Awareness and Control



This model is deliberately plastic, perhaps like a neural network. Readers should feel free to add or subtract concepts or activities; the linkages may also be changed. The purpose of the model is to identify Situation Awareness as part of a greater concept of knowledge awareness and timely access. The central focus of this model is Operational Memory which serves as a dynamic link between the noisy outside world and the, sometimes fuzzy, knowledge available to an individual or operational team engaged in some simple or complex control process. One important observation is that operational memory is not necessarily conscious; indeed rapid intuitive decisions may be made without apparent conscious control. This topic is addressed extensively by the popular writer (   ) in his books "Tipping Point" and "Blink". A significant cohort of Human Factors researchers currently communicate extensively through the "High Velocity Human Factors" Internet Technical Group. Topics of interest include the apparently intuitive decisions and actions of sports players, military and police, vehicle and process controllers and business and investment analysts.

Operational, working or short-term memory is notoriously limited in the amount of information it can hold. The classic work by Miller – "The Magic Number 7 Plus or Minus Two" refers to the capacity of short-term memory for distinct "chunks" of information. One difficulty with this theory lies in the content of a "chunk". With time, rehearsal, consolidation and learning a chunk can contain more and more "bits" of information. For example one can accurately recall one's telephone, identity number or long computer password, but not a set of random digits of the same length or objective information content. Similarly, one can recall in a timely way

Verbal Protocol Analysis has been used for many years to try to explain how control operators make decisions. However, there are often discrepancies between what an operator intends to do, recalls as having done and what he or she actually did. The rationalization may be related to the outcome of a particular decision or action. One has only to read the accounts of participants in or spectators of sports contests after the event and compare these with objective analyses of the activities to recognize the universal presence of hindsight bias in human perceptions. Perceptions are also considerably affected by expectancy as demonstrated convincingly by a plethora of visual illusions.

A Framework for Knowledge Awareness

The operational definition of KA in this study was adapted from Endsley's definition of SA and written as follows:

> *Knowledge Awareness is the perception of knowledge and information in the environment within a volume of time and space, the comprehension of their meaning and significance, and the projection of their impact in the near future.*

From the definition, it should be clear that Knowledge Awareness goes beyond simple recollection of what knowledge exists and where it lies. It encompasses the ability to mentally register pertinent knowledge, understanding the significance of that knowledge and its relationship to other items of knowledge and the task, and from there, infer or deduce the future state of the knowledge environment. To illustrate this, recall again the scenario from the introduction. The knowledge environment refers to the whole set of knowledge that exists in the company and every conceivable relationship these items of knowledge have with each other and with other entities or activities. KA refers to Adam and Zack's mental model of this reality, and it is from this internal re-creation of the actual knowledge environment that they make their knowledge-based decisions. This can be generalized beyond a company to any knowledge environment involving any number of individuals.

To being developing the framework, we first identify the *state* and the *process*. In this context, KA is the state while knowledge search is the process that develops the state. Note that in selecting a tangible rather than a purely cognitive activity as the process, the relationship resembles more closely Leckie *et al*.'s (1996) model of information seeking (see **Figure 1**) than Endsley's model of situation awareness (see **Figure 2**). The rational for this will become evident later in this sub-section. With that established, we proceed to determine the relationship between the state and the process.

Given the dynamic nature of knowledge search, where KA drives search while search outcomes in turn modifies awareness in an iterative process, it makes sense to present the state and the process in a cyclic relationship. This portrayal is consistent with related models in SA, information seeking and sensemaking. With the relationship established, we consider KA in relation to the knowledge transfer process.

The four-stage and three-phase models of knowledge sharing proposed by Chai (2000) and Hansen *et al*. (2005) respectively, present the awareness and search process as a distinct stage prior to transfer. Le Van (2006) who identified the three aspects of KA, also argues that all three aspects have to be met before one can proceed to transfer. This led to the depiction of awareness as a distinct stage before transfer, to reflect this understanding

Given this framework, the rational for depicting the tangible knowledge search as the process becomes clear. If the model instead depicted a purely cognitive process, it would have given the impression that KA is developed purely in one's mind, without the need to physically look for knowledge and verify assumptions. That would have run contrary to Hansen *et al*.'s (2005) three-phase model, which specified a search process before the transfer of knowledge. The model was intentionally kept simple to facilitate intuitive understanding of the framework; this was felt to be important, as KA is still a new construct.

Hypotheses Development

Nineteen antecedents were identified from extant literature primarily from the field of SA, supplemented by literature on sensemaking, information seeking and KM (see **Table 2** below). Of the 19 antecedents, four of them were identified as personal attributes. Personal attributes refer to factors that are internal to the individual as opposed to being imposed by the immediate environment or by circumstances. Therefore, attributes bear the same basic influence on KA across different situations and environments. The attributes were working memory, long-term memory, analytical ability, and sociability. From these antecedents, five hypotheses were developed for study.

Situation Awareness	Sense Making	Knowledge Management	Information Seeking
• **Analytical ability** • **Working memory** • **Long-term memory** • Attention • Automaticity • Bias and belief • Expectations • Expertise and generic knowledge • Fast changing conditions • Goals • Information • Mental models • Pattern matching • Time	• **Analytical ability** • Bias and belief • Culture • Fast changing conditions • Information • Preoccupation • Mental models • Expertise and generic knowledge • Specific knowledge in well-known situation • Time	• **Sociability** • Culture	• **Working memory** • Education

Memory

In summarizing, the theories behind SA, Endsley (2000) highlighted the role of working memory and long-term memory in maintaining SA. Citing the work of multiple authors (Endsley, 1988; Fracker, 1988; Jones & Endsley, 1996; Gugerty & Tirre, 1997; Adams *et al.*, 1995), Endsley (2000) explained that working memory was necessary in the successful integration, comparison and projection of information. Gugerty & Tirre (2000, p. 251) claimed that Working Memory "is the central bottleneck in information processing and its capacity varies considerably across individuals. Thus, SA is expected to be limited by working memory capacity".

When it came to long-term memory, Endsley (2000) portrayed it as a superset of working memory. If working memory is the set of actively handled memories, long-term memory represented all the possible memories that can be activated. A variation of this perspective was offered by Sarter and Woods (1991 cited in Endsley, 2000, p. 15) who "emphasized the importance of information that can be activated from long-term memory to support limited working memory." Therefore, a weak long-term memory would result in difficulties recalling information to support the development of SA. Adapting these insights to KA, we will see that both factors are applicable.

Imagine again the scenario in the introduction, a strong working memory would allow Adam to consider more information simultaneously, and consequentially identify relationships that Zack could not, giving Adam better KA. To make matters worse, Zack also had poor long-term memory, with the consequence being that he forgot information relevant to the task that he learnt a month ago, lowering his KA. With this short illustration demonstrating how memory influences KA, it was hypothesized that:

> *H1:* Good working memory contributes to higher knowledge awareness.
> *H2:* Good long-term memory contributes to higher knowledge awareness.

Analytical Ability

If memory provides the substance of knowledge, one's analytical ability provides the means to process and make sense of this knowledge. Wiig (2004, p. 130) explained that an increased "ability to analyze situations... leads to better and quicker understanding of broad ranges of situations." This view is in agreement with Rabbitt *et al*. (1989, p. 254) whose findings suggested that people who score well on IQ tests "more rapidly learn to… attend selectively to critical portions of complex scenarios, to make rapid and correct predictions of immanent events and to prioritize and update information in working memory". From these two statements, we see that a strong analytical ability enhances KA by guiding limited mental resources towards more important pieces of knowledge, and by enhancing understanding of the knowledge. This allows the individual to build a mental model that better reflects the knowledge environment and the way that it will evolve, helping him to value and identify unobvious sources of knowledge. To illustrate, supposed Adam and Zack from the earlier scenario decided to venture into investments. Having a strong analytical ability, Adam was able to infer the inverse relationship between Gold and the US dollar. As a result, he studies movements in the US dollar to guide his investments in Gold. Zack on the other hand was poor at analysis, and did not know what information to seek even though he had the same access to information as Adam. Not being able to appreciate the significant of the information, result in Zack having lower KA.

As further evidence, Schmidt & Hunter (1998, p. 271) found that general mental ability, is "a good predictor of job performance", especially in research and supervisory roles; research and supervisory roles being more knowledge intensive. They explained saying that "more intelligent people... acquire job knowledge more rapidly and acquire more of it" (ibid). Given the clear relationship between analytical ability and KA, it was hypothesized that:

> *H3:* Strong analytical ability contributes to better knowledge awareness.

Sociability

Andrews & Delahaye (2000, p. 801) identified social confidence as a factor that influences knowledge importing among scientist. They explained that individuals "comfortable in a broad range of working relationships would be expected to have access to wider knowledge sources than peers who were less at ease initiating contact." While their study examined knowledge processes in organization learning, it is easy to see how social confidence might affect the individual's exposure to knowledge sources. An interesting article supporting this notion comes from Nonaka & Konno (1998, p.40) who introduced the Japanese concept of "Ba", which they described as a "shared space for emerging relationships". Ba extends beyond the physical space to include face-to-face interactions, cyber activities and even exercise. This would imply that increased social interaction creates more opportunities for the exchange of knowledge and thus enhances KA.

While sociability is not an antecedent found in SA, a significant difference exists in the inputs to KA compared to SA, making sociability relevant. Unlike traditional applications of SA in aviation, where inputs come from a well-defined set of channels (e.g. instrument readings), KA inputs can be vague and highly varied. A chance discussion over coffee, or even variations of tone when conversing with a colleague, can become unexpected sources of new knowledge. This further supports the case for sociability as an important factor in KA. Therefore, it was hypothesized that:

> *H4:* Increased sociability contributes to better knowledge awareness.

Knowledge Awareness and Situation Awareness

While the prior four hypotheses addressed antecedents based on personal attributes, the next hypothesis proposes that a relationship exists between KA and SA. The relationship is likely to exist because both constructs are hypothesized to share a number of common antecedents. Given that the four antecedents were well reasoned in the prior sections, a correlation, at the very least, should exist between the two constructs. It might be that good SA contributes insights that help the individual become aware of how to access knowledge stored across the organization or that that good KA is a critical component in developing a good understanding of the situation. Because the causal relationship is still unclear, this study only went as far as to hypothesize that:

> *H5:* The individual's level of knowledge awareness correlates with his level of individual situation awareness.

Discussion

This study has shown that sociability and analytical ability are antecedents of KA. As intrinsic attributes, a knowledge worker high in both sociability and analytical ability can be expected to attain a relatively high level of KA across different situations.

A strong correlation was also found between SA and KA. While, a correlation alone cannot be used as evidence for causation, it gives impetus to studying the relationship between the two constructs. Note that the correlation is not the result of circularity, as the measures for each construct were developed separately using literature from their respective fields.

Identifying two new antecedents for KA and confirming the presence of a link between KA and SA establishes the contributions of this study to the areas of knowledge sharing and knowledge transfer. However, further insights can be gained by considering why hypotheses H1 and H2 were not proven, and by examining the unexpected influence of high workload.

Working & Long-term Memory: The Lack of Influence

While it could not be conclusively drawn from the analysis that working memory and long-term memory do not significantly influence KA, the effect sizes are small enough such that any influence seems to be minimal. This appears to be counter intuitive as an individual's ability to remember things must surely play a role in knowing where knowledge lies. A possible explanation for these results comes from the construct known as transactive memory.

In his seminal paper, Wegner (1986) describes transactive memory as the memory property of a group as a whole, where individuals within the group benefit from knowledge held in the memory of other individuals by communicating with these individuals. Working closely in groups of 3-5 students, our subject of study was thus likely to benefit from transactive memory. Therefore, even if an individual had poor memory, communicating frequently with his teammates allows the individual to compensate his own memory with the collective memory of the team. This may also explain why sociability was found to have a strong influence on KA, accounting for a quarter of its variance in the structural model.

In the same paper, Wegner (ibid) explained how information found by the team is channeled for storage by the designated domain expert in the team, and how individuals are more alert to knowledge relevant to their own domain responsibilities. This gives impetus to exploring how the individual's role in a team may affect his/her KA. The lack of a significant influence of a leadership role on KA in this study should not be a barrier to studying this, as it may be because the study sample involved small and tightly integrated teams, reducing the privileged position of a leader in accessing information. Larger teams may see greater KA in leaders or managers.

The Positive Impact of High Workload

The study found that high workload made a small positive contribution towards better KA. This seems contrary to the antecedent in SA, where a high workload was found to overwhelm individuals and decrease awareness (Endsley, 2000). A possible explanation comes from examining the measure for workload, which asked the respondent how much time he spent on the project. A high workload implies that more time was spent, allowing greater familiarity with the various aspects of the project. It may also be that more time was spent interacting with teammates, leading to greater transactive memory as explained by Wegner (1986).

Influence of Performance on Self-Assessment

Analysis of the data found a moderate correlation between the awareness constructs and perceived performance. This however, should not be taken as evidence that perceived performance had an undue influence on self-assessed SA and KA, with the reasons being two fold. Firstly, we expect higher levels of SA and KA to contribute to better overall performance, resulting in a correlation with performance. Secondly, actual performance is a grade given for the team as a whole, which is a less accurate reflection of individual performance than the individual's own perceived performance. This also explains the weak correlation between awareness and actual performance. However, this does not dismiss the argument for Perceived performance as an undue influence, with further study required to establish the actual relationship.

Conclusions

For researchers, the proposed framework for KA lays the foundation for subsequent research and highlights the need to take into account the development of KA as a prior stage to knowledge transfer. The identification of analytical ability and sociability as significant factors provides a starting point to develop a fuller understanding of the influences and processes underlying this construct. Finally, the differences between perceived and actual performance are a reminder to researchers of how different perspectives can yield very different measures that are both equally valid.

For KM practitioners, the study highlights the importance of enhancing KA as part of a larger KM strategy. It also points out the need to look beyond information systems to encouraging social interaction to enhance KA in an organization.

While this study yielded useful insights and contributed to the development of the theory underlying Knowledge Awareness, the study faced three limitations.

Firstly, the study relied on self-assessment through survey as the primary means for data collection. While a peer-assessment component was designed for this study, the low response rate meant that the moderating effects of peer-assessment could not be included in the analysis. A better approach would be to test directly each of the constructs. However, this would require the development of new assessment tools to for KA and SA in the knowledge context.

The second limitation results from the survey's target population. While surveying a homogenous group of students helped control for many factors, the students worked in tightly knitted groups on the same task for an extended duration. This may have masked the effects of differences in individual memory.

The third limitation faced was the sample size. Despite a relatively high response rate, the study had to work with a final sample size of 46. The small sample was the result of the small population size. A larger sample, either by collecting responses across multiple years or by selecting an alternative target population, would yield more stable results in analysis.

Future Research

This study being exploratory in nature, uncovered many potential areas for future study. The following paragraphs highlight five areas for consideration.

The first possibility would be to delve deeper into identifying the factors influencing KA. While this study identified analytical ability and sociability as strong factors, they were only measured superficially via self-assessment. Teasing out the various aspects of sociability or using more robust measurement techniques may yield further insights. Alternatively, 15 other antecedents were identified and listed in **Table 2** and can be considered for further study.

Secondly, while this paper proposed a general cyclic model for KA and knowledge search, this model was not directly tested in this study. The model can be validated through interviews or through experimentation.

A third possibility comes from Wegner (1986), whose description of transactive memory bears strong resemblance to KA as a prior stage to knowledge transfer. Briefly, individuals store via internal meta-memory the location and description of where knowledge lies externally (resembles KA). When knowledge is needed, the individual seeks out the information based on internal meta-memory (resembles knowledge search), before locating and acquiring that knowledge (knowledge transfer). In addition to insights on the processes underlying KA, literature on transactive memory could yield insights on team KA and the influences of individual responsibilities in a team. The relationship between KA and transactive memory certainly holds potential for investigation.

Fourth, the correlation between SA and KA raises several questions that deserve further examination. Firstly, one could investigate more deeply the applicability of SA in knowledge contexts. Secondly, the correlation poses the possibility that KA could be a special case of SA. Finally, it invites the adaptation of other concepts from SA to KA. Possibilities include team KA, strategies to improve KA and insights on how technology and design can enhance KA.

Finally, while sociability was found to have a linear relationship to KA, and was shown to influence KA strongly, a contrary view of sociability was expressed by Hexmoor (2000). Hexmoor believed that sociability and SA involves a tradeoff. He argued that "Sociable agents thrive on [communication] ...whereas goal-driven agents communicate sparingly to enhance their perception of the surrounding while minding the cost of communication." While this view came from agent theory, it seems reasonable, as one would imagine a highly sociable individual being preoccupied with socializing and becoming unaware of the situation around him. Thus, a study into the limits of sociability in relation to KA may be worth considering.