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A MANAGEMENT PROPOSAL
FOR
DETERMINING THE EFFECTS OF COMBAT STRESS
ON THE MAN-MACHINE INTERFACE
OF COMPLEX INFORMATION DISPLAY SYSTEMS

by

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A Management Proposal For Determining the Effects of Combat Stress On the Man-Machine Interface of Complex Information Display Systems

by

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Submitted in partial fulfillment
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ABSTRACT

This thesis culminates in a management plan for determining the effects of combat stress on the man-machine interface of complex information display systems. The objective is to provide to the reader both background information detailing the historical development of military attitudes towards combat stress and a survey of the physiological and psychological factors which influence the resolution of this problem. Current research in these areas is discussed with emphasis on research which strongly supports the problem's resolution. The management plan cites those agencies who have a specific background, expertise and capability of accomplishing portions of the research. For concepts requiring further study, individuals within established institutions who are currently addressing these areas are suggested. An overall program coordinator is recommended. In conclusion, recommendations for implementation of changes in the areas of training and acquisition are cited.

TABLE OF CONTENTS

I. INTRODUCTION

> The stress of war tries men as no other test that they have encountered in civilized life. Like a crucial experiment it exposes the underlying physiological and psychological mechanisms of the human being. (Grinker, 1945, p. ix)

A. PURPOSE

This thesis is a response to the same topic posed by Capt Tony Merrill, USN, PACOM/LANTCOM Division, J-6, Joint Chiefs of Staff. Due to the complex nature of determining the effect of combat stress on the man-machine interface of complex information display systems and the state of current technology and research in the associated fields, this thesis does not attempt to resolve the stress oriented question itself. Rather, this thesis culminates in a management plan to facilitate determination of the larger issue of the effects of combat stress.

The management plan orients the user towards those areas of research requiring further study while highlighting those governmental and private sector agencies which have accomplished in-depth research in pertinent fields. The author's hypotheses projecting causal relationships are detailed in this analysis. This thesis is meant to be informative in nature and not a critique of any management plans currently being developed by other governmental agencies.

B. STRUCTURE

This thesis is divided into seven component parts: this Introduction, Background, Physiological Considerations of Man-machine Interaction, Summary of Research on Psychological Human Factors, Human Factors Influencing Cognition and Decision-Making, Evaluation of Human Factors Military Standards and Acquisition Policies for Automated Data Processing Equipment (ADPE), and A Management Plan with Recommendations.

The Background section of this thesis addresses historical evolution of the definitions of combat stress. These definitions are the basis for the development of the terminology used in this thesis. It is also necessary to review a case study of a military situation where the impact of combat stress can be seen with some clarity. Multitudes of documents exist which detail the events of combat and the associated stressors. However, the shooting of the Iranian Airbus by the USS Vincennes, on 3 July 1988, is a combat scenario with documented data and reactions to stimuli containing conspicuous detail. The overall effects of combat stress are easily discernible in this scenario and provide a model for further evaluation.

Physiological Considerations of Man-Machine Interaction presents the physiological factors which impact cognition and decision-making with respect to information display systems. An understanding of these factors is integral to understanding the interactive processes involved. Research in this field is highlighted.

Summary of Research on Psychological Human Factors introduces psychological theory on determinants of varied cognitive mechanisms. Since there are highly diverse theories on the cognitive processes, only those theories whose supporting documentation expands and clarifies the definitions of combat stress, as defined in this thesis, are presented. The psychological implications of interaction with a complex information display system in a military organization is developed. Current research supporting these theories is highlighted.

The Factors Influencing Cognition and Decision-Making reveals conclusions determined to date in ongoing research. These conclusions are the basis for resolving the question of the effect of combat stress on the man-machine interface of complex information display systems. Studies of man-task mismatch and the impact of complexity and organizational elements are discussed. An understanding of research that must be accomplished is developed.

Evaluation of Military Standards and Acquisition Policies Concerning ADPE cultivates an understanding of what human factors cited in chapters III and IV are presently considered in current acquisitions of ADPE. This presentation reveals areas of deficiency whose resolution is necessary to preclude failure of newly acquired complex information display systems.

In summation, A Management Plan with Recommendations is proposed which incorporates the pertinent facts of the previous chapters into a comprehensive approach to resolving the effects of combat stress on the man-machine interface of complex information display systems. Recommendations on simulations and software are included.

II. BACKGROUND

A. DEFINITION OF COMBAT STRESS

Addressing the issues and problems of combat stress are tainted with the connotations elicited by the term itself. Historically, the study of the phenomenon has been undermined by preconceptions associated with the incapacitating effects of combat stress. These effects were linked to the concept of mental instability or genetic predisposition to mental weakness. To define the term "combat stress", it is important to review its historical preconceptions to ensure an unbiased definition is constructed.

Combat stress, from an American perspective, was initially addressed only through diagnosis and treatment of soldiers who became completely dysfunctional in battle. Prior to World War I (WWI), the United States military establishment diagnosed soldiers who suffered from an incapability to function in the war environment as suffering from some type of brain damage caused by the severe impact of air associated with an explosion. This diagnosis was termed "shell shocked". Studies conducted around 1916 determined that this phenomenon was a psychological disorder. Men, however, were expected to be able to conduct combat, protecting their family, country and ideals, regardless of the existing conditions.

Prior to World War II (WWII), the military diagnosed these same symptoms as "war neurosis" and "traumatic neurosis" and defined its origin as "due to a predisposing personality defect" (Figley, 1978, p. xv). Preinduction physicals during WWII, that attempted to predict this predisposing personality, resulted in a rejection rate three to four times greater than that of WWI. Despite these efforts, during WWII, there was a 300 percent increase in incidents of the disorder. The predispositional factors remained assumed and the terminology "Psycho" was coined--which tainted the affected soldiers with negative nuances. The underlying question became whether the soldier was incapable of fighting due to a psychological disorder or unwilling to fight due to cowardice. Figley suggests in his book that the term "exhaustion" was coined during WWII by a medical commander to lessen the negative connotations of the condition and discourage the use of the term "Psycho".

During the Korean War, with a heightened concern for the severe rigors encountered by their personnel, the United States Navy delineated dysfunctional sailors into categories of those suffering from "physical exhaustion" versus those suffering from "combat exhaustion". WWII statistics indicated that admission rates into field hospitals for dysfunction based on combat experience in the European theater combat divisions were 25 percent, while infantry battalions were 20 percent, and Southwest Pacific rates were even higher. Based upon these statistics, the Navy implemented a nine month rotation period--acknowledging an environmental causal factor thus limiting their personnel to its exposure. The Navy saw a reduction in occurrences of dysfunction caused by combat stress in their sailors.

In 1952, the military Diagnostic and Statistical Manual I described dysfunction caused by combat experience as a condition of gross stress reaction. Continued research advanced understanding of the complicated phenomenon.

> War has almost always been accompanied by great advances in the medical sciences. It is obvious that large numbers of sick and wounded demand from the ingenuity of doctors better methods of diagnosis and treatment. A host of new discoveries develop concurrently as necessity demands, and old fetishes, maintained by inertia and conservatism, are relinquished. (Grinker, 1963, p. 427)

Interrelationships between combat stress and all facets of the soldier's life were established. The emotional stress of combat was delineated into subcategories.

> The emotional stress is a complex network of unusual strains inherent in the combat situation. The stress is derived from different sources, which again mutually reinforce each other. Although complex, they can be reduced to four principal categories: the all-pervading threat of personal injury or death, the injury or death of friends with its powerful effect on the interpersonal relations previously described, the necessity to engage in continually hostile and destructive activity, and finally the effect of all these strains, both physical and emotional, on individual motivation to remain in combat. (Grinker, 1963, p. 33)

However, in 1968, the military's Diagnostic and Statistical Manual II replaced this description with the term "Adjustment Reactions of Adult Life" and defined it as "fear associated with military combat and manifested by trembling, running and hiding" (Figley, 1978, p. xvii). It is interesting to note that the period between the initial publication of the first manual and that of the second manual were not marred with any major American military wars, except the Korean Conflict. It suggests that the experiences recognized during and after previous combat experiences were ignored by the authors of this military document. The prejudice lived on.

After the Vietnam Conflict, a return to concentrated study of the effect of combat stress on the soldiers of the combat theater began. As soldiers returned to civilian life, marriage dissolutions, inability to maintain former jobs, homelessness, and violence against society increased significantly in the post-conflict veterans. This condition effected the study of the "Post Traumatic Stress Disorder" and its underlying causes. The symptoms of this disorder were often used as causal agents during trials of Vietnam Veterans for crimes against society. With compassion for the victims, society developed strong conflicting philosophies about this combat oriented dysfunction. Vietnam Veterans still carry the stigmatism of those negative philosophies today.

In 1991, conversation with junior officers of the Naval Postgraduate school revealed a predominant belief that combat stress reactions masked cowardice in the individual involved. A predisposition to the stress reaction was not noted however. Similarly, a senior officer with operational responsibility assigned to Air Force Space Command when queried about the effects of combat stress on the man-machine interaction of early warning radar systems responded that it did not exist in Space Command because they trained in a war-like environment.

Based upon the responses above, it is apparent that despite the advancements made in the medical communities at least a portion of the military operational community still holds biases concerning the definition of combat stress. Although the pervasiveness and intensity is unknown, connotations of cowardice or unacceptable weakness are still associated with the term. Grosser defines stress as "any force that pushes the functioning of important subsystems beyond their ability to restore equilibrium through ordinary, nonemergency, adjustment processes" (Grosser, 1964, p. 13). Modifying this definition, for the purpose of this thesis, combat stress is defined as follows:

Within a military situation, any force (internal, environmental, organizational) that pushes the functioning of important human subsystems beyond their ability to restore equilibrium through ordinary, nonemergency, adjustment processes, the consequences of which may be catastrophic events. Dysfunction due to combat stress shall not consider events of cowardice.

B. A CASE STUDY

On 3 July 1988, the AEGIS equipped, Ticonderoga class, guided missile cruiser, the U.S.S. Vincennes (CG-49) was assigned to the Persian Gulf and tasked with providing anti-air warfare coverage for friendly forces. While countering a sea-based hostile attack, by the Iranian Revolutionary Guard Corps (IRGC), the ship erroneously identified a civilian aircraft, Iran Air Flight 655, as a hostile airborne target and shot down the aircraft. All passengers and crew were killed. A synopsis of the personnel readiness, equipment readiness, environment, command and control configuration, and decision-making factors involved (as detailed in the Department of Defense's Formal Investigation into Circumstances Surrounding the Downing of Iran Air Flight 655 on 3 July 1988) follows.

1. Personnel/Equipment Readiness

Upon deployment to the Persian Gulf, the U.S.S. Vincennes was "in the highest state of training and readiness: C1 in Personnel, Supply, Equipment and Training: M1 in AAW [antiaircraft warfare], AMW [amphibious warfare], ASW [antisubmarine warfare], ASUW [antisurface warfare], C3 [Command, Control and Communications], EW [electronic warfare], and training areas." (Formal Investigation, 1988, p. 18) Training schedules prior to deployment were extensive and continuous for the ship. After deployment, training was continued at Naval Air Station Subic Bay, Philippines. An exercise in May 1988 included a scenario of an attacking aircraft. Equipment preventive maintenance documentation was properly recorded and had no significant discrepancies. The AEGIS combat system was working in accordance with requirements.

Within the Combat Information Center (CIC), a key position was manned by an unqualified person. "The Commanding Officer U.S.S. VINCENNES certified all officer watchstanders as qualified; however [name withheld] had not completed PQS [Personnel Qualification System] for AAWC [antiaircraft warfare commander]" (Formal Investigation, 1988, p. 21). This position coordinates activities of the ship's warfare systems. This officer's actions are not in question here; however, the lack of confidence in this person brought about strong assertions of other watchstanders' beliefs. "TIC's [Tactical Information Coordinator's] perception that there was an inexperienced, weak leader in the AAWC position led to the emergence of TIC in a leadership role. TIC's reports were accepted by all and could have influenced the final decision to launch missiles" (Formal Investigation, 1988, p. 45). Therefore, stress originating in the lack of confidence of an unqualified person, on duty, during a battle environment, was present in the CIC.

During the engagement of the IRGC's attacking boats, the U.S.S. Vincennes lost use of one gun due to a fouled bore. This phenomenon occurs when the gun does not fire off a round. Dependent upon the heat of the bore and the cause of the misfire, there exists the possibility of the projectile exploding in the gun. The consequences of this, on this ship, could have been damage to the ship and personnel located in areas other than those immediate to the gun itself. Until completion of detailed checklists required to clear a fouled bore, personnel in the CIC would be under the stress associated with the uncertainty of this event.

2. Environment

Three predominant factors bear further scrutiny in the environment of the U.S.S. Vincennes during the attack on the Iranian Airbus. These are: an intelligence induced expectation of attack, combat bias caused by an affirmation of the expectation of attack and excessive confusion levels.

The operational posture of the U.S.S. Vincennes was high on the day of the attack on the Iranian Airbus. Expectations of attack were prevalent due to intelligence reports highlighting increased air and naval activity in the Persian Gulf. In April 1988, the U.S.S. Samuel B. Roberts was severely damaged by Iranian mines: the United States took retaliatory action. From 30 June to 2 July 1988, Iraq conducted numerous air attacks on Iranian oil facilities and shipping. Iran responded with deployment of air assets and increased shipping attacks. Combat expectations were heightened when intelligence reports alerted U.S. forces to expect probable attacks on American assets in the Gulf during the holiday weekend. Intelligence advisories detailed the movement of hostile Iranian F-14 aircraft into Bandar Abbas. Sensitivity to the deaths aboard the U.S.S. Stark was renewed. In this unfortunate incident, a U.S. Navy ship, while participating in an exercise was shot by the Iraqis. The loss of American lives was high.

In an affirmation of the expectation of attack, during the morning of the third of July, Iranian Revolutionary Guard Corps gun boats, while challenging merchant vessels from the Strait of Hormuz's western approach, fired upon an American helicopter detached from the U.S.S. Vincennes. The helicopter and the U.S.S. Montgomery were reacting in defense of the merchant vessels. The U.S.S. Vincennes responded and was prepared to battle the IRGC gun boats.

On the U.S.S. Vincennes, confusion in the CIC became high during the confrontation with the attacking gun boats. Due to a fouled bore in one of its guns, the U.S.S. Vincennes maneuvered radically at high speed to maintain gunsighting of the attackers. This maneuver caused falling books, publications and loose equipment from the consoles and desks of the CIC. This environment was not one simulated in combat training scenarios conducted by the Vincennes. The effect on the crew would raise stress levels--possibly degrading their ability to analyze objectively combat information.

3. Command and Control

Although the Commanding Officer had revised the basic Battle Doctrine, this revision was implemented prior to arrival in the Persian Gulf and was trained while transitting Subic Bay.

Stress associated with difficulty in communicating intraship was vident. Communications internal to the ship were conducted on nets 15 , Degradation of the nets, provoked by the use of the net by an excessive number of personnel, caused difficulty in getting information from one station to another. Further, "Internal communications procedures, i.e. specific call ups in accordance with standard procedures, were known by operators but not always used" (Formal Investigation, 1989, p. 22). This deviation from procedures could be a significant stressor as ambiguity became prevalent between stations.

4. Decision-Making

The time period in which the U.S.S. Vincennes Commanding Officer had to decide whether or not to shoot the unidentifiable aircraft was significantly short.

> Time compression played a significant role in the incident. From the time the CO first became aware of a possible threat, until he made his decision to engage, the elapsed time was approximately three minutes, 40 seconds. Additionally, the Commanding Officer's attention which was devoted to the ongoing surface engagement against IRGC forces (the "wolf closest to the sled"), left very little time for him to personally verify information provided to him by his CIC team in which he had great confidence. The fog of war and those human elements which affect each individual differently--not the least of which was the thought of the Stark incident--are factors that must be considered. (Formal Investigation, 1988, p. 43)

In summation, on the day of the attack of the Iranian Airbus, the personnel of the U.S.S. Vincennes were subjected to not only the stressors of battle, but were also subjected to the stressors detailed above. The extent of these stressors on the final outcome of the incident will never be known. However, elimination of the causes of these stressors should be considered for future use to maximize the capabilities and utilization of the personnel in combat.

III. PHYSIOLOGICAL CONSIDERATIONS OF MAN-MACHINE INTERACTION

> Human engineering, also known as human factors, human factors engineering, engineering psychology, or ergonomics, is based upon the assumption that the design of man-made devices, systems, and environments can enhance or degrade their use by people. This scientific applied discipline emphasizes the human as one component of the system or environment. Human engineering is a young developing discipline cutting across such areas as engineering, physiology, medicine, anthropology, and psychology. (Hendricks, 1983, p. 1-1)

Human factors' relationships, associated with the human performance model, are depicted by Van Cott below. These processes may be delineated into, sensory, response, storage and the information processing subsystems.

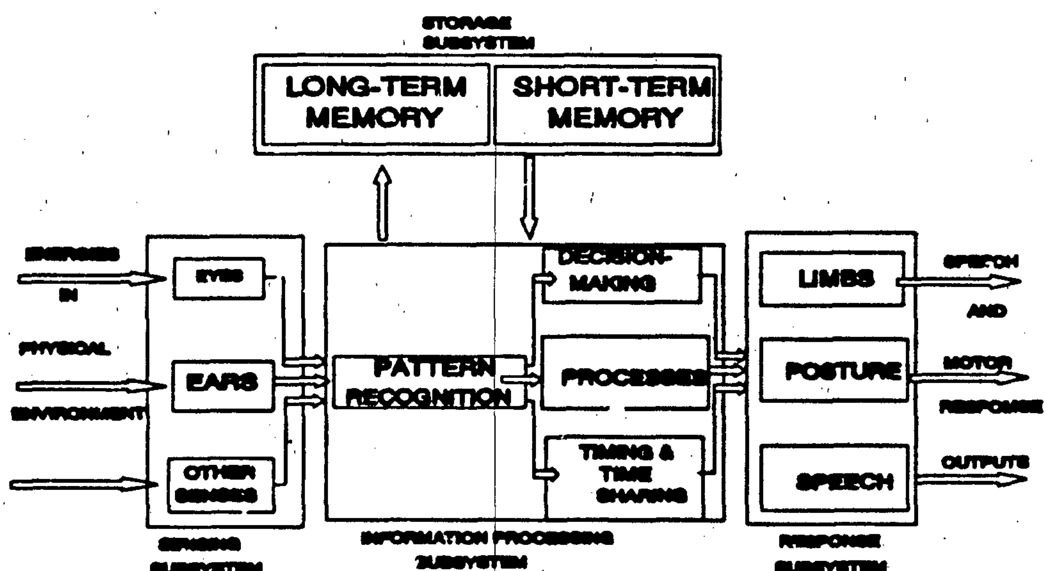

Figure 1. The Human Information Processing System (Van Cott, 1972, p. 18)

The sensory subsystem consists of the reception of stimuli (received through sight, sound, smell, touch and taste) from the equipment and the environment to the human. This newly encoded energy is stored in memory (a component of the storage subsystem) then manipulated by some information process (a function of the information processing subsystem). The response subsystem executes the processed information into actions. This system deals with such items as the body dimensions, muscle strength and ranges of motion associated with the operation of equipment. For the purpose of this thesis, the storage subsystem and the information processing functions will be dealt with in Chapter IV, Summary of Research on Psychological Human Factors.

A. THE SENSORY SUBSYSTEM

> In the design of a man-machine system, the human senses may be considered candidates for directly detecting and measuring conditions about performance or about events in its environment....For the designer to take advantage of a human sensor's sensitivity, resolving capability, or information transmission capacity, he must do so indirectly by changing or selecting conditions external to it: the energy or information source, its location, intensity and coding; the rate and manner of information presentation; etc. (Van Cott, 1972, p. 19)

The physiological components of the sensory subsystem are an established entity in man-machine interaction. Apart from glasses and hearing aids, there is very little that can be done to manipulate the user's ability to perceive a stimuli. Aids, such as electromechanical or optical sensors, may be used by operators to perceive stimuli outside the range of the user's abilities. Tactile and motion cues, though not experienced at the conscious level, may disorient the user, for example the lack of a click after depressing a typing key forces the typist to watch the screen for confirmation. Therefore, generally, the stimuli must be manipulated to satisfy the requirements of the user.

> Visual cues are the strongest and most immediate of those applied to human senses. Strong cues tend to subordinate weaker ones, and visual cues may subordinate sound cues or sensations of one's motion. However, as discovered in research using aircraft and flight simulators, inconsistency of several strong cues can produce disorientation, vertigo, or even nausea. A confusing set of strong visual cues may have the same effect. (Beam, 1969, p. 231)

The operational stimuli, which are a component of the hardware/software system, may be induced electromagnetically, mechanically, thermally or chemically. The sensing of this stimuli is typically nonlinear. Therefore, a doubling of sound energy does not double loudness. In actuality, a tenfold increase in sound energy is necessary to elicit a perception of a doubling of sound. (Van Cott, 1972, p. 20) This phenomenon further complicates the evaluation of sensors in man-machine interaction.

The populace limits of the sensing subsystem include both sensing thresholds and sensing limits. The threshold is "that point on an intensity scale below which we do not detect a stimuli and above which we do" (Bailey, 1982, p. 53). Above this sensing threshold, a diverse range of sensing limits exist. A reflection on the number of people who wear glasses and the magnitude of the differences in their prescriptions is a good example of this concept. Color blindness, which is found in eight percent of the male population and one percent of the female population, is another limitation which must be evaluated in this category.

Another facet of the sensing subsystem is the identification of a stimuli or its magnitudes based upon an absolute rather than a relative basis. This happens when it is impractical or undesirable to use a reference stimuli. Examples of this would be when a pilot estimates his altitude or when an infantryman estimates the speed of a tank. Similarly, it occurs when a radar console operator mentally extrapolates a position (due to activities which dominate his logic processes) based upon a previous radar indication. The implications of a poor absolute judgement can be massive, with an incorrect decision resulting in loss of life and/or equipment.

The design implications of the sensing parameters are numerous. The parameters vary from individual to individual and it is necessary to conduct experiments with users who are representative of the education, training and physical parameters of the operator population. Furthermore, the designer must consider the variations caused by adverse work conditions. Military systems are developed for use during war. The environment of the battlefield is plagued with boredom, stress, confusion and the fear of death. These sensory inputs cause variation in the user abilities which must be accounted for in the successful design of the system. Numerous medical encyclopedias have been written establishing the limits of human sensing. The sensing thresholds of the Sensory Subsystem have been well documented in the Joint Army-Navy-Air Force Steering Committee sponsored Human Engineering Guide to Equipment Design. The energies that stimulate human sensors have been thoroughly studied by G.H. Mowbray and J.W. Gebhard and documented in their Man's Senses as Information Channels, a report published by Johns Hopkins University. These studies are the basis of a comprehensive adaptation by Harold P. Van Cott of the American Institutes for Research and Melvin J. Warrick of the Aerospace Medical Research Laboratory, Wright Patterson Air Force

Base. Their adaptation, included in the Guide, is documented in Man as a System Component. Visual, speech, auditory and other sensory forms are included as well in the Guide. The Guide remains a comprehensive survey of the sensory subsystem requirements for man-machine interaction.

B. RESPONSE SUBSYSTEM

The response subsystem consists of the human physiological capability to react to a stimuli. This process takes into consideration the voluntary and involuntary reflexes controlled by the brain, anthropomorphic traits of the user, the feedback mechanism required for response correction, and the variability within individuals. These individual response capabilities vary from day to day, and from one time of day to another. They are seriously impacted by fatigue, tension, tremor and pain. Boredom, which is very difficult to measure, also increases variability and degrades performance.

The rate with which information can be transmitted by a response system is assumed to be from less than three bits per second to a maximum of about nine bits per second. For verbal responses a maximum rate of eight bits per second has been indicated, and keypressing has a maximum rate of about two and eight-tenths bits per second (Van Cott, 1972, p. 34). The variability within the human race is a consideration in response capabilities. Targeting for a capabilities exhibited by the majority of the user population is recommended for system design. All size considerations and parameters must be recognized as well.

As with the Sensory Subsystem, the Response Subsystem has numerous medical journals dedicated to the subject. Similarly, the Human

Engineering Guide to Equipment Design thoroughly addresses the subject. A survey of the system design implications of the Response Subsystem is addressed in Bailey's Human Performance Engineering: A Guide for System Designers.

IV. PSYCHOLOGICAL CONSIDERATIONS OF MAN-MACHINE INTERACTION

The brain's cognitive processing is the least understood mechanism of the human factors. A survey of this facet introduces the amount of information processed, transmission delays and reaction times, upper limits of information transmission rate, information compression, pattern recognition, learning, memory storage and decision-making. The basic concepts of each is detailed below.

A. REACTION TIMES, THE AMOUNT OF INFORMATION PROCESSED, AND TRANSMISSION DELAYS

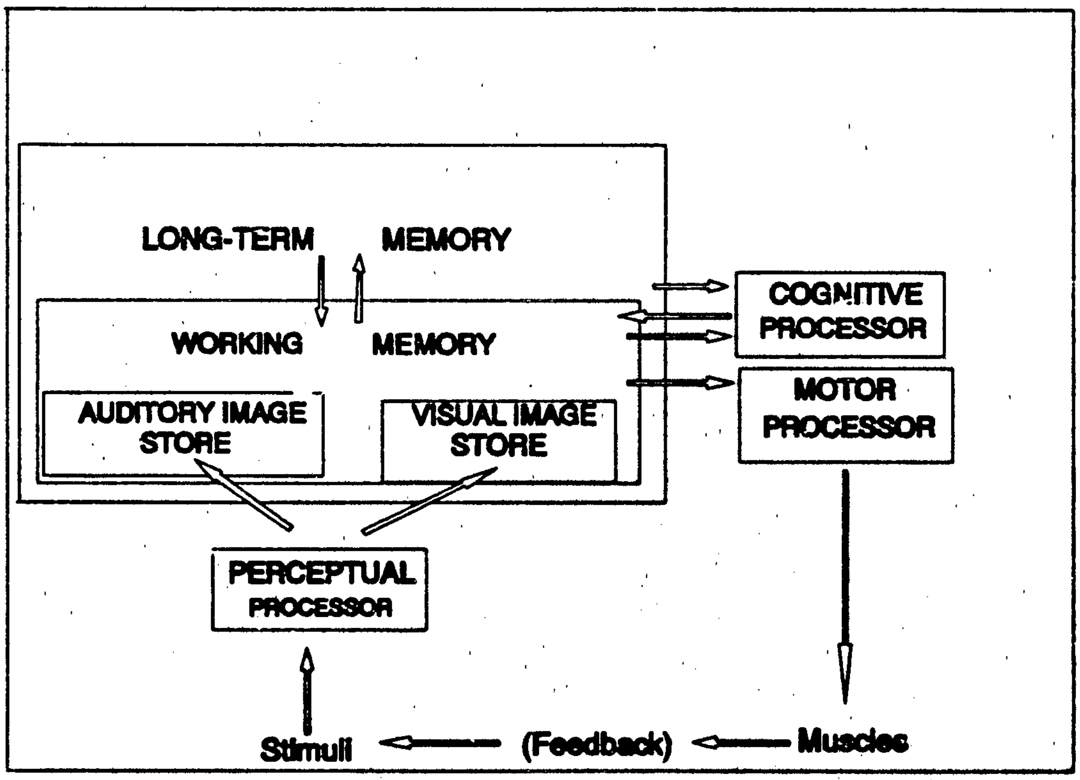

Figure 2. The Model Human Processor (Card, 1983, p. 26)

Scientific experimentation can approximate the amount of information processed during a specific task through task trials and statistical analysis. The mind works as a Perceptual Processor, Visual Memory Store, Auditory Memory Store, Working Memory Store, Long-Term Store, Cognitive Processor and Motor Processor in decision-making. As the complexity of the task increases, the time required to make a decision increases as well. This function is not a linear one since humans have the capability of grouping tasks together and then deciding which groups must have further attention. This hierarchical arrangement saves time. (Card, 1983, pp. 65-78) The previous figure presents the interactions of the cognitive processes in decision-making.

Addressing a rational decision-making process, the approximation of the time required to make the decision is computed as follows: "To a first order approximation, the response time of people is proportional to the information-theoretic entropy of the decision."(Card, 1983, p. 72) This information-theoretic entropy incorporates the innate difficulty of making the decision given the uncertainty of the facts. The information processed is correlated to "bits--the logarithm to the base two of equally likely alternatives" (Van Cott, 1972 p. 26). This correlation takes into consideration the probability of the occurrence of the response, the probability of the occurrence of the stimuli, and the conditional probabilities of the responses given the stimuli. Statistical determination of the amount of information processed can be made using this information. (Card, 1983, p. 74) By knowing the amount of information processed and applying the information-theory entropy factor, the time to reach the decision can be approximated.

The simple reaction time required to process a stimuli and respond with one motor movement requires the use of the Perceptual Processor, the Visual Image Store, the Working Memory, the Cognitive Processor and the Motor Processor. Using values determined in research, the average simple reaction time was found to be 100-400 milliseconds. Simple matching requires 130-640 milliseconds with name matches and class matches requiring approximately 380 milliseconds and 450 milliseconds respectively. (Card, 1983, p. 66)

The reaction times cited are the shortest possible with no delays. Some factors that impact transmission delay and influence decision time are: "the sense used, the characteristics of the input signal, signal rate, whether or not anticipatory information is provided, the response requirements of the task, and the individual differences in age, sex, training, experience and instructions." (Van Cott, 1972, p. 29)

B. UPPER LIMITS OF INFORMATION TRANSMISSION RATES

The upper limits of the information-transmission rate for the human can not be specifically defined since it varies from task to task. Experimentation on keying times for a typewriter, based on Fitt's Law, was found to be influenced by the characteristics of the text, layout of the keyboard, training and practice. (Card, 1983, pp. 51-66)

C. INFORMATION COMPRESSION

The human mind may select information from a variety of inputs, retrieve information from storage, selectively use data and "compress" this sum into an idea. The mind may use all data or may respond to certain distinct stimuli. The process accentuates the importance of the perception of stimuli. Information compression is the user's combination of information from a variety of sources. The user may add information from memory and respond selectively to input stimuli. While not proven conclusively, there appears to be a linear relationship between the amount of information compression and the time allocated to accomplish the task. (Beam, 1989, p. 29)

D. PATTERN RECOGNITION

Pattern recognition is one of the best documented aspect of cognitive processing factors. Pattern recognition deteriorates when: the number of stimuli increases, the patterns become more redundant, the patterns are symmetric and novel patterns are presented. (Van Cott, 1972, p. 30)

E. LEARNING

Learning is often delineated from training and is defined by Bailey as "the conditions under which a behavior is acquired." Training, similarly, is defined as "the effective and efficient way to obtain knowledge, skills or attitudes at identified levels and under particular conditions" (Bailey, 1982, p. 465). However, learning is best considered an adaptive process by which the human survives in his environment (Van Cott, 1972, p. 30). In this survival process, both learning and training occurs. To stringently differentiate between the two leaves each at a loss. Each requires a portion of a cognitive skill termed "search control knowledge". With experience and feedback, a search control knowledge is developed which helps a human proceed through a problem and its alternatives in an expeditious manner. With enough of this search control knowledge the person can proceed directly to the appropriate solution of a situation. (Card, 1982, pp. 365-373) It is obvious that learning takes place for the human to resolve the problem. Whether or not the problem is the only focus of attention does not influence the survival mechanism.

F. MEMORY STORAGE

Memory may be considered in its component parts of Auditory Information Store, Visual Image Store, Working Memory and Long-Term Memory. The auditory and visual subcomponents (the perceptual memories) encode physically stimuli received from the sensors. The characteristics of the stimuli are noted, such as loudness, brightness, length. The Working Memory rapidly encodes the physical code of the perceptual memories into representation. If the perceptual code fades before the Working Memory can develop a representation for it, the stimuli is lost to the human as a piece of data for processing. It is possible for the Cognitive Processor to dictate to the Working Memory which trait of the perceived stimuli is to be encoded--that information is noted while other information if ignored.

Long-term Memory stores information in related chunks. Information is retrieved from the Working Memory and associated with like information. A retrieval cue is linked to all information stored in Long-Term Memory. Long-Term Memory chunks never deteriorate; however, their retrieval into the Working Memory is hampered by a functional loss of the retrieval cues. Long term memory has implications for training and design. It involves the integration and recall of information acquired over a long period of time from sources such as experience or operational plans. The accuracy of the information after lengthy periods of time is under study. (Card, 1983, pp. 35-41)

Difficulties are noted with each of the types of memory. The perceptual memories may not encode all the aspects of the stimuli due to sensory limitations, shortness of time, bias towards one aspect of the stimuli or direction of the Cognitive Processor. A common problem is the inability to recall a specific item if their is a like item already in the memory.

The Working Memory is susceptible to interference from acoutiscal facets of the data, i.e., if words sound alike they may be confused. Similarly, the Long-Term Memory may be confused with semantics. Items that have similar meanings may be confused in the Long-Term Memory. As the Long-Term Memory associates larger amounts of information, this semantic confusion increases. (Card, 1983, pp. 79-82)

G. DECISION-MAKING

Decision-making is often delineated from problem solving in research. Problem solving is defined by Bailey as the "discovery of a correct solution in a situation that is new to an individual"; while, decision-making is defined as "weighing of known alternative responses in terms of their desirability and then selecting one of the alternatives". In this context decision-making starts from uncertainty at the beginning and ends in certainty. Due to the uncertainty of the world, decision-making can become very complex and require instruction, performance aids, or training. There is great variability in a population's ability to make decisions. Risk, bias and fear are all factors which can influence the process of decision-making. (Bailey, 1982, pp. 141-143)

Decision-making, in its simple form, is known to consist of the facets described above: the perception of the stimuli, the encoding of the data in the perceptual memories, the representation of portions of this data into the Working Memory, the association of the data with like information in the Long-Term Memory, the search of Long-Term Memory for required data and feedback. (Card, 1982, pp.65-76) The method by which the actual choice of the final alternative in the decision process and the influences upon it are still under research. Much documentation has been accomplished in development of aids to this process; however, the uniqueness of man continues to evade conclusive determination of the final decision mechanism.

V. FACTORS INFLUENCING COGNITION AND DECISION-MAKING

> An understanding of neurotic reactions to combat requires knowledge not only of the observable clinical symptoms and behavior which appear when the ego has begun to weaken, but also of the psychological mechanisms underlying successful adaptations to the combat situation. Owing to the intangible and complex nature of psychological mechanisms, the psychodynamic processes are difficult to isolate, to measure and to describe. (Grinker, 1963, p. 118)

A. MAN-TASK MISMATCH

The combat environment produces distress signals affecting all parts of the mind and body. It is an evolutionary protective mechanism that has enabled the human species to survive successfully since the dawn of man. In battle, stress wears away enthusiasm and eagerness and over prolonged periods produces a weariness to battle. Anxiety, which originally was specifically oriented, spreads over the entire environment and is heightened by the most trivial sounds. Tension leads to restlessness; sleep dwindles and may be accompanied by nightmares. Appetite is reduced and physical ailments such as gastrointestinal distress are common. Irritability increases. (Grinker, 1963, p. 54) In this environment, errors occur more frequently and the study of their cognitive basis may be confronted in a variety of ways. With an understanding of cognitively based error, the effect of stress in this process can be studied. The current research by Jens Rasmussen and James Reason addresses these errors from a perspective that a man-task mismatch is the foundation for errors in a stressed environment. The following is a review of their theories.

1. **Human Error and Technical Systems**

The interaction of man and machine in any environment is influenced by numerous factors. As defined by Jens Rasmussen, this interaction is depicted in the figure below.

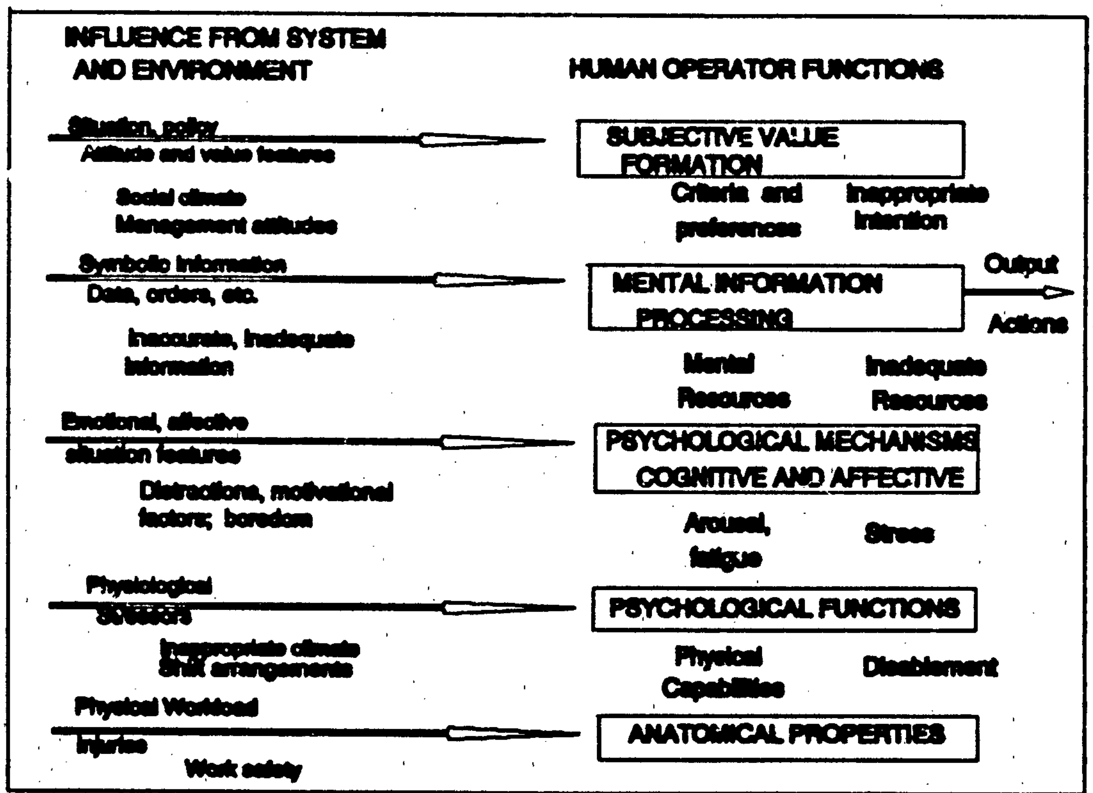

Figure 3. Interaction of man-machine system (Rasmussen, 1987, p. 28)

Errors that occur which cause an unacceptable state in the man-machine environment may be studied from a causal position. Human variation should not be considered the cause of errors; rather, the most constructive approach to evaluation is study of the factors which precipitated the human error. "The resulting relevant 'internal malfunctions' are then correlated with each of the steps in an assumed work procedure by careful consideration of potential interference in the different elements of the decision sequence and the combined effects of possible inappropriate acts are assessed for different alternative system configurations." (Rasmussen, 1987, p. 28)

2. Principles for Systematic Classification of Errors

Errors effected in a man-machine environment require further classification for study and numerous approaches have been taken to accomplish this. In 1964, research suggested adjustment to stress and its associated errors could be approached from the stages of the catastrophic event (Miller, 1964, p. 11). Current research addresses errors from the causal approach. As detailed by Reason, errors can be classified in a matrix consisting of eight primary error groupings (PEGs), with five basic error tendencies (BETs), applicable against eight information processing domains (IPDs). All errors are then further identified by situational factors. The following figure details the interrelationships of this classification system.

a. *Basic Error Tendencies*

The five BETs are ecological constraints, change-enhancing biases, resource limitations, schema properties, and strategies and heuristics. A discussion of these follows.

Basic Error Tendencies

	ECOLOGICAL CONSTRAINTS	CHANCE EN-HANCEMENT	RESOURCE LIMITATIONS	SCHEMA PROPERTIES	STRATEGIES HEURISTICS	Primary Error Grouping
SENSORY REGISTRATION	X	X				False Sensations*
INPUT SELECTION			X	X	O	Attention Failures*
VOLATILE MEMORY			X	X	O	Memory lapses*
LONG TERM MEMORY			O	X	X	Inaccurate recall*
RECOGNITION PROCESSES	O	O	X	X	X	Misperceptions*
JUDGEMENTAL PROCESSES		X	X	X	X	Errors of judgement*
INFERENTIAL PROCESSES			X	X	X	Reasoning Errors*
ACTION CONTROL			X	X	X	Unintended words/actions*

X=Primary Mode O=Secondary Mode *=Primary Error Grouping

Figure 4. Matrix for Classifying Primary Error Groupings (Reason, 1987, p.10)

Ecological constraints are those limitations which have developed in man through an evolution process based upon human movement above ground, at three to four miles per hour, under normal gravity (Reason, 1988, p. 6). Today, environments and systems do not always function under these domains; aircraft and ships may operate under other than normal gravitational pull. Numerous weapons systems travel at speeds greater than four miles per hour. Therefore, errors occurring in these environments may be based in a mismatch of what the human system has evolved to expect and what the physical reality is.

Change-enhancing biases occur due to the imperfect human psychological scaling mechanisms. These mechanisms are intended to only sense change and tend to attenuate quantities found in steady states and exaggerate measurements for changing quantities. (Reason, 1987, p. 7)

Resource limitations are a major cause of errors. Human capabilities are limited by the amount of information which can be sensed, memory storage limitations, the amount of information processing the mind can accomplish, and the amount and speed with which the human can respond. (Reason, 1987, p. 7)

The constancy of the environment and our routine dealings with this environment make up the subcategory of schema properties. While this familiarity enhances the human capability to quickly solve routine problems, a failure occurs when the mind elects a familiar response in an unfamiliar environment. This is caused by fitting data to the wrong environment, use of best guesses to fill missing information, and relying heavily on known schema. (Reason, 1987, p. 8)

The use of "rules of thumb" incorporate the error of heuristics. These actions and inputs may be very unsuited for the environment at hand, leading to error. Further, the strategic approach to solving a problem may consist of actions not appropriate to the environment. Errors of this kind are similar to losing a chess game.

b. Information Processing Domains

The eight IPDs which make up the primary error groupings deal with the human information processing stages and operations. These consist of sensory registration, input selection, temporary memory, long-term memory, recognition processes, judgmental processes, inferential processes and action control. Reason elected to classify the domains in this manner due to the pattern in which error data "clustered in psychological literature" (Reason, 1987, p. 8). It should be noted that none of these cognitive functions are structurally distinct and overlap occurs among each. However, delineation is possible with consideration of the primary process.

c. *Primary Error Groupings*

With the combination of the BETs and the IPDs, formation of the PEGs is possible. Eight PEGs are developed in this manner and are identified as false sensations, attentional failures, memory lapses, inaccurate recall, misperceptions, errors of judgment, inferential errors and unintended actions. In these categories, if the BETs are known to provide the greater influence, a primary node is depicted. Within the same categories, if the certainty of interaction is suspect or the influence of the BET is actuated in an earlier process, then the formation of a secondary node is present.

False sensations are the direct or indirect cause of many human errors. The discrepancy occurs when the human subjective experience of the environment conflicts with the reality in which the human functions. This may arise due to sensory distortion or misrepresentation of fact. Errors caused by the cognitive processes misinterpreting the stimuli received is not covered in this category. Situations in which false sensations are experienced are : "during and immediately after exposure to steady-state inputs in any modality; in conditions of simultaneous and successive contrast; when viewing two-dimensional representations of three-dimensional objects; in atypical force environments involving periods of constant velocity rotation, or variations in the strength or direction of the gravito-inertial vector; during and immediately following exposure to visual or inertial rearrangement; when viewing large-scale moving visual scenes; in high-speed flight; under water" (Reason, 1987, p. 10).

Attentional failures address a universal control process which is limited in its effect on a variety of cognitive domains. These failures are caused by coping with distractions, processing simultaneously numerous inputs, focusing on one or two key messages, dividing attention between two tasks, time limiting the completion of appropriate cognitive combinations of information, monotonous monitoring, custodial and verification tasks. (Reason, 1987, p. 11)

Memory lapses address the volatile memory. It consists of forgetting listed items, forgetting intentions, and losing track of previous actions. It is interesting to note that the majority of experimental literature deals with the forgetting of listed items. (Reason, 1987, p.11)

The absent-minded misuse of words, signals and actions make up the category of unintended words and actions. This includes slips of tongue, in sign language the slip of hand, slips of action and the Freudian slip. (Reason, 1987, p. 11)

Recognition failure encompasses the incorrect interpretation of sensory inputs. This can be caused by incomplete sensory inputs and a strong expectation for another stimuli. Subdivisions consist of experimental manipulation, mishearing speech, misreading text, misreading signals and instruments, misperceptions in routine actions and misperceptions in people. (Reason, 1987, p. 12)

Recall and the recollection of subcategories are addressed in inaccurate and blocked recall. The objects of the process determine the categories: misremembering places, sentences, stories, faces, events and finally blocked recall. Reason clarifies that blocked recall is properly considered with long-term memory failures based upon evidence of schematic biases. (Reason, 1987, p. 12)

Errors of judgement are categorized by the task involved. These divisions are: psychophysical misjudgments, temporal misjudgments, misconceptions of chance, misconceptions of covariation, misjudgments of risk, misdiagnoses, fallacies in probability judgements and erroneous social assessments.

When evaluating stress and its effects on man-machine interface, the errors produced in high stress situations should be categorized using the principles of Rasmussen and Reason. In this framework, the cognitive process being inhibited may be identified and a resolution to the cause can be addressed. Through this structured approach, assist in overcoming the "intangible and complex nature of psychological mechanisms" which confounded Grinker in 1963 (Grinker, 1963, p. 118).

B. ORGANIZATIONAL ELEMENTS AND COMPLEXITY

Research indicates that organizational structure with its component discipline, expectations and linkage influence cognition and decision-making. Also, both the complexity of any task and the complexity of the environment, with its component parts, affect the performance of a system u_er. Consideration of these factors are necessary for a comprehensive approach to solving the impact of stress of man-machine interface.

1. High Reliability Organizations

High Reliability Organizations (HROs) are a subject of extensive research by Karlene H. Roberts, Haas School of Business Administration, University of California. As defined in her article, Some Characteristics of One Type of High Reliability Organization, a HRO is a complex, hazardous, organization whose failure could lead to catastrophic result; but, whose safety record over thousands of events remains high (Roberts, 1990, p. 160). This specific article deals with the organizational safety on a flight deck of a nuclear powered aircraft carrier. Since ADPE is utilized in war environments, often its failure can contribute to a catastrophic result; therefore, details of the organizational elements enumerated in this article are particularly useful in studying the interaction of the organization and the ADPE user in a combat situation.

The negative affects of complexity on the flight deck were found to be countered by a number of factors. Training in a wide variety of scenarios prepared the crew members for normally unexpected complications. Activities, which if intermingled would cause a catastrophic result, were kept separated. Geographic separation on the flight deck, the use of the buddy system for monitoring, the color-coding of uniforms were all separation practices. Fueling aircraft and munitions loading were cited as examples. " Numerous indirect information sources" which culminated in command and control structures supported the separation practices. (Roberts, 1990, p. 165)

Tight coupling (system connections which are time dependent, invariant in sequence, unidirectional, containing little flexibility) often leads to catastrophic results in an emergency situation. On the aircraft carrier, the tight coupling required to land the aircraft was overcome by layers and layers of actions used to achieve this goal. This diversity indicated that the landing was in fact a loosely coupled activity capable of withstanding emergencies. (Roberts, 1990, p. 166)

Tight coupling caused by the hierarchical structure of the military was overcome through the barter system evoked by the senior enlisted personnel. As a buffer to an absolute directive, these personnel effected a looser coupling through negotiation with the junior officers. These actions created both mission and motivational changes, i.e., the time constraints of the supply system's documentation were circumvented through negotiations on paperwork deadlines. (Roberts, 1990, p. 167)

As a counteracting agent to both complexity and tight coupling, redundancy was prevalent. This existed in not only back-up computer systems, but, also, in duplication of actions on the flight line. An example used was that of the number of personnel, who within the confines of their normal duties, check to ensure the arriving aircraft's landing gear is down.

In a study of the effects of combat stress on the man-machine interface of complex information display systems, the facets which produce an HRO should be considered. For, if these factors are deficient in the combat environment, their contribution to stress and malfunction should be evaluated.

2. On Dealing with Complexity

Dietric Dorner, of the University of Bamberg, addressed complexity and the cognitive processes in his research titled "On the Difficulties People Have in Dealing with Complexity" (Dorner, 1987, pp. 97-109). Simulation modeling was used to identify difficulties encountered in a critical situation and the limitations of a simulation should be considered in the results.

Dorner found his subjects to suffer from: insufficient consideration of processes in time, difficulties in dealing with exponential developments, thinking in causal series instead of causal nets, thematic vagabonding, encystment, decreasing willingness to make decisions, tendency to delegate and exculpation tendencies. These difficulties are now clarified.

a. *Insufficient Consideration of Processes in Time*

Trend analysis was not conducted by the personnel involved in complex task decision-making during Dorner's research. These subjects failed to determine the past tendencies of processes included in the decision and opted to use the existing state as a determinant. This failure lead to incorrect assumptions and decisions. (Dorner, 1987, p. 90)

b. *Difficulties in Dealing with Exponential Developments*

During the simulation, subjects appeared to have no ability to determine exponential growth. Although cases of exponential growth surrounded the subjects, they were unable to project growth exponentially and were surprised at the true outcome of an exponentially developing phenomenon. Situations of fishing in the north sea, oil consumption, and cases of diphtheria were examples of the factors evaluated. (Dorner, 1987, p. 99)

c. ***Thinking in Causal Series***

Complexity entails actions in a net of events versus in a series. Subjects of the simulation focussed on what they perceived to be the main cause of an event versus the causal net of events. In the foreign policy portion of the simulation this phenomenon was the most significant. The result of thinking in a causal series was deficiencies in the decision due to consideration of an inadequate number of factors. (Dorner, 1987, p. 100)

d. ***Thematic Vagabonding***

Individuals who were uncomfortable with topics under discussion were found to quickly and often change the focus to other topics. This jumping from one topic to the next brought superficial coverage of the topic and inadequate consideration in the decision-making process. (Dorner, 1987, p. 101)

e. ***Encystment***

This phenomenon was the opposite of the thematic vagabonding. Subjects engrossed themselves in topics with which they felt comfortable. They examined all details minutely and would not proceed on to other factors requiring consideration. Due to this phenomenon, again, all factors required in the complex decision-making were not addressed. (Dorner, 1987, p. 102) *f. Decreasing Willingness to Make Decisions*

Analysis of the decisions made during the simulation determined that subjects became reluctant to make decisions. In these cases, the decision was postponed or not made at all. The complexity of the situation appeared to overwhelm the subject. (Dorner, 1987, p. 102)

g. Tendency to Delegate

Closely related to postponing decision-making was the tendency to delegate the responsibility for decision-making. The complexity involved in the decision was addressed with exasperation and an ultimate delegation of responsibility. This delegation often occurred after a failure on the part of the participant. (Dorner, 1987, p. 102)

h. Exculpation Tendencies

Exculpation tendencies is the refusal to accept responsibility for failures and the tendency to find external causes for the personal failures of the individual. Blame was often placed against other's laziness, management's inability or the programming of the simulation. This phenomenon was found to inhibit the decision-making capabilities of the subjects in the simulation. (Dorner, 1987, p. 103)

i. Behavior Experienced Prior to Decision-Making

Prior to making the complex decision required by the simulation, the subjects were found to exhibit behavior not normally tolerated in their complex decision-making environments. The increase in the tolerance of risk was seen after failures and prior to continued decision-making. Mastering the situation using any method became key to the subjects. Tolerance of violation of rules and regulations, also, was exhibited by the participants. This further reinforced the idea of "success at any cost". Subjects also had an increased tendency to try and escape. The risk of failure was perceived to be too great for them.

Despite the fact that Dcrner's research was limited by the parameters of a simulation, his observations should be seriously considered as resultant behavior of system users making decisions, while under stress. These factors must be incorporated and analyzed in further study of stress, cognition and decision-making.

3. Task Classification

In the development of any simulation or system, a comprehensive development of the underlying tasks with their interfaces to all subenvironments is essential. Research supporting the standardization of this process, based upon a project of the Advanced Research Agency of the Department of Defense, was compiled by Edwin A. Fleishmann. The subsequent book, Taxonomies of Human Performance (Fleishmann, 1984, pp. 1-514), is a detailed report on the methodology which best accomplishes development of underlying task from these approaches: behavior description, behavior requirements, abilities and task characteristics, task strategies, ability requirements and task characteristics. Since this study addresses well the task definition problem, its use in simulation development is encouraged.

VI. EVALUATION OF MILITARY STANDARDS AND ACQUISITION POLICIES CONCERNING AUTOMATED DATA PROCESSING EQUIPMENT

A. HUMAN FACTORS CONSIDERATIONS IN SYSTEM ENGINEERING

ADPE systems that are procured by the Department of Defense have all gone through some type of design process in their development. The purpose of this process is to insure the optimization of system performance through maximization of user capabilities. This performance is defined as "the result of a pattern of actions carried out to satisfy an objective according to some standard" (Bailey, 1972, p. 4). The two most common standards are quality and quantity; however, for use in military design and acquisition, a set of military standards are published to achieve this goal. The human factors considered in the design process varies with the particular design discipline used. The systems engineering approach has advanced to become the predominant design method for systems acquired by the DOD. This approach is defined as follows:

> Systems engineering is the application of scientific and engineering efforts to:
>
> a. Transform an operational need into a description of system performance parameters and a system configuration through use of an iterative process of definition, synthesis, analysis, design, test and evaluation;
>
> b. Integrate related technical parameters and assure compatibility of all physical, functional, and program interfaces in a manner which optimize the total system definition and design;
>
> c. Integrate reliability, maintainability, safety, survivability, human and other such factors into the total engineering effort to meet cost, schedule, and technical performance objectives. (USAF MIL-STD-499A, 1974, p. 23).

It is interesting to note that the systems engineering approach is divided into phases which correlate with the acquisition phases as defined by the Defense Acquisition Regulation. The seven phases of systems engineering (program planning, project planning, system development, production, distribution, operations and retirement) are iteratively addressed using seven steps (problem definition, value definition, value system design, system synthesis, system analysis, optimization, decision-making and planning for action). The result of this detailed process is a comprehensive study of all facets of the system of interest.

> The systems engineering method recognizes each system as an integrated whole even though composed of diverse, specialized structures and subfunctions. It further recognizes that any system has a number of objectives and that the balance between them may differ widely from system to system. The methods seek to optimize the overall system functions according to the weighted objectives and to achieve maximum compatibility of its parts. (Morton, 1959, p. 87)

Designers seeking to measure human performance often mistakenly assess system performance. However, human performance is only one of many system design considerations. It is imperative to separate the evaluation of human performance with the system (man-machine interface) from the system performance without the human factors. Despite the momentous advancements made in technology, the human remains the most complex element within the system and this facet must undergo rigorous examination. The human element is, in fact, the most likely cause for an accident or system failure (Bailey, 1982, p. 14). Designers usually have little control over the actual people selected as users for their systems. Managers, with pride in their units, usually select their most capable people to operate new systems in the test and evaluation phase of acquisition. Unfortunately, these operators are often not representative of the population of users as a whole. Because systems are designed for groups of users, it is necessary to deal with the strengths and weaknesses expected in the user population. Therefore, standards should be based upon the capabilities and talents of the group--set within a framework of limits most representative of the population.

The systems engineer uses a human performance model to analyze the man-machine interface with complex information systems. This model consists of the general state or condition of the human, the activity (to include any required tools or equipment), and the context in which an activity is performed. Using the iterative system engineering process, each of these facets are evaluated for optimization. Numerous publications are used to document the findings and recommendations of these phases. A modification of Bailey's representation of this process (Bailey, 1982, p. 25) in the following figure details this documentation as well. The basic general, applied general and specific research categories denoted by Bailey are redistributed to the physiological, psychological and environmental categories of research in the following figure.

B. ANALYSIS OF MILITARY STANDARDS AND POLICIES

Military Standards are written to provide guidance to the system engineer and acquisition team for defining system requirements and specifications. The use of military standards by acquisition teams is not mandatory. If cited in an acquisition document, they may be defined as directive (requiring contractor compliance to the letter) or guidance (requiring contractor compliance with the intent of the document).

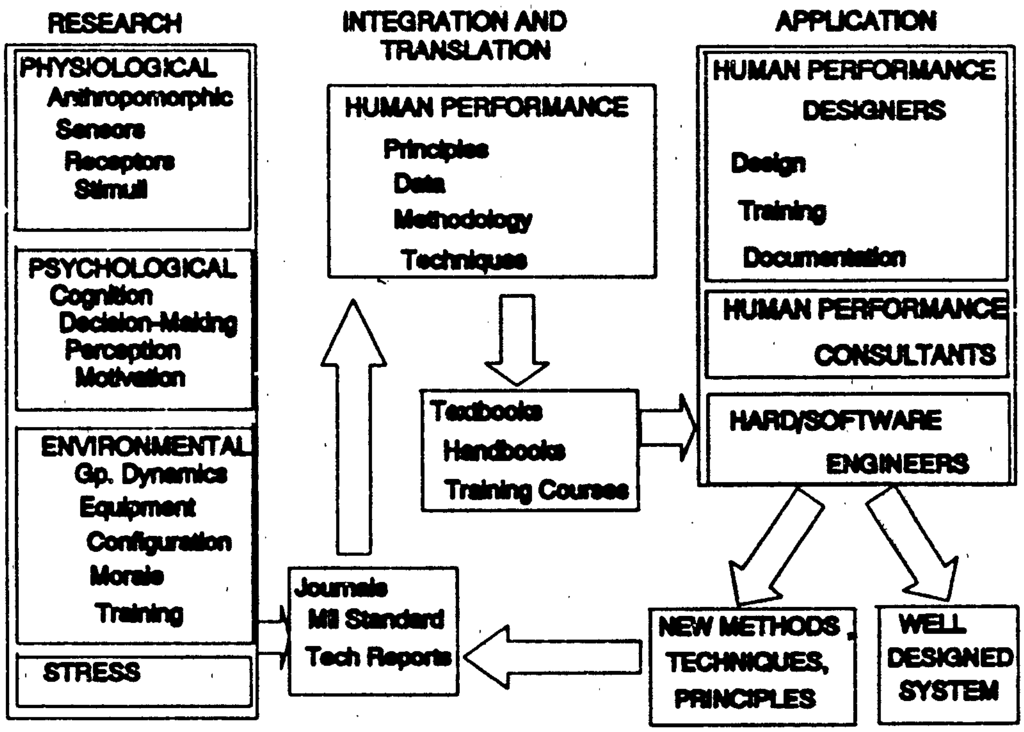

Figure 5. Human Performance Engineering

The Military Standard 1472D (Mil-Std 1472D), Human Engineering Design Criteria for Military Systems, Equipment and Facilities specifically establishes general human engineering criteria for system design and development. It is approved for use by all the military departments, regardless of the publishing agency. Its goal is to achieve required performance levels by users of the system, with a minimum of skill, training time and personnel requirements. It attempts to foster standardization among systems while achieving man-machine reliability. It is interesting to note that a nongovernmental publication, Human Engineering Guide to Equipment Design, was sponsored by a governmental steering committee and is referred to frequently in this military standard.

The pertinent information contained within the guide is not incorporated in the military standard. This fact acknowledges the lack of governmental documentation on specific human factors considerations. In further supporting this supposition, Mil-Std-1472D details that "...any discrepancy between the force criteria of this standard and the physical qualification requirements shall be resolved in favor of the latter." (Mil-Std 1472D, 1989, p. 2) The basic human engineering design criteria is defined in military standards as follows:

> The summation of available knowledge which defines the nature and limits of human capabilities as they relate to the checkout, operation, maintenance or control of systems or equipment, and which may be applied during engineering design to achieve optimum compatibility between equipment and human performance. (Mil-Std 1472D, 1989, p. 12)

This definition is exactly as required by the system engineering design procedures. Further, the objective of the regulation, which is:

> Military systems, equipment and facilities shall provide work environments which foster effective safety and health, and which minimize factors which degrade human performance or increase error. Design shall be such that operator workload, accuracy, time constraints, mental processing and communications requirements do not exceed operator capabilities. Design shall also minimize personnel and training requirements within the limits of time, cost and performance trade-offs. (Mil-Std 1472D, 1989, p. 17)

supports the intent of system engineering. Military Specification (Mil-H-46855B), Human Engineering Requirements for Military Systems, Equipment and Facilities, correctly defines human engineering; however, it specifies human engineering as an activity which should be integrated with the total system engineering effort versus as a component of the systems engineering effort. In their definition of system engineering, human engineering is not reflected. This elimination of human engineering as an integral component of the systems engineering process might allow limited or no scrutiny in the area of human factors. This discrepancy fosters an impression that human engineering is possibly not a valid consideration in certain systems. This impression could lead to system deficiencies which could have been easily avoided in the early acquisition stages. A review of each of the general human factors areas which compose the human performance model follows.

1. Sensory Subsystem

Numerous sensory definitions are specified in Mil-Std 1472D. Advisory signal, decibel, effective temperature, luminance ratio, noise-canceling, peak-clipping and wet bulb globe temperature are all used in requirements dealing with the sensory subsystem. The detailed requirements, addressing the majority of sensory responses, are very general.

> Sufficient contrast shall be provided between the displayed information and the display background to ensure that the required information can be perceived by the operator under all expected lighting conditions. (Mil-Std 1472D, 1989, p. 27)

A few expanding references do clarify some deficient areas.

> The luminance contrast (See 3.17) within the indicator shall be at least 0.1. This 0.1 luminance contrast requirement does not apply to special displays specifically designed for legibility in sunlight. For low ambient illumination applications (e.g., Mil-L-25467), this ratio should be at least 9.0 (See 3.17), with the background luminance less than the figure luminance. (Mil-Std 1472D, 1989, p. 34)

However, overall the specifications dealing with the sensory subsystem are very generic in nature and would be open to significant debate if made directive upon a contractor. The only area seriously documenting the sensory subsystem human factors is that of aircraft design. Many specifications, which are very thorough, have been developed for implementation during aircraft procurement and development. Air Force Systems Command Design Handbook (DH-1) titled Human Factors Engineering clearly details the sensory requirements of military systems. Tolerance and tolerance time of stress factors, outside the "comfort zone" include descriptions of effects and limits. The following graphical representation of these limits is an example of the myriad of figures used to detail the sensory response subsystem requirements.

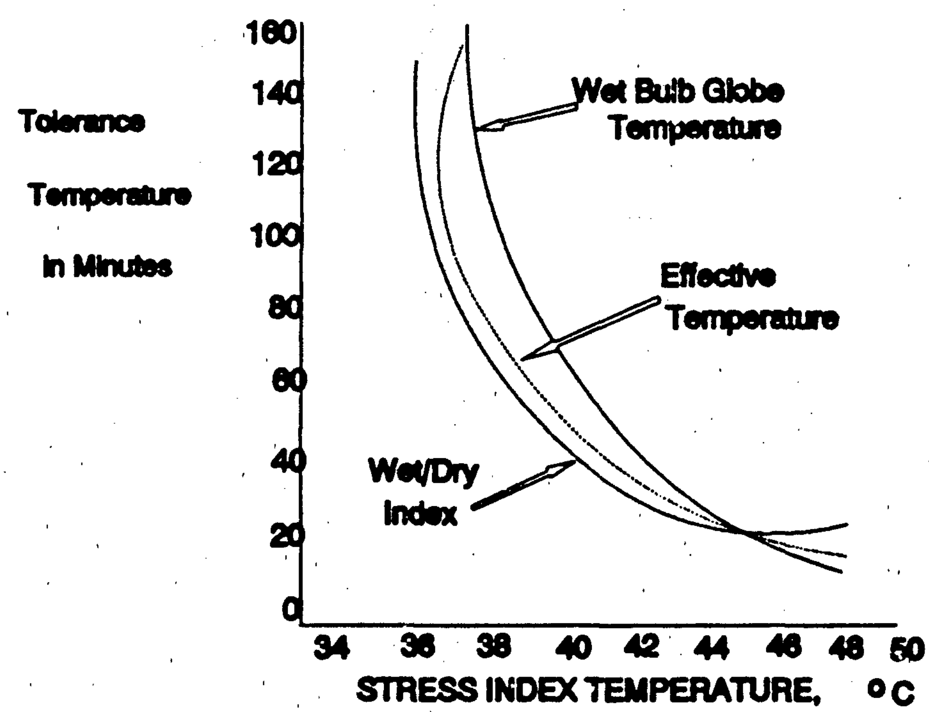

Figure 6. Human Hot Tolerance for Three Environmental Indices (DH-1, 1980, p. DN 3C2-1)

> ...Performing light work in a hot tolerance situation results in rising skin temperature, followed by a rising body core temperature. Vasodilation and sweating commence, but cannot completely compensate. As the core temperature continues to rise the heart rate increases and eventually may reach 70 beats per minute (or more) above normal.

As his body continues to store heat, the individual (1) begins to lose concentration or focus on a task, (2) becomes irritable or sick, and (3) loses the desire to drink. With sudden postural changes, syncope may occur. If not removed from the environment, the individual will go into heat stroke (complete loss of thermo-regulation) after which he will soon die. (DH-1, 1980, p. DN 3C2-1)

The effect of acoustical noise is addressed by DH-1. Speech interference levels, noise criteria, sound levels, articulation index, prediction intelligibility are all analyzed in detail. The decision for the use of audio versus visual presentation is presented. For example,

...When information must be presented independently of the orientation of the head: when a person's duties require him to move about or to turn his head and body in different directions, visual presentation is undesirable because of the possibility that he might miss some important information or be so confined in his movements that his performance is inefficient. (DH-1, 1980, p. DN 3F2-7)

As well, the other sensory response elements are discussed and graphed for use in engineering of military systems. However, none of these elements are specifically annotated for use in ADPE systems. It is up to the designer to extrapolate from the document those items that are applicable to the system.

Mil-Std 1472D sites as supplemental the following: Markings for Aircrew Station Displays, Design and Configuration of; Aircrew Station Controls and Displays for Rotary Wing Aircraft, Aircraft Station Vision Requirements for Military Aircraft, Acoustical Noise Limits in Helicopters. Shipboard human factors considerations are limited to those addressing safety such as: Walkway Compound, Nonslip and Walking Matting, Nonslip and Airborne Sound Measurements and Acceptance Criteria of Shipboard Equipment. The disparity in consideration of sensory subsystem human factors in an ADPE environment is evident.

2. Cognitive Information Processing

Just as the understanding of cognitive information processing was vague and fragmented so are the military standards applicable to this process. Mil-Std 1472D declares:

> Military systems, equipment and facilities shall provide work environments which foster effective safety and health, and which minimize factors which degrade human performance or increase error. Design shall be such that operator workload, accuracy, time constraint, mental processing and communications requirements do not exceed operator capabilities. Design shall also minimize personnel and training requirements within the limits of time, cost and performance trade-offs. (Mil-Std 1472D, 1989, p.17)

It further clarifies that translation of information from one display into another is not acceptable, since this is an area of possible error. Pattern recognition is addressed as well as training. However, the remainder of the military standard addresses the general procedures used to operate the system, with no item specifically addressing bias, the limits of human cognitive processing ability, information compression or memory storage.

3. Response Subsystem

The final area of the human factors considerations under the human performance model, response subsystems, is thoroughly documented in Mil-Std 1472D. Physical parameters for reach, touch, height, line of vision, etc. are numerically clarified for both males and females. Levels of sound, levels of light, responses to warning indicators are all discussed. Since these factors are the easiest to measure, the thoroughness of the military standard is not surprising.

VII. A MANAGEMENT PLAN WITH RECOMMENDATIONS

The Department of Defense continues to invest millions of dollars in ADPE as a response to mission requirements and diminished manning levels produced by defense cutbacks. Maximum utilization of this equipment is necessary for both success in military goals as well as accomplishment of routine tasks with limited manpower. In the combat environment, successful operation of information display systems can only be assured after the comprehensive study of the effect of combat stress on the users of these systems. Deficiencies in system performance produced by the effects of combat stress can then by identified and their causes corrected. Only upon completion of these tasks can true assurances be given that mission goals can be achieved successfully with a minimum of loss of life and equipment.

Studying the effects of combat stress could be accomplished through simulations of combat environments: measurements could be recorded of the deviations noted during the experiments. The results would give documented proof that combat stress does impact the man-machine interface of complex information display systems. However, this approach does not address the orderly correction of deficiencies required to preclude system degradation due to combat stress. Resolution would require a separate project whose mission would have to be closely married to the results of the original investigation. Some of the implications discovered in the original research could be lost/misconstrued in this transition.

All branches of the service, currently have concerns about the effect of combat stress on the users of their weapon systems. Each has commenced some type of effort to address these concerns. Since this is a military wide problem, a joint service approach to addressing the issues is needed. This merging of talents would use the capabilities of each service to its fullest, minimize redundant study and control cost. A prime candidate to coordinate the efforts of this study would be the U.S. Army's Materiel and Readiness Command who has already published guidelines "to aid in the inclusion of human factors considerations in the design of Management Information Systems" (Hendricks, 1983, p. iii).

A comprehensive approach to determining the effects of combat stress would begin by defining the system users' baseline for physiological and psychological requirements. This baseline would document thoroughly the limitations of sensory and cognitive processes over which the user has no control. Simulation or experiments would be developed with user baseline requirements being met. These trials should be rigorously scrutinized for experimental limitations and documented accordingly. The simulation should address as closely as possible the various stressors inherent to the combat environment. The research would be conducted using scientific methodology to determine the effects of combat stress. The results should then be documented in technical papers which include recommendations for resolution. Implementation of needed changes could then be accomplished through modification to the initially established user baseline military standards and through modification of existing combat or organizational doctrine. In conclusion, initial training on the effects of combat stress would be initiated for junior officers in their early training. Those in supervisory positions would need this information to successfully achieve their mission objectives. Senior officers and those officers slated for command positions would receive indepth training on the effects of combat stress and the options available to them to minimize its effect.

A. THE DEFINITION OF USER CAPABILITIES

To address the effect of combat stress on the man-machine interface of complex information systems, it is first necessary to establish what the normal performance of the user is. These levels of performance can only be accepted as "unstressed" when the mean physiological and psychological requirements of the user population are met. From this basis, the effects of combat stress can be determined. As illustrated earlier, there exists deficiencies in military documentation on both the physiological and psychological requirements for users of information display systems.

Although numerous journals and texts delineate the anatomical, cognitive, and sensory requirements of the user's of ADPE, the military establishment does not have a consolidated document that reflects these requirements. The Army Materiel Development and Readiness Command's Human Engineering Guidelines for Management Information Systems (Hendricks, 1983, pp. 1.1-10.7), which was jointly published by the Army Management Information Directorate and Human Engineering Laboratory, is a cursory overview of the requirements for a comprehensive information display system. Although it presents well the basic needs to be considered in system design, it fails to expand the requirements to the level necessary for the study of combat stress or for the complete design of an information display system. The Army's military standard, Human Engineering Design

Criteria for Military Systems, Equipment and Facilities, is currently supplemented by the Human Engineering Guide to Equipment Design with more comprehensive documentation on the physiological capabilities and requirements of system users. However, this cross reference system is complicated and confusing and does not present the material in a clear, concise manner that is readily available for use by the researcher or systems designer.

The Air Force System Command Design Handbook (DH-1) has excellent documentation for systems design; however, extrapolating the information that is pertinent to the complex information display user from data that appears to pertain to aircraft displays is a complex and time consuming task. Each area does have similar requirements, however, much of the documentation currently published in this handbook could be extracted for ready use by researchers of combat stress and information display system designers.

The format most understood by the system designer and the requirements processor is the military standard. These documents are concise and clearly written to facilitate their use in system design and development. They could also be used as the basis for research in combat stress.

It is recommended that the current documentation in Human Engineering Requirements for Military Systems, Equipment and Facilities, and the supplemental information in the Human Engineering Guide to Equipment Design be compiled with extractions from the Systems Command Design Handbook. If clarification or further research is necessary, the requirements could be addressed by the Human Engineering Division, Armstrong Aerospace Medical Research Laboratory, Wright Patterson Air Force Base, Ohio. This organization has provided much research in this area with recent documentation of these contributions in the Handbook of Perception and Human Performance, Volumes One and Two.

B. SIMULATION AND EXPERIMENTATION

Currently, there exist rudimentary computer simulations which address the impact of stress. Alphatech, Incorporated, of Burlington, Massachusetts, in their study of "Information Gathering and Decision-making Under Stress" have created the Team Optimal Stopping with Communication Alternatives (TOSCA) program under prime contract N00014-88-K-0545. However, close examination of this program reveals little differentiation of types and intensity of stressors. Its use appears to be for educational purposes only--teaching the rudimentary concepts of the limiting effects of stress to students. This program has been used successfully in the teaching environment of the Naval Postgraduate School with statistical analysis accomplished on the resulting data.

The Office of Naval Technology, with contributions from the Naval Ocean Systems Center, San Diego, California and the Naval Training Systems Center, Orlando, Florida, has commenced preparation for a study on "Tactical Decision-Making Under Stress". Their approach of simulation in realistic operational scenarios is well suited for the research required to determine the effects of combat stress. Research in task development based in the research of the Advanced Research Projects Agency of the Department of Defense and compiled by Fleishmann (Fleishmann, 1984, pp. 1-514) should be used to ensure the simulation is a comprehensive, orderly study. Inclusive documentation on the limitations of the simulations would assist in the analysis of the research data. With the addition of error categorization and analysis as detailed by Jens Rasmussen and James Ready, cognitive processes that are inhibited by the stressors could be identified. Results of this research could be published as technical reports with their corresponding, appropriate classifications. With these modifications, serious consideration should be given to expanding the Office of Naval Technology's current tasking to encompass the larger question at hand.

With the return of military officers from the Persian Gulf War, a large body of knowledge is available to researchers on stressors associated with a combat environment. Many of these officers, a significant number of whom deal with information display systems, will be returning for follow on education at the Air Force Institute of Technology and the Naval Postgraduate School. The current experience of conflict is a wealth of information that could be tapped in support of the resolution of the combat stress question. Within the Naval Postgraduate School, there is a cadre of experts in the human factors arena led by Gary K. Poock, PhD., Professor of Operations Research and Man-Machine Systems. Due to the attendance by officers of all services at the Naval Postgraduate School and the human factors expertise available there, it is recommended that the Naval Postgraduate School undertake this survey and its associated supporting analysis of data. It is further recommended that surveys of these officers commence immediately to glean their perceptions of the types and influence of stressors in the combat environment. This information could then be crossfed to researchers developing the simulation or experimental models.

C. IMPLEMENTATION

The results from the combat stress research could be returned to the Human Engineering Division, Armstrong Aerospace Medical Research Laboratory, Wright Patterson Air Force Base, Ohio. Using the findings of the study, the baseline military standards originally prepared by the Human Engineering Division could be revised to include the appropriate changes. These documents would then become the foundation for equipment modification and design. If the resulting findings were also forwarded to the Naval Postgraduate School, the Air Force Institute of Technology and the Command and Staff colleges, appropriate operational research and analysis could be accomplished to establish recommendations for any needed changes in operational logistics and tactics.

Simultaneously, the studies of Karlene H. Roberts, of the University of California-Berkeley, on High Reliability Organizations (Roberts, 1990, pp. 160-176), bear further scrutiny. The factors determined to positively influence the military High Reliability Organizations should be implemented to ensure maximum system performance and mission effectiveness. A government contract with this tasking should be considered. Review of her findings could then be developed by the aforementioned military educational institutions which could then develop recommendation for necessary changes in military doctrine or tactics.

D. RECOMMENDATIONS

The findings of the research on the effect of combat stress will be ineffective if they are not thoroughly documented, used in system design, implemented in operational concepts, taught to personnel supervisors, and incorporated in acquisition practices. Documentation, design and operational concepts were addressed in implementation. Training and acquisition recommendations are now given.

1. Training

To counteract the preconceptions, concerning the effects of combat stress, exhibited by junior officers, training on these factors should begin early in the officers' career. As a supervisor of enlisted personnel, a large number of whom use information display systems, this knowledge is necessary for the effective utilization of personnel. Training could be accomplished in conjunction with other supervisory training received by junior officers.

To ensure senior officers and commanders have all the tools necessary for mission accomplishment, comprehensive training on the effects of combat stress should be accomplished at the appropriate Command and Staff institution. Since command decision is often based upon the inputs of information display systems, the understanding of possible system degradation is essential to the senior officer.

2. Acquisition Practices

The problem faced by many acquisition personnel in the Department of Defense today is a lack of sufficient military standards detailing human factors for ADPE acquisition. The existing military standards do cover a vast amount of the "tangible" elements but factors regarding specifics such as the physiological and psychological attributes are lacking. Due to limited crossfeed of ADPE acquisition problems, DOD agencies do not have a comprehensive network for sharing common problems in the area of ADPE acquisition. Therefore, errors in procurement have a high probability of being repeated either due to acts of omission or acts of commission. The existence of effective military standards would save time, money, and lives.

One of the reasons that government-purchased equipment fails to perform in accordance with specification is due to the lack of emphasis on man-machine interface and its inherent constraints. Human factors must be considered at every step of the acquisition process. The following gives examples of each.

In the Mission Element Needs Statement (MENS), the mission deficiency is thoroughly cited, alternative solutions must be given and identification of associated costs detailed. The MENS should make human factors an integral part of all considered alternatives. This is one of the first documents that the organizational chain will review and it is imperative that this crucial factor be highlighted to upper l vel managers. If applicable, lack of effective man-machine interface in the current system should be cited as a reason for deficiency.

In the system decision papers, specific requirements for attention to human factors should be cited in all milestone documentation. At each of the milestones (separating the phases of procurement: initiation, concept development, design, development, deployment, and operation), evaluation should scrutinize the human factors challenged during that particular phase. For example, after the development phase is complete, milestone checks should be made to evaluate whether personnel who are representative of the user population were utilized for testing.

The most critical documentation for the implementation of human factors in acquisition is the Statement of Work (SOW). The system requirements must be written in such a way that it is made known to contractors, in an unambiguous manner, that human factors are a key area of concern. Established military standards must be cited--correctness of military standard identification numbers should be verified. The SOW must also contain a statement requiring the contractor to ensure that the human factors effort is part of system engineering activities that define, develop, integrate, and validate the system according to the requirements. A mandatory Human Engineering Plan should be cited on the Contract Data Requirements Listing and clarified as a Data Item Description. Specifically, the SOW should direct the contractor to conduct a human factors program addressing human engineering, biomedical factors, manpower and personnel, simulation/equipment for training, and human factors' test and evaluation. The criticality of human factors must be emphasized to the contractor frequently and the contractor must understand that human factors design criteria shall be considered in design of all system components.

The SOW should dictate to contractors the requirement to have human factors personnel participate in all system requirement and design reviews. Contractors should establish procedures that ensure design changes are incorporated in developmental prototypes and in production models of the information display systems. During the technical evaluation, emphasis should remain on the human factors aspect of the contract and assurance should be obtained that criteria has not been altered or changed.

The human factors aspect of ADPE acquisition is extremely challenging and difficult. However, if we are to insure the successful implementation of our systems, we must scrutinize the application of human factors to the design and production of our systems. Only after successful operational test and evaluation of these "human sensitive" systems, under near real world battle conditions, will we be assured of true system effectiveness.

E. CONCLUSIONS

Research currently available in the field of stress and cognition reveals that stress has a definite impact on the performance of system users. Very little research has been conducted on combat stress. Understanding the impact of combat stress and its subsequent degradation of system performance is rapidly becoming a serious concern to military commanders. Advanced technology, smaller theaters of operation, shorter periods of time for decision-making are all factors in this situation. This management plan is offered as a proposal to facilitate determining the effects of combat stress on the man-machine interface of complex information display systems. The leading edge of technology is upon us and we now must address our successful use of that leading edge.

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