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A study of some human factors and their impact on command and control systems

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A STUDY OF SOME HUMAN FACTORS AND THEIR IMPACT ON COMMAND AND CONTROL SYSTEMS

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THESIS

A STUDY OF SOME HUMAN FACTORS AND THEIR IMPACT ON COMMAND AND CONTROL SYSTEMS

by

James Anderson Grace

MARCH 1980

Thesis Advisor: Prof. Donald P. Gaver

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A STUDY OF SOME HUMAN FACTORS AND THEIR IMPACT ON COMMAND AND CONTROL SYSTEMS		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis, March 1980
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Lieutenant James Anderson Grace, USN		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		12. REPORT DATE March 1980
		13. NUMBER OF PAGES 66
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Naval Postgraduate School Monterey, California		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

C2
Command and Control
Human Factors
Decision Maker

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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(Page 1) S/N 0102-014-6601

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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A Study of Some Human Factors
And
Their Impact on Command and Control Systems

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS TECHNOLOGY

from the

Naval Postgraduate School

March 1980

ABSTRACT

A preliminary analysis of some human factors as they relate to Command and Control (C2) is performed. A general model of a C2 system is discussed, and a node within that system is isolated for further study. The human factors of informational loading, informational relevancy, and data availability are discussed and then an experiment is performed to ascertain whether any relationships exist between these factors. Comments on the test procedures and the experimental medium used, the WES (Warfare Effectiveness Simulator) wargame, are made in view of possible pitfalls that can be experienced in human factors research. This work should be regarded as a pilot study.

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I. INTRODUCTION

An S3-A Viking on ASW patrol ahead of a carrier task group in the eastern Mediterranean picks up a hostile air search radar on its ESM (electronic sensory measures) gear. This information is relayed to the ASW air control ship which in turn alerts the task group commander on the EW (electronic warfare) net. The task group commander orders the duty AEW (airborne early warning) aircraft to alter its flight pattern to attempt to get a visual/radar fix on the intruder. The AEW aircraft gets a radar contact and an ESM LOB (line of bearing) that correlates with the contact. These both correlate with the S3-A's initial intercept. The AEW aircraft enters a hostile surface symbol into the ship-aircraft data link at the correct position and the hostile is now on the scopes of all NTDS (navy tactical data system) equipped ships. The task group commander now orders one of the SAG (surface action group) units to engage the hostile with Harpoon missiles. Scratch one hostile platform.

This is the tactical OTH (over the horizon) targeting problem solved (under ideal conditions) by command and control assets currently available to the fleet. The task group commander, utilizing rapid correlation of information derived from sensors external to his flagship, evaluates and prosecutes a hostile platform beyond the range of his own shipboard sensors. The SAG unit has fired upon a hostile platform its own sensors have not detected, but based on in-

formation readily available via its NTDS link with the carrier and the AEW aircraft. A classic example of command and control at work.

Command and control (C2) assets have frailties too; susceptibility to jamming and to deception, lack of available data, and vulnerability to damage, just to mention a few. In order to guard against system frailties we must understand how the system, or parts of it, functions in time of stress. If we can begin to observe how the system functions, we may be able to decipher which parts of the system are most crucial to the good performance of such a system. This paper will attempt to isolate a portion of a C2 system and will analyze and attempt to predict its actions under various conditions of stress through the use of gaming and simulation techniques.

II. COMMAND AND CONTROL SYSTEM

A command and control system can be viewed as a large, ponderous beast that everyone wants to get hold of, disect, define, catalogue, and make faster, better, and invulnerable. As yet, though, the beast has not been caught. The main thrust of this study will be directed not at an entire C2 system, but rather at one of its many complex parts, that point at which man and machine interact to create a decision or a series of decisions which I will call a decision point. A decision point can be thought of as existing at any of various levels of the chain of command. For example, consider the RIO (radar intercept officer) in the back seat of an F-14, a CIC (combat information center) aboard a ship, or a TFCC (task force command center) aboard an aircraft carrier.

To facilitate our discussion we should first take a look at what the general shape of a C2 system is and observe how some of its basic functions interact. We will need to agree on some basic definitions for this discussion; beginning with what exactly is a C2 system. For the purpose of this study, we shall define it as a system that is capable of extracting data from the environment, sorting and analyzing that data, and passing that refined data (information) on to a decision point. After the decisions are made, the system must be capable of passing that decision on to the appropriate action units that can interact with the environ-

ment in accordance with such decisions.

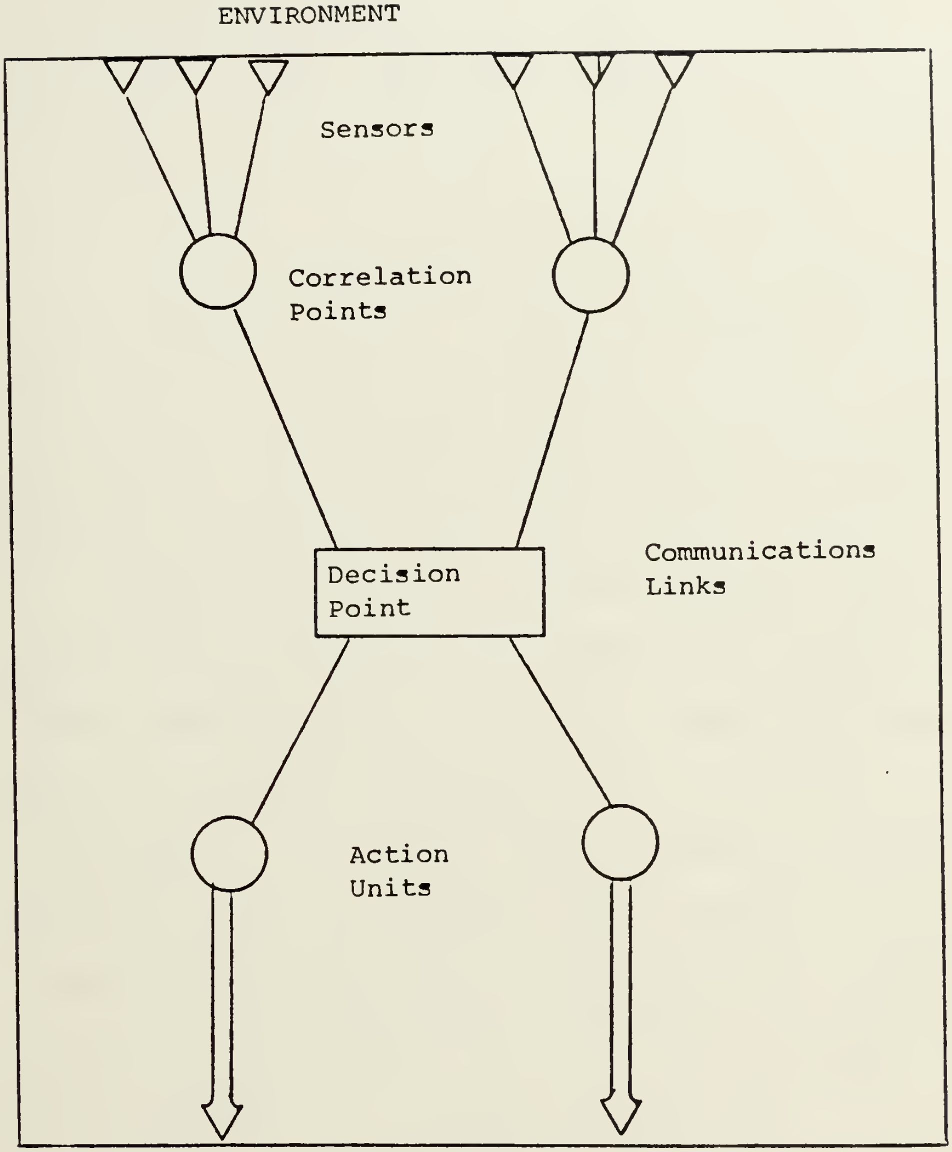
The term environment, as used herein, refers to the object world at large outside of our C2 system. It gives rise to a finite, although large and constantly varying, amount of data that is subject to retrieval by the system through any of a series of sensors. The environment is subject to change by manipulations done by actors. Friendly and neutral actors rarely make or influence an unfavorable change. Hostile actors, however, will be attempting to change the environment to their advantage; which would mean depriving friendly sensors of information, or presenting them with false or conflicting data. Also to be addressed later will be the tactic of overloading the environment with data in an attempt to bog down a C2 system. A sensor can be one of various sources of data, such as an intelligence agent in the field or a BMEWS (Ballistic Missile Early Warning System) radar site.

Once the sensors have gathered data from the environment, it is passed along the data links or other communications means to a correlation point. Inputs to a correlation point can come from sensors or from other correlation points. Here the available data and raw information are assimilated, verified and reformatted as processed information that can be readily used to aid in a decision making process. This information is conveyed via some communications system to a decision point. Decisions and necessary information are then relayed to waiting action units. The environ-

ment is then altered by actors, new data becomes available, and the cycle repeats. Figure II-a graphically shows the system we have described.

Our C2 system has some basic operating characteristics and limitations that we should familiarize ourselves with. As is true of any system that deals with flows and quantities (here of information), this system is sensitive to overloading, so our study should reflect this, and the situation will be discussed in more detail in Chapter III. Data flows through the system from the sensors up, and at each point it experiences some time delay attributable to communications relay time, correlation checks, human oversight, or even the old "pigeon hole" syndrome. This time delay reflects on the data's true worth, since the less delay the information has associated with it, the more appropriate the decisions based on it are likely to be. A classic example of this is found in the problem of OTH targeting, where information only minutes old may be tactically useless. Another example is that of the NMCC (National Military Command Center) getting delayed information about an in-progress nuclear attack, since the NMCC will only exist for scant minutes during such an attack.

Our C2 system is, of course, also vulnerable to physical damage. Satellites, ground stations, microwave networks and ground cable are all vulnerable to sabotage, EMP (electro magnetic pulse) effects or vaporization by a nuclear blast. Elimination of any point of our C2 system will begin



C2 System Model

FIGURE II-a

to degrade system performance. Assuming for the moment that system performance is measured by some combination of time/volume flow of data measurement, then eliminating any point or link in our system obviously degrades its performance.

There is a difference between the output of sensors and the output of correlation points (data vs refined data or information), but if we accept the output of both as a time/volume flow of information to be refined at the next node up the chain of command, then both should appear to behave in a similar manner in our macro-system view. The model in Figure II-a, which has been basic in our discussion of the overall system structure, is still much too complicated to study in depth as a single entity. In order to justify the narrowing down of our field of study of the system, we are going to have to establish and justify one new concept, namely that a decision point is merely a specialized or evolved form of correlation point. To this end, let us take a closer look at the functions of the two.

The function of a correlation point is to take inputs from any number of various sources and analyze these inputs. Inputs can come directly from sensors or they can come from other correlation points. The evaluation process consists of taking information available and determining whether or not it is consistent with other information on the same subject, or, if not, figuring out what the significance of the difference is. Dissimilar portions of information are pieced

together, first in order to develop the overall picture of what is happening, and then, after the initial picture is clear, to keep an accurate track of that picture. An example of this would be a destroyer CIC using its radars to detect incoming aircraft, and reporting the number, altitude and probable type of aircraft to the AAW (anti-air warfare) coordinator on the flagship.

The output of a correlation point is information, usually of a lesser volume but in a more readily usable form which is passed to another correlation point or to a decison point. Thus the major act of a correlation point is to process and summarize large volumes of information into more easily used information and to reduce raw informational bulk.

A decision point functions in a similar manner. It receives inputs from various sources and performs some basic functions of comparison and interpretation of the information. After the information has been consolidated the decision point demonstrates its difference from a correlation point. In addition to passing on refined information, the decision point also utilizes its own output of information to make one or more decisions based on the situation it perceives. The decision becomes part of the information passed on to action units and sensor units.

So it appears to be a valid concept that since decision points and the correlation points have most of their processes in common (the difference being that the decison

point is active - making independent additions to the information in the form of decisions) they can in fact be analyzed as to their efficiency in basically the same way. Remember before that we stated that a CIC was a good example of a correlation point. In conflicts in which the destroyer is a senior participant, it (the CIC) is fully capable of acting as a decision point. We will now proceed with this assumption of similarity of roles in mind.

We can examine our C2 system in terms of a series of nodal structures, or a network. The output (raw information or data) from a series of sensors flows into one or more correlation points, and the output (processed data, or refined information) from a series of correlation points flows into one or more decision points. But now, going on the predication that a decision point is nothing more than a specialized correlation point, and considering that all transactions between entity types involve compatible time/volume flows of information (otherwise extreme congestion and delay would occur), we can assume that the structure of the system in Figure II-a is actually composed of several smaller nodal pieces similar to the one shown in Figure II-b.

We can now examine this smaller piece of the system more carefully. If we allow ourselves the luxury of deciding what the time/volume flow of information coming through the communications lines will be (i.e. constructing our own inputs into the node in question) we can see that several

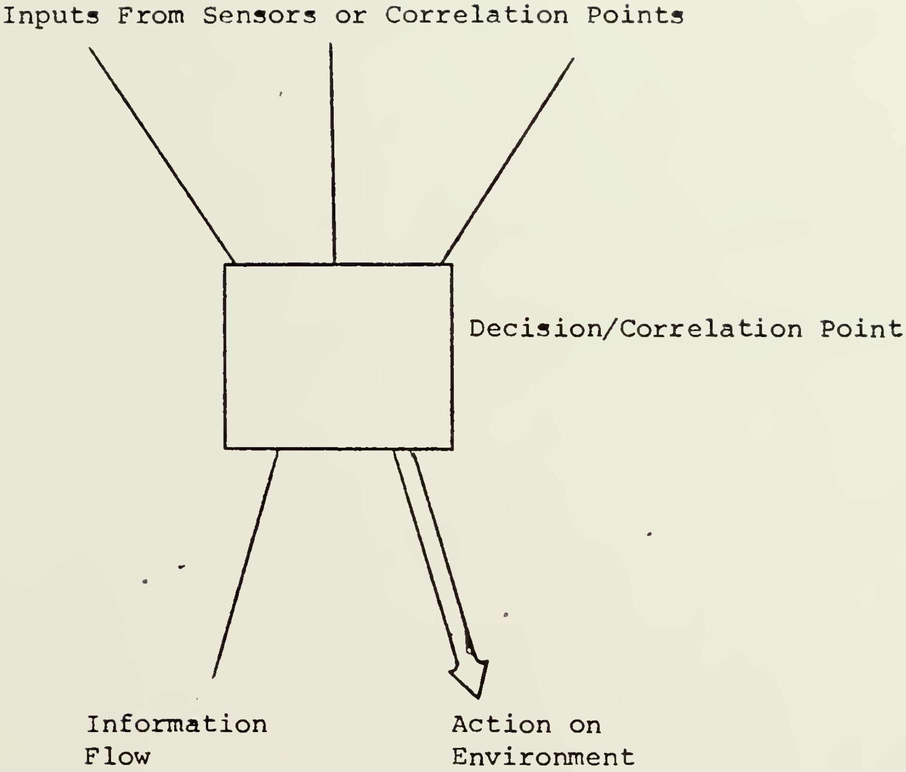


FIGURE II-b

Basic Nodal Structure of a C2 System

points worthy of examination appear. First, does the communications link have a sufficient capacity to handle the volume of traffic, or will message traffic back up as a result of overloading? What occurs when the flow reaches the node? Certainly there is some time loss caused by the processing delays, but the important questions to be addressed are; 1) what occurs in the node itself during different loading levels, these ranging from a lack of information to saturation with "information", thus exceeding its capacity to perform its correlation function; 2) what effects do inaccurate or reputedly inaccurate information have on the ability of a decision point to function normally through all load levels?

There are essentially three things that can occur at an overloaded point. First, the information processing and storing process can just get slower and slower, falling further and further behind the actual military situation, until the process either grinds to a halt or the load levels subside, allowing the system to catch up. This would be the case with a relatively inflexible system, for example one that is very hardware/software oriented. Now we can consider making a human far more prominent in the system, in which case two new possible alternative actions arise. A human could opt for processing only that information he deemed necessary and significant at the time, allowing other information to fall by the side. This decision would prevent the system from bogging down, but at the same time, this selec-

tive scrapping of information means that decisions are not based on all available information. This example is relevant to the TAO (Tactical Action Officer) on a surface combatant in an active threat environment from submarines, surface ships and aircraft. His screening system (CIC) may break down partially and he will be forced to do some gross and accordingly inefficient screening himself.

The other human alternative would be to sense that the system is getting hopelessly behind and take the drastic action of completely scrapping his automated picture of the situation, dumping his backlog, and restarting his picture from scratch. An example of this would be the following: when NTDS units are in a multi-ship link, extraneous information generated by the participating units will sometime overtax the onboard computer of one of the units, causing it to fall behind and show other symptoms such as the refusal to accept new inputs. By dropping out of the link, purging the memory of the computer and reloading the program, an NTDS unit can come back into the link and rebuild its tactical information in a total time of about ten minutes.

Our model should consider all three of these aspects of behavior, since most C2 systems are man-machine types. Another pertinent item to be considered is that of validity of data and data sources and the impact of these items on the ability of the decison makers to function. Man tends to hedge decisions against uncertainty, so our model should be sensitive to any real or perceived inequities in informa-

tional validity.

In summary, in this chapter we have defined the basic structure of a general command and control system model, studied its functional parts, and determined that a general similarity exists between its internal functional parts that allows us to examine one of these parts (a correlation or decision point) as a general case. This leads us on to examine in the next chapter how load and validity should affect this decision/correlation point model, and to then proceed to design a model for simulation of nodal behavior under conditions that might be reasonably anticipated to occur during a crisis.

III. A DISCUSSION OF HUMAN FACTORS

The correlation/decision point we examined in Chapter II can be thought of in one form as a command center. In shifting attention from a C2 system analysis to an analysis of a particular node within the system, we will hereafter refer to the correlation/decision point as command center. This the point is at which "it all happens", the point where available inputs terminate, and from which come the results of the decision making process. Here is where the man-machine interface exists to aid a decision maker, and where the decision maker exists. A command center can be as simple and basic as a manually plotted CIC, or as highly automated as the NMCC, but its basic function remains the same: to monitor the situation for which the command center is responsible, and to attempt to make correct, timely, decisions. The purpose of this chapter will be to examine those factors that affect a command center under stress conditions in order to develop a model that will effectively simulate a command center's response to stress.

A command center is subject to stress in various forms that can adversely effect its performance. A command center can be overworked or underworked, both of which impair effectiveness. The higher the level of irrelevant information mixed in with pertinent information, the more strain is put on the command center's filtering process. The amount of information available on a subject of interest can detract

from efficiency if it is too little or too much. A command center's normal activities can be disrupted for a time if a completely unexpected event of significance catches it by surprise -- a sort of shock factor. All these variable situations affect the command center's ability to make timely and accurate decisions to various degrees. It is these factors which we will examine in detail. Our computer model for simulation of crisis reflects the interplay of these factors.

A. LOAD LEVELS

Loading levels on a command center play an important part in examining a command center's response to stress. The average person can assimilate a new piece of data about a situation every three minutes with optimum results for retention and understanding.[1] At higher rates of input he will tend to become overloaded with more information than he can comprehend and use. Consider how much data can potentially be thrown together concerning tactical situations. It should be apparent that an appropriate filtering and condensing process in the command center becomes very important to ensure that the decision maker will not be inundated with data. On the other hand, if the command center becomes underloaded, it's efficiency will also be impaired. This is perhaps because of a underutilization data available and the tendency of the human mind to wander when not challenged.

This concept of load level's effects is illustrated

graphically in Figure III-a where we see a plot of informational load versus QQI (quality-quantity index). The QQI is a measure of complex decision making which is "an indicant of the degree to which the decision making sequence during the playing period (of the experiment) reflects an overall strategic effort".[2] We can see from the figure that the goodness of a decision peaks at about 10 pieces of information per playing period (thirty minutes in the referenced experiment). Notice that having insufficient information seems to have a more adverse effect (a steeper slope) than the overloaded situation has.

The graphs in Figures III-a and III-b both warrant some further discussion as to their origin. During a two year period beginning in February of 1971, a Purdue University research team conducted a series of experiments concerning the effects of load and relevance on decision making. This work was done under contract to the Office of Naval Research (ONR) Code 452. The data used to derive the curves for the graphs was taken during interactions in the Tactical and Negotiations Game, where "individuals fill positions of national decision makers with responsibilities for the military, economic, intelligence and negotiations functions of a nation engaged in a limited war."[3] The graphs may tentatively be considered valid for our intended use since they were taken under simulated kinds of military stress situations that we are attempting to consider in this study.

The concept of loading, utilizing the QQI graph of Fig-

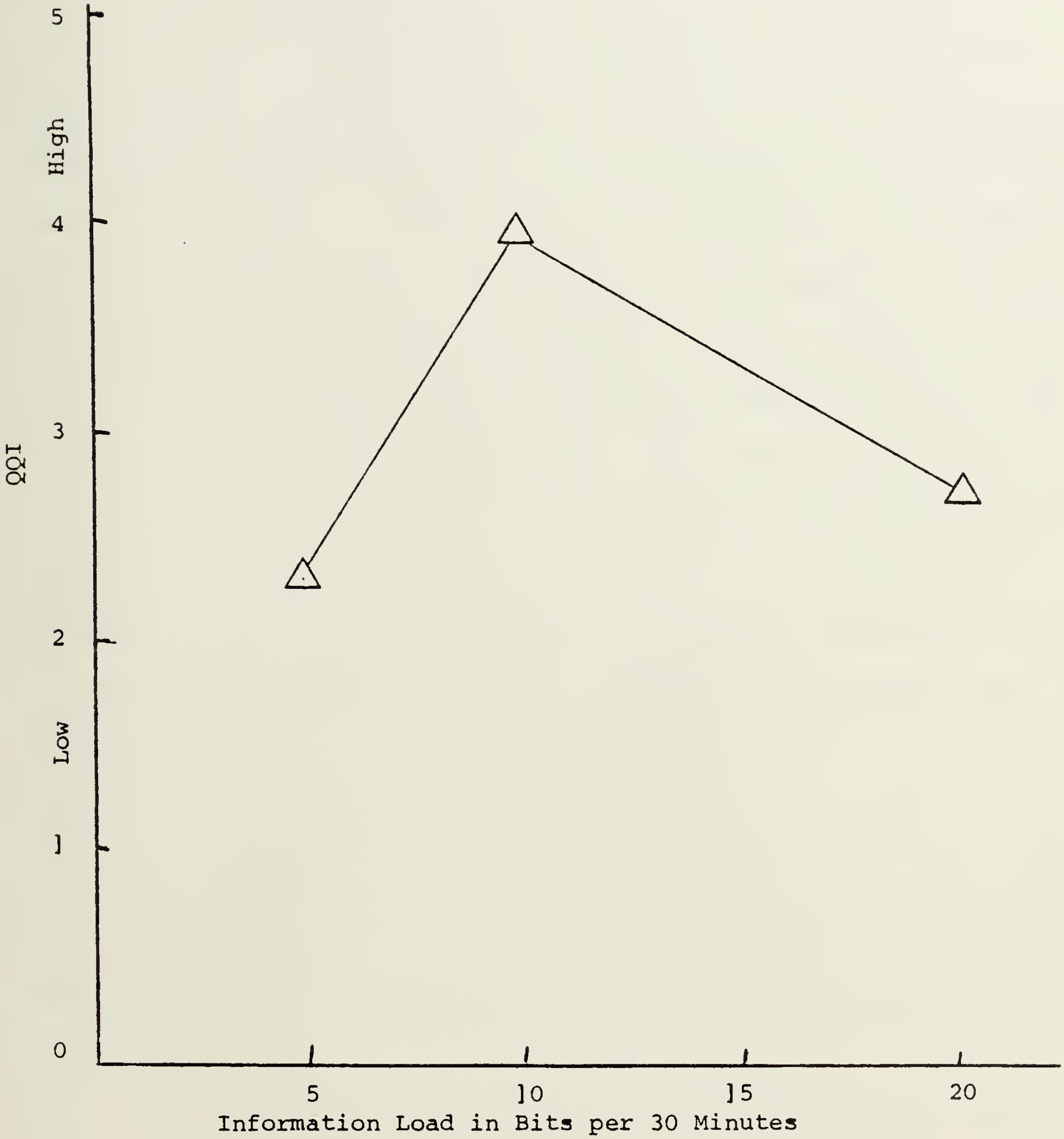


FIGURE III-a

*Taken from <u>Relevance and Load: Effects on Simple and Complex Decision Making</u> by S. Streufert

ure III-a, will be the first major item we will include in the construction of our command center response model. Since this loading factor is subjective, we will want to generalize the subjects' inputs. We could ask whether the subjects of the validation are overloaded, underloaded, or optimally loaded; thereby utilizing all three given points on Streufert's graph in Figure III-a. However, having experienced decision making processes in the fleet, I feel that the extra alternative of slightly overloading or underloading should also be available. For this, we will have to interpolate two more points on the graph, between already existing points. Thus our validation subjects will be presented with five choices of perceived loading levels; quantitative values for these subjective feelings can be taken from the graph. The load level, for the purpose of this study, will be strictly considered to be whether the command center (the blue or orange team in a war game) perceives it is overworked, underworked, or working under an optimal load situation at the time the experimental input is required.

B. RELEVANCY

Information relevancy is the next item of importance that we should address, and its importance cannot be underestimated. A considerable amount of irrelevant material is pulled in by sensors or is added on by incoming reports, or sometimes is even required by outgoing reports. Once

again, the command center filtering process becomes vital in protecting the decision maker from too much irrelevant information which would bog down or delay his decision making process. Of course relevancy can be many things to many people at different times. No two decision makers think or make decisions exactly alike. What one may consider important another may deem extraneous. A decision maker may focus on one particular problem for a period of time, making some valuable information on another subject appear irrelevant at the time for his purposes. We will have to be sensitive to this concept when designing and validating our response model.

To observe how informational relevancy affects the decision making process, we can examine Figure III-b, a plot of percent of relevant information versus the Q&I for various load levels (remembering that 10 is the optimal load). We can observe that 40% relevancy is a significant break point, where the optimal and underload situations begin to improve steadily, and where the overload situation reaches peak efficiency, falling off thereafter. While logically all situations should improve as relevancy increases, the overload curve suggests a possible breakdown in the filtering process whereby it becomes increasingly difficult to sort out the relevant material when relevancy goes beyond about 40%.

This aspect of decison making will also be included in our command center response model. Again, since relevancy is a subjective input, we want to keep the inputs general-

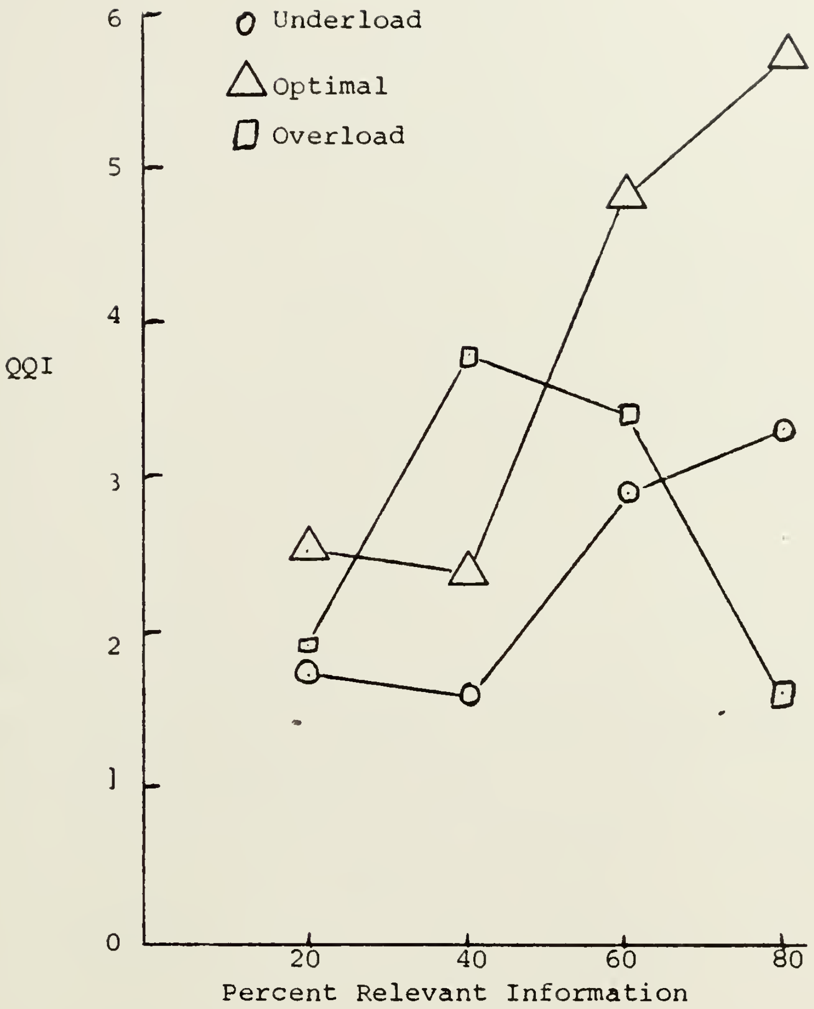


FIGURE III-b

*Taken from Relevance and Load: Effects on Simple and Complex Decision Making by S. Streufert

ized to prevent too much disparity between subjects' responses. The graph in Figure III-6 is divided into 20% increments, so in order to avoid any interpolation errors over points that Streufert's experiments did not cover, we will allow only subjective inputs divisible by 20. This will also give the generalization of inputs that we desire. This input will be combined with earlier input of load level to enter Figure II-6 to get a second MWI rating for the time the input is requested. For the purposes of this study, we will strictly consider percent relevancy as that amount of all information being presented to the decision maker that is relevant to the task at hand (localization of a submarine contact, reordering a convoy, avoiding detection by opposing airborne search assets, or whatever particular evolution the decision maker is concerning himself with at the time the input is required).

C. DATA AVAILABILITY

Another important factor in the decision making process is the availability of information (here speaking strictly of relevant information) to the decision maker. Availability of information has a couple of different concepts influencing it. First there is the accuracy of information. The accuracy, or supposed accuracy of information, can have a significant effect on our command center. When we discuss accuracy by itself, we become immersed in the question: how accurate is accurate enough? What are the effects of varying

degrees of accuracy on the effectiveness of the command center? What happens if the information comes from a questionable source?

How accurate is accurate enough? Let's take the example of OTH targeting of the Navy's Harpoon missile. In a manual, unclassified game of Harpoon targeting conducted during September 1979 by the author, it was shown that a knowledge of an opponent's position did not always guarantee successful attack. Opponent's course and speed were needed for successful targeting at longer ranges. Information on neutral shipping was necessary to prevent undesired activation of the missile's terminal homer on the wrong ship. These findings were consistent with fleet experience and show that "some information", without regards to its accuracy, may not be sufficient to guide a successful operation. Accuracy errors of a mile or more can seriously jeopardize OTH targeting validity, especially since Harpoon is a "fire and forget" weapon: there is no capability to correct firing data after launching.

Does a carrier task group need to anticipate attack within the next week, the next two days, or the next four hours, or when? The computer and communications assets available to us today can give us a great deal of timely, accurate, data if that data is available. What becomes of us if that data is not available, or the use of communications or computers is denied us by an adversary? How well will we function then?

Lack of information forces the command center to extrapolate available information to make required decisions, and tends to cut down on the number of non-required decisions made. Man is a conservative animal by nature, and will usually fail to extract as much certainty as possible from available data, thereby complicating this situation. As incorrect data items enter the picture, the quality of decisions being made will be inherently degraded. Extraneous information can likewise interfere with a decision making process.

Another important aspect of informational accuracy is the perceived accuracy of the source of that information. What happens if the source has proved to be unreliable in the past? During National Week XXIII in the Mediterranean during the summer of 1977, the USS VOGE simulated firing three Harpoon missiles under the direction of the USS SARATOGA, which was acting as SSSC (surface sub-surface coordinator). All three weapons were poorly targeted and were ruled as misses. The TAO on VOGE made an entry into his exercise log that since the SARATOGA did not have an accurate picture of what was going on in the exercise, the VOGE would no longer fire weapons based solely on her directions. Looking back at the introduction, we can see our smooth and efficient C2 system is being jeopardized by source reliability, a completely internally generated problem.

An adversary has the capability of influencing the accuracy of information we can gather on him. He can distort our

concept of what is actually taking place by cover and deception tactics. He can attempt to thwart our sensors by jamming or destroying them, and do the same thing with our communications and data links. Our own EMCON (emmision control) conditions can deprive us of available information. On the other hand, our technological advances will limit the ability of the adversary to jam us, and our experience and training can limit his ability to deceive us. Physical damage can be reduced by hardening our systems.

So a command center can be denied information, or be given information that is actually inaccurate or is perceived to be inaccurate. The decision maker may, by oversight or inexperience, not be able to find the information he needs. All this affects his actual supply of available information. How should we incorporate this into any system model? An experienced operator can usually gauge how much more information he needs to be sure of a decison. The accuracy of his information may not, however, linearly affect his decision processes. For example, a commander can obviously better judge a situation if he has 70% of the data than if he has 35%, but will his judgement be twice as good? Any model of a system should consider this and perhaps examine an exponential curve as well, and then determine during model validation which reflects reality more accurately.

So data availability will be the third and last major variable that we will include in our response model. We will again measure this factor as a subjective response of a sup-

ject in a decision making role. While we attempted to generalize the inputs of load level and relevancy by providing a set of "canned" responses (which we were in fact fairly limited to by the [illegible] channel), with this response we will allow total freedom between 0 and 100%. Functional use of the data availability variable in the model will be linear or exponential as discussed earlier. For our study, we will strictly define data availability to be that amount of relevant data the decision maker has available to him compared to what he feels he needs to be completely aware of his current situation (does he know the position of all enemy units, what is the status of the last weapon fired at a submarine, are his radars being actively jammed, etc.).

D. SHOCK FACTOR

The last item that needs to be addressed in our discussion of response to stress is what occurs when a command center and its decision maker are "caught short", i.e. are confronted by a situation that develops rapidly and for which they are unprepared. This situation must be met with a crisis management approach as opposed to the normal game plan, and invariably pulls available assets away from their normal tasks, degrading efficiency. This could be caused by successful deception tactics by the adversary or a breakdown in the intelligence system, as witnessed by the fall of the Shah of Iran.

This will be addressed as a "shock factor". Non-existent

under normal operating conditions, it is purely the result of total surprise and little or no preparation, and will temporarily degrade the command center efficiency since some normal functions must be put aside while a response to a new, unanticipated situation is generated. The impact of such a shock factor is currently undefined and unexplored, but should be incorporated into any stress related model.

Accordingly we shall employ our concept of a shock factor into our model. It will act as a time-limited degradation of overall efficiency. Initial values will be 10% degradation for a 15 minute period, with the possibility of changes during the analysis process. An event capable of bringing on the "shock factor" will be defined for this study as one which is unexpected or unprepared for and that disrupts the normal activities of the command center (decision maker and his staff) by requiring an immediate, bootstrap response.

F. MODEL INTERACTIONS AND CONSTRUCTION

Having discussed what I feel are the important variables to be included in our command center response model, it is now time to examine how the variables should interact. Since we are dealing with subjective inputs, we might want to offer a choice of responses that can be equated to a further subjective input. If asking the question, "On a scale of 1 to 10, how has your day been?", you might expect to get a reasonable response of an individual's subjective

view of how well, or effectively, his day has been going. This is the basis for the final input we will be dealing with; the individual decision maker's gut feeling of how well he feels his command center is functioning (its efficiency). We will allow the decision maker the range of 0 to 100%.

We will be attempting to relate the final input of the decision maker's estimate of his command center's efficiency to his previous estimates of load, relevancy and data availability in the next section. We want to have our model estimate of efficiency easily comparable to the decision maker's overall estimate. Hence, we need to have our model's estimate come out in a range of 0-100%. The first step here is to scale down the three major variables to a maximal individual value of one (thereby ensuring no numerical weight advantage of one variable over another). In order to allow us to compare relative values among the three variables, we should assign each variable a weight factor; where these weight factors add up to 100. This should allow a maximum additive value of the three variables multiplied by their weight factors of 100. The shock factor, a multiplicative variable that affects the whole process, should be multiplied by the sum of the three major variable inputs (when in effect) to produce a final model estimate of efficiency.

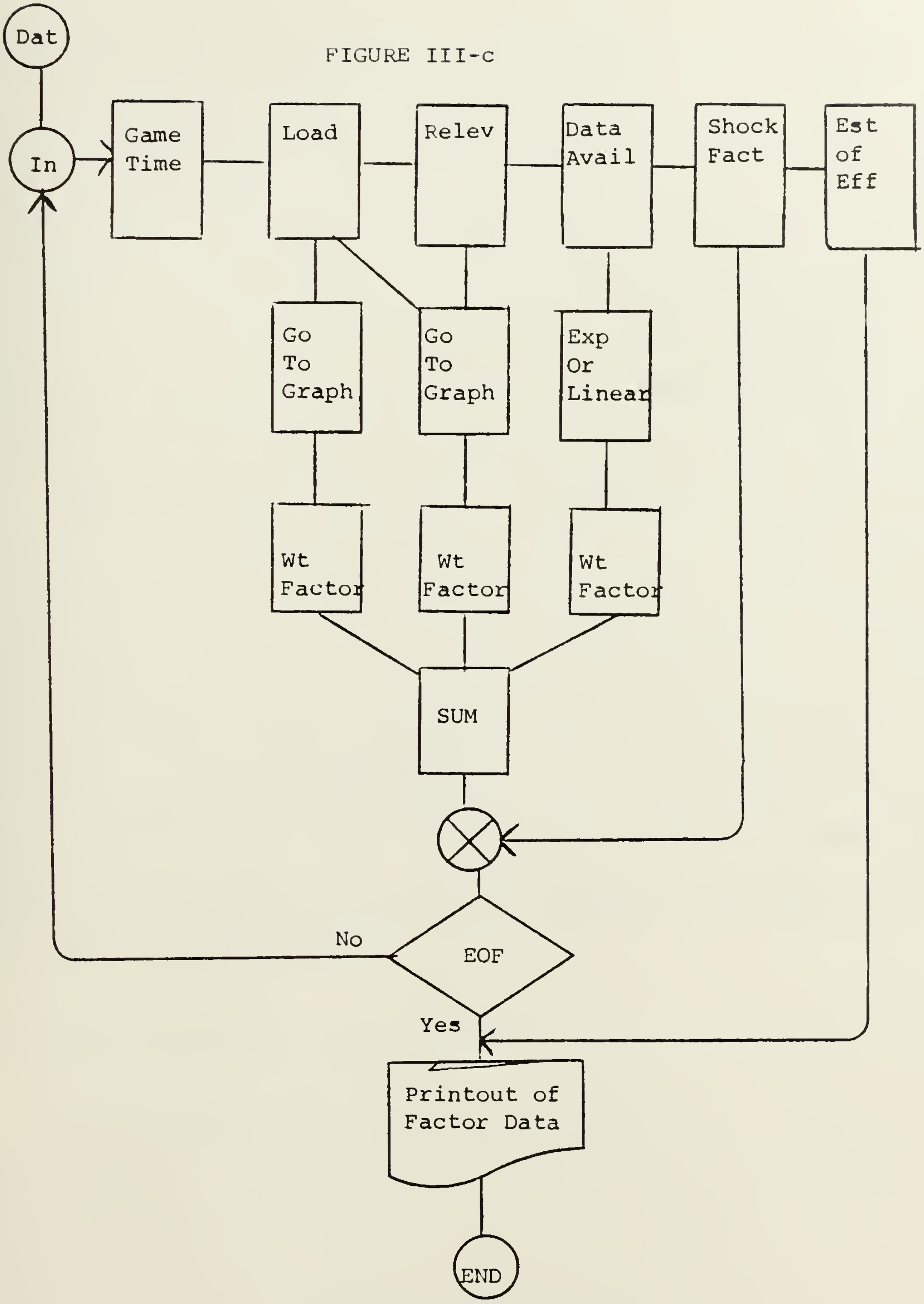
The model will then be fed with all the variable values discussed earlier in the chapter, plus the operational time into the war game at which the data was taken, to generate

an output of game time, model generated efficiency, and estimated efficiency. The basic outline of this model is illustrated in Figure III-c. The model program should also accumulate statistics on average variance between generated and estimated results and a record of individual variances for the production of a bar graph. This completes our discussion of the basic model.

F. TEST ENVIRONMENT - WES

The data will be collected during runs of the wargame WES. WES is a computer driven, interactive, multi-player wargame. The players consist of two opposing teams (Blue and Orange) and an umpire or exercise supervisor. Each team has a graphics display and a status board to monitor their forces and contacts with. In addition, each team has the ability to maneuver forces, activate or deactivate sensors, and to conduct attacks utilizing force weapons by inputting orders on a command terminal. The game can be played with existing, canned scenarios or players can build their own scenario databases at the investment of tens of man-hours. By building a database the players can define the capabilities of all sensors, weapons, and platforms, and can pick the starting locations for the opposing forces. Artificial intelligence can be introduced into the game via messages from the exercise supervisor to concerned sides. Computer algorithms determine the outcome of sensor detections and weapons damage effects. The game is free play from the

FIGURE III-c



Model Function Flowchart

start. Ideally a team consists of three to four players.

The specific scenario used for or data collection will be a canned convoy scenario. Blue will be given five escort vessels (with 1 assigned a shipboard helicopter) and MPA (Maritime Patrol Aircraft) support to take a convoy of twenty-two assorted merchant vessels through contested waters in a hot war. Orange forces will consist of two submarines, one intelligence gathering ship, and ten long range air reconnaissance aircraft. Orange's goal will be to inflict as much damage as possible on the merchant convoy, while Blue's goal will be to maximize the survival of merchant ships. Figure III-d shows the disposition of opposing forces at game start, with Blue forces transiting from right to left. At game start opposing forces have no contact with each other, with Blue having only the intelligence that Orange forces are to their west. Data will be gathered from the Blue command center.

G. DATA COLLECTION AND REDUCTION

Having constructed our model, we must now undertake its application. In order to do this we will use experimental data gathered from a series of wargames using the WES (warfare effectiveness simulator) in the CS Lab at the Naval Postgraduate School. Data collection will be done in three forms. First, through the data collection form shown in Figure III-e; next by means of a voice recording of significant events in narrative form, and lastly by the use of close ob-

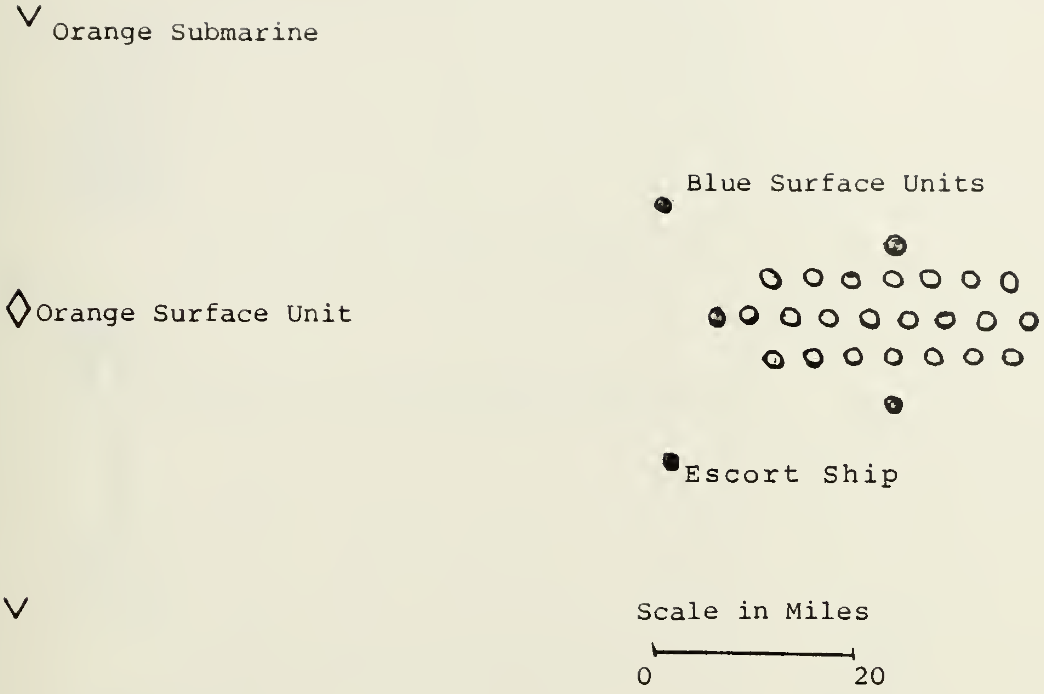


FIGURE III--d

Disposition of Opposing Forces at the Start of WES Game

Game Time	Loading					Relevancy					Data Availability %	Shock Check if Yes	Estimated Command Center Efficiency %
	Lo		Optimal		Hi				%				
	1	2	3	4	5	20	40	60	80	100			

FIGURE III-e

Data Collection Form

servation.

The data collection form is designed to take a minimal amount of time and effort to fill out during the actual play of the game. It can be filled out by checking three blocks and writing down three numbers. Past experience by the author in collection of data in fleet exercises has shown that the less complicated a form is, the more readily it will be used during a high concentration effort on the part of the individual filling it out. The tape recorder will be used to note significant events in narrative form that the data sheet would not account for (as opposed to a narrative type log being kept up). This narrative could point out discrepancies in form entries later during the analysis phase, or could be used to confirm that data. Data collecton will be supervised by the author in an effort to ensure some conformity in the reasoning behind the log entries made.

The objective of this analysis effort will be to correlate the inputs of the first four sections of the data form to the last section, that of the individual's perception of the efficiency of his command center. This will involve a quantitative analysis of subjective inputs. This self assessment could provide some misleading data, so as a part of the analysis we must examine the data for any possibly related inconsistencies. The output of the model will give us the ability to observe each run of the data in three different ways. We will get a printout which will enable us to build a graph of generated versus estimated efficiency dur-

and each run. We will also get a printout of the average difference between the generated and estimated efficiencies for each run. Lastly we will be able to construct a bar graph showing in 5% increments the difference between the model generated efficiencies and the subject estimated ones.

There are several variables within the model that allow us to manipulate the data. The primary method of manipulation will be in changing the respective weights of the input variables of load, relevancy, and data availabillity. We can adjust time/weight factors with the shock factor. We can explore linear and exponential effects of data availability. We cannot expect different decision makers' results to be the same in all cases. For that matter, their basic inputs may vary also. We should be aware of a learning curve, since data will be gathered on consecutive games. From the results of this analysis, we should be able to draw some conclusions as to where the decision makers in the experiment place their emphasis when making decisions, i.e. what factors of those we have examined are most critical to them.

This chapter has served to construct a model that will reflect which of the discussed variables (load, relevancy and data availability) are most important to the decision makers in our experiment. The next chapter will discuss the data collected and the analysis of that data in the context of our model analysis.

CHAPTER THREE FOOTNOTES

1. Susan C. Streufert, *Relevance and Load Effects on Simple and Complex Decision Making*, (Purdue University, 1972), p. 4.

2. Siegfried Streufert and Susan C. Streufert, *Relevance and Load Effects on Simple and Complex Decision Making*, (Purdue University, 1973), p. 8.

3. *Ibid*, p. 4.

IV. ANALYSIS OF THE DATA

In this chapter we will analyze the data gathered from the NEWS game in three different contexts. We first want to examine the raw data. During the examination we will be looking for any inconsistencies that might indicate that the data is invalid for our intended use, doing a analysis of the variables of load, relevancy and data availability. We will accomplish this by graphing out the data vs time, pointing to any obvious differences in the data, and discussing what reasons might explain the differences.

As you may recall from the last chapter, we wanted to examine two variations within our model. Firstly, we wanted to see if data availability had more of a linear or exponential effect on our subject's perceived command center efficiency. We were also concerned with how the extrapolation of two extra points on the load curve might affect our results. This clarification of variations will be the focus of the second portion of this chapter. Here we will use as an analysis tool the standard deviation between the model generated efficiency and the subject's perceived command center efficiency. The basic concept here is that the smaller the standard deviation, the better the match between the subject's estimate of his command center's efficiency and the model's generated estimate over the course of the game (data collection period). The final section of this chapter will deal with the analysis of our data, attempting to

determine whether there are any consistent patterns among the variables of the model that could be practically significant. Once again using the root mean squared difference between the subject's and the model's efficiency estimates as an analysis tool.

A. EXAMINATION OF THE DATA

This analysis of the raw data will be easier to understand if we first explain the sequence of events that takes place in the WES scenario. The game can essentially be broken down into six definite time periods or phases. In Phase I the subjects (Blue commanders) establish the rules of sensor use, and the rules of engagement; these are the initial inputs. In Phase II Blue makes inital contact with the Orange forces and Blue begins the localization process. In Phase III Orange air assets arrive and Blue's airborne ASW capability is destroyed. In Phase IV preliminary attacks are made by Blue on Orange submarine units. In Phase V Orange Missiles attack Blue surface forces. Phase VI sees the destruction of both Orange submarines, and Blue prepares for attacks on the Orange surface unit.

Looking at Figure IV-a, a plot of the four subject's perceived loading levels throughout the game, we see some baseline disparities that we might expect within a group of decision makers. However, there are three definite trends that seemed to be followed. The load levels tend to drop off

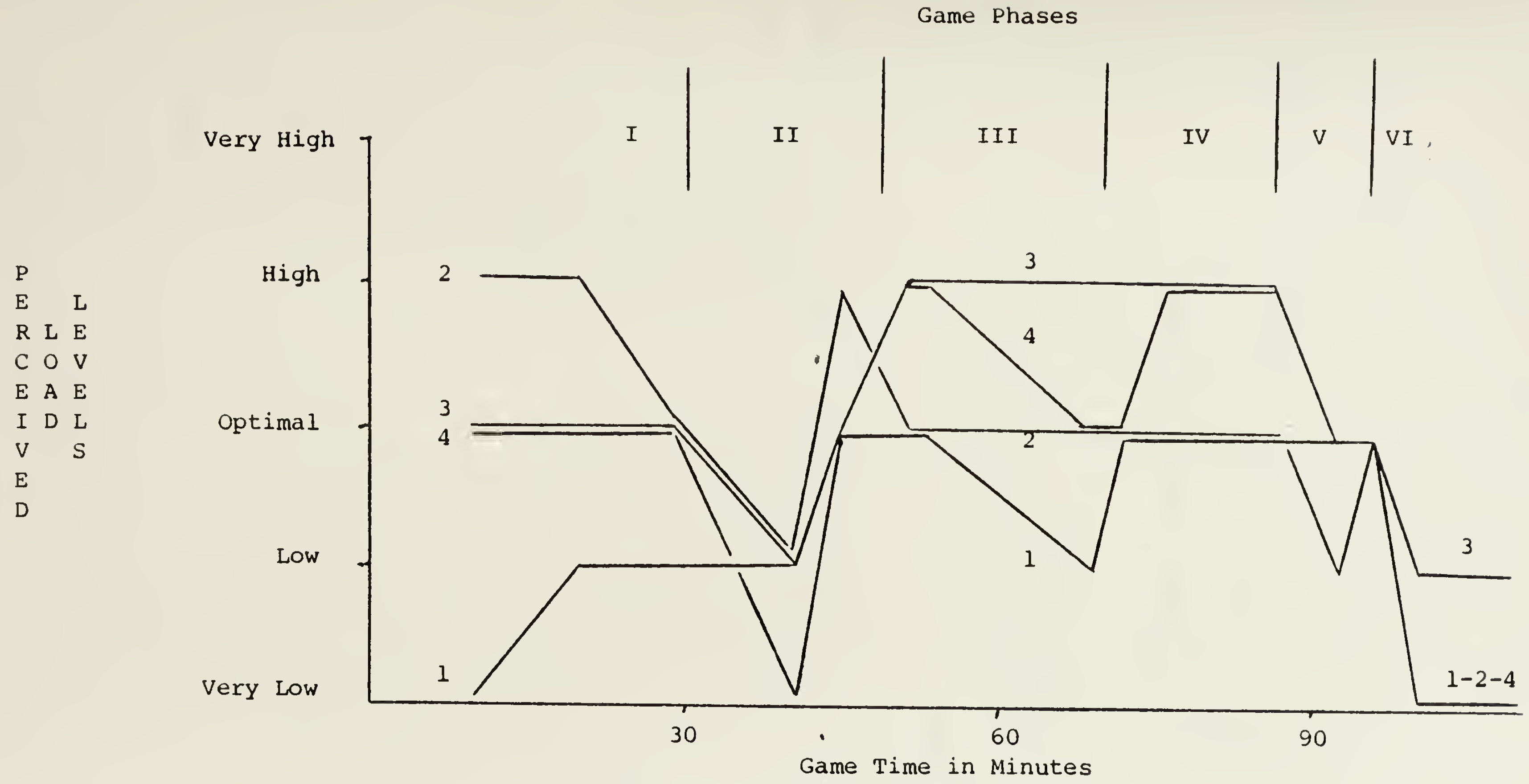

Game Phases
I
II
III
IV
V
VI
PERCEIVED LOAD LEVELS
Very High
High
Optimal
Low
Very Low
2
3
4
1
3
4
2
1
3
1-2-4
30
60
90
Game Time in Minutes

FIGURE IV-a

towards the end of Phase I of the game, by which time most orders have been passed out and as yet contact with opposing forces has not been made. In the intial contact phase the load levels begin to increase and remain high until the end of Phase V. There is some tendency for the load to drop down at the end of each phase of the battle, then rising for the next series of encounters. After Phase V load levels all re-cede to low levels.

These results all tend to reflect about the same concept of how the general scenario went: initially load levels were high while handing out orders, then the levels dropped off while Blue is attempting to obtain data on activities of the opposing forces. Load levels increased again after contact, and remained fairly high during the process of localization and destruction of the opposing force. After the opposing force was neutralized, the load levels went back down.

Moving on, let's look at Figure IV-b, a plot of the subject's perceived informational relevancy vs. time. Note that relevancy was never perceived to be less than 60%. Relevancy seems to have taken two tracks. One track tends to remain at or near 100% throughout the course of the game. The other track starts at a lower level and reflects a further lowering during Phases II-V, those where contacts and combat are occurring. The high degree of relevancy reflected throughout could be explained by the data environment. In the computer driven wargame, not much data exists that is irrelevant to the overall game. The alternate track

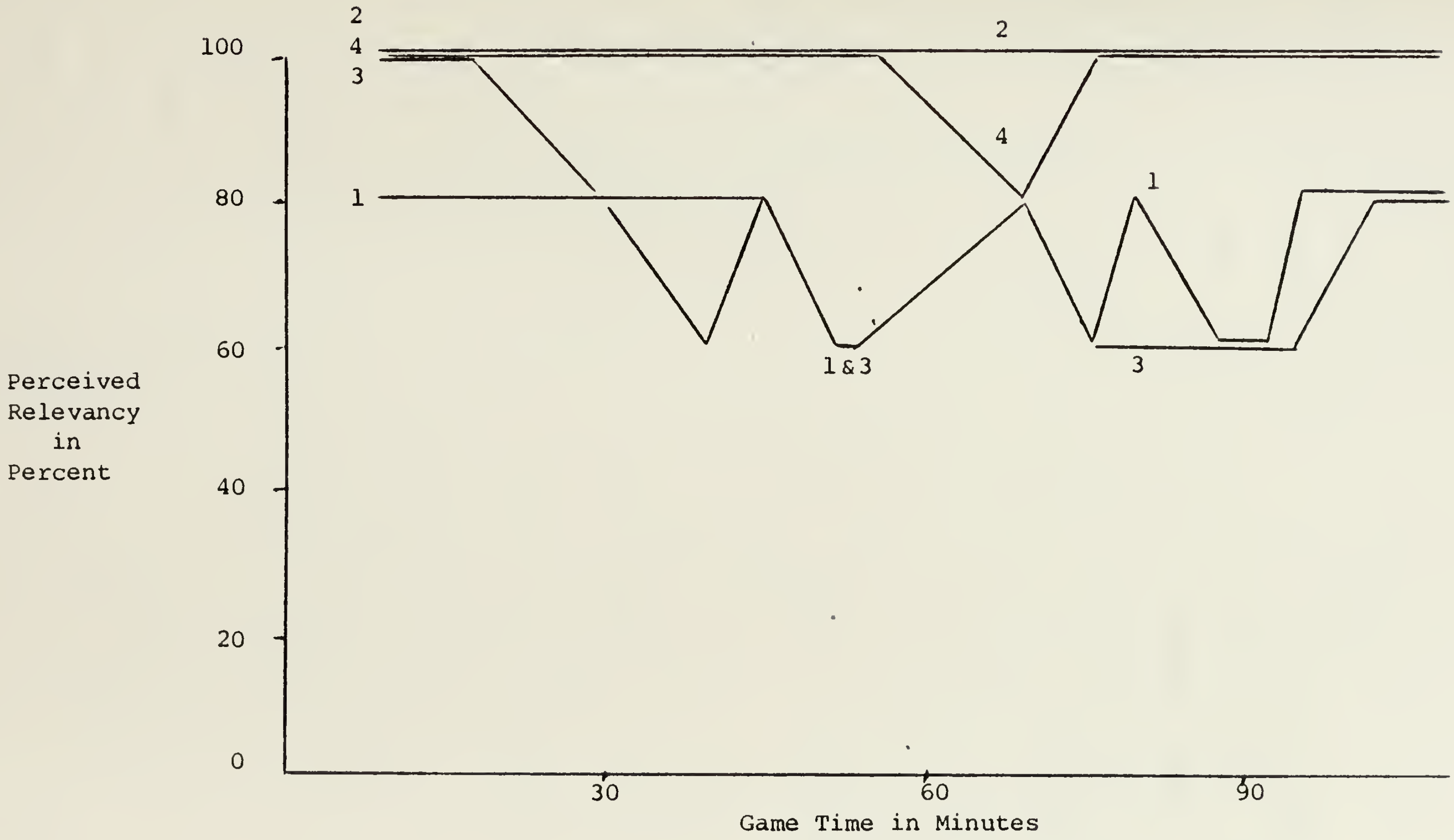

Perceived
Relevancy
in
Percent
100
80
60
40
20
0
2
4
3
1
2
4
1
1&3
3
30
60
90
Game Time in Minutes

FIGURE IV-b

of lower relevancy could have been caused by a decision maker's concentrating his mental efforts on a small portion of the tactical situation but still being exposed to information concerning the overall situation.

Now let's examine figure IV-c, a plot of perceived data availability *vs.* time. In this plot we see three fairly consistent sets of data and one set whose baseline is far lower than the others. This lower baseline plot shows an exaggerated increase as time goes on -- an increase that is minimal in the other three sets of data. This lower set of data will have to be considered when examining the data output of the model in the last section of this chapter, since it is so low that it may not be totally explainable as a difference in decision making styles.

Lastly, we should look at figure IV-d, a plot of perceived command center efficiency *vs.* time. Note again that there is one low baseline plot at the beginning (not from the same data set as the low baseline plot referred to in the last paragraph). The overall general trend of the graph is that the command center efficiency is degraded during contact and combat, and that as combats are resolved, the efficiency rises. It is possible that the low baseline plot may be traced to the subject's feeling that the initial distribution of orders and rules of engagement involved too much effort and detracted from the command center's ability to function. This low baseline should be kept in mind as we explore the results of the model analysis in the last section

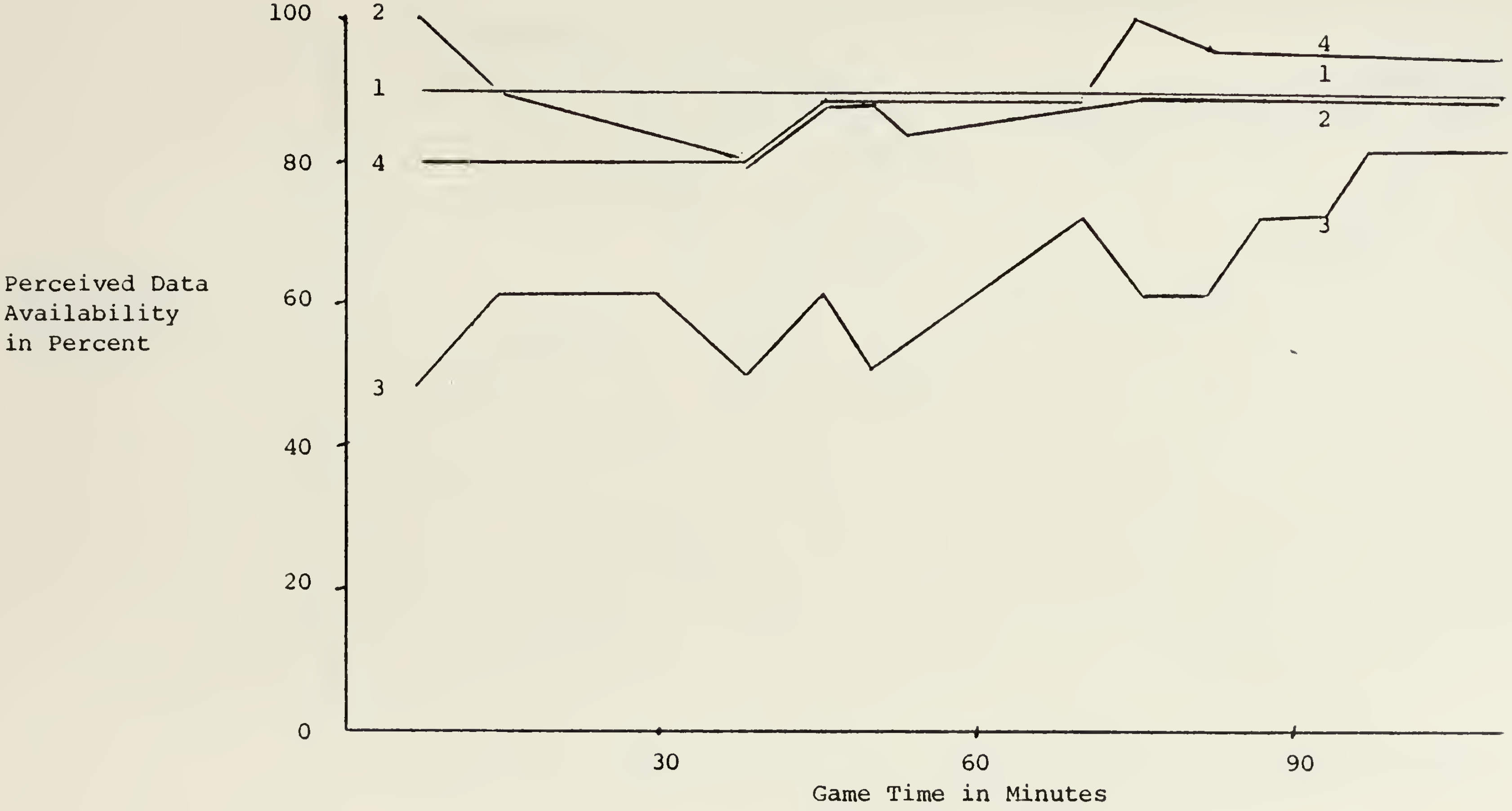

Perceived Data Availability in Percent
100
80
60
40
20
0
2
1
4
3
4
1
2
3
30
60
90
Game Time in Minutes

FIGURE IV-c

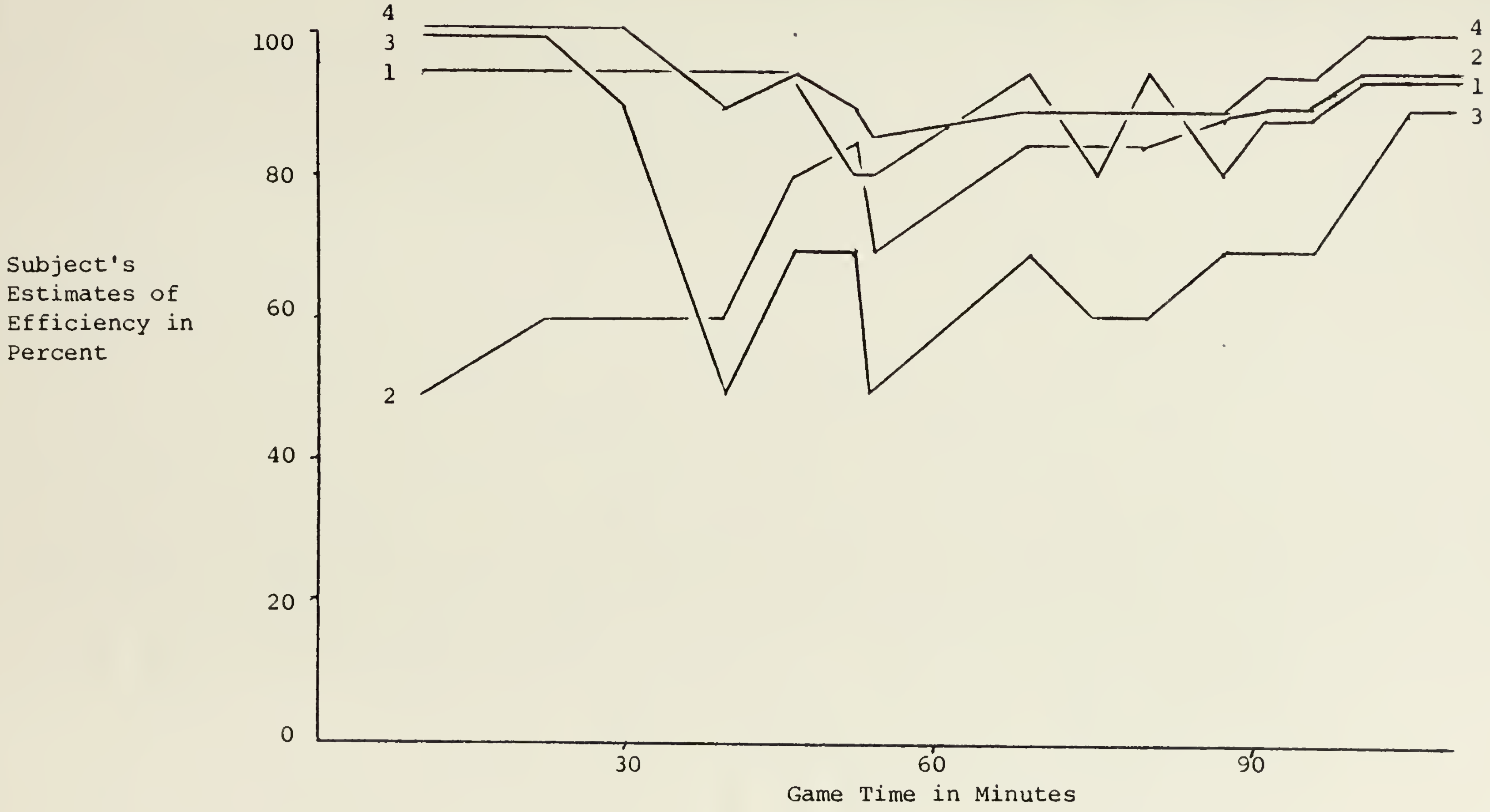

Subject's Estimates of Efficiency in Percent
100
80
60
40
20
0
4
3
1
2
4
2
1
3
30
60
90
Game Time in Minutes

FIGURE IV-d

of this chapter though.

[illegible]. MODEL VARIATIONS

The data were run through four versions of our model. The first version of the model was as discussed in the last chapter (linear data availability function). The second version was different in that the data availability function was exponential instead of linear, that is to say that having 50% data availability created in the model an effectiveness value of 75%, and so on down an exponential curve. A third version of the model consisted of entering the relevancy graph, grouping the high and very high responses together instead of grouping the optimum, high and low responses together. The last version consisted of a combination of the second and third versions. The reason these versions were put together was to attempt a sensitivity analysis of these versions in an effort to determine which version was actually closer to how the subjects functioned.

In order to determine which version of the model, if any, was consistently closer to the way the subjects functioned, we need to establish some measure of fit between the model generated efficiencies and the subject's estimates. For this purpose I choose to take the standard deviation between the subject's estimates and the model generated efficiencies for the duration of each game. Since I was doing a factor analysis which required 36 runs of the data through

the model per data set, I could then construct a graph of increasing standard deviations for each data set run through each version of the model. I ranked each group of 36 runs from lowest to highest standard deviation and graphed them.

Figure IV-a graphically portrays the most obvious difference of the four sets of data when run through each model. The curves of the linear and exponential data availability functions have considerably lower standard deviations than the curves representing the involvement of the interpolated high load and low load functions that are used to enter the relevance graph of Figure III-b. You recall that we added two extra points to the graph in Figure III-a. Since there were no corresponding lines of information in Figure III-b, it was necessary to see whether utilizing the higher valued entry lines or the lower value entry lines was more in line with reality after observing the results of the experiment. This signifies that, for one set of data, the first or second versions of the model are most nearly in line with the subject's responses. The other sets of data showed this same trend, only to a lesser degree.

By doing this sensitivity analysis on the model, driving the standard deviation down by examining the effects of changing some inner functions of the model, we can now say that the results that we are interested in should probably come from one of the first two versions of the model. The next section of this chapter will deal with what the data may show us about the decision makers in our experiment.

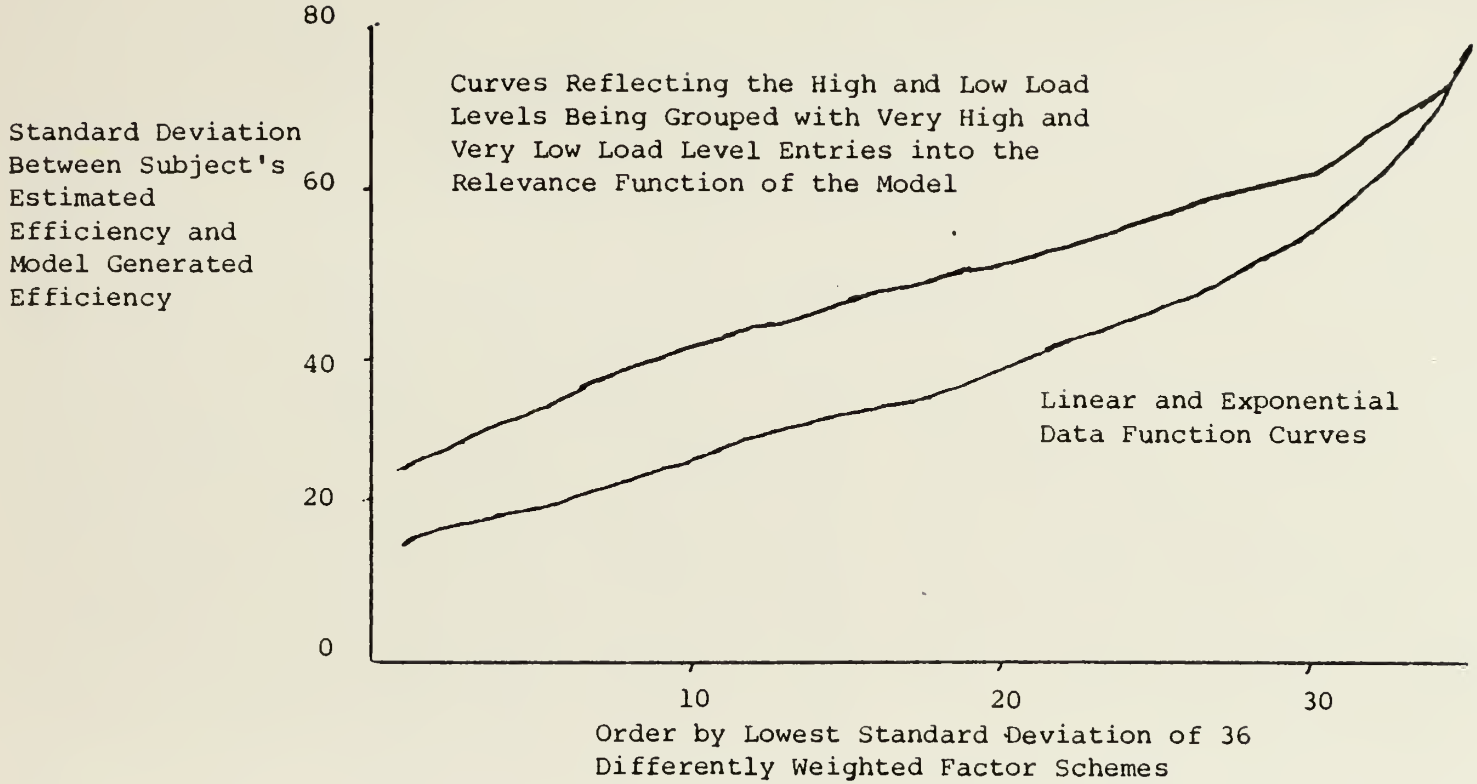

Standard Deviation Between Subject's Estimated Efficiency and Model Generated Efficiency
80
60
40
20
0
Curves Reflecting the High and Low Load Levels Being Grouped with Very High and Very Low Load Level Entries into the Relevance Function of the Model
Linear and Exponential Data Function Curves
10
20
30
Order by Lowest Standard Deviation of 36 Differently Weighted Factor Schemes

FIGURE IV-e

C. MODEL RESULTS

Having determined that two of the versions of the model may apply to the results of the model runs, we now want to see exactly what information we could derive from the those results. The process of analysis will be to first order each data set run by standard deviation. We will plot the results again, but this time we will plot the relative weights assigned each primary variable of the model (load, relevancy, and data availability) vs. the order of the run by standard deviation. What we would hope to find in our graphs is a common factor that will tell us something about the subject's perception of behavior in the environment in which the data was taken.

Figure IV-f is characteristic of the appearance of all these graphs. We see load level having the heaviest weight at the lowest standard deviation, with relevancy and data availability at the lowest point. As we move back in the order, we see that the weight of the load factor decreases as the relevancy factor increases, the data availability remaining constantly low. This interaction was common for all plots in that the data availability always started at the lowest point and moved up slowly as load and relevancy interacted. Load and relevancy were almost equally divided as the important factor (highest weight) of all the runs. That would lead us to the conclusion that the amount of data availability is of the least concern to the subjects tested.

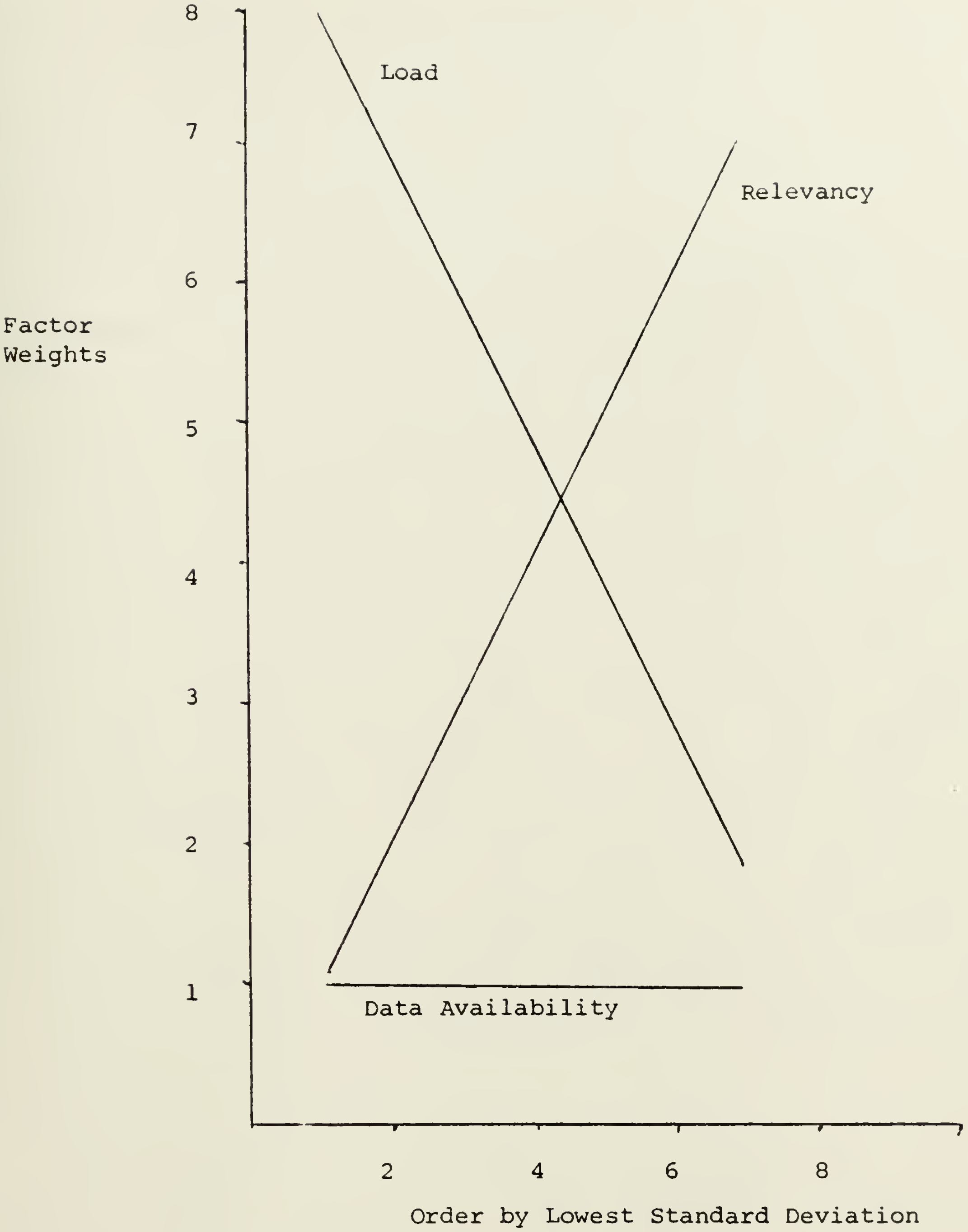

8
7
6
5
4
3
2
1
Factor Weights
Load
Relevancy
Data Availability
2
4
6
8
Order by Lowest Standard Deviation

FIGURE IV-f

Noting also that the best correlation was accrued (smallest standard deviation) when load was weighted heaviest, we can draw the conclusion that the subject's assessment was almost entirely driven by his loading.

But is this conclusion valid in a broader sense, or have the results been biased in some fashion? The fact that the data availability variable comes out as being least important of our three major variables leads us to re-examine the data taking environment, namely the NES game. A closer look at the lab environment and the game indicates that there is considerably more data available to the decison maker than would be expected in a real command center in tactical operations, and the close proximity of the data physically to the decision maker tends to further exaggerate this availability. This generous data availability was properly spotlighted by the model, so we can make some statement to the effect that the model did at least function well enough to pick up the correct weighting factor of the data availability in our analysis.

From the analysis of the data we have been able to accomplish three things. We have conducted a sensitivity analysis to determine how to adjust model functions to optimally reflect the subject's self assessments of the command center situation. We have then been able to determine, within the test environment, which variables in the model were most crucial and least crucial to the decision making processes of our test subjects. Perhaps more importantly, we

have seen the need for a new source of test data to further investigate the area of human factors via factor analysis, recognizing that we can make no broad statements based on the data and source we used in this study. The concept of the shock factor, which we also wanted to investigate, received insufficient data for any analysis.

V. STUDY RESULTS AND COMMENTS

In closing this study of human factors in a command center environment, I think it is essential that we discuss three major areas that have influenced the initiation, progress, and results of the study. We want to first discuss some of the problems of dealing with a topic of human behavior. Next we examine the testbed from which the data came, especially since that testbed is newly installed at the Naval Postgraduate School. Lastly we discuss the motivation for the project and whether it lived up to expectations.

A. PITFALLS OF HUMAN FACTORS RESEARCH

Any research done involving human factors is susceptible to some potential pitfalls that need to be planned around or compensated for. When you take data from a group of individuals, you must be sure that they are as homogeneous or heterogeneous as is required by the research you are attempting to do. In the case of this thesis I required a homogeneous group of field experienced military officers. My subjects in this case were all O-3's with 4-6 years of field experience in operational billets. Since the participants were making decisions in a wargaming environment, the fact that decision makers all exhibit different mental processes in accordance with their personal traits and experience was

considered when the data was evaluated and analyzed. The environment in which any data is gathered can have a definite influence on that data. The environment for the data is discussed in detail in the next section on LES as a data source.

There are two more important pitfalls which may have adversely affected this study. The first is the utilization of self-assessment as a portion of the data collection. It is possible that this could generate some dangerously misleading data for individuals. In order to facilitate detection of this problem and in an effort to minimize any potential effects it might have, I employed the assessments of several individuals in the test game instead of any single individual. By graphing out the raw data I could look for any inconsistencies which would indicate that the self-assessment was a problem in the data (this problem did not appear). The other pitfall is that of attempting to utilize totally subjective responses from participants, comparing one set of personal evaluations with an overall personal evaluation to achieve quantitative results. For confidence in the results, a careful selection of objective quantitative measures should be sought, to correlate objective data with subjective evaluation. For example, data relevancy could be obtained by counting the data provided to the subject as either relevant or irrelevant.

H. NWES AS A DATA SOURCE

The experimental data was taken from participants playing a convoy scenario using the NWES program at the C3 Lab at the Naval Postgraduate School. The data gathered here is subject to possible bias because of the environment from which it was taken. Let's take a close look at the game itself and its good and bad points, and consider their respective impacts on the data.

The game is played in a secure lab. This lab is capable of being divided up into three smaller areas, or command centers (Blue, Orange, and Umpire). Each area has one color graphics display using symbology similar to an NTDS presentation. The teams can change the scale of their displays as well as select which items (air-surface-subsurface-friendly-enemy-neutral-or any combination thereof) they desire to have displayed. In addition to the graphics display, each area has an order input CRT and a status board CRT from which information can be queried. Other stations are available in each area to utilize decision aids if available and desired. The game itself is time variable from real time to 1/6th real time. Information, interactions between units, and displays are generated in one game minute intervals. Life-like time delays for order responses are built into the program, along with equipment failures based on the mean time between failures listed in the game's database. The database can be that of a previously run, canned

scenario, or the user can create his own scenario and database (at the expense of many tens of man-hours).

There are some obvious advantages to using the WES game for collection of data. Since it is run in a secure mode, classified, real life databases can be used by participants, making the evolution more realistic. The game is computer driven, so the need for excessive amounts of manual umpiring and battle damage assessment disappears.The program has the advertised capability of reviewing the game with graphics as it was played by saving the game on tape. New technology of sensors or weapons can readily be created in the database, and new decision aids can be utilized in the command areas to evaluate their usefulness to the decision makers.

WES does have several limitations as a research tool for a project like ours. The first is the current lack of realistic, off-the-shelf scenarios. The force capability parameters are not accurate, and, importantly, force composition always favors the blue side. Another weakness is that all communications are done through one CRT terminal, so there is nothing available to simulate the detrimental effects of multiple lines of communications (confusion, redundant or conflicting reports). The amount of data available to the players appears to be more than would be considered realistic, and it is certainly more centralized and easily attainable than would generally be the case in a tactical environment. The pressure of a tactical environment does not exist. These factors all combine to eliminate some of the pressure

out on an actual command center. This is a significant problem since it makes the concept of reliance on WES as a sole data source for time or workload constrained experimentation questionable.

Aside from the game's characteristic limitations, there are other problems to be encountered in this new facility of simulation techniques. With any new testbed like the C3 Lab, there are growing pains. It has taken time to resolve interface problems between the C3 Lab and the host game computers. Hardware problems at the host computers have caused planned experimentation to be cancelled. Little or no coordination between host and users has been evident when crypto card removals are executed. Most host computers are not capable of running more than one WES game at a time, and unscheduled entries into the system tend to slow the game down intolerably. Pre-emption by higher authority can monopolize the host computer for periods of up to a week. However, better scheduling and coordination will eventually evolve into a more reliable system, or so it is hoped.

C. IMPORTANCE OF HUMAN FACTORS IN C2

The human factors impact on a C2 system is one of the least discussed and investigated areas in the field. The graduate level program at the Naval Postgraduate School is a mixture of technical courses with the addition of some National Security Affairs courses. The only insight into human

factors was obtained during our study of computer graphics, where we learned how to make graphics more attractive and pleasing to the human eye. Since the curriculum was generated with the advice and consent of the best C2 minds in the nation, it is safe to say that they are more concerned with the technical aspects of the field. What I find annoying about this is that since a C2 system is designed around a decision maker (read human being), I, as a graduate level expert in the field, have little or no concept outside of fleet tactical experience of how a human in the system will react in various situations.

This thesis was undertaken in an attempt to observe and analyze how some human operators actually behaved in a command center (an area in which I had some experience). Although there were several reference sources available (see bibliography), they were for the most part vague, general, and as a whole not very instructive. By taking graphically portrayed and experimentally related information on loading and relevancy and combining them with my own concepts of data availability, I set up an algorithm to analyze these three major variables. Although the data source was not comprehensive (as discussed in [illegible] as a data source) I profited from the admittedly incomplete and preliminary study of human reactions that has been described here.

Human factors research in the C2 context needs to be pursued with more vigor. Although he is not as glamorous as creating new hardware for C2 architecture, the man-in-the-

loop should not be overlooked. Considering human needs and frailties could save many headaches and dollars in the long run. It is important to remember that all the communications devices, displays, and their interfaces, plus various decision aids are finally in the service of a human decision maker with human capacities and human frailties.

D. SUMMARY

This thesis has attempted to provide some insights into the human factors that should be considered when discussing a C2 system. Along these lines we discussed a general model for a C2 system. We then examined the human variables of load, relevancy, and data availability and how they function individually in the human decision process. Our next step was to develop an algorithm with which we could perform a factor analysis on the afore mentioned variables to determine if there was any set pattern used by decision makers within these variables.

The data gathered did present a discernable pattern when put through the algorithm. However, because of the environment from which the data was gathered, we can only determine that the pattern was valid for the test environment, and we cannot make any broader statement. There was a potential weakness in the data in that it was composed entirely of subjective inputs being related to objective inputs. After subjective and objective inputs have been correlated the

process and model should be able to make more definitive statements and reach broader conclusions. We have carried out a pilot study toward that goal.

This work offers several items to the reader. A general description and model of a C2 system have been provided. Some insights are gained into individual human factors and the problems encountered when attempting to do research on them. Potential pitfalls of dealing with human factors, subjective inputs, and an oversimplified environment are identified. Although the purpose of finding a solid pattern of interrelationships between the variables on a broad scale could not be accomplished, there is sufficient merit in the work to warrant consideration of experimental redesign and further studies in this area.

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