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A PROPOSED COMPUTER-ASSISTED DECISION
MAKING SYSTEM FOR
THE HELLENIC NAVY DECISION MAKERS

by

Haralabos Athanasopoulos

March 1987

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The Hellenic Navy currently avoids the use of computers in all functional areas except for routine bookkeeping. Some individual, societal cultural and institutional military factors that influence this attitude are explored. To correct this situation, it is proposed that a staff Information Systems Officer specialty be established, capable of creating the interface between the decision maker and modern computer systems. A computer-assisted decision making system is proposed that can be used by the Hellenic Navy decision maker. FInally, three representative problems are proposed and solved using such system, to demonstrate the power of modern computer-assisted decision making.

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A Proposed Computer-assisted Decision Making System for the Hellenic Navy Decision Makers

by

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Submitted in partial fulfillment of the requirements for the degree of

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ABSTRACT

The Hellenic Navy currently avoids the use of computers in all functional areas except for routine bookkeeping. Some individual, societal, cultural and institutional military factors that influence this attitude are explored. To correct this situation, it is proposed that a staff Information Systems Officer specialty be established, capable of creating the interface between the decision maker and modern computer systems. A computer-assisted decision making system is proposed that can be used by the Hellenic Navy decision maker. Finally, three representative problems are proposed and solved using such system, to demonstrate the power of modern computer-assisted decision making.

THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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I. INTRODUCTION

There exist people and whole societies of people that are not technologically oriented or inclined. Usually, these peoples' lives and functioning patterns are ruled by their deep roots and attachment to their highly traditional and cultural values. Furthermore, these people have a tendency not to readily accept or adopt solutions that are offered by technological innovations and their agents. They have this tendency even though they are exposed to and aware of the numerous successful solutions that other, technically oriented people and societies have found in their pursuit of controlling consumption of scarce natural resources, of restoring and preserving the endangered planet's environment, of improving mankind's living standards, and generally in advancing science and improving whatever the scientific research can produce. The latter invest in research[1] and find solutions by using new and highly technical methods of problem solving. The former are characterized by some kind of inconvenience when it comes to trusting and adopting such technological methods and solutions. We think that the biggest problem between these two groups of people is the fact that they cannot communicate properly either because they do not understand each other or because they do not know how to deal with one another, or both.

This naturally applies to the respective military societies as well since they are a natural part of their societies and they are characterized by the same cultural norms and ways of living, thinking and general functioning.

In this thesis, we will adopt the relatively new division of the military into two broad categories: the "institutional" military and the "occupational" military [Ref. 1]. *Institutional* refers to the military that is grounded in its own special values and norms. Its members are not motivated by self-interest but, rather, by service to a higher goal: duty, honour, country. It is the institutional military who do not readily implement technology. The *occupational* military is usually motivated by self-interest, not only by the call of duty. They are the ones who pursue technological answers to problems.

[1] This is what research does; it smooths out contradiction, makes things simpler, logical and coherent.

The Greek military is recognized as belonging to the typically institutional military. The Hellenic Navy, though, after a long period of preparation, has adopted computers in fields like inventory control and payroll, mainly due to the complexity of modern operations. However, it is, in the whole, very reluctant to extensively adopt the computer, not only as a decision aid, but generally in anything outside the above mentioned fields, unless the technological innovation is correctly introduced. On the other hand, it is highly likely that they will soon have to consider computer aid in many other fields because modern naval warfare, military operations and weapons are reaching new heights of complexity every day. Therefore, decision-making in the Navy will have to become faster, more effective and more rational than ever before. This is a field in which the Greek military leader should consider the use of computers very soon. But given he is of the institutional military, he will not readily allow the computer to take an active part in his decision making activities and procedures, because this is a field where personal and organizational experience and intuition are the main and traditional factors.

The goal of this thesis is to try to influence the institutional military leader's attitude toward the usefulness of the computer, especially its use in decision-making processes. In Chapter II we investigate and expose to him the real reasons for which we believe he is not prepared to readily accept and adopt high technology solutions to his problems, especially his decision making problems. We claim that the reasons are hidden behind his culture and stable norms.

Then we will try to model an indicated method of approach, one that will possibly succeed in changing his attitude towards accepting and adopting technological innovations. This is done in Chapter III by some in depth analysis of the diffusion of technological innovations.

Chapter IV contains some essential pieces of information about current technology and computers which we feel that an institutional military should know, if he is interested in surviving the "computer revolution", which we think that he is neither totally aware of, nor properly prepared for.

After a review of modeling concepts and of the decision making process, in Chapter V we present the capabilities, limitations and the current status of the computer in assisting decision making. Then we propose an indicated procedure, that may, according to our expectations and based on our arguments, contribute in changing the Greek naval decision maker's attitude toward computer-assisted decision making.

Finally, in Chapter VI we develop two different kinds of programs in order to find fast and rational solutions to some typical naval decision making problems, using the computer. We use two powerful techniques that find application in Operations Research, namely computer simulation and linear/non-linear optimization. The listings of the developed programs are given in the appendices.

Hopefully, the transfer of knowledge about himself, about the others and about the computer that will be attempted in this thesis, together with a modest "demonstration" of the ability of the computer in assisting decision making, will be persuasive and will help the institutional military, specifically the Hellenic Navy, to develop a basis on which *to at least consider the possibility* of including the computer in existing and future decision making situations. This would be for us a reasonable and justified achievement.

II. THE INSTITUTIONAL MILITARY

A. BACKGROUND

There are two related crises in today's world. The first and most visible is the population/environmental crisis. The second, more subtle but equally lethal, is humankind's relationships to its extentions, institutions, ideas, technology and progress, as well as the relationships among the many individuals and groups that inhabit the globe. The most important and fundamental difference between these various groups is the difference in culture.

If both crises are not resolved, neither will be. Despite our faith in technology and our reliance on technological solutions, there are no technical solutions to most of the problems confronting human beings. Furthermore, even those technical solutions that can be applied to environmental problems cannot be applied rationally and with determination, until mankind transcends the intellectual limitations, imposed by our institutions, our philosophies, our religions and our cultures. Compounding all of this is the reality of politics.

Politics is a major part of life -beginning in the home and becoming more and more visible as power is manifest in the larger institutions on the local, national and international levels. But apart from power and politics, culture still plays a prominent visible role in the relations between the East and the West, for example. Culture has always been an issue, not only between Europe and Russia, but among the European states as well. The Germans, the French, the Italians, the Spanish, the Portuguese, the Greeks and the British as well as the Scandinavians and the Balkan cultures, all have their *own* identity, language, systems of nonverbal communication, material culture, history and *ways of doing things* [Ref. 2: p. 1].

At the moment, Europe is prosperous, temporarily calm and causing few problems. But what about the clash of cultures in the Middle East, the Far East, the multiple African and Latin American cultures, that are all demanding to be recognized in their own right? Any Westerner who was raised outside these cultures and claims he really understands and can communicate with any of them is deluding himself. In all these crises, the future depends on man's ability to transcend the limits of individual cultures. To do so, however, he must first *recognize and accept* the multiple hidden dimensions of unconscious culture; because every culture has its own hidden, unique form of unconscious culture [Ref. 2: p. 2].

Technology is not likely to *directly* assist in this direction because these are human problems. Hardin argues [Ref. 3] that single-track, Newtonian (Apollonian) approach will satisfy only the politicians and the big exploiters who stand to gain from oversimplification of issues. What is needed is a more comprehensive, Darwinian (Dionysian) approach [Ref. 4: p. 188] that can be used as a basis for establishing priorities, alternatives and options.[2] In other words, unless human beings and human decision makers can learn to pull together, control the resources and regulate consumption and production patterns, they are headed for disaster. It is impossible to cooperate or to do any of these things unless we understand or know each other's *ways of thinking*.

Mankind is then in need of the best possible decisions and solutions. This is a great responsibility and we would like to believe that the top decision makers, no matter to what society they belong, are aware of their responsibilities as much as of the difficulty of really understanding each others' way of thinking.

A good part , though, of the decision makers are military and today, as in the past, military forces are major users of current technology. Understandably, this improves their effectiveness and helps them in accomplishing their specific objectives. The question, however, is whether they could use technology to assist or even improve their part of decision-making.

The point is that while maintaining a degree of autonomy, *any* military force necessarily reflects the society and the culture of which it is a part. Therefore, since this thesis is focused on the military decision making, we should try first of all to understand the military and their societies.

B. CULTURE AND THE MILITARY

1. Facts about Culture and Context

In order to be able to understand better the military societies and their idiosyncrasies, we must look into the cultures they are part of, because everything depends and is deeply rooted in each culture and its extentions.

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[2]According to the old Greek system, there are two types (systems) of evolution and progress; the Apollonian, "which tends to develop established lines to perfection", and the Dionysian, "which is more apt to open new lines of research".

Culture is man's medium and all aspects of human life are touched and altered by culture. This means personality, how people express themselves (including shows of emotions), the way they think, how they move, how problems are solved, how their cities are planned and laid out, how transportation systems are organized and function, as well as how economic, government and military systems are put together and function.

Nevertheless, and in spite of many differences in detail, anthropologists agree on three characteristics of culture; it is not innate, but learned; the various facets of culture are interrelated -you touch a culture in one place and everything else is affected; it is shared and in effect defines the boundaries of different groups.

One of the functions of culture (and in fact a major structural feature of the unconscious culture) is to provide a highly selective screen or filter between man and the outside world. In its many forms, culture therefore designates what we pay attention to and what we ignore. This screening function provides structure for the world and protects the nervous system from "information overload".[3] *The degree to which one is aware of the selective screen that one places between himself and the outside world* can be measured on the "context" scale. The degree of "context" or the position that a culture holds on the context scale is one of the major characteristics of culture and it can be used for general culture's classification purposes. That is, one can classify cultures as being near the low-context (LC), the middle, or the high-context (HC) end of such a continuum [Ref. 2: p. 86]. Under this notion, we can define people as being low-context (LC) and high-context (HC). As one moves from the low to the high side of the scale, awareness of the selective process increases. Therefore, what we pay attention to, context, and information overload are all functionally closely related. But who uses more and who uses less of this selective "filtering" and when?

2. **Context, Timing and Stability**

The solution to the problem of coping with increased complexity and greater demands on the system seems to lie in the preprogramming of the individual or the organization. This is done by means of the "contexting" process and it all depends on how people use *time* and *space*.

---

[3]Information overload is a technical term applied to information-processing systems. It describes a situation in which the system breaks down when it cannot properly handle the huge volume of information to which it is subjected.

According to Hall [Ref. 2: p. 17] people, their societies and cultures can be characterized as "monochronic" (M-time) and "polychronic" (P-time). Monochronic time and polychronic time represent two variant solutions to the use of both time and space as organizing frames for all activities. Space is included because the two systems (time and space) are functionally interrelated. M-time emphasizes schedules, segmentation and promptness. P-time systems are characterized by several things happening at once. They stress involvement of people and completion of transactions rather than adherence to preset schedules. P-time is treated as much less tangible than M-time. Polychronic time, as the term implies, is nonlinear, while monochronic time is linear.[4] It is in this respect that cultures very often contrast with each other. M-time people overseas are psychologically stressed in many ways when confronted by P-time systems such as those in Latin America and the Middle East. In markets and stores of Mediterranean countries, one is surrounded by other customers vying for the attention of a clerk. There is no order whatsoever as to who is served next and to the northern European or American, confusion and clamor abound. In a different context, the same patterns apply within the governmental bureaucracies of the Mediterranean countries: a cabinet officer, for instance, may have a large reception area outside his private office. There are almost always small groups waiting in this area and these groups are visited by government officials, who move around the room conferring with each. Much of their business is transacted in public instead of having a series of private meetings in an inner office. Particularly distressing to Americans is the way in which appointments are handled by polychronic people. Appointments just don't carry the same weight as they do in the United States. Things are constantly shifted around. Nothing seems to be solid or firm, particularly plans for the future, and there are always changes in the most important plans right up to the very last minute.

In contrast, within the Western world, man finds little in life that is exempt from the iron hand of M-time. In fact, his social and business life, even his sex life, are apt to be completely time-dominated. Time is so thoroughly woven into his existence that we are hardly aware of the degree to which it determines and co-ordinates everything we do, including the molding of relations with others in many subtle ways. By *scheduling* we *compartmentalize* ; this makes it possible to concentrate on one thing

[4]There are many different and legitimate ways of thinking; people in the West value one of these ways above all others --the one we call "logic", a linear system that has been with us since Socrates. In contrast, a P-time person can be said to be "parallel processing", which is also, interestingly enough, the current wave of research into computer architecture.

at a time, but at the same time it denies us context. M-time people speak of time as being saved, spent, wasted, lost, made up, accelerated, slowed down, crawling or running out. These metaphors should be taken very seriously, because they express the basic manner in which time is conceived as an unconscious determinant or frame on which everything else is built. M-time scheduling is used as a classification system that orders the fast, busy, high-tech life of the Western civilization. Without M-time scheduling and systems, it is very doubtful if our industrial civilization could ever have developed as it has. Furthermore, the great use of computers in the M-time societies has an interesting role, because the more you work and depend on computers the more you need to respect and obey tight time-keeping rules and scheduling; the computer does not waste time and demands strict programming. The reverse also holds: the more you exercise scheduling, the more you need to work and depend on computers. It is a closed and increasing loop that characterizes the fast-paced, time-conscious societies, like the monochronic; but the same do not apply to the polychronic ones.

Scheduling is difficult if not impossible with P-time people unless they have mastered M-time technically as a very different system, one they do not confuse with their own but only when it is situationally appropriate, much as they use a foreign language.

Theoretically, when considering social or military organizations, P-time systems should demand a much greater centralization of control and be characterized by a rather shallow or simple structure. This is because the top man[5] deals continually with many people, most of whom stay informed as to what is happening: they are around in the same spaces, are brought up to be deeply involved with each other and continually ask questions to stay informed. In these circumstances, delegation of authority and a build-up in bureaucratic levels should not be required to handle high volumes of business. As function increases, one would expect to find a small proliferation of small bureaucracies as well as difficulty in handling the problems of outsiders. In polychronic countries, one has to be an insider[6] or else have a "friend" who can make things happen.[7]

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[5]Also in HC systems, people in places of authority are personally and truly responsible for the actions of subordinates down to the lowest man. In LC systems, responsibility is diffused throughout the system and difficult to pin down. Paradoxically, when something happens to a low-context system, everyone runs for cover and "the system" is supposed to protect its members. If a scapegoat is needed, the most plausible low-ranking scapegoat is chosen.

[6]All bureaucracies are oriented inwards, but P-type more so.

There is still an interesting point to be made that concerns the act of administration as it is applied in these two settings. Administration and control of HC polychronic people is a matter of job analysis. Administration consists of taking each subordinate's job and identifying the activities that go to make up the job. These are then named and frequently indicated on the elaborate charts with checks that make it possible for the administrator to be sure that each function has been performed. In this way, it is felt, absolute control is maintained over the individual. Yet, how and when each activity is actually attended to is up to the subordinate. To schedule his activities for him would be considered as a tyrannical violation of his individuality. In contrast, LC M-time people schedule the activity and leave the analysis of the parts to the individual. A P-type analysis keeps reminding the subordinate that his job is a system and is also part of a larger system. M-type people, by virtue of compartmentalization, are less likely to see their activities in context as a part of the larger whole.

Both systems have strengths as well as weaknesses. There is a limit to the speed with which jobs can be analyzed, although once analyzed, proper reporting can enable a P-time administrator to handle a surprising number of subordinates and tasks. Nevertheless, organizations run on the polychronic model are limited in size, depend on having gifted men at the top and are slow and cumbersome when dealing with the business of outsiders or have to perform changes in their system. No one likes to give up his stereotypes, especially so the P-type and this is because *HC actions are by definition rooted in the past, slow to change and highly stable.* Even when it comes to every day transactions with LC people there are many problems to be solved; HC polychronic transactions feature preprogrammed information that is in the receiver and in the setting,[8] with only minimal information in the actual coded, explicit, transmitted part of the message. LC monochronic transactions are the reverse. Most of the information must be vested in the explicit code and in great detail in the transmitted message in order to make up for what is missing in the context. HC communication, in contrast to LC, is economical, fast, efficient and satisfying; however, time must be devoted to programming, *but not in haste.* And this is because HC polychronic cultures, more than often, place completion of a job in a special category much lower than the importance of being nice, courteous, considerate and sociable to others. As a

[7]Anglos generally do not understand, in fact distrust, the role of the intermediary and don't know how to use it themselves.

[8]What an organism perceives is influenced in four ways: by status, activity, setting and experience. But in man one must add another crucial dimension: culture.

consequence, their action chains[9] are built around human relations. To be too obsessional about achieving a work goal at the expense of getting along is considered by them aggressive, pushy and disruptive. In effect, two people engaged in the same task, one of them polychronic and the other monochronic, will view the entire process from very different angles and will have not only a different set of objectives but different priorities as well.

Applying all the above important cultural facts and differences to the military, we can then claim that there are military societies which consist of polychronic high-context people (P-time, HC) and some other military societies which consist of, *in many ways* different, military, which are monochronic and low-context (M-time, LC).

However, there is one further basic distinction we feel we should make between the various military organizations. It is the relatively new and bold distinction of the military which we mentioned in our introduction; the "institutional" and the "occupational" military. This is necessary if we wish to make our study more complete.

C. INSTITUTIONAL VS OCCUPATIONAL MILITARY

1. The I/O Thesis

For nearly fifteen years some behavioral scientists, primarily sociologists, interested in military organizations have debated the issue of whether the military is an institution or an occupation. Charles Moskos, professor of sociology at Northwestern University, is the preeminent scholar on the subject, having first proposed the "institution vs. occupation" (I/O) thesis in the mid-seventies as a way of understanding changes that seemed to be taking place in the all-volunteer forces. Moskos' theoretical and empirical work on I/O is by no means universally accepted; but it has created a tremendous amount of interest and stimulated an enormous literature. In June 1985 the U.S. Air Force Academy hosted a conference to examine Moskos' and others' formulations concerning the U.S and several other foreign military forces. [Ref. 1]

The I/O thesis postulates a continuum on which military organizations can be placed. At one end the organization is virtually separate and autonomous - "institutional" - and at the other it mirrors the larger society, or is "occupational".

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[9]An action chain is a set sequence of events, a transaction, in which usually two or more individuals participate. The degree to which one is commited to complete an action chain is another way in which cultures vary. In general HC cultures, because of the high involvement people have with each other, tend toward high commitment to complete action chains. This is the main reason behind their characteristic "stability". In a quite opposite way, that shows their "instability", LC people will break a chain at the drop of a hat if they don't like the way things are going or if something or someone better comes along.

While no military force is at either extreme, and the two conditions are not mutually exclusive, the notion of such a continuum is useful as a way of understanding how social trends can affect the military, their decisions and, ultimately, how well they will perform; it is by no means implied that one is "better" than the other, they are just different.

2. **Institutional**

The institutional military is grounded in its own special values and norms. Its members are not motivated by self-interest but, rather, by service to a higher goal; "duty, honour, country" captures the idea. Members of an institutional military see themselves as following a calling or a profession [Ref. 1: p. 2]. Pay is usually lower for recruits than that offered to their age counterparts in the civil sector. There are non-pecuniary benefits unique to the institutional military, e.g. housing, subsistance, clothing, early retirement, medical and family care, and the like. Members of an institutional military resolve their grievances through the chain of command rather than by collective action. Other attributes are that members are on call 24 hours a day, they and their families are subject to relatively frequent displacement and they are subject to a military disciplinary system that differs from civil law. Most members of an institutional military are subject to the hazards of combat and, in the extreme case, may have to sacrifice their lives. Finally, military leadership clarifies the meaning of service, sets no limits of obligation for military personnel and creates and sustains a corporate moral code.

It appears that nations with a long history, especially of fighting defensive wars, are more likely to develop institutional military. Long detente periods do not favour institutionalism.

3. **Occupational**

As characterized by Moskos, at the other end of the continuum, the occupational military is defined by competition and its effects on wages. Supply and demand determine the rewards that a serving member receives. For the individual, self-interest rather than the needs of the organization is paramount. The occupational model assumes no important differences between a civilian job and a military career, at least with respect to compensation and most aspects of lifestyle. One is paid according to his skill and degree of availability, i.e people who are in short supply earn more than those who are not. Further, all pay, allowances and benefits are combined in a single salary. The work orientation of these military is shifting to a sense of "it's just another job". Further, because the military mission has become so dependent on technology, the status of some service occupations has changed. The U.S Air Force, for example, is forced to rely on civilian experts and other "outsiders". The prestige of wearing wings has diminished and those in managerial roles are perceived as having higher status. [Ref. 1: p. 2]

We could say that relatively new and technically oriented nations, that usually fight offensive wars or never had the chance of fighting at all, are more likely to have occupational-type military forces. Leadership does not act to shape and clarify values or moral codes, so consequently the social forces define values by default. Defensive war is generally the antidote to occupationalism, which could be characterized, with a small probability of error as a peacetime phenomenon.

4. **Cross-national comparison of some known military**

At this point, it would be helpful to try to identify and characterize some of the well known military communities under the I/O thesis concept, as they were examined during the earlier mentioned conference. [Ref. 1: pp. 5-7]

The French military has been and continue to be more of an institution than an occupation: there are very few women in uniform; conscription, although still in force, is diminishing in terms of its democratizing effects; the army, which has not been in combat for over 20 years, is returning to traditional values like rigor, discipline and esprit; moonlighting by servicemen is strictly prohibited by French law; there is an extreme form of pay decompression: senior NCOs earn 25 times the salary of recruits; and the public images of the French civil service and the military are good: both are seen as prestigious and competent. We can conclude with the observation that the high status of the military reflects a sharply rising unemployment rate and a gradual shift towards more conservative values.

In the UK forces, we can observe that the British regimental system -in which men are recruited, trained and permanently assigned to a local regiment- has most of the trappings of an institution: it becomes a family for its members, a home, an instiller of pride; and for its officers it becomes a social club. There is no room for moonlighting. Military service in Britain is seen as filling a vital need in the same way that medical or religious professions do. But the modern military has to sell itself to prospective applicants in terms of training, adventure, service to country, as it can be seen by some current advertisements for officer programs. They all emphasize institutional rather than occupational aspects of service: "It's tough...can you take it?"

Also, the British military pay policies are supposed to provide a "fair reward for services" but are not intended to compete with the private sector; there is an elaborate system of special allowances. In contrasting U.S and UK values that underlie each nation's military service, we can say that the U.S societal norms are incompatible with maintaining a military force -Americans tend to be distrustful of standing armies- while in Britain there has long been a close tie between the civil and military sectors.

In West Germany, Bundeswehr enjoy a high degree of popular legitimacy because its defensive role is seen as important; proximity to Warsaw Pact forces is a constant reminder. Germany has both conscript and volunteer soldiers; the latter go through a trial enlistment and, as regular soldiers, they earn special education benefits. The orientation of the military is primarily occupational, with much training oriented towards civilian jobs. The use of conscription is a "guarantee of intellectual interchange" between the military and the general public, but conscription is not popular. Unlike the French, the Germans have a high degree of pay compression: the highest ranking enlisted earns only 2.2 times as much as a recruit. Also, in contrast to the French force, there is a good deal of moonlighting among military personnel and such work is seen as "an important leisure activity". The Bundeswehr is a wholly new creation of post-war Germany and its founders deliberately sought to make it occupational in character, for obvious reasons. There is, however, a generation gap in that young NCOs favour the present arrangement while older regulars are more inclined towards a separate, institutional military.

In the Dutch military, on the surface the force appears to be one of the most unconventional in the world: unionized conscripts, 70 percent reserve, and a high degree of occupational orientation. Yet, there is a deep sense of the need for an armed force and if there is war the Dutch will support the military by their participation.

The Greek forces were characterized primarily as being institutional, perhaps more so than any other Western force. Institutionalism is interwoven into Greece's continuous struggle for existence, through the aeons. Although there has been conscription for 40 years, the Greek military maintains its own separate norms and lifestyle. There is a high degree of pay decompression: a draftee earns $6/month and a senior sergeant's pay is $500. Military wives are accorded status commensurate with their husband's rank. Moonlighting is not only strictly prohibited by law, but it is also rarely conceived by the military themselves. There are separate legal systems, and all crimes involving military are tried in their own military courts. An unspoken public concern is that an institutional military can lead to another takeover of the government, not an unknown occurrence in Greece all through its long history. Since the mid-1970s there have been moves towards more democratization of the forces: some pay compression has occured, separate recruiting for technical occupations only is done, conscripts are given more freedom, women are slowly, but not too successfully, introduced into the forces, and there is agitation for a military union. The draft will continue to operate (although with reduced terms of service) and we can conclude that there is strong public support for the military.

In the Australian forces, according to a recent attitude survey, there is a high institutional orientation among army officers, although the navy and air force are more evenly divided. Among enlisted, the non-technical tend to be institutionally grounded, while technical NCOs see themselves as job holders. The air force pilots have the highest professional or institutional orientation of all groups when they are on flying status, but if they have non-flying jobs their orientation shifts to "it's just a job". A relatively new Australian policy that emphasizes officer education - undergraduate degrees, etc. - may be counterproductive: those officers with more formal education are institutionally oriented and less likely to remain for long careers. The Australian forces do not use retention bonuses, but retirement pensions are affected significantly by length of service: A commander retiring with 20 years of service receives a $40,000 tax-free lump sum payment in addition to his annual pension (which includes cost-of-living provisions), much like a Greek officer. The national industrial relations climate is changing in a parallel development with the military: surveys of active duty personnel have shown an increase from 30 percent to 70 percent favouring "collectivism" in the last six years.

The Israeli armed forces have some peculiarities.[10] Israeli Defence Force (IDF) has a permanent cadre that is 10 percent of the total force. Of the remainder, 65 percent are reservists and 25 percent conscripts. There is universal service required of all citizens who reach age 18: three years for men, two years for women. All former military men remain in an active reserve status until the age of 55, women until 34. Members of the small permanent cadre are not "career oriented" and they tend to leave active duty at a relatively early age. Legitimacy of the armed forces stems from a strong sense of obligation. Conscripts serve without payment and, on the basis of the nation's history, with a high probability of injury or death. Reservists serve 40 to 60

[10]Most of them are also found in Switzerland's forces.

days a year and are compensated only by their employers - or not at all if they are self-employed. There are few perks accorded military people; only air force pilots are provided base housing (because they are on permanent alert status). Because the country is so small, it is rare that a family is ever relocated. The larger society has high regard for the IDF. Social psychological studies have shown that senior officers enjoy prestige ratings of 96 (on a scale of 100), higher than those accorded religious or academic figures. Veterans' discharge papers show their fitness ratings, a practice that can affect job offers. In the last decade or so, the IDF has shifted from a "militarocratic" to a democratic model because of public criticism of the 1973 and 1982 wars. However, the size of the IDF has nearly doubled and there have been qualitative changes: officers have become more professional in their work but narrower in their perspectives of external matters. Moreover, during the Lebanese war, some highly regarded senior officers requested to be relieved and some reservists refused to answer their call-ups.

Finally, the U.S military appear to be on the occupational side of the I/O continuum, with the Air Force at the far end of that side. Career military people are largely motivated by self-interest and the military mission has become very much dependent on technology and budget. The occupational mentality is a reflection of the pervasiveness of economics. Historical evidence supports the notion that most people join the military out of financial need and that higher values come later [Ref. 1: p. 5]. The mixture of races and ethnicities in the forces and their relations cannot favour institutionalism, with a slight exception for the Marines, because "Marines do everything together" [Ref. 1: p. 5]. The global commitment of the U.S military forces and the revolution in labour force participation by American women has created serious conflicts: military men have added responsibilities at home because of their wives' careers, and wives are increasingly reluctant to accept the demands on them (e.g., to move frequently) made by the military. The growth of interest and investment in family service programs and in improving cohesion reflects the military's concerns about reducing these conflicts, promoting, however, occupationalism even more.

D. THE CONNECTION

Let us then try to express a conclusion that could summarize what appears to look like a fair result of our research, up to this point.

As things become more and more complex, as they inevitably must with monochronic, fast-evolving, high-pitched, high-tech, highly computerized LC military societies, the more difficult it becomes for the polychronic, slow-changing, high-filtering, low-tech, hardly computerized HC military to interact, communicate and exchange information with them. This is something to be expected, since they apply a different degree of filtering, in trying to cope with the overload of information they are both facing. However, since they both need to take the best possible decisions for the common benefit, some way of more effective communication must be found.

One wonders if it is possible to develop strategies for balancing the two apparently contradictory needs of the HC military: *the need to adapt and change* (by moving in the low-context direction) and *the need for stability* (high-context). History is full of examples of nations and institutions that failed to adapt by holding on to high-context modes and norms too long. The fact is that one cannot back-up with technology, once it is established. The instability of low-context societies, however, on the present-day scale is quite new to mankind. And furthermore, there is not enough experience to show us how to deal with change at such fast rate.

At this point, it appears that we could attempt to establish the desired connection of all the above with the discussed and interesting I/O thesis: institutional military are or have to be, in the whole, P-type HC people, while the occupational are usually M-type LC people. This conclusion, will hopefully allow us to realize the difficulties in attempting to persuade an institutional military to understand, appreciate, adopt and cope, from then on, with the much needed transition into high technology and computerization.

III. THE DIFFUSION OF AN INNOVATION

A. UNDERSTANDING THE CONCEPT

In order to be able to introduce the institutional military into a "new" highly technological computerized environment, different to their norms and with different ways of functioning, communicating and even thinking and living (for a good deal of them), we must proceed systematically and with great caution, keeping in mind all the facts and ideas that we mentioned so far. There is no time to be wasted. We must approach or communicate with them in a special way.

Until recently, most such approaches have been based upon a *linear* model of communication, defined as the process by which messages are transferred from a source to a receiver. Such a one-way view of human communication describes certain types of communication; many ways of "passing over" new ideas do indeed consist of one individual, such as a change agent, informing a potential adopter about a new idea. But many other approaches are more accurately described by a *convergence* model, in which communication is defined as a process in which the participants create and share information with one another to reach a mutual understanding [Ref. 5: p. 63].

Conceptually, we will use the two important concepts of uncertainty and information. *Uncertainty* is the degree to which a number of alternatives are perceived with respect to the occurrence of an event and the relative probabilities of these alternatives. *Information* is a difference in matter-energy that affects uncertainty in a situation where a choice exists among a set of alternatives [Ref. 5: p. 64]. The concept of information is a favourite in the field of communication research. The field really began to grow as an intellectual enterprise once Claude Shannon and Warren Weaver proposed, in 1949, a theory of communication that was organized around the notion of information [Ref. 6].

One kind of uncertainty is generated by an *innovation*, defined as an idea, practice, or object that is perceived as new by an individual, an organization or another unit of adoption. An innovation presents an individual or an organization with a new alternative or alternatives, with new means of solving problems. But the probabilities of the new alternatives being superior to previous practice are *not* exactly known by the individual problem-solver. Thus, they are motivated to seek further information about the innovation in order to cope with the uncertainty that it creates [Ref. 7: xviii]. Newness in an innovation need not just involve new knowledge. Someone may have known about an innovation for some time but not yet developed a favourable or unfavourable attitude toward it, nor have adopted or rejected it. The "newness" aspect may well be expressed in terms of persuasion or a decision to adopt.

B. WHAT IS DIFFUSION

Diffusion is the process by which an innovation is communicated through certain channels over time among the members of a social system. It is a special type of communication, in that the messages are concerned with *new* ideas. *Communication* is a process in which participants create and share information with one another in order to reach a mutual understanding. This definition implies that communication is a process of convergence (or divergence) as two or more individuals exchange information. It is the newness of an idea that gives diffusion its special character, because then uncertainty is involved; and uncertainty implies a lack of predictability, of structure, of information.[11]

1. Technological innovations, information and uncertainty

Presently, almost all of the new ideas are technological innovations, and we often see that "innovation" and "technology" are used as synonyms. An interesting definition of technology [Ref. 7: p. 12] that involves uncertainty (and information) is that *"technology is a design for instrumental action that reduces the uncertainty in the cause-effect relationship involved in achieving a desired outcome"*.

Technology usually has two components: (1) a *hardware* aspect, consisting of the tool that embodies the technology as material or physical objects, and (2) a *software* aspect, consisting of the information base for that tool. For example, we often speak of (1) "computer hardware", consisting of semiconductors, transistors, electrical connections and the metal frame to protect these electronic components, and (2) "computer software", consisting of the coded commands, instructions and other information aspects of this tool that allow us to use it to extend human capabilities in solving certain problems. But even though the software component of a technology is often not so apparent to observation, we should not forget that technology almost always represents a mixture of hardware and software aspects.

[11] In fact, information represents one of the main means of reducing uncertainty.

According to the above definition of technology, it is a means of uncertainty reduction for individuals (or organizations) that is made possible by the information about cause-effect relationships on which the technology is based. This information usually comes from scientific R&D activities when technology is being developed. Thus, there is generally an implication that technological innovations have at least some degree of benefit or advantage for its potential adopters. But this advantage is not always very clear or impressive, at least to the eyes of the intended adopters.

A technological innovation, computers for example, creates one kind of uncertainty in the minds of potential adopters about its expected consequences, as well as representing an opportunity for reduced uncertainty in another sense (that of the information base of the technology). The second type of potential uncertainty reduction, the information embodied in the innovation itself, represents the possible efficacy of the innovation in solving an individual's known need or problem; this advantage provides the motivation that pushes one to exert effort in order to learn more about the innovation. Once such information-seeking activities have reduced the uncertainty about the innovation's expected consequences to an acceptable level for the individual (or organization), then a decision to adopt it or reject it can be made. Thus, the innovation-decision process is essentially an information-seeking and information-processing activity in which the individual or the organization is motivated to reduce uncertainty about the advantages and disadvantages of the innovation (of the computer, in our case).

2. Characteristics of innovations

Technological innovations are not, in general, always diffused and adopted rapidly, especially when HC P-time people are concerned; and by now we should be able to guess why. But again, the rate of adoption depends on the adopter as much as on the innovation itself; it took five or six years for the (electronic) pocket calculator to reach widespread adoption in the United States, while the HC Japanese and Chinese still prefer to use the abacus for their everyday transactions (although they manufacture calculators at a rate faster than anyone else). On the other hand, new ideas such as the metric system or using seat belts in cars may require several decades to reach complete use. It is mainly the following characteristics of innovations, as perceived by individuals, that help to explain their different rate of adoption.

1. *Relative advantage* is the degree to which an innovation is perceived as better than the idea that it supersedes. The degree of relative advantage may be measured in economic terms, but cultural, social-prestige factors, convenience and satisfaction are also often important components.

2. *Compatibility* is the degree to which an innovation is perceived as being consistent with the existing values, context, past experiences and needs of the potential adopters. An idea that is not compatible with the prevalent values and norms of a cultural and social system will not be adopted as rapidly as an innovation that is compatible. The adoption of an incompatible innovation often requires the prior adoption of a new value system. For example, a HC P-time adopter of computer technology should first adopt the M-time values and ways of communicating.

3. *Complexity* is the degree to which an innovation is perceived as difficult to understand and use. If one needs to develop new skills to understand the innovation, it will surely take much longer for the desired adoption.

4. *Trialability* is the degree to which an innovation may be experimented with on a limited trial basis. An innovation that is trialable represents less uncertainty to the individual who is considering it for adoption, as it is possible to learn by doing.

5. *Observability* is the degree to which the results of an innovation are visible to others. The easier one can see the results, the more likely he or she is to adopt the innovation.

These are not the only qualities that affect adoption rates, but it is indicated that they are the most important ones in explaining rate of adoption [Ref. 7: p. 14].

3. Heterophily, ignorance and diffusion

An obvious principle of human communication is that the transfer of ideas occurs most frequently between two individuals who are alike, similar, or homophilus [Ref. 7: p. 18]. *Homophily* is the degree to which pairs of individuals or systems who interact are similar in certain attributes, such as culture, beliefs, education, social status, and the like.[12] In a free-choice situation, when an individual can interact with any one of a number of other individuals, there is a strong tendency for him to choose someone who is most like him -or herself. However, *one of the most distinctive problems in the communication of innovations is that the participants are usually quite heterophilous.* When a change agent, for instance, is much more technically competent than his "client", they simply do not speak the same language and their communication is ineffective.[13] The effectiveness of their communication depends on the complexity of the task to be carried-out and the *ignorance* that they share; that is, they are more than likely unaware of the important differences that exist between their cultures, their "timing", their context, even the fact that they are indeed heterophilous. Instead, misunderstandings may be attributed to other irrelevant factors like personality or

[12]This term and its opposite, *heterophily*, derive from the Greek words "homoios" and "heteros", meaning alike/equal and different/not equal (respectively). Thus, homophily literally means affiliation or communication with a similar person.

[13]In fact, when two individuals are identical regarding their technological grasp of an innovation, no diffusion can occur as there is no new information to exchange. The very nature of diffusion demands that at least *some* degree of heterophily be present between the two participants.

political direction. So, the whole communication process and the desired diffusion of a technological innovation to the adopter may become very difficult, painfully slow or even uncertain at times.

4. The Innovation-decision process

Therefore, in order to achieve a successful diffusion, the following steps of the *innovation-decision process*, suggested by Rogers [Ref. 7: p. 36] ought to be successfully completed, a process through which an individual (or other decision-making unit) passes from first knowledge of an innovation to forming an attitude toward the innovation, to a decision to adopt or reject, to implementation of the new idea, and to confirmation of this decision. The decision-maker seeks information at the various stages in the innovation-decision process in order to decrease uncertainty about the innovation. The five main steps in the process for an individual or any other decision-making unit are:

1. knowledge
2. persuasion
3. decision
4. implementation
5. confirmation

Knowledge occurs when a decision-maker is exposed to the innovation's existence, obtains software information that is embedded in a technological innovation and gains some understanding of how it functions and of what it has to offer. *Persuasion* occurs when a decision maker forms a favourable or unfavourable attitude toward the innovation. *Decision* occurs when a decision maker engages in activities that lead to a choice to adopt or reject the innovation. At the persuasion and decision stages, the decision maker seeks innovation-evaluation information in order to reduce uncertainty about an innovation's expected consequences. *Implementation* occurs when a decision maker puts an innovation into use. *Confirmation* occurs when a decision maker seeks reinforcement of an innovation decision that has already been made, but he or she may reverse this previous decision if exposed to conflicting messages about the innovation.

C. SUPPLYING THE KNOWLEDGE

Since we are interested in persuading an institutional military to form a favourable attitude towards a given innovation, namely the introduction and the utilization of the computer into its decision process, we must carry it through the very first and fundamental step of the innovation-decision process; the acquisition of the (favourable) knowledge. The best person to approach and attract would be the institutional military *decision maker*, for two simple reasons: (1) because he is the one who makes the decisions, after all and (2) because he is the one who benefits directly from the adoption of such innovation. Therefore, in the following chapters we will carefully attempt to provide a framework for the transfer of such desired knowledge, in order to prepare the grounds for his persuasion and decision to adopt, trying not to put him off by exposing him to technical and mathematical details. It is important to proceed in such a way in order to counter a uniform pattern of objection that occurs whenever it is proposed to use technical and mathematical methods in a field in which such methods are not traditional.

IV. ON HIGH TECHNOLOGY AND THE NEED FOR MILITARY COMPUTERIZATION

A. GENERAL

The purpose of this chapter is to help a hypothetical High-Context (HC) institutional military decision maker, a Greek officer in our case, to realize and appreciate the current information and computer revolution.

To achieve the above, we will outline the existing status of the computer and the possible future development and applications to the Navy. The importance of the computer as a tool will be investigated, as well as the possible related problems, in an attempt to see if the use of the computer is likely to be beneficial for the institutional military decision maker. The expected consequences of the impact that the computer is soon bound to have on every area of military life, operations and personnel will be mentioned.

The transfer of this preliminary knowledge is necessary in order to be able to discuss a desired application, namely to introduce a certain degree of computerization into his existing decision making process, which is now based on a nearly non computer-assisted scheme.

We will address the issue by refering to the Navy, but it must be kept in mind that the same discussion applies to any other military service. So, this chapter will have the form of a hypothetical advisory report or letter to an equally hypothetical top level Greek naval decision maker, an Admiral. Although he may be a man of wit and open mind, and he may have given indications of a quite unusual technological understanding and appreciation, he is still a conservative and very busy Admiral who prefers to learn something new at his own pace and certainly not in public, to avoid possible and unnecessary embarrassment. Therefore this introduction should be short, quite conservative, simple, rational and persuasive; not making obvious our apparent communication gap, with very few (if necessary) numbers or new terms and with a certain touch of history (since most Admirals have the, often successful tendency to turn into scholastic historians in their retirement).[14]

[14]What follows could be a draft, not an actual report/recommendation format that we would really turn in to an Admiral.

B. A LETTER TO AN ADMIRAL

In order to be able to discuss the relationship between the modern device which is called digital computer and the Navy and its people, we must make several reasonable assumptions concerning both the Navy and the computer. These assumptions are:

1. That the Navy will continue in the next 25 years to have, in general, the same mission and objectives that it has had and still has today; these are "to support and protect, by any means, our national interests over the vital national area, and to be able to deter any possible attack by any potential enemy".

2. That the State will remain determined and able to support financially the Navy's objectives -at least for the near future- and that the Navy will try its best to optimize the methods and procedures required/adopted in meeting these objectives, including beneficial technological innovations.

3. That the Navy will continue to suffer the existing shortage in personnel relative to its need, due to our unfavourable rate of population increase, compared to that of our possible enemies.

4. That the technological progress is closely related to today's tremendous accumulated amount of knowledge and information and that it is much more difficult today to keep up with such rapid progress than it ever was before.

5. That the micro-electronics and computer revolutions are not only here to stay, but are likely to expand in every field of human activity, due to its obvious positive contribution to the progress of our species, so far.

6. That the superpowers will continue:

   a. to make the best use of high technology and computer power for the benefit of their defense and the support of their international interests; and that they will not go back to old-fashioned and romantic hot or cold war methods.

   b. to support and provide their allies with updated technology, according to their importance in their respective alliance

7. That a Navy's effectiveness was, is and will be inter-related to the beneficial utilization of the current technology, the implementation of which will not necessarily be always "clean" or ethical.

8. That whenever we come across moral or cultural problems, that some people fear as dangerous because of the man-machine interaction, we will be able to restore the confidence and acceptance of the people concerned. It is our responsibility to keep technology in touch with human nature and culture and to make certain that the tools of computing do not overpower those that rely on them.

Probably some of the above assumptions look too obvious to be mentioned. However, we have good reason to believe that they must be remembered, since our modern society is passing at this very moment through the most difficult point of its existence. It is neither our intention nor necessary to go through these reasons in this study. The point is that society, and by extension military society, was never as complicated as today. Moreover, the contrast or even the conflicts of the involved cultures are as obvious as never before. One reason is that low-context (LC) societies adjust quickly and much more effectively to technological changes than high-context (HC) ones [Ref. 2: p. 39].

1. The Navy and the computer

But let us see in what fields of our Naval activities the computer can help us or should be expected to be able to help in the future. Is, for example, the computer going to solve our present and future problems and help us expand and improve the power and the effectiveness of our Navy? What do we need to achieve the above?

We are indeed in need of "something" that will be able to deal with our problems with pre-determined:

a. speed, accuracy, reliability, predictability, patience

and "something" that

b. can work 24 hours a day, even in a hostile environment, without getting bored or frustrated or sick, with no need for social security and to socialize, with the minimum rate of errors and at the same time saving us time, money, potential and possibly precious man-power.

This must be a very devoted and determined worker or tool or device; which is exactly what the computer has already proven to be. But there is nothing magic behind the computer. It may not be able as such to completely solve all our problems; but it certainly has been a great tool to help us take the fastest and most error-free decisions possible, by doing much of the hard work as well as performing tasks impossible for the humans. At the same time it allows us to concentrate on the final decisions, or to develop new skills and new projects. The modern Navy has to cope with an increasing amount of information, at an increasingly high rate of speed, that has to be stored and processed. We cannot possibly hope that we can manage without computer aid. It makes no difference if the information is about a missile launched at us, the best choice and procurement of a new weapon system, the up-coming shortage of sterilized bandages, helicopter fuel or 9 X 16 heavy duty destroyer's boiler nuts; they can all contribute to the loss of our life or freedom.

It has been suggested that one of the biggest problems science must face in the next 20 years is the "explosion of information" *the computer itself* has brought about. Most young scientists are ignorant of what was done 10 years ago (and so are most young officers) even in their own fields of specialization. They are both condemned to (mostly) repeat the mistakes of their elders and to (occasionally) repeat their accomplishments. This can now be avoided by using computers to access the enormous mass of information which exists in large data bases at many different places of the world, or exchange information and ideas with other users of similar interests. The access can be possible through high speed, highly reliable and easy to use computer networks that virtually criss-cross the globe. However, they must follow the *safety* rules which apply when using networks: *carelessness in networks kills, a high level of security costs.*

The most indicated way to proceed is to utilize the scientific approach, which dictates that we go from simple things to the more complicated ones. Non-scientific oriented people usually try to cope directly with complex situations, use their intuition and covered behind the much acclaimed shield of "experience" may end up commiting tragic mistakes. However, behind the use of this machine is not only the scientific approach, but *a terribly fast one.* What could be a good example of the processing speed of a typical computer is the fact that it took a mainframe only about 55 seconds to process *and* print this thesis.

We should not be forgetting that our era is an extraordinary and very high pitched one. Changes happen very rapidly. Such will be the future to come. In a rapidly changing situation, intuition and experience are counter-productive, because they are not given enough time to receive and process the feedback of new things and ideas. This is something extremely important in our HC military society. In such an environment one needs computer literacy and simulation. It is very difficult to come to the real results by the direct study of reality, because the conditions can change as much as our opinions on what we observe. But with computer simulations we can associate all symptoms to find (or indicate) the illness. The study of a simulation can bring out more real results. We can have passive simulations for study as much as we can have active simulations for designing, such as the C^3I functions that currently find wide application in the Navy.

Mentioning simulation; we cannot help but recall what happened at our Naval War College recently.[15] It was the day of the official presentation of the new state-of-the-art computerized Tactical Combat and War Game Simulator and the Fleet Admiral, in his speech, was really running out of praise for the new "machine". Then, near the end, facing the grand total of his senior officers and ships' Commanding Officers, he said to the Chief of the Navy (with distinct sarcasm) that now it would be easier for him to evaluate correctly the abilities of his officers to command and to take correctly the most indicated decisions, under simulated real-time battle conditions. As

[15] We are sure the Admiral remembers it.

he said, he never really felt that he had that chance during fleet maneuvers, but now he will.[16]

Besides its amusing side, however, this incident alone easily demonstrates not only the present, but also the future capability of sophisticated computer systems to give invaluable help in various Strategic, Tactical, Administrative and Managerial situations, however complex, cumbersome or unpleasant they may be. Moreover, did it ever occur to us that we might sometimes train Captains to make the *wrong* decisions? We may have done this without realizing it, possibly because we are already transformed into inflexible conservatives by virtue of our age or by the very system itself, by the time we become instructors. Our present computer experience allows us, though, to believe that in the future, education and special training can be carried out by the computers more effectively, insuring better understanding and quicker and more positive results [Ref. 8: p. 275].

But how do the HC, institutional-type military feel about all this? At this point let us recall our last assumption; people usually fear that [Ref. 8: p. 20]:

1. they may lose their privacy
2. they may lose their job or its prestige
3. they may be given fewer choices by the computer
4. they may not be appreciated any longer or become dehumanized
5. computers cannot or should not be trusted

The interaction between human and machine will become part of the Navy's daily routine. However, personnel must not be allowed to become frustrated or anxious about their ability to use machines or the impact of a machine on their life or career. *Time must be taken* to integrate computers properly so that they are viewed not as a threat, but rather as a useful tool. People will not use machines if they do not feel comfortable about their ability to do so, or if they do not trust the answers because they do not understand the processes involved.

Human experience must still be utilized. The wealth of information a person has gathered during a career will be questioned if people do not feel that their knowledge and experience is appreciated and useful. Moreover, people do not want to be inconvenienced and will not use a tool if it is not readily accessible. All new systems must be designed with the user in mind, while still maintaining the importance of security for the computer system. A comprehensive history of each system should be

[16]We would rather not mention the reaction of the Commanding Officers.

maintained and personnel need to be flexible enough to work around a failed system in cases of emergency. This is very important because a big controversy of using a computer system is the *overdependence* that may result [Ref. 8: p. 470].

To ensure the above, a new specialty of officer *must*, we repeat, *must* be established; the Information Systems Officer (ISO), that will allow a group of officers to be trained in all phases of computer technology/programming, hardware and management. With a comprehensive background in the computer field and their own career path, these officers will be able to provide help and direction to Navy users and to maintain continuity of the systems Navy-wide.

The rest of the Navy community will only need to have a general knowledge of what computers may be used for and how to access the system they need to do their jobs. All the designed applications should therefore be flexible, interactive and "user-friendly".

In this way, the computer will, with an almost certain degree of success (judging from its present rate of development) be able to guide us into better analysis, decisions and solutions when dealing with the increasingly complex future systems that we are bound to be facing. This can be achieved and enhanced by using more sophisticated operations research methods and techniques. To give only a few examples, consider the decision-making steps required to be taken in:

1. the already complicated amphibious operations, that require an amazing degree of synchronization, cooperation with other branches of the armed forces and information exchange and evaluation, to be carried out successfully and with the minimum sacrifice
2. the weapons acquisition process
3. the submarine operations
4. the small but speedy guided missile boats, where we already use aircraft, to expand our horizon with their radars, in order to launch an Exocet from 60 or more miles. Imagine if the aircraft could carry a small replica of your boat's guidance computer, that you could remotely control. Then you only need to supply your Exocet with more range and you don't need to get nearer to your target. With tomorrow's computers you could have such a compact and sophisticated replica of your launching system. Or, instead of an aircraft, you could use another boat in your squadron which is nearer your target, but has already run out of her deadly load.

There already exist many "off-the shelf" software packages that can be used to assist us in taking these kind of decisions with much better precision and higher probability of final success.

2. The Electronic Battleship

Of course, such thinking should not lead us to visualize a remote-controlled electronic battleship 25 years from now , with no need for a crew. We will always be in need of a crew, but it will be smaller, smarter and probably a lot happier. Her Captain will be there on the bridge, and he may as well be making history if he decides that he should dare to do something totally against any other human or computer advice or expectation, basing his decisions on the thousands-of-years-old inherited to him seamanship, experience and intuition that overides computer assistance at this stage of the naval operation. But until that moment, we will have to make sure that our future Captain will have all the knowledge and the current computer-power and technology to back him up, to be there in the first place. Because it is expected that through fancy future simulation methods (which we believe them to be the computer's most valuable future task), the computer will be able to guarantee the most accurate, ambiguous-free and safely positive pattern recognitions and air-sea-land surveillance ever achieved -through hostile, poor visibility or long distance situations- something that human perception is not capable of performing without a serious degree of uncertainty or error. Naval operations will be carried out more successfully and accurately, especially since the future "machines" are expected to give us even better and earlier predictions of the weather condition and changes, a well known uncertainty factor, critical for the accomplishment of any naval operation.

3. Conclusions

This is the kind of battleship and the kind of Captain and machinery we should expect to face in battle some 25 years from now. So, we must place ourselves among them, otherwise we are condemned to destruction or be at their mercy. Nothing will be a secret to the strong one anymore and the ones that will not manage or refuse to "keep up with the Jones's" will be destined to extinction or will be forced to "agree". We believe that perhaps this is the whole point behind the arms race. Eventually, the only ones that you could safely shoot at will be either the naive or the ignorant children. Would you shoot then? Conversely, this brings the computer-power to eventually play the role of the international non-human pacifier.

Now, this is where one can innocently ask: "Who is more powerful: the man or the computer?" But when we reach such a point, the question will be, "What should we do now that we have all the power we always wanted to support our naval purposes?" In the past we were looking for this power to help us carry out our mission. In the future our questions may be, "Should we reconsider the objectives and missions of our Navy? Would we have to reconsider our very first and fundamental assumption?" These are the questions that the Admiral will have to consider and decide upon. Whatever he decides, though, we must primarily face the present and the near future.

So, to come back to the Navy, since we missed the industrial revolution due to the vagaries of history, we must join, and we are perfectly capable of participating in the present computer revolution. After all, the Romans were the engineers and the Greeks were the brains. Once we achieve a firm grasp of computer literacy, the only road to follow is the road of computer software production and utilization. It is too late to start in the computer hardware area, like the Romans (i.e., any technologically advanced society) have; hardware is getting cheaper and smaller as time passes and it has almost reached its (presently) expected limits.[17]

We have not attempted to put our finger on future computer applications that will be of great importance to the Navy, or to claim that "everything is going to be O.K" in our future. All we have tried to do is to point out the fundamental importance of the computer to the future of the Navy and that we must try very hard to keep pace with the computer revolution, provided we are still interested in maintaining our freedom, dignity and prosperity; otherwise we will miss the boat completely. This conclusion looks inevitable if we examine the past rationally and critically; and we believe that this is the best way to look into the future. Because, repeating the words of George Santayana, a nineteenth-century philosopher, "those who do not learn from history are destined to repeat it".

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[17]The natural limits to computer hardware are set by the speed of light (they have it), by the size of the molecule of matter (they are almost there) and by the overheating of the machinery involved (the Romans will surely take care of this).

V. INTRODUCTION TO MODELING AND MODERN DECISION MAKING

A. THE SCIENCE OF DECISION MAKING

All of us have encountered situations and problems that have required the making of a decision: the choosing between competing opportunities or alternatives. Most everyday problems are resolved without too much difficulty or without serious consequence if the "correct" alternative is not selected, from among the many available ones. There are problems, however, for which we, as decision makers, want to do our utmost to ensure that the best possible solution is chosen. Such problems occur in most professions: in the military, business, industry and government, as well as in personal situations. There are hard choices and hard decisions when you are in the field!

Since the 1940s, our ability to understand, structure and resolve decision problems has improved tremendously. This is due to increased study of applied problems by mathematicians and other scientists, and the development of new mathematical techniques and the power of the computer. A new science of decision making has been evolving. This has produced a set of ideas, approaches and procedures that can be considered to form a modern framework and focus attention on its centerpiece: the mathematical model.

Starting with the Operations Research carried out in Great Britain and the United States during World War II, there has been a tremendous effort over the last 35 years devoted to scientific and mathematical analysis of various military, economic, industrial and biomedical systems. The focus has been on *decision-making*, since it turns out that much of what is involved in the feasible operation of a system can be meaningfully interpreted in terms of decision processes.

It is claimed that decision making is more art than science and that intuition and experience are the main resources of a decision maker. While we are in no position to refute this view, we do believe that most decision-making situations can be understood and handled better by the application of the more disciplined approach to problem analysis that is imposed by *Systems Analysis.* With better understanding (and more *precise* inputs and analysis structure) come better decisions; the *science* of decision making is still developing. [Ref. 9: p. 3]

1. Decision-aiding models

For most decision problems, an experimental setting cannot be imposed upon the system in question or the system under study. We are constrained in any attempt to evaluate alternative solutions to a problem using the real-world system as a test bed. Therefore, we must make a deliberate effort to abstract the needed information that "describes" the problem and system. This information must then be organized to form a *substitute* for the actual or contemplated system. In this way, we can now work on the actual problem but within a system that we artificially created by abstracting the suitable information. *Abstracting*, the gathering and organizing of information, is the basic process for all decision making. If conducted properly, it will lead to clear and concise statement of the problem; an understanding of what alternative solutions, if any, are possible; and indications of means of choosing among alternatives.

The term information is used here in a most general sense and all parts of the problem are covered by related information. Because a decision problem includes the new system's definition, resources, constraints (political, economical, organizational) and actual or simulated data.

The hope is that once this information has been gathered (not an easy task for most problems), a structure or framework can be developed as an aid to the analysis. Certain principles for analyzing the information content of decision problems have evolved over the past few years. They combine to form the powerful concepts of *decision-aiding models*. As usual, Shakespeare had the words for it:

When we mean to build,
We first survey the plot, then draw the model
And when we see the figure of the house,
Then must we rate the cost of the erection.

(King Henry The Fourth, Part II, Act I, scene 3)

Models are used as aids in the understanding of a problem. As an aid to decision making, a properly constructed and valid model can predict the outcome of each possible solution and sometimes even the optimal solution. Thus, we can establish some scale that allows us to compare alternative choices and to select one of them for implementation The *criterion* according to which we decide on the selection of an alternative may vary; it can be the cost, or some other measure of utility or effectiveness, or even a judgmental and intuitive criterion.

Models have been classified into three basic types. The *iconic model* looks like what it is supposed to represent, like an architectural model or a planetarium representing the celestial sphere. The *analogue model* relates the properties of the entity being modeled with other properties that are both descriptive and meaningful, like the concept of time as described by the hands and markings of a clock. Finally, the *symbolic model* or the *mathematical/logical model* represents a symbolic description of the process or problem under investigation, like the famous translation into quantitative terms of the relation $e = mc^2$ [Ref. 9: p. 15].

In parallel, models can be predictive, normative, descriptive or prescriptive. For the decision situations that we will be refering to in this thesis, the model structures will be *mathematical and prescriptive.*

Many military decision makers rely on their mental models and their intuition to make decisions. The human mind's ability to resolve situations by intuition based upon experience is not well understood, but is quite remarkable. A mathematical model should try to encompass, explain and extend the intuitive concepts. A model might challenge our intuition about a system, and any counterintuitive results may only mean that we did not correctly understand the problem complexities in the first place, or that important constraints were ignored. Moreover, we should be able to use the model to solve any inconsistencies.

2. **Elements of a model**

A *model* is a way of abstracting the real world so that not only the static picture of the real phenomenon is obtained, but also the dynamic (stochastic) interrelationships. With an appropriate model of a real-world situation, we should be able to predict certain outcomes or determine how the real world would behave if we implemented a particular alternative decision.

Models have two major components: *variables* and *relationships.* In many real situations, it is possible to enumerate thousands of relationships and/or[18] variables. The skill of the model builder enables him to capture the essence -only the important variables and relationships- to produce a meaningful and useful model. In the model, the variables represent either numerical values (which are counts, measurements, results, etc.) or codes (which identify items, people, projects, etc.). The relationships (equations, constraints, inequalities) are expressed in procedures for

[18]Maybe we really need to use just "or". It appears to us that "or" always contains the meaning of "and/or".

computing the values of certain variables, once the values of others are known. These procedures are often used for computing the values of variables at some future time, given the values at a present or past time.[19]

In nearly all models it is found that the variables can be classified[20] into four categories [Ref. 9: p. 17].

1. *Controllable or Decision Variables.* These are variables whose values can be determined by the decision process.
2. *Uncontrollable Variables.* These are variables that are not under the control of the decision maker, but represent the "state of the world" as interpreted by the model.
3. *Result or Output Variables.* These are variables characterizing the results of processes in the real world and are usually defined by controllable variables.
4. *Utility or Value Variables.* The decision maker will set a utility or value on the results of the process. The value is a function of controllable and uncontrollable variables.

Uncontrollable variables are of two types: those whose values are computed in the modeling process and those which are inputs to the model. The latter represent the effect of the environment on the system. For the model to operate, it is necessary to obtain estimates of the values of these input variables over the time span of interest.

With uncontrollable variables there are degrees of uncertainty. Sometimes the estimates are so sufficiently accurate that we can assume that the variables take on specific values. This leads to what is called *deterministic models*: the uncontrollable variables are assumed to be determined. When this cannot hold, a most accurate model will be one that represents the variables as statistical quantities and takes the variations from reality specifically into account. These are known as *probabilistic or stochastic models.*

The utility or value variables are computed by a formula from the result variables; the formula is called the *objective function* or *measure of effectiveness.* The controllable variables that give the best available utility are said to be the *optimum.*

3. The quantified decision problem

In most cases the model builder assumes the *decision problem* to be of the following nature [Ref. 9: p. 18]: *Find the values of the controllable (decision) variables which produce the best utility (value) as measured by the utility variable(s), given the assumptions about the uncontrollable variables.*

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[19]Something to remember: *constraints are obligatory, objectives are optional.*

[20]This classification of variables is used in the powerful computer modelling language GAMS. We will use GAMS later to model a typical military problem.

All modeling processes allow us to compute present and future values of result variables. Some models (and their associated computational processes) enable us to determine the utility-optimizing values of the controllable variables. The latter is known as *optimization* and, when considering situations over time, the former is called *prediction*. [Ref. 9: p. 19]

Once a model has been shown to be an accurate representation of the problem situation, it can be called a "simulation model" and then it becomes a powerful experimental device. A valid simulation model enables us to measure the effects of changes to the problem structure without modifying the real-world system being modeled. Thus, simulation models are used to answer " *What if...* " questions of different types, like: (1) "What if we set the decision variables at certain values?" and (2) "What if an uncontrollable variable takes on a different value?"

The advantage of providing a quantitative basis to a decision maker is *not* that it makes his decision easier, for in many cases it may actually make his choice more difficult. The advantage is that he knows better what *the consequences* of his decision will be [Ref. 10: p. 23].

However, to completely describe the decision problems, we should not overlook their qualitative or "fuzzy" side, since it is a dimension that is too often encountered in real life decision situations. Not all variables in decision-making can be quantified; there are many "fuzzy" variables which impose further constraints upon the human's abilities as a problem solver and as a decision maker. It is not our intention to include qualitative variables in this study, but we feel that for the sake of completeness and future stimulation they should only be mentioned.

4. **Decision problems and fuzzy sets**

It would be quite comfortable if we always had to deal with quantifiable variables because there are established ways to handle them, especially with the help of Operations Research and probability theory. However, real-life decision problems often considered by high-level decision makers (and somehow more so by the HC institutionals) involve a considerable number of *qualitative* variables. The description or even the classification of such variables can be characterized by the term "fuzzy" and it can be said that they have certain degrees of "memberships" that are measured on a (0.0 - 1.0) *possibility* scale and they are manipulated by "membership functions". They follow the rules of *fuzzy sets*, a new area of modern mathematics [Ref. 11: p. B138]. These variables and their membership functions are handled by the equally new *fuzzy* *set theory* and they can follow what it is called "possibility distributions", in contrast with the probability distributions of probability theory.

In the decision process and problems, certain forms of *imprecision* or *vagueness* occur that are intrinsic to the problem and for which the probability calculus seems to be inadequate [Ref. 12: p. 4]. Bellman and Zadeh[21] give a concise abstract classification of these forms of imprecision in terms of "classes in which there is no sharp transition from membership to non-membership" [Ref. 11: p. B141].

To many people today, it looks quite obvious that fuzzy set theory and probability theory should be viewed not as rivals, nor necessarily even as complimentary, but rather as similar logical systems. They have a common core that is adequate for many aspects of decision analysis and they differ in certain well-defined features that may, or may not, be relevant in particular applications.

We feel that it could be beneficial for our purposes to try to provide the institutional decision maker with the advantages of both quantitative and qualitative bases, to make his primary decision easier; that is, to help him decide on the adoption of computers as assisting tools for possible better decision-making.

It has been long recognized that the four decision elements -the alternatives, the criteria, the outcome confidence in terms of the criteria, and the preference- are indeed varied with time and situations. This is especially true when the decisions are of great importance or of high stake and they are unfamiliar to the decision maker. The variability of these four elements causes great "fuzziness" in our understanding of the decision-making. To understand this variability and reduce the fuzziness we need a broader comprehension of human psychology and behavior than that contained in the pure mathematical and structured description of decision-making.

Fuzzy set theory is attractive because it allows us to consider decision situations that are describable only or mainly in qualitative, verbal terms. Further, a rigorous calculus is provided, with which one can manipulate the resulting fuzzy sets. However, we by all means, do not want to leave the reader with the impression that fuzzy set formulations are always straightforward, even though fuzzy sets are eventually manipulated using non-fuzzy operations [Ref. 13: p. 101]. Furthermore, fuzzy set concepts and formulations could be seen as being high-context products;

[21]Now, some 25 years after Zadeh's original call for a new mathematics, fuzzy set theory has clearly become accepted in the literature and most authors do not feel the need to explain or justify their use of the techniques involved. However, it has not always been so, and there was much early debate about the need for any alternatives whatsoever to probability theory, which to some extent still continues in many areas.

therefore, we have the feeling that the fuzzy set theory would be rather appealing to the HC institutional decision makers, perhaps because the theory itself was introduced and developed primarily by HC mathematicians and scientists.[22]

It is not our intention to elaborate on the usefulness or the expected results of the application of the fuzzy set theory on decision making. We only wish to make the point that fuzzy sets appear to be very appropriate for handling and analyzing qualitative variables, that is to say, for handing high-level "unstructured" decisions,[23] decisions in which the computer can not, as yet,[24] offer significant assistance.

Although we believe that a forthcoming possibility/probability theory combination will greatly improve decision making in the future, for the purposes of this thesis we will remain faithful to the traditional quantitative methods of modeling decision-making.

5. **The decision process steps**

The decision process that has evolved over the past few years [Ref. 9: p. 26] can be looked at as a model of the modeling process. It involves a series of interrelated steps or stages that can be viewed as the decision process adaptation of the scientific method.

For most purposes, the steps required in solving a decision problem are:

1. Formulating the problem
2. Developing a mathematical model to represent the system under study
3. Deriving a solution from the model
4. Testing the model and the solution
5. Establishing controls over the solution
6. Putting the solution to work

These steps can be viewed as accomplishing the following: for any problem we need to define the broad objectives and goals of the system; examine the (possibly new) area we are working in; determine the alternative courses of action available to the decision maker; develop some statement, verbal or otherwise, of the problem to be investigated; translate the problem into a suitable logical or mathematical model which

[22]It is worth mentioning the fact that by going through the existing literature on fuzzy sets, one can see that almost the ninety percent comes from authors that represent HC cultures, about fifteen percent of which are Greek or of Greek origin.

[23]Later on we will have the chance to investigate these decisions in more detail.

[24]Software engineers working in fields like artificial intelligence and expert systems have the faith that soon the computer will be able to assist in these types of decision-making.

relates the variables of the problem by realistic constraints and a measure of effectiveness; find a solution which optimizes the measure of effectiveness; compare the model's solution against reality to determine *if* we have actually formulated and solved the real-world problem we started with; determine when the real-world situation changes and reflect such changes into the mathematical model; and, most important, implement the solution into operation (not just filling out a report) and observe the behavior of the solution in a realistic setting. As our ability to develop precise mathematical models of operational problems is not a highly developed science, we must be sensitive to discrepancies in the solution and feedback to the model refinements that will cause future solutions to be more realistic and accurate.

The mathematical model is central to this decision-making methodology -it offers understanding of the process and the problem under investigation; it provides a vehicle for the evaluation and comparison of alternative solutions; it enables us to evaluate the effects of a change of one variable on all the others; and finally, it provides us with a quantitative basis to sharpen and evaluate our intuition of the process under investigation.

The role of the mathematical model in decision making can be summarized diagrammatically in Figure 5.1.

In discussions on decision-making we usually come across a division of the process into three phases, characterized by H.A. Simon [Ref. 14: p. 54] as "finding occasions for making a decision; finding possible courses of action; and choosing among courses of action". These phases may be used to describe the decision maker's activities[25] and they may be labeled as (1) *intelligence*, (2) *design* (*or search*) and (3) *choice* [Ref. 15: p. 89].

Table 1 lists some general decision making operations usually associated with intelligence, designing and choice [Ref. 16: p. 137].

It should be mentioned that an operation may be used in more than one activity and that there is no prespecified ordering of the operations. The operations may involve complicated decision aids, such as simulation models.

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[25]However, as a representation of managerial decision processes this classification is seriously incomplete, according to B.J. Loasby who adds that a choice is not effective without *implementation*. It is dangerous to assume, either that what has been decided will be achieved, or that what happens is what was intended. Partly because implementation is so uncertain, but fundamentally because decisions are made in circumstances and by processes which are liable to lead to error, there is then usually some kind of assessment of the success of the decision made.

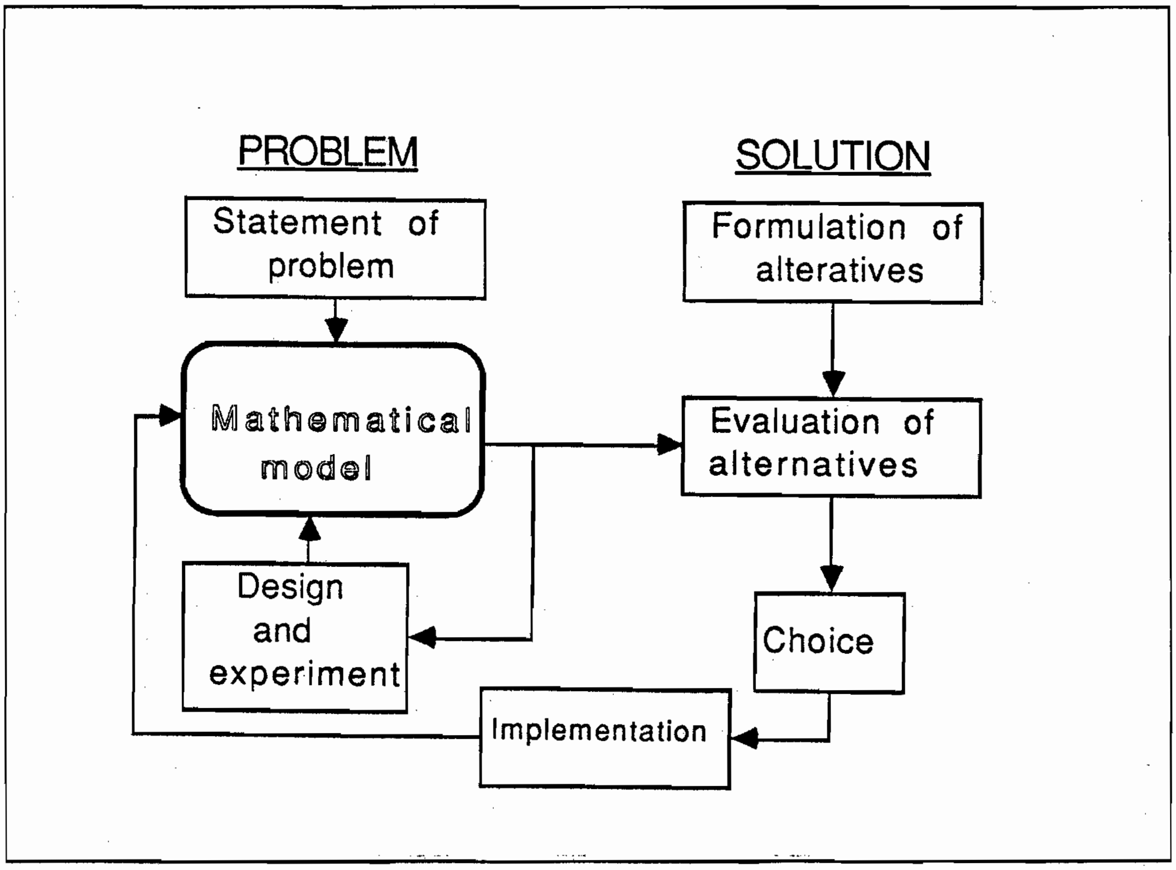

Figure 5.1 The role of the mathematical model

B. DECISION MAKING WITH COMPUTERS

1. Current computer capabilities and limitations

Processes of importance in any scientific field characteristically possess two types of complexities: conceptual and arithmetic. Even after we have overcome formidable conceptual obstacles in the construction of a mathematical model of a particular process, we often find ourselves frustrated by an inability to use this model to obtain the numerical results required for a definitive answer to a specific question. In many cases we believe that we understand the logical nature of the basic interactions. Yet, because of the very large number of interactions involved, we are often unable to achieve some desired numerical conclusions to check hypotheses. [Ref. 17: p. 8]

The digital computer has greatly altered this state of affairs. It possesses the specific ability to perform vast amounts of arithmetic and, more generally, to perform

TABLE 1

GENERAL DECISION MAKING OPERATIONS

Intelligence

- Gather data
- Identify objectives
- Diagnose problem
- Validate data
- Structure problem

Design

- Gather data
- Manipulate data
- Quantify objectives
- Generate alternatives
- Assign risks or values to alternatives

Choice

- Generate statistics on alternatives
- Stimulate results of alternatives
- Explain alternatives
- Choose among alternatives
- Explain choice

many kinds of symbol manipulations and logic operations. It is, therefore, an appropriate challenge at an appropriate time to determine whether or not the computer can be used, in conjuction with various guiding mathematical theories and knowledge of a specific field, to study decision-making techniques in particular situations.

However, there are two different types of mental manipulations that are performed inside the human brain [Ref. 18: p. 284] and are critical to human decision making: (a) *the analytic* and (b) *the intuitive*. (The analytic is performed inside the left cerebral hemisphere and the intuitive inside the right hemisphere). From our earlier discussion on the two different ways of thinking, among others, between the HC, P-time, (and in extension institutional military) people and the LC, M-time (and in extension occupational military) people, we can claim that the institutional is a more intuitive thinker (and in extension decision maker) than the occupational, who tends to be more of an analytic type of thinker and decision maker.

But computers are powerful tools only for certain kinds of tasks. Their potential to support intuitive (right hemisphere) processing is just beginning to be explored and developed. Despite much talk about heuristic cognitive styles and heuristic computer models, it is unlikely that *intuition* can be successfully modeled. [Ref. 18: p. 286]

The point we want to make with this argument is that *if* the computer was able to completely assist decision making, then it would be more of a realistic assistant to the occupational than to the institutional military. Thus, we are better off focusing on the different but complementary roles which man and machine play in solving managerial problems.[26] Therefore, we should investigate how the computer can assist in the analytic information processing.

Studies of specific decisions and general studies of decision making have indicated the potential benefits of computer support for decision making. These potential benefits can be divided [Ref. 16: p. 125] into two categories: *displaced cost* and *added value*.

Displaced cost results from reduced costs for data collecting and computation and data presentation in support of decision making. In these mechanical tasks, the (dollar) value of computer support is measurable.

Added value results from investigating more alternatives, doing more sophisticated analysis of alternatives, using better methods of comparing alternatives, making quicker decisions and so on. Often it is difficult to identify the added value because it does not occur on a routine basis, but it is generally accepted that small improvements in decision making can result in high added value. For example, in 1972, an airline's computer-supported decision to redeploy aircraft in only one route was reported to have increased profit $300,000 in one month [Ref. 16: p. 126]. Such potential benefits continue to stimulate management's interest in computer support for decision making [Ref. 19: p. 65].

Computer hardware and software vendors also have an interest in the development of computer support for decision-making because such support can help justify large data bases, data base management systems, additional computing power, new programming languages, time sharing and terminals. Also, computer support for

[26]While computers cannot be intuitive, they can support intuitive processes in man if designed properly. Flexible interactive systems using natural written language, natural speech, color, visual images, graphics and which even generate random thoughts for decision makers to contemplate are better suited for complex tasks than routine processing systems. Use of these design principles may successfully extend human problem solving capability in complex organizations like today's Navies. But success will depend on how well designers and decision makers comprehend the nature of the partnership between man and machine. This is exactly what the Human Factors engineers are dedicated on.

decision making can encourage the executives of the customer to take a personal interest in computers and can help the computer salesperson encourage "management involvement" in data processing.

The use of computers in decision making can be described in terms of various types of decisions. Following R.N. Anthony [Ref. 20: p. 15], decisions can be classified as:

1. *Strategic Planning*: decisions related to setting policies, choosing objectives and selecting resources.
2. *Management Control*: decisions related to assuring effectiveness in acquisition and use of resources.
3. *Operational Control*: decisions related to assuring effectiveness in performing specific tasks.
4. *Operational Performance*: decisions that are made in performing the specific tasks.

Simon [Ref. 21: p. 103] classifies decisions as *structured* (*programmable*) or *unstructured* (*nonprogrammable*) depending on whether or not the decision making process can be described in detail *before* making the decision. A decision may be unstructured because of novelty, time constraints, lack of knowledge, large search space, need for nonquantifiable data and so on. G.A. Gorry and M.S. Scott Morton [Ref. 22: p. 55-70] combined Anthony's and Simon's categories as shown in Table 2 .

TABLE 2

TYPES OF DECISIONS AND DEGREES OF DECISION STRUCTURE

	Operational Performance	Operational Control	Management Control	Strategic Planning
Structured	Payroll Production	Accounts Receivable	Budget Analysis	Tanker Fleet Mix
↓	Airline Reservations	Inventory Control	Short Term Forecasts	Site Location
↓	Dispatching	Production Scheduling	Long Term Forecasts	Mergers
Unstructured	Solving a Crime	Cash Management	Budget Preparation	Product Planning

Gorry and Scott Morton claim that most existing computer support for decision making is for structured decisions, that some progress has been made in supporting semistructured decisions and that almost no computer support is used for unstructured decisions.[27] They argue that it is the semistructured and unstructured decisions (especially management control and strategic planning) which are of the greatest concern to decision makers. They call systems which are intented to support these types of decisions *Decision Support Systems* (*DSS*). Thus, DSS are a subset of Management Information Systems (MIS), since MIS include all systems which support any management decision making. DSS can be divided into two general categories: data-oriented systems and model-oriented systems. Data-oriented systems provide functions for data retrieval, analysis and presentation. Both generalized and special purpose software packages are included in this category. Systems in this category are usually developed by persons with data processing or computer science backgrounds. The model-oriented systems provide accounting, simulation or optimization models to help make decisions. These systems usually are developed by persons with management science and operations research backgrounds.

Because DSS have high potential value for both users and suppliers of computer services, one would expect to find many DSS in use. Yet the literature on the applications of computers in government and business indicate little explicit use of DSS, despite their potential for displaced costs and added value. Therefore, many things must be changed and corrected, at least when DSS come to assist a HC institutional military decision maker. In the next section we will suggest a procedure which will, as we expect, make things easier and support our purposes.

2. The proposed procedure for a "transparent" system

There are many opinions on why data-oriented and model-oriented systems have not had much success in supporting decision making. In general, the main problem seems to be a mismatch between DSS design or performance and the requirements of decision makers or decision-making. The causes of this mismatch may be technical (for example, poor response times) or nontechnical (such as different personal preferences). Because of the mismatch, many systems which are developed cease to be used or are used for routine report generation rather than for direct support of decision makers. Observations from studies of decision-making and decision makers

[27]Since then (1971), there are unstructured decisions that are supported, to a certain degree, with spreadsheets, like cash management and budget preparation, even by portable microcomputers.

[Ref. 16: p. 151] indicated four major problems in the designs of existing DSS, which put some limitations to their usefulness and operability:

1. Existing DSS do not provide the representations which decision makers need for semistructured and unstructured decisions
2. Existing DSS usually support only one or two of the three basic activities (intelligence, design and choice) of decision-making
3. Existing DSS do not provide enough support (and introduce additional requirements) for conceptualization and memory, two areas where decision makers are observed to need help
4. Existing DSS require specification of the decision-making process in advance and do not support a variety of styles, skills and knowledge; thus they do not help decision makers exercise *the personal control* which they are accustomed when making semistructured and unstructured decisions.

Instead, we feel that the computer (or DSS, if it is prefered) must:

1. only *support* the decision maker and not attempt to *replace* his judgment. It should not try to provide the "answer" nor impose a predefined sequence of analysis.
2. be designed in a way that allows quick easy extentions and alterations.
3. provide an interface[28] that effectively buffers the user from the computer.
4. allow the *interactive* dialogue[29] to be based on the specific decision maker's concepts, vocabulary and *definition* of the decision situation.
5. provide *communicative and context-sensitive* display devices[30] and output generators.

The key words to a better system are *flexibility*, *ease* and *friendliness* of use, and *adaptivity*. A decision maker, especially an institutional military one, will not use a system lacking these attributes. It is hard to see any reason why he should. As far as he is concerned, this *interface* is the *system itself* and the main issue in the design of a successful decision support computer system should be *how the system should appear to the user*. This is not a difficult arrangement, since the same system may be presented in a variety of modes, even better with more than one mode combined to satisfy more potential users. The system could then be operated in *programmer mode*, *expert mode*, *novice mode* or even *natural query mode*. In Appendix A we present the basic differences between these possible modes. However, the selection of the appropriate mode involves many tradeoffs between efficiency and software overhead costs.

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[28]This interface should generally be tailored to the user. It is seen as critical to overcoming the decision maker's fear or dislike of the computer and it must be stressed that *the system is what the user sees it to be.*

[29]Strategic planning and policy analysis are problem areas where a dialogue is rarely possible.

[30]The computer is "silent" when it comes to output or results display; it returns nothing unless the programmer asks it to do so. So, it is up to the programmer to decide on the type of the desired output and the contained information.

Computer programmers and software developers are taught (and try their best) not to waste CPU time. In this way, they often produce programs that cannot easily be "enjoyed" by many and they can be totally discouraging for the novice. It is obvious that in our case, this should be avoided at any cost for the sake of acceptance. At the introductory stage, applications written for the institutional military decision maker should be presented and run in the novice mode. It is important that the program, its details and the operating/updating procedures should be "transparent" to him, even if he does not intend to operate or maintain the system by himself. He should be required only to:

1. express the problem as best as he can
2. provide the constraints known to him or set by himself
3. make available all the existing experience and data that are or can be related to the problem
4. express his specific initial questions

to a person *in his staff*, an "intermediary" as we will be calling him from now on, who knows the system's operation. Ideally, this person can be the Information Systems Officer (ISO) that we mentioned in Chapter IV, especially if he also happens to be an operations researcher. Alternatively, the intermediary might be a systems analyst, an operations researcher, or the actual programmer who put the system or the application together under the order of the decision maker. They could substitute the ISO, provided they have adequate military training; otherwise, they can simply assist him. The intermediary would be the one to have the knowledge and the responsibility of the operation and maintainance of the system and the related data bases, so that the system will provide quick answers and responses to the "What if..." questions asked by the decision maker that will challenge its robustness.

The intermediary is an absolute necessity, not a luxury. This is because the *institutional* decision maker will never do the work of the operator or attempt to find his own solutions using the computer himself, even if he knew how to do it! But would this mean that the intermediary would eventually become indispensable to the decision maker and conversely too powerful? Or the decision maker will soon give-up the computer assistance, feeling perhaps that he does not have the control he is accustomed to have? The answer is yes and no; it all depends on the position that the intermediary will hold in the decision-making circle. Our proposal is modest:

It requires *an act of faith* by the top decision makers. The hardware and most of the necessary software is assumed readily available and is currently used in the kinds of tasks that we mentioned in the Introduction. There exist people in the Navy who are *capable* and *more than willing* to play the role of the "intermediary". And then, two absolutely important relationships must be established and firmly maintained:

1. *The potential intermediary must recognize that supporting the decision process of the Navy is the central issue, not the design of computer systems.*
2. *The decision maker must define and establish the intermediary as part of his own planning team and not as a technician.*

In Figure 5.2 we lay out the basic proposed relationship between the decision maker and his intermediary. In this model we can see their shared and interrelated responsibilities.

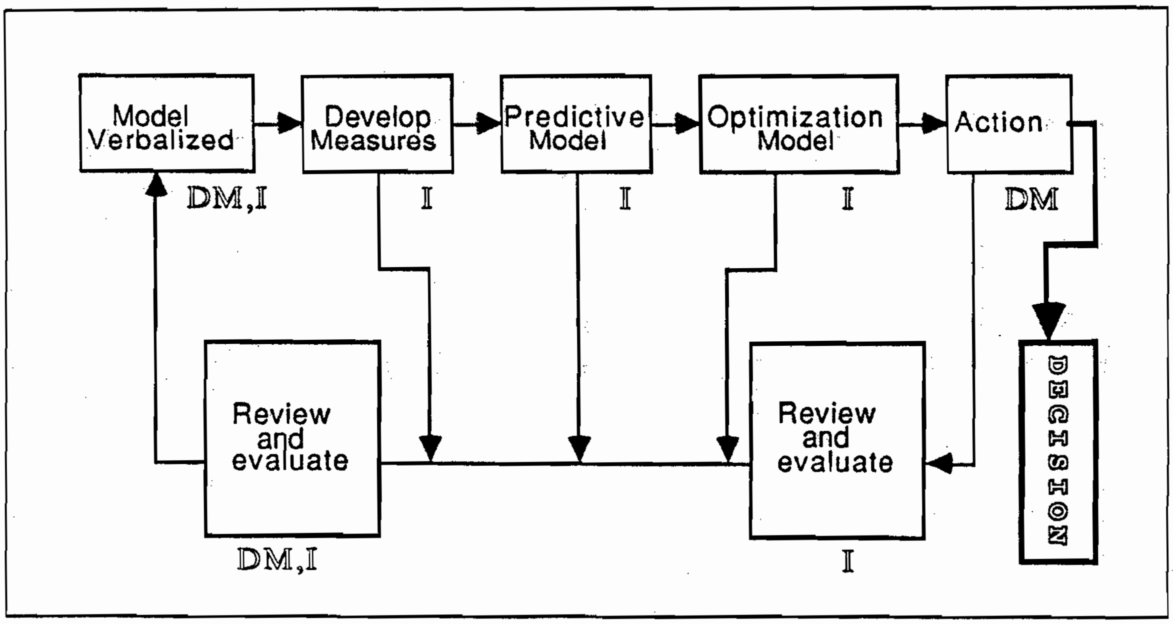

Figure 5.2 The decision maker - intermediary cooperation

In the figure, each activity is designated as "DM", "I" or "DM,I" to indicate that the particular task is the prime responsibility of the decision maker or the intermediary, or is to be shared. In the upper left, the decision maker and the intermediary work together to verbalize the model. Then the intermediary is given the task of finding measures for the factors which have been enunciated. The entire process is a series of feed-back loops, since the intermediary must return to the decision maker for review and evaluation of his work at the completion of each of the tasks assigned primarily to him. In each loop, the decision maker and the intermediary also jointly consider revisions of previous steps.

If the two agree on the model's general form and the measures to be used, the intermediary proceeds to construct explicit predictive or optimization models which will be appropriate for the situation. For instance, he may first develop regression predictive models and then go on with linear or non-linear optimization models.

Then the decision maker decides and takes some action. He can challenge the data, the intermediary or the system. The intermediary is often given the opportunity to review and evaluate the results. Together, they then determine whether a complete rerun of the process is necessary.

The model that is finally developed determines the information requirements for this particular decision problem or area through its predictive variables, criteria, solution and sensitivity information. The decision maker will then have better understanding[31] and adequate information to make his decision. The intermediary on the other hand will keep all the useful functions and data that can be collected if the problem was important or simply interesting, document the problem and its solution(s) and make himself available for his next assignment.

The above proposed requirements and cooperation are likely to by established and maintained without much difficulty, if we remember that *both* the decision maker and the intermediary are HC institutional military.

There is, however, one *quality* that the intermediary should have. It is the ability to be able to communicate with LC M-time technically oriented people, from whom he is going to acquire the "know how". It is imperative that he is at least aware of the facts and arguments that we mentioned so far in this study. The communication with the LC occupational military must be as effective as possible. This is the reason that we suggested earlier to the Admiral to make sure that the new specialty of naval officer is established; the ISO will be his intermediary.[32]

In Figure 5.3 we lay out the basic model of the proposed system, as it is viewed by the decision maker.

---

[31] Since a computer model can quickly evaluate many "runs" of a given plan and anticipate the consequences of different sets of assumptions, the model helps clarify the feasibility of the plan's objectives. If none of the plan's practical alternatives and valid sets of assumptions lead to the desired goals, there may be a defect somewhere in the established objectives.

[32] Along with all the other potential duties that he will be capable of doing.

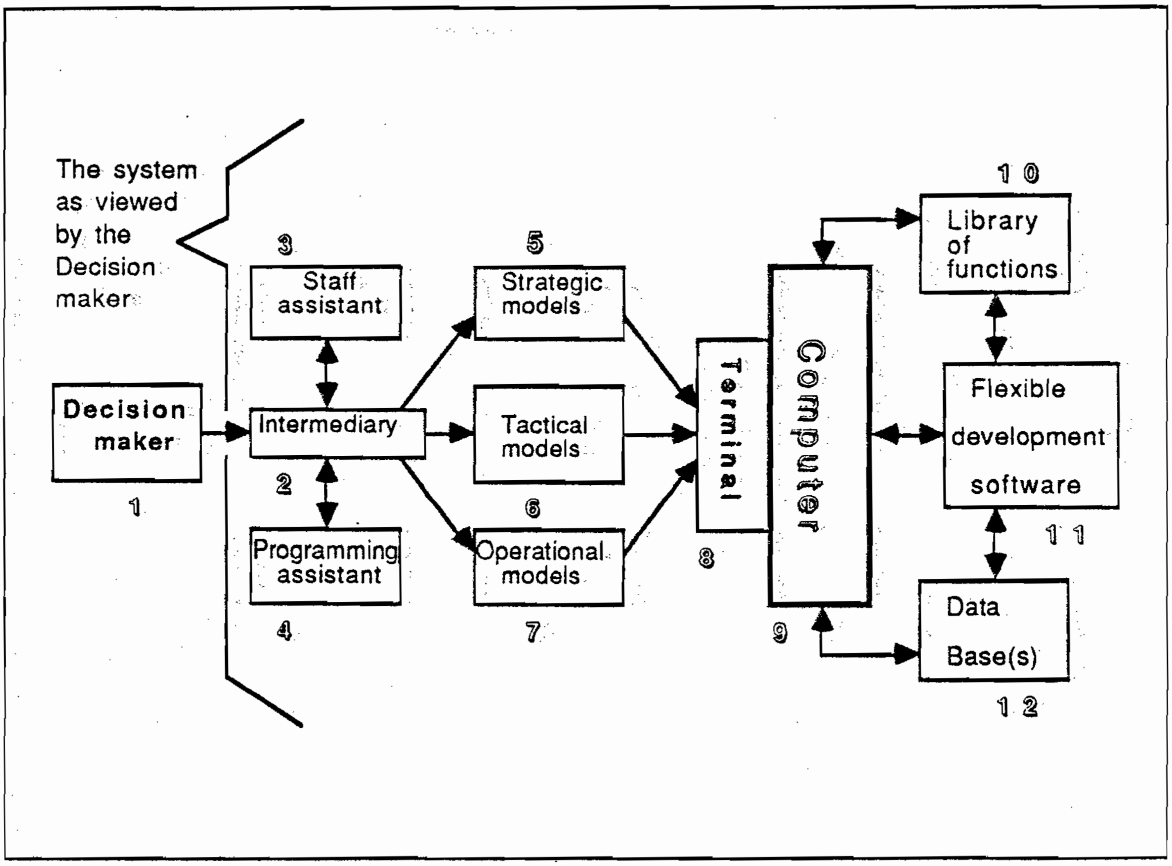

Figure 5.3 The basic computer-transparent decision-making system

The whole system is transparent to the decision maker, beyond the intermediary. The intermediary creates and runs the models on the computer. The decision maker would not even have to be near the computer or the terminal. But if he decides to be there, he will have the very exciting benefit of having immediate[33] interactive answers to his "What if..." questions, make "goal seeking" or be given results from reverse calculations.

But let us take a more detailed look into the model of the proposed transparent system.

[33]When we say "immediate" we mean response times that range from few seconds to few minutes, depending on the required changes or additions. We characterize such responses to "What if..." questions as exciting, to say the least.

3. The transparent system model and its details

The concept behind the model in Figure 5.3 is very different from the DSS approach. Here, there may be no single pre-written integrated DSS-type program. One of the main roles of the intermediary is to build -very quickly- the needed system from a general library of functions and data bases. If such building is possible, then the system can accommodate a much wider range of user requests and needs. The user, i.e., the decision maker, is required to have very little knowledge of the system's capabilities and certainly no knowledge of the system's routines; for him the intermediary *is* the system.

Another major advantage of such a system is that it can be small enough to run on a microcomputer. This means that the system can be installed or based almost anywhere that it will be required or beneficial for it to be. Thus, it can be used equally well on board ships, at small remote bases or at the private office of the top decision makers. There is no need to say that it can also be as big and expanded as we want it to be, depending on the needs of the major flag commands. And one can always access a possible central major system from a terminal, using the right network.

There are four major subsystems[34] and their sub-subsystems, as we can see them in Figure 5.3:

1. the decision maker (block #1)
2. the intermediary with his assistant(s), the decision models and the computer (blocks #2, 3, 4, 5, 6, 7, 8 and 9)
3. the software support for the computer (blocks #10 and 11)
4. the decision support data base(s) (block #12)

The starting point for putting the system together will obviously be to generate the "primitive" data bases (block #12) and functions (block #10), the library of routines that form the basis for the system that the intermediary draws on, extends and modifies. These functions can be for instance FORTRAN or APL library functions, statistical packages, optimization packages etc.

The data base performs many functions in the decision making support system. First, it supports the development of models by providing the historical data needed to develop the relationships between the variables and when analyzed help in the estimation of the parameters and coefficients in the various equations. Second, the data base integrates the three levels of models and allows data to be simultaneously

[34]The crude model has really only two major subsystems: the decision maker and the intermediary.

available to all levels of models. Third, the data base keeps the models up-to-date over time. In this way the models respond to changes in the organization and the environment. Fourth, the data base combines several data sources. These sources include external data such as DoD, political, economical or industrial data (i.e., from external agencies and the civil sector) and internal data (i.e., from the different Navy departments).

The software that will be used for the development of the programs, in block #11, can be a package which could contain simple computing tools like an editor and a word-processing package.

Finally, it is suggested that the three different types of decision models (blocks #5, 6 and 7) are grouped and used separately for greater flexibility and faster operation. The connection between blocks #8 (the terminal) and #9 (the computer) can be a remote connection through some network, as we mentioned earlier. The same applies also for the connection of block #9 (the computer) and blocks #10 (the functions library) and #12 (the data base). The function of the rest of the blocks of the model in Figure 5.3 are self-explanatory.

We would like to make a final remark: As soon as the system is set up and in working order, the intermediary or his assistants must provide for the system to be operated in at least two modes; the *novice mode*, for the important reasons we have already mentioned, and the mode that suits *their* skills. We feel that we should stress again this serious factor because we believe it is critical to the acceptance and to the success of the whole system.

In the next chapter we will attempt to present a few examples of the way that a system like the one we just proposed can assist us to take some fast and hopefully better decisions on some typical Naval decision problems.

VI. COMPUTER-ASSISTED SOLUTIONS TO SOME COMMON NAVAL DECISION SITUATIONS

A. THE NAVAL PROBLEMS

There is an enormous variety of situations in the modern Navy that needs better and faster answers. This is because the importance or the consequences of some naval problems are considered to be critical, too costly or too risky. Therefore, judging by the current and future state of the affairs in the Navy, our only hope to get better answers probably lies in using Operations Research (OR) methods, so that at least we have the feeling that our ability to find solutions does not only depend on experience and intuition, but also on the proven rationale of the OR methods.

In this chapter we will attempt to give only a modest demonstration of how the combination of OR methods and the computer can assist naval decision-making, by finding answers to some typical naval problems. We assume that we have a transparent system, like the one we suggested in the previous chapter, set and running for us by the intermediary and his assistants. A data base exists and contains many kinds of data internal to the Navy, as well as external data. In our functions library we can find many useful functions and "off-the-shelf" packages, like FORTRAN and Linear and Dynamic Programming optimizers, modeling and statistical tools etc. The intermediary (i.e., *the system*) is now ready to get his hands on some naval problems.

B. COMPUTER-ASSISTED OPERATIONS RESEARCH TECHNIQUES

Operations Research provides a number of methods and techniques that can be appropriate for solving naval problems. For our purposes we chose to present and demonstrate the solutions to three such problems, using OR methods and the computer as an assistant to the modeling and solution procedures: (1) a problem where we wish to optimize the desired utility, during the planning of a hypothetical naval operation, (2) a problem where we need to simulate our defensive tactical planning, in order to see which preplanned course of action is likely to give better results, assuming a random enemy appearance, and (3) a problem where we wish to choose, after proper evaluation, the best weapon (judging from the respective probability of kill) to be installed on a new aircraft.

1. Optimization

As an example of an optimization situation we will use the following realistic scenario.

The country is engaged in war since it was invaded by a potential enemy by air, land and sea. The only way to force the enemy to withdraw his assaulting forces is to immediately answer back with all available weapons, in conjunction with continuing the already successful resistance to the invasion.

The Navy is about to plan and execute its part of the retaliation attack on the enemy. The operations department believes that the best way to handle the situation is to attempt a massive combined attack on most of the enemy's important military power sites and support installations in his own land, with the hope that, if successful, such an action will have the desired impact on the enemy's morale and military power. The decision maker of this "aggressive" department wants to cause the *maximum possible damage* to the enemy and he is prepared to take necessary risks. However, the decision makers in the logistics and the technical support departments, being more risk aversive and more conservative, argue that they would rather set a desired level of damage and *minimize the total expected cost* of the operation.

We suggest that it is worth examining both strategies, so that the final decision maker is provided with a more complete perspective. Here we have decided to demonstrate a solution to the problem that supports the more conservative approach for handling the crisis. In this way, the objective of the operation is to cause a desired and prespecified *minimum* level of damage on the targets to be attacked, according to their relative importance and the class in which they are categorized, by using the available weapons for the attack (under several restrictions on both the availability and the types of weapons). The decision maker wants to know which would be the best allocation of the available weapons so that the desired minimum damage would be achieved, keeping the total expected cost of the operation at the allowable minimum.[35]

There are many deterministic (i.e., well defined) and probabilistic/stochastic (i.e., uncertain) factors and constraints that should be considered in such large scale operation and we cannot possibly include all of them in a single model for the purposes of this thesis. However, an expanded and enriched model containing most of the

[35]Under such a defensive scenario, traditionally the institutional military is not bound to set cost as a restriction. However, in our model we are minimizing the cost of the operation either because we feel that the economic situation of the country should not be severely damaged, or because we just want to get an idea of what is this operation going to cost, at a minimum.

desired aspects of such an operation may be constructed by the intermediary and his team, and solved using the suggested system.

Following our model in Figure 5.3, the intermediary (blocks #2, 3 and 4) collects all the necessary data (that he cannot readily draw out of his data base, i.e., in block #12) and constructs a computer model (in block #5, 6 or 7) like the one that is exhibited in Appendix B. From his functions library (blocks #10 and 11) he selects and uses the appropriate language, modeling and computing tools. As his main modeling tool he chooses to use GAMS/MINOS, a very powerful and exciting mathematical modeling and linear/nonlinear optimizer package[36] and then he runs his application on the computer system (block #8 and 9).

The input parameters of interest, on which *sensitivity analysis* can be applied were chosen to be the following:

1. time of the attack
2. weather conditions at the targets' area and the probability with which they may be expected for the time of the year when the attack is taking place
3. minimum number of weapons of all types assigned to the various targets
4. minimum desired damage on the various targets
5. minimum desired weighted damage on the different classes of targets
6. initial cost of the weapons to be used
7. the military value of each target
8. the probability that the various targets will be damaged by one unit of the different weapons, if they are hit by the respective weapon
9. the weight of the various targets according to their respective class
10. upper and lower bounds on the number of the various weapons that can be used or preferred to be used
11. the cost of the actual ammunition to be used
12. the training level of the pilots available and the cost of their training
13. the probability of assigning different training level pilots on different aircraft
14. the allowed or desired ammunition load on the different platforms
15. the probability with which the different weapons are expected to survive their mission, based on the attack conditions

---

[36]GAMS (a general algebraic modeling system) was developed by the World Bank in the Seventies and works fine with MINOS (modular in-core nonlinear optimization system) that was developed at the Department of Operations Research, Stanford University. A major advantage of GAMS is that the programmer can use his familiar mathematical format to code the constraints and equations. Its disadvantage though is that it is not yet interactive. The combined GAMS/MINOS optimizer version for a microcomputer was used in this example; more details can be found in Appendix B.

As we mentioned earlier, the above are only a portion of the actual realistic factors that must be taken into account. Only some basic costs are considered; human losses are not considered.

The output of the model is designed to give the following information:

1. the availability and the suggested usage of the different weapons
2. how many weapons of each type are needed to cause the desired minimum damage and on which target they should be allocated
3. the minimum cost of the operation
4. the expected damage value, so that it can be compared with other methods of solving the problem.

For an experienced intermediary or programmer, the entire modelling and solving process is estimated to take a few hours, and the actual processing of the model and the generation of the answers by a typical microcomputer actually takes about three minutes and only seconds by a mainframe. It does not take much additional time to run a sensitivity analysis. We did not attempt to solve the same problem manually, but we expect that it would take much longer, and doing sensitivity analysis would certainly take a vast amount of time.

The only information that the institutional decision maker really wants to see are the results contained in the output, but he can see much more if he has the time or the desire. We leave it up to him to look in Appendix B for the complete optimization process and the computer model and its documentation.

The report, however, an intermediary would typically return to the decision maker would look like the one in Table 3. The weapons used are short range ballistic missiles (SRBM), two types of medium range ballistic missiles (MRBM1 and MRBM2) and two types of long range bombers (B1 and F-111). We required the minimum use of four new B1 bombers in order to collect useful real-battle data on the behavior of the involved crew and equipment for further analysis and evaluation.

2. The benefits of computer simulation

In several places earlier we briefly mentioned *simulation*. Here we will explain in a simple fashion what simulation is and how we could use it to help us attack some Navy problems.

Simulation is a strategy that is generally used for generation and manipulation of data or the repetitive cycling of a model when environmental or setting factors preclude normal methods. These factors include limitations like time, money, personnel or equipment; and various safety considerations. Furthermore, many experiments

TABLE 3

OPTIMAL WEAPONS ALLOCATION

Weapons to be used

	MIN	MAX	SUGGESTED
SRBM		150	105
MRBM1		100	100
B1	4	10	9
F111		85	85
MRBM2		105	105

Suggested optimal allocation

	SRBM	MRBM1	B1	F111	MRBM2
T1					19
T2	27				
T3					17
T4		11			
T5		2			16
T6	10				
T7	11				
T8	7				
T9	4				
T10					28
T11				12	
T12				18	
T13					24
T14				47	
T15		28			
T16		17		8	
T17		14			
T18	45				
T19		14			
T20		14	9		

MINIMUM EXPECTED COST
of operation is approx. $2.6 billion

Achieved DAMAGE VALUE is 1559

cannot be done on a small scale -for example an atomic bomb either has a critical mass or it does not, and one cannot do small scale experiments in this area.[37]

[37]This example was given by Professor R. W. Hamming in one of his lectures on simulation at the Naval Postgraduate School.

This strategy is based on the mathematical manipulation of complex models which places the decision maker in a *controlled* "real life" situation, using simulation computer programs. Most programs of this type allow the user to input a series of parameters and then process them in a compressed fashion through the model. The resultant information is displayed for user perusal and may include pertinent comments and outline significant data. In general, there is no predefined learning "path". Instead, the decision maker is allowed to learn through actual manipulation of these processess. These types of programs are frequently used in statistical analysis and can also be very effective learning tools for the decision maker. We find that concepts, lessons learned and decisions taken via computer simulations are likely to be retained by the decision maker longer.

The word simulation seems to imply fancy things, but in fact we have been doing simulations all our life without thinking about them. Whenever we are making any "size" of decision in our mind we are doing a simulation by imagining what might happen before deciding on a course of action. What is new is the ability of a computer to carry out vastly more elaborate simulations, especially in more technical areas and when, as we mentioned earlier, situations are changing rapidly.

A computer which is running simulation programs is to a great extent the laboratory of the past, where we tried out ideas before putting them into practice. The pace of modern development, however, is such that we also do not have the time to carry out a long sequence of laboratory experiments, each slightly larger or different than the previous one. We must get to full scale practice rapidly, *or else be outclassed by others*, including a possible enemy. And this is something that matters a great deal in the military and political situations.

Thus, simulation is an increasingly necessary tool. It is fortunate that computers are now available to help us model reality and in so far as the model is accurate we will get the corresponding outcomes of the experiments.

It is found [Ref. 23: p. 6] that some of the most prevalent and important military uses of simulation are in:

1. technical evaluation
2. doctrinal evaluation
3. force-structure evaluation
4. planning
5. training and education

To get a feeling of computer simulation, in the rest of this chapter we will present two examples of how simulation and simulation results can be used by the intermediary in order to assist the decision maker.

a. A detection problem

Our first example on the use of simulation fits in the following scenario. The Navy wishes to monitor all traffic through a certain navigation channel. All surface ships transiting that channel must be be detected, if possible. Submarines cannot use this channel because it is neither deep nor safe enough. To achieve such close monitoring, it is decided that detecting sonobuoys should be placed at certain positions. Enemy ships can transit the area by approaching from any direction. There is only one type of sonobuoy available at the moment and only a limited number of them can be used in this operation.

The decision maker wants to know which should be the "best" positioning of his sonobuoys, so that he can have the highest probability of detecting the transiting enemy ships, since Air Force support is limited and only on request.

The input parameters that are considered as input to his problem, given the above constraints, are the following:

1. the number of the sonobuoys available
2. the coordinates of the sonobuoys
3. the characteristics of the available type of sonobuoys
4. the assumed bivariate normal distribution of the independently appearing enemy ships
5. the "randomness" of the above appearance
6. the size of the navigation channel

The intermediary decides to write a computer program in FORTRAN, to simulate the detection process of one thousand random appearing "targets". To create bivariate random coordinates for the 1000 targets he uses a library function that generates standard normal random variables and he tries different sonobuoys arrangements within the given detection-possible area.

The output is designed to provide the probability of detection of the targets, for any given arrangement of the available sonobuoys. The intermediary may try as many arrangements as he thinks is satisfactory, probably including the one that the decision maker would have used trusting his experience and intuition. Finally, the arrangement that gives the highest detection probability is suggested to the decision maker.

In Appendix C, besides the simulation solution, we also computed the probability of detection for the given in Appendix C sonobuoy arrangement, so that the reader can compare (the based on) Detection Theory analytical estimations to the one given by the computer simulation. This time, it does not take very long to compute the probability of detection manually, for one arrangement and one random target, using the "confetti approximations".[38] However, trying many arrangements and many targets it is another matter. The simulation program, though, can offer what could be the best arrangement to the decision maker in a matter of minutes. The intermediary would return to the decision maker a solution report that would contain the following information:

> Admiral, the probability that we will detect a random enemy ship, given this suggested pattern, is .664. However, we can try to find a better pattern because theoretically the "ideal" probability for our 16 sonobuoys is .915. We can find the best pattern in a few minutes. ....

b. Weapons evaluation

Finally, in this second example we can see how simulation results can be used. The scenario is as follows:

Three 20mm and three 30mm cannons are being considered for use in the F-14 aircraft. The cannons have different characteristics such as: accuracy, weight, rate of fire, lethality per round etc., etc. The cannons are being evaluated by the Navy using a manned simulator which records data for 10 pilots engaging in simulated air-to-air combat using each system. For each of the cannons the following average data is obtained:

1. probability of obtaining firing position during the engagement PA (function of cannon weight, skill of pilot, etc.)
2. average number of rounds fired per engagement for each cannon N (function of cannon rate of fire, etc.)
3. probability of hitting threat aircraft per round, for each cannon PH (function of cannon accuracy, muzzle velocity, weight, pilot skill, etc.)
4. probability of kill given a hit (for each round), expressed in terms of vulnerable area (AV) divided by average exposed area of threat aircraft during engagement (A), i.e., PKH = AV/A (function of explosive charge per round, fragmentation, etc.)

[38]As these approximations were presented in the lectures of Professor J. N. Eagle, at the Naval Postgraduate School.

The decision maker wants to choose one of the above six gun systems and he thinks that it would be reasonable to base his choice on the best "probability of kill" and the minimum number of rounds needed to achieve an acceptable probability of kill, say 65 percent.

The problem then is (a) to calculate the probability of a kill per engagement, for each cannon system and (b) to find the number of rounds one needs to fire to achieve a 0.65 kill probability, for each gun system.

The results of the mentioned simulation, that is A, AV, PA, PH and N, are stored in the data base of the intermediary's system (block #12 in Figure 5.3) and are used by a simple FORTRAN program, as it appears in Appendix D, written by him or his programmers for this purpose. A couple of hours after he was given the assignment, he returns to the decision maker with the following results, taken from his program's output, that will help him make a rational and objective decision:

```
       R E S U L T S   FOR GUN SYSTEM NO. 1
=================================================
 INPUT VALUES (FOR THIS GUN SYSTEM)
-------------
 A = 12.500
 AV=  3.000
 PA=  0.700
 PH=  0.300
 N =     26
------------
 PROBABILITY OF KILL (PK) WITH ABOVE N IS   0.600
------------
 NOTE:  PK <.650
     FOR PK >.650,    36  ROUNDS OF FIRE ARE NEEDED
```

```
       R E S U L T S   FOR GUN SYSTEM NO. 2
================================================
 INPUT VALUES (FOR THIS GUN SYSTEM)
-------------
 A = 12.500
 AV=  3.000
 PA=  0.800
 PH=  0.500
 N =     20
-------------
 PROBABILITY OF KILL (PK) WITH ABOVE N IS   0.738
-------------
   FOR PK >.650,    14  ROUNDS OF FIRE ARE NEEDED
```

```
       R E S U L T S   FOR GUN SYSTEM NO. 3
================================================
 INPUT VALUES (FOR THIS GUN SYSTEM)
-------------
 A = 12.500
 AV=  3.000
 PA=  0.700
```

```
PH=  0.400
N =     30
--------------
 PROBABILITY OF KILL (PK) WITH ABOVE N IS   0.666
--------------
      FOR PK >.650,    27  ROUNDS OF FIRE ARE NEEDED


       R E S U L T S   FOR GUN SYSTEM NO. 4
================================================
 INPUT VALUES (FOR THIS GUN SYSTEM)
--------------
 A = 12.500
 AV=  3.000
 PA=  0.800
 PH=  0.600
 N =     10
--------------
 PROBABILITY OF KILL (PK) WITH ABOVE N IS   0.631
-------------
  NOTE:  PK <.650
   FOR PK >.650,    11  ROUNDS OF FIRE ARE NEEDED


       R E S U L T S   FOR GUN SYSTEM NO. 5
================================================
 INPUT VALUES (FOR THIS GUN SYSTEM)
--------------
 A = 12.500
 AV=  3.000
 PA=  0.800
 PH=  0.700
 N =     18
--------------
 PROBABILITY OF KILL (PK) WITH ABOVE N IS   0.771
-------------
      FOR PK >.650,    10  ROUNDS OF FIRE ARE NEEDED


       R E S U L T S   FOR GUN SYSTEM NO. 6
================================================
 INPUT VALUES (FOR THIS GUN SYSTEM)
--------------
 A = 12.500
 AV=  3.000
 PA=  0.900
 PH=  0.800
 N =     12
--------------
 PROBABILITY OF KILL (PK) WITH ABOVE N IS   0.830
-------------
      FOR PK >.650,     7  ROUNDS OF FIRE ARE NEEDED
```

From the above results it is expected that the decision maker will consider the procurement of either system #5 or system #6, provided that cost considerations or other factors still support this choice.

VII. CONCLUSIONS AND RECOMMENDATIONS

In this thesis we admitted the fact that the Greek Navy, like most other institutional military establishments, will not readily accept or implement the use of computers in the area of decision making. In our effort to try to change this attitude and persuade the Greek Navy decision maker *to at least consider* the possibility of granting more trust to computers, we conducted an in-depth research to find a rational reason behind his attitude. Operations Research not only provided us with the methodology to carry out this research but gave us also the appropriate techniques to attempt a what we believe it is proper (for our case) diffusion of the use of the computer in the decision-making activities.

The following conclusions can be expressed as results of our research:

1. the fact that the institutional military does not accept technological innovations in fields like decision making is a function of his own nature, culture, idiosyncrasies and established norms

2. that the communication between high context polychronic and low context monochronic people is difficult and inefficient, if consideration of their basic cultural differences is not taken into account. This is likely to be most evident in the area of high technology and computers

3. that computers are and will continue to be increasingly able to assist the decision maker in his difficult and controversial tasks, provided that they are used as tools and not as magic decision making machines

4. that the institutional military and in particular the Greek Navy decision makers will have a lot to benefit from the wider use of computers, not to mention that very soon they will not be able to do much without them

5. that the diffusion of a technological innovation like the use of computers as valuable tools in the decision-making process must be done with great care, so that it will not be rejected by the institutional military.

As a result of the above conclusions we are suggesting a diffusion model, which we believe may succeed in changing the Greek Navy decision maker's attitude. According to our model, we recommend the high priority establishment of a new specialty of staff officer, the Information Systems Officer (ISO), who would be the necessary interfacing link between the computer and the naval society. His primary jobs will be (a) the firm establishment and the smooth continuity of the various major or minor computer systems in the Navy, (b) to provide the much needed interface and to buffer the communication channels between the occupational and his fellow institutional counterparts and (c) play the role of the "intermediary" between the decision makers and the "transparent" decision-assisting computer system, of which again we recommend the high priority installation. The ISO will have to be a person with firm grasp of computer technology and the charisma of intercultural communication.

We do not recommend the use of one of the existing Decision Support Systems (DSS), which are likely to do a better job for the occupational military or business decision makers. They are neither very well established nor novice-friendly enough for the Greek Naval decision maker, even in their "friendliest" mode. It is our belief that what is proposed in this thesis is what it is needed right now: an off-the-self "put-together", transparent and flexible system which can be installed almost anywhere quickly, easily and without too much money and prolonged "teething" problems under "high-calibre" expertise and patronage. Furthermore, it is going to be more than enough for helping the Greek Naval decision makers to realize that the computer is a very valuable and fast tool, not only for supporting their inventory, decorating the Naval War College or driving F-16s, but also for most of their decision making situations and general or specific problem-solving. The computer is only going to support and enhance their always invaluable experience and intuition, not replace them. We hope that the few examples given in this thesis will contribute in this direction and hopefully will provoke further reasoning and discussion.

APPENDIX A
USER INTERFACE MODES

The examples in this Appendix present four different interface modes, as it was suggested in Chapter V . Each one utilizes a linear programming algorithm (the same for each case) which requires user specification of such parameters like selling price and estimated sales. The program itself retrieves production and cost data from a permanent set of data bases. (The user inputs in each session are italicized).

In Table 4 we can see how programmer's mode can look like.

TABLE 4
PROGRAMMER MODE

run LPxxx	
? f/2	(output file will be on unit 2)
23.50 500k 200k end	(input data)
? link lpz-lpxxx, rpt2, rpt4	(creates special program lpz from library of routines)
? save lpz	(stores lpz in permanent form)
? run/debug	(runs the program in "debug" mode, allows the programmer to interrupt execution and access machine level)

Programmer mode is obviously not for the inexperienced user. In Table 5 we see how an expert mode would look like. Dialogues in this style are only limited by the ingenuity of the system designer. They are highly general and must be tailored to the user. Most DSS interfaces are of this style. In Table 6 we can see how novice mode should look like.

TABLE 5
EXPERT MODE

run LPxxx	
ready	
input price? *23.5*	
sales? *500,000*	
safety stock? *200,000*	
check input?	(asks if the user wishes to print out input data, user strikes ENTER)
LPxxx running	(system automatically runs the program)
reports? *help*	(asks user which report he wishes to have printed out; user replies by asking for list of options)
reports available	SOLN-summary of LP solution COST-summary of cost data SENSY-sensitivity analysis of solution
reports? *SOLN COST*	

It can be noticed that the novice mode is polite, long-winded and structures the user's dialogue. It tries to minimize the skills and knowledge needed to run the system and generally includes routines to check for errors and to advise or prompt the user.

Finally, in Table 7 we see how a natural query mode might look like, judging from current "expert systems" designs.

TABLE 6

NOVICE MODE

run LPxxx

please enter input data
selling price (S) ?
23.50

estimate sales at this price (in units) ?
500,000

desired inventory safety stock (in units) ?
200,000

input data complete; you may double-check input figures NOW,
type "yes" if data are OK, type "no" if data are not correct

is input price 23.50 OK?
yes

is input sales 500,000 OK?
yes

is input safety stock 200,000 OK?
yes

LPxxx is now running; please wait...

execution completed.

do you wish to see the solution in detail? type "yes" or "no"
no

reports available are: COST summarizes cost coefficients and totals
SENSY performs sensitivity analysis

type the name of the report(s) you would like
(separate names by comma or blank) ?
COST

TABLE 7

NATURAL QUERY MODE

Solve the LPxxx, with Marketing Department's best estimates for next year.
See how sensitive the output is to changes in demand.
I will review and plan what else to look at.

APPENDIX B

A WEAPONS ALLOCATION PROBLEM

```
??GAMS 2.02 PC AT/XT                                  87/03/08 23:31:07  PAGE 1
NONLINEAR COST MINIMIZATION FOR  WEAPONS VS TARGET ALLOCATION



 * Author: LCDR Harry Athanasopoulos HN ( NPS, March 1987)

 * System: IBM Personal Computer XT, 640K RAM, Intel 8087, 20 MB HD
 *         KEDIT version 3.51 editor
 *         GAMS/MINOS version 5.0 optimization package

 * Note 1: The GAMS program can be found in pages 1 through 6 of
           this output listing. The results that should be shown to
           the decision maker can be found in the last two pages of
           this listing (pages 23 and 24). The rest of the listing
           is only useful to the intermediary, for sensitivity etc.

   Note 2: Key to input variables

           SRGM     : Short range ballistic missiles
           MRBM1    : Medium range ballistic missiles of type one
           MRBM2    :  -"-    -"-     -"-       -"-      -"-   two
           B1       : New type of long range bomber
           F111     : Long range bomber
           SILOS    : Enemy ballistic missile sites
           SPARES   :  -"-  spare parts depos
           POWPLANT :  -"-  power plants
           CRUISE   : Cruise-type missiles
           BOMB     : 1000 lb bombs
           ASM      : Air-to-surface missiles
           ABOMB    : Nuclear bomb
           EXPERT   : Pilots with expert training level
           INTERM   :  -"-   -"-  intermediate training level

 ********************************************************************
 * Begin GAMS program :
 ********************************************************************

 SETS  I weapons to be allocated        / SRBM,MRBM1,B1,F111,MRBM2 /
       J targets to be attacked                       / T1 * T20 /
       K target classes      / SILOS,SHIPYRDS,AIRPORTS,SPARES,POWPLANT /
??GAMS 2.02 PC AT/XT                                  87/03/08 23:31:07  PAGE 2
NONLINEAR COST MINIMIZATION FOR  WEAPONS VS TARGET ALLOCATION


       L types of aircraft load            / CRUISE,BOMB,ASM,ABOMB /
       P pilot level of training                 / EXPERT,INTERM /
       W time and weather conditions  /DAYGOOD,DAYBAD,NITEGOOD,NITEBAD/


 PARAMETER  CLASSWGT(K) min. exp. weighted damage to class k targets
       / SILOS     85
         SHIPYRDS  78
         AIRPORTS  88
         SPARES    92
         POWPLANT  90 /
```

```
PARAMETER  B(J)  min. # of weapons of all types assigned to targets j
        / T1        5
          T6        6
          T10       10
          T14       15
          T15       15
          T16       10
          T20        8 /

PARAMETER  OC(I) original unit cost of weapon i in dollars
        / SRBM       200000
          MRBM1      300000
          B1       35000000
          F111     25000000
          MRBM2      500000 /

PARAMETER  D(J) minimum expected damage to target j  (percent)
        / T1     .80
          T2     .75
          T3     .75
          T4     .85
          T5     .70
          T6     .80
          T7     .70
          T8     .69
          T9     .60
          T10    .95
          T11    .69
          T12    .78
          T13    .90
          T14    .98
          T15    .98
          T16    .93
          T17    .90
          T18    .90
          T19    .90
          T20    .95 /

PARAMETER  MV(J)   military value of target j
        / T1     60
          T2     50
          T3     50
          T4     75
```

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NONLINEAR COST MINIMIZATION FOR WEAPONS VS TARGET ALLOCATION

```
          T5     40
          T6     60
          T7     35
          T8     30
          T9     25
          T10   150
          T11    30
          T12    45
          T13   125
          T14   200
          T15   200
          T16   130
          T17   100
          T18   100
          T19   100
          T20   150 /

TABLE ALPHA(I,J) prob. target j is UNDAMAGED by ONE unit of weapon i
                T1    T2    T3    T4    T5    T6    T7    T8    T9   T10
```

```
      SRBM  1.00   .95  1.00  1.00  1.00   .85   .90   .85   .80  1.00
     MRBM1   .84   .83   .85   .84   .85   .81   .81   .82   .80   .86
        B1   .96   .95   .96   .96   .96   .90   .92   .91   .92   .95
      F111  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00   .96
     MRBM2   .92   .94   .92   .95   .95   .98   .98  1.00  1.00   .90

            +T11   T12   T13   T14   T15   T16   T17   T18   T19   T20
      SRBM  1.00  1.00  1.00  1.00  1.00  1.00  1.00   .95  1.00  1.00
     MRBM1  1.00   .98  1.00   .88   .87   .88   .85   .84   .85   .85
        B1   .99   .98   .99   .98   .97   .98   .95   .92   .93   .92
      F111   .91   .92   .91   .92   .98   .93  1.00  1.00  1.00  1.00
     MRBM2   .95   .96   .91   .98   .99   .99  1.00  1.00  1.00  1.00

TABLE U(J,K)   weight of target j with respect to class k targets
            SILOS  SHIPYRDS  AIRPORTS  SPARES  POWPLANT
       T1    90       0         0        0        0
       T2    85       0         0        0        0
       T3    85       0         0        0        0
       T4    95       0         0        0        0
       T5    82       0         0        0        0
       T6     0      90         0        0        0
       T7     0      88         0        0        0
       T8     0      87         0        0        0
       T9     0      80         0        0        0
      T10     0       0        92        0        0
      T11     0       0        87        0        0
      T12     0       0        91        0        0
      T13     0       0         0       79        0
      T14     0       0         0       95        0
      T15     0       0         0       95        0
      T16     0       0         0        0       92
      T17     0       0         0        0       78
      T18     0       0         0        0       79
      T19     0       0         0        0       85
      T20     0       0         0        0       95

```



```
PARAMETER  LIMIT(I)    upper limit of weapon i usage
      / SRBM    150
        MRBM1   100
        B1       10
        F111     85
        MRBM2   105 /

PARAMETER  LOWER(I)    lower limit of weapon i usage
      / SRBM  -   0
        MRBM1     0
        B1        4
        F111      0
        MRBM2     0 /

PARAMETER  LC(L)       cost of aircraft load in dollars
      / CRUISE   300000
        BOMB       1000
        ASM      150000
        ABOMB   1000000 /

TABLE        PL(I,L)   loading of l on carrier (weapon) i
               CRUISE  BOMB     ASM  ABOMB
      SRBM        0      0       0     0
      MRBM1       0      0       0     0
      B1          6     40       0     1
      F111        0     10       4     0
      MRBM2       0      0       0     0
```

```
TABLE       PC(I,P)    training cost of pilot on weapon i
                 EXPERT    INTERM
      SRBM          0.0       0.0
      MRBM1         0.0       0.0
      B1        2000000   1500000
      F111      1500000   1000000
      MRBM2         0.0       0.0

PARAMETER  WPROB(W)   probability of occurrence of w
      / DAYGOOD  .80
        DAYBAD   .20
        NITEGOOD .65
        NITEBAD  .35 /

TABLE       SPROB(P,I,W)  prob. that weapon i will not survive mission
                       DAYGOOD   DAYBAD   NITEGOOD   NITEBAD
      EXPERT.SRBM        1.0       1.0       1.0        1.0
      EXPERT.MRBM1       1.0       1.0       1.0        1.0
      EXPERT.B1          .03       .05       .05        .07
      EXPERT.F111        .04       .06       .06        .08
      EXPERT.MRBM2       1.0       1.0       1.0        1.0
      INTERM.SRBM        1.0       1.0       1.0        1.0
      INTERM.MRBM1       1.0       1.0       1.0        1.0
      INTERM.B1          .07       .09       .09        .11
      INTERM.F111        .09       .11       .11        .14
      INTERM.MRBM2       1.0       1.0       1.0        1.0

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NONLINEAR COST MINIMIZATION FOR  WEAPONS VS TARGET ALLOCATION


PARAMETER  PPROB(P)   probability of pilot p  onboard weapon w
      / EXPERT  .60
        INTERM  .40 /

PARAMETER   TC(I)       total cost of weapons ;
            TC(I) = (OC(I)+SUM(P,PPROB(P)*PC(I,P))
                  * SUM((P,W),PPROB(P) * WPROB(W) * SPROB(P,I,W))
                  + SUM(L,LC(L) * PL(I,L)))


VARIABLES
      X(I,J)  the number of weapons i to be assigned to target j
      DAM     damage value
      COST    cost to be minimized;
POSITIVE VARIABLE X;

EQUATIONS
  OBJECTIVE     objective function definition
  EXPDAM(J)     restriction on minimum expected target j damage
  MINFIRE(J)    minimum number of all weapons used on target j
  CLASSDAM(K)   lower bound of expected damage on target class k
  MAXDEF(I)     upper bound of # of weapon i used on targets j
  MINDEF(I)     lower bound of # of weapon i used on targets j
  DAMAGEDEF     damage definition ;

EXPDAM(J)..  1-PROD(I,ALPHA(I,J)**X(I,J)) =G= D(J);
MINFIRE(J).. SUM(I,X(I,J)) =G= B(J) ;
CLASSDAM(K)..  SUM(J,U(J,K)*(1-PROD(I,ALPHA(I,J)**X(I,J)))) =G=
               CLASSWGT(K);
OBJECTIVE.. COST =E= SUM(I,TC(I)*SUM(J,X(I,J)));
MAXDEF(I)..  SUM(J,X(I,J)) =L= LIMIT(I);
MINDEF(I)..  SUM(J,X(I,J)) =G= LOWER(I);
DAMAGEDEF..  DAM =E= SUM(J,MV(J)*(1-PROD(I,(ALPHA(I,J)**X(I,J))))) ;

MODEL WAR /ALL/ ;
```

```
 260
 261   SOLVE WAR USING NLP MINIMIZING COST ;
 262
 263   OPTION DECIMALS = 0 ;
 264
 265   * Create and display  parameters for output interpretation:
 266
 267   PARAMETER REPORT (J,I) suggested usage of weapon i on target j ;
 268   PARAMETER REPORT2(I,*) weapons restrictions and desired usage ;
 269   PARAMETER REPORT3        total min expected cost ;
 270   REPORT(J,I)          =  X.L(I,J) ;
 271   REPORT2(I,'MIN')     =  LOWER(I) ;
 272   REPORT2(I,'MAX')     =  LIMIT(I) ;
 273   REPORT2(I,'USED')    =  SUM(J,X.L(I,J)) ;
 274   REPORT3              =  COST.L ;

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NONLINEAR COST MINIMIZATION FOR  WEAPONS VS TARGET ALLOCATION


 279
 280
 281   DISPLAY '      ========================================================== ';
 282   DISPLAY '         F   I   N   A   L       R   E   P   O   R   T        ';
 283   DISPLAY '      ========================================================== ';
 284
 285
 286   DISPLAY REPORT ;
 287   DISPLAY REPORT2 ;
 288   DISPLAY REPORT3 ;
 289   DISPLAY DAM.L   ;

   51  **********************************************************************
   52  * End GAMS program   -   Begin Output :
   53  **********************************************************************
??GAMS 2.02 PC AT/XT                              87/03/08 23:31:07   PAGE 7
NONLINEAR COST MINIMIZATION FOR  WEAPONS VS TARGET ALLOCATION
SYMBOL LISTING


SYMBOL        TYPE    REFERENCES

ALPHA         PARAM   DECLARED       130  DEFINED        130         REF        250
                             252          257
B             PARAM   DECLARED        70  DEFINED         71         REF        251
CLASSDAM      EQU     DECLARED       245  DEFINED        252 IMPL-ASN           261
                             REF          259
CLASSWGT      PARAM   DECLARED        63  DEFINED         64         REF        253
COST          VAR     DECLARED       238 IMPL-ASN        261         REF        254
                             261          274
D             PARAM   DECLARED        86  DEFINED         87         REF        250
DAM           VAR     DECLARED       237 IMPL-ASN        261         REF        257
                             289
DAMAGE1       PARAM   DECLARED       232  DEFINED        232         REF        277
DAMAGE2       PARAM   DECLARED       233  DEFINED        233         REF        278
DAMAGEDEF     EQU     DECLARED       248  DEFINED        257 IMPL-ASN           261
                             REF          259
EXPDAM        EQU     DECLARED       243  DEFINED        250 IMPL-ASN           261
                             REF          259
I             SET     DECLARED        55  DEFINED         55         REF      2*228
                             229          230     2*250       251      2*252     2*254
                           2*255        2*256     2*257       270        271       272
                             273     CONTROL        228       250        251       252
                             254          255       256       257        270       271
                             272          273
J             SET     DECLARED        56  DEFINED         56         REF      3*250
                           2*251        3*252       254       255        256     3*257
                             270          273   CONTROL       250        251       252
```

```
                                        254        255       256       257       270       273
K            SET      DECLARED           57  DEFINED          57       REF       252
                                        253  CONTROL         252
L            SET      DECLARED           58  DEFINED          58       REF     2*230
                          CONTROL           230
LC           PARAM    DECLARED          182  DEFINED         183       REF       230
LIMIT        PARAM    DECLARED          168  DEFINED         169       REF       255
                                        272
LOWER        PARAM    DECLARED          175  DEFINED         176       REF       256
                                        271
MAXDEF       EQU      DECLARED          246  DEFINED         255 IMPL-ASN        261
                                        REF         259
MINDEF       EQU      DECLARED          247  DEFINED         256 IMPL-ASN        261
                                        REF         259
MINFIRE      EQU      DECLARED          244  DEFINED         251 IMPL-ASN        261
                                        REF         259
MV           PARAM    DECLARED          108  DEFINED         109       REF       257
OBJECTIVE    EQU      DECLARED          242  DEFINED         254 IMPL-ASN        261
                                        REF         259
OC           PARAM    DECLARED           79  DEFINED          80       REF       228
P            SET      DECLARED           59  DEFINED          59       REF     2*228
                                      2*229  CONTROL        228       229
PC           PARAM    DECLARED          196  DEFINED         196       REF       228
PL           PARAM    DECLARED          188  DEFINED         188       REF       230
PPROB        PARAM    DECLARED          223  DEFINED         224       REF       228
                                        229
REPORT       PARAM    DECLARED          267 ASSIGNED         270       REF       286
```

```
??GAMS 2.02 PC AT/XT                                   87/03/08 23:31:07   PAGE 8
NONLINEAR COST MINIMIZATION FOR  WEAPONS VS TARGET ALLOCATION
SYMBOL LISTING


SYMBOL       TYPE     REFERENCES

REPORT2      PARAM    DECLARED          268 ASSIGNED         271       272       273
                                        REF         287
REPORT3      PARAM    DECLARED          269 ASSIGNED         274       REF       288
SPROB        PARAM    DECLARED          210  DEFINED         210       REF       229
TC           PARAM    DECLARED          227 ASSIGNED         228       REF       254
U            PARAM    DECLARED          145  DEFINED         145       REF       252
W            SET      DECLARED           60  DEFINED          60       REF     2*229
                          CONTROL           229
WAR          MODEL    DECLARED          259  DEFINED         259       REF       261
WPROB        PARAM    DECLARED          204  DEFINED         205       REF       229
X            VAR      DECLARED          236 IMPL-ASN         261       REF       239
                                        250         251       252       254       255       256
                                        257         270       273


SETS

I            WEAPONS TO BE ALLOCATED
J            TARGETS TO BE ATTACKED
K            TARGET CLASSES
L            TYPES OF AIRCRAFT LOAD
P            PILOT LEVEL OF TRAINING
W            TIME AND WEATHER CONDITIONS


PARAMETERS

ALPHA        PROB. TARGET J IS UNDAMAGED BY ONE UNIT OF WEAPON I
B            MIN. # OF WEAPONS OF ALL TYPES ASSIGNED TO TARGETS J
CLASSWGT     MIN. EXP. WEIGHTED DAMAGE TO CLASS K TARGETS
D            MINIMUM EXPECTED DAMAGE TO TARGET J  (PERCENT)
LC           COST OF AIRCRAFT LOAD IN DOLLARS
LIMIT        UPPER LIMIT OF WEAPON I USAGE
LOWER        LOWER LIMIT OF WEAPON I USAGE
```

```
MV            MILITARY VALUE OF TARGET J
OC            ORIGINAL UNIT COST OF WEAPON I IN DOLLARS
PC            TRAINING COST OF PILOT ON WEAPON I
PL            LOADING OF L ON CARRIER (WEAPON) I
PPROB         PROBABILITY OF PILOT P  ONBOARD WEAPON W
REPORT        SUGGESTED USAGE OF WEAPON I ON TARGET J
REPORT2       WEAPONS RESTRICTIONS AND DESIRED USAGE
REPORT3       TOTAL MIN EXPECTED COST
SPROB         PROB. THAT WEAPON I WILL NOT SURVIVE MISSION
TC            TOTAL COST OF WEAPONS
U             WEIGHT OF TARGET J WITH RESPECT TO CLASS K TARGETS
WPROB         PROBABILITY OF OCCURRENCE OF W
```



```
VARIABLES

COST          COST TO BE MINIMIZED
DAM           DAMAGE VALUE
X             THE NUMBER OF WEAPONS I TO BE ASSIGNED TO TARGET J


EQUATIONS

CLASSDAM      LOWER BOUND OF EXPECTED DAMAGE ON TARGET CLASS K
DAMAGEDEF     DAMAGE DEFINITION
EXPDAM        RESTRICTION ON MINIMUM EXPECTED TARGET J DAMAGE
MAXDEF        UPPER BOUND OF # OF WEAPON I USED ON TARGETS J
MINDEF        LOWER BOUND OF # OF WEAPON I USED ON TARGETS J
MINFIRE       MINIMUM NUMBER OF ALL WEAPONS USED ON TARGET J
OBJECTIVE     OBJECTIVE FUNCTION DEFINITION


MODELS

WAR


COMPILATION TIME     =          0.611 MINUTES
```



```
---- OBJECTIVE   =E=  OBJECTIVE FUNCTION DEFINITION

OBJECTIVE..  - 200000*X(SRBM,T1) - 200000*X(SRBM,T2) - 200000*X(SRBM,T3)

       - 200000*X(SRBM,T4) - 200000*X(SRBM,T5) - 200000*X(SRBM,T6)

       - 200000*X(SRBM,T7) - 200000*X(SRBM,T8) - 200000*X(SRBM,T9)

       - 200000*X(SRBM,T10) - 200000*X(SRBM,T11) - 200000*X(SRBM,T12)

       - 200000*X(SRBM,T13) - 200000*X(SRBM,T14) - 200000*X(SRBM,T15)

       - 200000*X(SRBM,T16) - 200000*X(SRBM,T17) - 200000*X(SRBM,T18)

       - 200000*X(SRBM,T19) - 200000*X(SRBM,T20) - 300000*X(MRBM1,T1)

       - 300000*X(MRBM1,T2) - 300000*X(MRBM1,T3) - 300000*X(MRBM1,T4)

       - 300000*X(MRBM1,T5) - 300000*X(MRBM1,T6) - 300000*X(MRBM1,T7)
```

```
       - 300000*X(MRBM1,T8) - 300000*X(MRBM1,T9) - 300000*X(MRBM1,T10)
       - 300000*X(MRBM1,T11) - 300000*X(MRBM1,T12) - 300000*X(MRBM1,T13)
       - 300000*X(MRBM1,T14) - 300000*X(MRBM1,T15) - 300000*X(MRBM1,T16)
       - 300000*X(MRBM1,T17) - 300000*X(MRBM1,T18) - 300000*X(MRBM1,T19)
       - 300000*X(MRBM1,T20) - 3.8061E+7*X(B1,T1) - 3.8061E+7*X(B1,T2)
       - 3.8061E+7*X(B1,T3) - 3.8061E+7*X(B1,T4) - 3.8061E+7*X(B1,T5)
       - 3.8061E+7*X(B1,T6) - 3.8061E+7*X(B1,T7) - 3.8061E+7*X(B1,T8)
       - 3.8061E+7*X(B1,T9) - 3.8061E+7*X(B1,T10) - 3.8061E+7*X(B1,T11)
       - 3.8061E+7*X(B1,T12) - 3.8061E+7*X(B1,T13) - 3.8061E+7*X(B1,T14)
       - 3.8061E+7*X(B1,T15) - 3.8061E+7*X(B1,T16) - 3.8061E+7*X(B1,T17)
       - 3.8061E+7*X(B1,T18) - 3.8061E+7*X(B1,T19) - 3.8061E+7*X(B1,T20)
       - 2.5808E+7*X(F111,T1) - 2.5808E+7*X(F111,T2) - 2.5808E+7*X(F111,T3)
       - 2.5808E+7*X(F111,T4) - 2.5808E+7*X(F111,T5) - 2.5808E+7*X(F111,T6)
       - 2.5808E+7*X(F111,T7) - 2.5808E+7*X(F111,T8) - 2.5808E+7*X(F111,T9)
       - 2.5808E+7*X(F111,T10) - 2.5808E+7*X(F111,T11) - 2.5808E+7*X(F111,T12)
       - 2.5808E+7*X(F111,T13) - 2.5808E+7*X(F111,T14) - 2.5808E+7*X(F111,T15)
       - 2.5808E+7*X(F111,T16) - 2.5808E+7*X(F111,T17) - 2.5808E+7*X(F111,T18)
```



```
      OBJECTIVE   =E=  OBJECTIVE FUNCTION DEFINITION

       - 2.5808E+7*X(F111,T19) - 2.5808E+7*X(F111,T20) - 500000*X(MRBM2,T1)
       - 500000*X(MRBM2,T2) - 500000*X(MRBM2,T3) - 500000*X(MRBM2,T4)
       - 500000*X(MRBM2,T5) - 500000*X(MRBM2,T6) - 500000*X(MRBM2,T7)
       - 500000*X(MRBM2,T8) - 500000*X(MRBM2,T9) - 500000*X(MRBM2,T10)
       - 500000*X(MRBM2,T11) - 500000*X(MRBM2,T12) - 500000*X(MRBM2,T13)
       - 500000*X(MRBM2,T14) - 500000*X(MRBM2,T15) - 500000*X(MRBM2,T16)
       - 500000*X(MRBM2,T17) - 500000*X(MRBM2,T18) - 500000*X(MRBM2,T19)
       - 500000*X(MRBM2,T20) + COST =E= 0 ; (LHS = 0)

---- EXPDAM      =G=  RESTRICTION ON MINIMUM EXPECTED TARGET J DAMAGE

EXPDAM(T1)..  (0.1744)*X(MRBM1,T1) + (0.0408)*X(B1,T1) + (0.0834)*X(MRBM2,T1)
       =G= -0.2 ; (LHS = -1 ***)

EXPDAM(T2)..  (0.0513)*X(SRBM,T2) + (0.1863)*X(MRBM1,T2) + (0.0513)*X(B1,T2)
```

```
        + (0.0619)*X(MRBM2,T2) =G= -0.25 ; (LHS = -1 ***)

EXPDAM(T3)..  (0.1625)*X(MRBM1,T3) + (0.0408)*X(B1,T3) + (0.0834)*X(MRBM2,T3)
        =G= -0.25 ; (LHS = -1 ***)
REMAINING 17 ENTRIES SKIPPED

---- MINFIRE     =G=  MINIMUM NUMBER OF ALL WEAPONS USED ON TARGET J

MINFIRE(T1)..  X(SRBM,T1) + X(MRBM1,T1) + X(B1,T1) + X(F111,T1) + X(MRBM2,T1)
        =G= 5 ; (LHS = 0 ***)

MINFIRE(T2)..  X(SRBM,T2) + X(MRBM1,T2) + X(B1,T2) + X(F111,T2) + X(MRBM2,T2)
        =G= 0 ; (LHS = 0)
```



```
      MINFIRE     =G=  MINIMUM NUMBER OF ALL WEAPONS USED ON TARGET J

MINFIRE(T3)..  X(SRBM,T3) + X(MRBM1,T3) + X(B1,T3) + X(F111,T3) + X(MRBM2,T3)
        =G= 0 ; (LHS = 0)
REMAINING 17 ENTRIES SKIPPED

---- CLASSDAM    =G=  LOWER BOUND OF EXPECTED DAMAGE ON TARGET CLASS K

CLASSDAM(SILOS)..  (4.3599)*X(SRBM,T2) + (15.6918)*X(MRBM1,T1)
        + (15.838)*X(MRBM1,T2) + (13.8141)*X(MRBM1,T3) + (16.5636)*X(MRBM1,T4)
        + (13.3266)*X(MRBM1,T5) + (3.674)*X(B1,T1) + (4.3599)*X(B1,T2)
        + (3.4699)*X(B1,T3) + (3.8781)*X(B1,T4) + (3.3474)*X(B1,T5)
        + (7.5043)*X(MRBM2,T1) + (5.2594)*X(MRBM2,T2) + (7.0874)*X(MRBM2,T3)
        + (4.8729)*X(MRBM2,T4) + (4.2061)*X(MRBM2,T5) =G= -352 ;
        (LHS = -437 ***)

CLASSDAM(SHIPYRDS)..  (14.6267)*X(SRBM,T6) + (9.2717)*X(SRBM,T7)
        + (14.1391)*X(SRBM,T8) + (17.8515)*X(SRBM,T9) + (18.9649)*X(MRBM1,T6)
        + (18.5435)*X(MRBM1,T7) + (17.2652)*X(MRBM1,T8) + (17.8515)*X(MRBM1,T9)
        + (9.4824)*X(B1,T6) + (7.3376)*X(B1,T7) + (8.205)*X(B1,T8)
        + (6.6705)*X(B1,T9) + (1.8182)*X(MRBM2,T6) + (1.7778)*X(MRBM2,T7) =G=
       -267 ; (LHS = -345 ***)

CLASSDAM(AIRPORTS)..  (13.8757)*X(MRBM1,T10) + (1.8384)*X(MRBM1,T12)
```

```
        + (4.719)*X(B1,T10) + (0.8744)*X(B1,T11) + (1.8384)*X(B1,T12)
        + (3.7556)*X(F111,T10) + (8.205)*X(F111,T11) + (7.5877)*X(F111,T12)
        + (9.6932)*X(MRBM2,T10) + (4.4625)*X(MRBM2,T11) + (3.7148)*X(MRBM2,T12)
        =G= -182 ; (LHS = -270 ***)
REMAINING 2 ENTRIES SKIPPED
```



```
---- MAXDEF      =L=  UPPER BOUND OF # OF WEAPON I USED ON TARGETS J

MAXDEF(SRBM)..  X(SRBM,T1) + X(SRBM,T2) + X(SRBM,T3) + X(SRBM,T4) + X(SRBM,T5)
        + X(SRBM,T6) + X(SRBM,T7) + X(SRBM,T8) + X(SRBM,T9) + X(SRBM,T10)
        + X(SRBM,T11) + X(SRBM,T12) + X(SRBM,T13) + X(SRBM,T14) + X(SRBM,T15)
        + X(SRBM,T16) + X(SRBM,T17) + X(SRBM,T18) + X(SRBM,T19) + X(SRBM,T20)
        =L= 150 ; (LHS = 0)

MAXDEF(MRBM1)..  X(MRBM1,T1) + X(MRBM1,T2) + X(MRBM1,T3) + X(MRBM1,T4)
        + X(MRBM1,T5) + X(MRBM1,T6) + X(MRBM1,T7) + X(MRBM1,T8) + X(MRBM1,T9)
        + X(MRBM1,T10) + X(MRBM1,T11) + X(MRBM1,T12) + X(MRBM1,T13)
        + X(MRBM1,T14) + X(MRBM1,T15) + X(MRBM1,T16) + X(MRBM1,T17)
        + X(MRBM1,T18) + X(MRBM1,T19) + X(MRBM1,T20) =L= 100 ;
        (LHS = 0)

MAXDEF(B1)..  X(B1,T1) + X(B1,T2) + X(B1,T3) + X(B1,T4) + X(B1,T5) + X(B1,T6)
        + X(B1,T7) + X(B1,T8) + X(B1,T9) + X(B1,T10) + X(B1,T11) + X(B1,T12)
        + X(B1,T13) + X(B1,T14) + X(B1,T15) + X(B1,T16) + X(B1,T17) + X(B1,T18)
        + X(B1,T19) + X(B1,T20) =L= 10 ; (LHS = 0)
REMAINING 2 ENTRIES SKIPPED

---- MINDEF      =G=  LOWER BOUND OF # OF WEAPON I USED ON TARGETS J

MINDEF(SRBM)..  X(SRBM,T1) + X(SRBM,T2) + X(SRBM,T3) + X(SRBM,T4) + X(SRBM,T5)
        + X(SRBM,T6) + X(SRBM,T7) + X(SRBM,T8) + X(SRBM,T9) + X(SRBM,T10)
        + X(SRBM,T11) + X(SRBM,T12) + X(SRBM,T13) + X(SRBM,T14) + X(SRBM,T15)
        + X(SRBM,T16) + X(SRBM,T17) + X(SRBM,T18) + X(SRBM,T19) + X(SRBM,T20)
        =G= 0 ; (LHS = 0)
```

```
EQUATION LISTING    SOLVE WAR USING NLP FROM LINE 261

      MINDEF      =G=  LOWER BOUND OF # OF WEAPON I USED ON TARGETS J

MINDEF(MRBM1)..  X(MRBM1,T1) + X(MRBM1,T2) + X(MRBM1,T3) + X(MRBM1,T4)
       + X(MRBM1,T5) + X(MRBM1,T6) + X(MRBM1,T7) + X(MRBM1,T8) + X(MRBM1,T9)
       + X(MRBM1,T10) + X(MRBM1,T11) + X(MRBM1,T12) + X(MRBM1,T13)
       + X(MRBM1,T14) + X(MRBM1,T15) + X(MRBM1,T16) + X(MRBM1,T17)
       + X(MRBM1,T18) + X(MRBM1,T19) + X(MRBM1,T20) =G= 0 ;
       (LHS = 0)

MINDEF(B1)..  X(B1,T1) + X(B1,T2) + X(B1,T3) + X(B1,T4) + X(B1,T5) + X(B1,T6)
       + X(B1,T7) + X(B1,T8) + X(B1,T9) + X(B1,T10) + X(B1,T11) + X(B1,T12)
       + X(B1,T13) + X(B1,T14) + X(B1,T15) + X(B1,T16) + X(B1,T17) + X(B1,T18)
       + X(B1,T19) + X(B1,T20) =G= 4 ; (LHS = 0 ***)
REMAINING 2 ENTRIES SKIPPED

---- DAMAGEDEF    =E=  DAMAGE DEFINITION

DAMAGEDEF..  - (2.5647)*X(SRBM,T2) - (9.7511)*X(SRBM,T6) - (3.6876)*X(SRBM,T7)
       - (4.8756)*X(SRBM,T8) - (5.5786)*X(SRBM,T9) - (5.1293)*X(SRBM,T18)
       - (10.4612)*X(MRBM1,T1) - (9.3165)*X(MRBM1,T2) - (8.1259)*X(MRBM1,T3)
       - (13.0765)*X(MRBM1,T4) - (6.5008)*X(MRBM1,T5) - (12.6433)*X(MRBM1,T6)
       - (7.3752)*X(MRBM1,T7) - (5.9535)*X(MRBM1,T8) - (5.5786)*X(MRBM1,T9)
       - (22.6234)*X(MRBM1,T10) - (0.9091)*X(MRBM1,T12) - (25.5667)*X(MRBM1,T14)
       - (27.8524)*X(MRBM1,T15) - (16.6183)*X(MRBM1,T16)
       - (16.2519)*X(MRBM1,T17) - (17.4353)*X(MRBM1,T18)
       - (16.2519)*X(MRBM1,T19) - (24.3778)*X(MRBM1,T20) - (2.4493)*X(B1,T1)
       - (2.5647)*X(B1,T2) - (2.0411)*X(B1,T3) - (3.0616)*X(B1,T4)
       - (1.6329)*X(B1,T5) - (6.3216)*X(B1,T6) - (2.9184)*X(B1,T7)
       - (2.8293)*X(B1,T8) - (2.0845)*X(B1,T9) - (7.694)*X(B1,T10)
       - (0.3015)*X(B1,T11) - (0.9091)*X(B1,T12) - (1.2563)*X(B1,T13)
```



```
      DAMAGEDEF    =E=  DAMAGE DEFINITION

       - (4.0405)*X(B1,T14) - (6.0918)*X(B1,T15) - (2.6264)*X(B1,T16)
```

```
     - (5.1293)*X(B1,T17) - (8.3382)*X(B1,T18) - (7.2571)*X(B1,T19)
     - (12.5072)*X(B1,T20) - (6.1233)*X(F111,T10) - (2.8293)*X(F111,T11)
     - (3.7522)*X(F111,T12) - (11.7888)*X(F111,T13) - (16.6763)*X(F111,T14)
     - (4.0405)*X(F111,T15) - (9.4342)*X(F111,T16) - (5.0029)*X(MRBM2,T1)
     - (3.0938)*X(MRBM2,T2) - (4.1691)*X(MRBM2,T3) - (3.847)*X(MRBM2,T4)
     - (2.0517)*X(MRBM2,T5) - (1.2122)*X(MRBM2,T6) - (0.7071)*X(MRBM2,T7)
     - (15.8041)*X(MRBM2,T10) - (1.5388)*X(MRBM2,T11) - (1.837)*X(MRBM2,T12)
     - (11.7888)*X(MRBM2,T13) - (4.0405)*X(MRBM2,T14) - (2.0101)*X(MRBM2,T15)
     - (1.3065)*X(MRBM2,T16) + DAM =E= 1755 ; (LHS = 1755)
```



```
---- X          THE NUMBER OF WEAPONS I TO BE ASSIGNED TO TARGET J

X(SRBM,T1)
                    (.LO, .L, .UP = 0, 0,  +INF)
  -200000         OBJECTIVE
        1          MINFIRE(T1)
        1          MAXDEF(SRBM)
        1          MINDEF(SRBM)

X(SRBM,T2)
                    (.LO, .L, .UP = 0, 0,  +INF)
  -200000         OBJECTIVE
      (0.0513)     EXPDAM(T2)
        1          MINFIRE(T2)
      (4.3599)     CLASSDAM(SILOS)
        1          MAXDEF(SRBM)
        1          MINDEF(SRBM)
     (-2.5647)     DAMAGEDEF

X(SRBM,T3)
                    (.LO, .L, .UP = 0, 0,  +INF)
  -200000         OBJECTIVE
        1          MINFIRE(T3)
        1          MAXDEF(SRBM)
        1          MINDEF(SRBM)

REMAINING 97 ENTRIES SKIPPED


---- DAM        DAMAGE VALUE


DAM
                    (.LO, .L, .UP =  -INF, 0,  +INF)
        1          DAMAGEDEF


---- COST       COST TO BE MINIMIZED


COST
                    (.LO, .L, .UP =  -INF, 0,  +INF)
        1          OBJECTIVE
```

```
NONLINEAR COST MINIMIZATION FOR  WEAPONS VS TARGET ALLOCATION
MODEL STATISTICS    SOLVE WAR USING NLP FROM LINE 261


MODEL STATISTICS

BLOCKS OF EQUATIONS      7       SINGLE EQUATIONS     57
BLOCKS OF VARIABLES      3       SINGLE VARIABLES    102
NON ZERO ELEMENTS      597       NON LINEAR N-Z      195
DERIVATIVE POOL         68       CONSTANT POOL        62
CODE LENGTH           3879

GENERATION TIME        =          2.175 MINUTES


EXECUTION TIME         =          2.458 MINUTES

??GAMS 2.02 PC AT/XT                            87/03/08 23:39:56   PAGE 18
NONLINEAR COST MINIMIZATION FOR  WEAPONS VS TARGET ALLOCATION
SOLUTION REPORT     SOLVE WAR USING NLP FROM LINE 261


                  S O L V E      S U M M A R Y

      MODEL    WAR                      OBJECTIVE  COST
      TYPE     NLP                      DIRECTION  MINIMIZE
      SOLVER   MINOS5                   FROM LINE  261

**** SOLVER STATUS       1 NORMAL COMPLETION
**** MODEL STATUS        2 LOCALLY OPTIMAL
**** OBJECTIVE VALUE         2632361022.6000

 RESOURCE USAGE, LIMIT            5.450      1000.000
 ITERATION COUNT, LIMIT          68          1000
 EVALUATION ERRORS                0             0

      M I N O S  ---  VERSION  5.0   APR  1984
      = = = = =
      courtesy of B. A. Murtagh and M. A. Saunders,
                    Department of Operations Research,
                    Stanford University,
                    Stanford  California   94305   U.S.A.


 WORK SPACE NEEDED (ESTIMATE)  --     9505 WORDS.
 WORK SPACE AVAILABLE          --    18880 WORDS.

 EXIT -- OPTIMAL SOLUTION FOUND
 MAJOR ITERATIONS                7
 NORM RG / NORM PI    .000E+00
 TOTAL USED                  5.58 UNITS
 MINOS5 TIME                 3.10 (INTERPRETER -        1.17)

                                LOWER     LEVEL     UPPER    MARGINAL

---- EQU OBJECTIVE                .         .         .       -1.000

  OBJECTIVE   OBJECTIVE FUNCTION DEFINITION


---- EQU EXPDAM      RESTRICTION ON MINIMUM EXPECTED TARGET J DAMAGE

        LOWER     LEVEL     UPPER    MARGINAL

T1      -0.200    -0.200    +INF   1.0000E+6
T2      -0.250    -0.250    +INF   1.0000E+6
T3      -0.250    -0.250    +INF   1.0000E+6
```

T4	-0.150	-0.150	+INF	1.0000E+6
T5	-0.300	-0.300	+INF	1.0000E+6
T6	-0.200	-0.200	+INF	1.0000E+6
T7	-0.300	-0.300	+INF	1.0000E+6
T8	-0.310	-0.310	+INF	1.0000E+6
T9	-0.400	-0.400	+INF	1.0000E+6
T10	-0.050	-0.050	+INF	1.0000E+6
T11	-0.310	-0.310	+INF	1.0000E+6
T12	-0.220	-0.220	+INF	1.0000E+6
T13	-0.100	-0.100	+INF	1.0000E+6

EQU EXPDAM RESTRICTION ON MINIMUM EXPECTED TARGET J DAMAGE

	LOWER	LEVEL	UPPER	MARGINAL
T14	-0.020	-0.020	+INF	1.0000E+6
T15	-0.020	-0.020	+INF	1.0000E+6
T16	-0.070	-0.070	+INF	1.0000E+6
T17	-0.100	-0.100	+INF	1.0000E+6
T18	-0.100	-0.100	+INF	1.0000E+6
T19	-0.100	-0.100	+INF	1.0000E+6
T20	-0.050	-0.050	+INF	1.0000E+6

---- EQU MINFIRE MINIMUM NUMBER OF ALL WEAPONS USED ON TARGET J

	LOWER	LEVEL	UPPER	MARGINAL
T1	5.000	19.302	+INF	.
T2	.	27.027	+INF	.
T3	.	16.626	+INF	.
T4	.	10.881	+INF	.
T5	.	18.512	+INF	.
T6	6.000	9.903	+INF	.
T7	.	11.427	+INF	.
T8	.	7.206	+INF	.
T9	.	4.106	+INF	.
T10	10.000	28.433	+INF	.
T11	.	12.418	+INF	.
T12	.	18.159	+INF	.
T13	.	24.415	+INF	.
T14	15.000	46.873	+INF	.
T15	15.000	28.065	+INF	.
T16	10.000	24.066	+INF	.
T17	.	14.168	+INF	.
T18	.	44.891	+INF	.
T19	.	14.168	+INF	.
T20	8.000	22.722	+INF	.

---- EQU CLASSDAM LOWER BOUND OF EXPECTED DAMAGE ON TARGET CLASS K

	LOWER	LEVEL	UPPER	MARGINAL
SILOS	-352.000	-99.350	+INF	.
SHIPYRDS	-267.000	-103.370	+INF	.
AIRPORTS	-182.000	-51.590	+INF	.
SPARES	-177.000	-11.700	+INF	.
POWPLANT	-339.000	-35.390	+INF	.

---- EQU MAXDEF UPPER BOUND OF # OF WEAPON I USED ON TARGETS J

	LOWER	LEVEL	UPPER	MARGINAL
SRBM	-INF	104.560	150.000	.
MRBM1	-INF	100.000	100.000	-7.389E+7
B1	-INF	8.808	10.000	.
F111	-INF	85.000	85.000	-1.631E+7
MRBM2	-INF	105.000	105.000	-2.291E+7

---- EQU MINDEF LOWER BOUND OF # OF WEAPON I USED ON TARGETS J

	LOWER	LEVEL	UPPER	MARGINAL
SRBM	.	104.560	+INF	.
MRBM1	.	100.000	+INF	.
B1	4.000	8.808	+INF	.
F111	.	85.000	+INF	.
MRBM2	.	105.000	+INF	.

	LOWER	LEVEL	UPPER	MARGINAL
---- EQU DAMAGEDEF	1755.000	1755.000	1755.000	EPS

DAMAGEDEF DAMAGE DEFINITION

---- VAR X THE NUMBER OF WEAPONS I TO BE ASSIGNED TO TARGET J

	LOWER	LEVEL	UPPER	MARGINAL
SRBM .T1	.	.	+INF	2.0000E+5
SRBM .T2	.	27.027	+INF	1.8718E+5
SRBM .T3	.	.	+INF	2.0000E+5
SRBM .T4	.	.	+INF	2.0000E+5
SRBM .T5	.	.	+INF	2.0000E+5
SRBM .T6	.	9.903	+INF	1.6750E+5
SRBM .T7	.	11.427	+INF	1.6839E+5
SRBM .T8	.	7.206	+INF	1.4962E+5
SRBM .T9	.	4.106	+INF	1.1074E+5
SRBM .T10	.	.	+INF	2.0000E+5
SRBM .T11	.	.	+INF	2.0000E+5
SRBM .T12	.	.	+INF	2.0000E+5
SRBM .T13	.	.	+INF	2.0000E+5
SRBM .T14	.	.	+INF	2.0000E+5
SRBM .T15	.	.	+INF	2.0000E+5
SRBM .T16	.	.	+INF	2.0000E+5
SRBM .T17	.	.	+INF	2.0000E+5
SRBM .T18	.	44.891	+INF	1.9487E+5
SRBM .T19	.	.	+INF	2.0000E+5
SRBM .T20	.	.	+INF	2.0000E+5
MRBM1.T1	.	.	+INF	7.4151E+7
MRBM1.T2	.	.	+INF	7.4139E+7
MRBM1.T3	.	.	+INF	7.4145E+7

VAR X THE NUMBER OF WEAPONS I TO BE ASSIGNED TO TARGET J

	LOWER	LEVEL	UPPER	MARGINAL
MRBM1.T4	.	10.881	+INF	7.4159E+7
MRBM1.T5	.	2.288	+INF	7.4137E+7
MRBM1.T6	.	.	+INF	7.4143E+7

MRBM1.T7	.	.	+INF	7.4122E+7
MRBM1.T8	.	.	+INF	7.4124E+7
MRBM1.T9	.	.	+INF	7.4096E+7
MRBM1.T10	.	.	+INF	7.4178E+7
MRBM1.T11	.	.	+INF	7.4185E+7
MRBM1.T12	.	.	+INF	7.4181E+7
MRBM1.T13	.	.	+INF	7.4185E+7
MRBM1.T14	.	.	+INF	7.4183E+7
MRBM1.T15	.	28.065	+INF	7.4183E+7
MRBM1.T16	.	16.517	+INF	7.4176E+7
MRBM1.T17	.	14.168	+INF	7.4169E+7
MRBM1.T18	.	.	+INF	7.4168E+7
MRBM1.T19	.	14.168	+INF	7.4169E+7
MRBM1.T20	.	13.914	+INF	7.4177E+7
B1 .T1	.	.	+INF	3.8053E+7
B1 .T2	.	.	+INF	3.8049E+7
B1 .T3	.	.	+INF	3.8051E+7
B1 .T4	.	.	+INF	3.8055E+7
B1 .T5	.	.	+INF	3.8049E+7
B1 .T6	.	.	+INF	3.8040E+7
B1 .T7	.	.	+INF	3.8036E+7
B1 .T8	.	.	+INF	3.8032E+7
B1 .T9	.	.	+INF	3.8028E+7
B1 .T10	.	.	+INF	3.8059E+7
B1 .T11	.	.	+INF	3.8058E+7
B1 .T12	.	.	+INF	3.8057E+7
B1 .T13	.	.	+INF	3.8060E+7
B1 .T14	.	.	+INF	3.8061E+7
B1 .T15	.	.	+INF	3.8061E+7
B1 .T16	.	.	+INF	3.8060E+7
B1 .T17	.	.	+INF	3.8056E+7
B1 .T18	.	.	+INF	3.8053E+7
B1 .T19	.	.	+INF	3.8054E+7
B1 .T20	.	8.808	+INF	3.8057E+7
F111 .T1	.	.	+INF	4.2115E+7
F111 .T2	.	.	+INF	4.2115E+7
F111 .T3	.	.	+INF	4.2115E+7
F111 .T4	.	.	+INF	4.2115E+7
F111 .T5	.	.	+INF	4.2115E+7
F111 .T6	.	.	+INF	4.2115E+7
F111 .T7	.	.	+INF	4.2115E+7
F111 .T8	.	.	+INF	4.2115E+7
F111 .T9	.	.	+INF	4.2115E+7
F111 .T10	.	.	+INF	4.2113E+7
F111 .T11	.	12.418	+INF	4.2086E+7
F111 .T12	.	18.159	+INF	4.2097E+7
F111 .T13	.	.	+INF	4.2105E+7
F111 .T14	.	46.873	+INF	4.2113E+7

VAR X THE NUMBER OF WEAPONS I TO BE ASSIGNED TO TARGET J

	LOWER	LEVEL	UPPER	MARGINAL
F111 .T15	.	.	+INF	4.2114E+7
F111 .T16	.	7.550	+INF	4.2110E+7
F111 .T17	.	.	+INF	4.2115E+7
F111 .T18	.	.	+INF	4.2115E+7
F111 .T19	.	.	+INF	4.2115E+7
F111 .T20	.	.	+INF	4.2115E+7
MRBM2.T1	.	19.302	+INF	2.3397E+7
MRBM2.T2	.	.	+INF	2.3399E+7
MRBM2.T3	.	16.626	+INF	2.3393E+7
MRBM2.T4	.	.	+INF	2.3406E+7
MRBM2.T5	.	16.224	+INF	2.3399E+7

```
MRBM2.T6        .        .        +INF   2.3410E+7
MRBM2.T7        .        .        +INF   2.3408E+7
MRBM2.T8        .        .        +INF   2.3414E+7
MRBM2.T9        .        .        +INF   2.3414E+7
MRBM2.T10       .      28.433     +INF   2.3409E+7
MRBM2.T11       .        .        +INF   2.3398E+7
MRBM2.T12       .        .        +INF   2.3405E+7
MRBM2.T13       .      24.415     +INF   2.3405E+7
MRBM2.T14       .        .        +INF   2.3414E+7
MRBM2.T15       .        .        +INF   2.3414E+7
MRBM2.T16       .        .        +INF   2.3413E+7
MRBM2.T17       .        .        +INF   2.3414E+7
MRBM2.T18       .        .        +INF   2.3414E+7
MRBM2.T19       .        .        +INF   2.3414E+7
MRBM2.T20       .        .        +INF   2.3414E+7

                          LOWER     LEVEL      UPPER    MARGINAL

---- VAR DAM              -INF   1559.150     +INF         .
---- VAR COST             -INF  2.6324E+9     +INF         .

  DAM          DAMAGE VALUE
  COST         COST TO BE MINIMIZED


**** REPORT SUMMARY :         0     NONOPT
                                  0 INFEASIBLE
                                  0  UNBOUNDED
                                  0     ERRORS

??GAMS 2.02 PC AT/XT                         87/03/08 23:39:56   PAGE 23
NONLINEAR COST MINIMIZATION FOR  WEAPONS VS TARGET ALLOCATION
E X E C U T I N G


----     281      =====================================================


----     282          F   I   N   A   L      R   E   P   O   R   T


----     283      =====================================================


----     286 PARAMETER REPORT       SUGGESTED USAGE OF WEAPON I ON TARGET J
```

	SRBM	MRBM1	B1	F111	MRBM2
T1					19
T2	27				
T3					17
T4		11			
T5		2			16
T6	10				
T7	11				
T8	7				
T9	4				
T10					28
T11				12	
T12				18	
T13					24
T14				47	
T15		28			
T16		17		8	
T17		14			
T18	45				
T19		14			
T20		14	9		

```
----     287 PARAMETER REPORT2       WEAPONS RESTRICTIONS AND DESIRED USAGE

                  MIN          MAX          USED

SRBM                           150          105
MRBM1                          100          100
B1                 4            10            9
F111                            85           85
MRBM2                          105          105


----     288 PARAMETER REPORT3         =   2632361023 TOTAL MIN EXPECTED COST


----     289 VARIABLE  DAM.L           =         1559 DAMAGE VALUE
```

```
??GAMS 2.02 PC AT/XT                             87/03/08 23:39:56  PAGE 24
NONLINEAR COST MINIMIZATION FOR  WEAPONS VS TARGET ALLOCATION
E X E C U T I N G

**** FILE SUMMARY

INPUT   C: GAMS2.02A WAR.GMS
OUTPUT  C: GAMS2.02A WAR.LST

EXECUTION TIME       =         0.641 MINUTES
```

APPENDIX C
A DETECTION PROBLEM

```
C                          DOCUMENTATION
C                         ===============
C
C    THIS PROGRAM SIMULATES THE DETECTION OF A TARGET, WHEN THE TARGET
C APPEARS RANDOMLY INSIDE A GIVEN PATTERN OF 16 SONOBUOYS. THE PATTERN
C OF THE POSITIONS OF THE SONOBUOYS IS GIVEN BY THE COORDINATES OF
C THEIR CENTERS. DETECTION OCCURS WHEN THE TARGET APPEARS EITHER
C WITHIN 2 NM FROM THE SONOBUOY OR AT A DISTANCE BETWEEN 30 AND 33
C NAUTICAL MILES (NM) FROM IT, 360 DEGREES AROUND IT. IN THE CASE
C OF OVERLAPPING SONOBUOY LETHAL AREAS, THE TARGET IS ACCOUNTED AS
C BEING 'HIT' ONLY ONCE.
C THE RANDOM TARGETS HAVE BIVARIATE NORMAL DISTRIBUTION WITH MEAN
C ZERO, STANDARD DEVIATION 25 NM AND ARE INDEPENDENT FROM ONE ANOTHER.
C A TARGET'S RANDOM  COORDINATES ARE GENERATED USING THE 'LNORM'
C ROUTINE FOR STANDARD NORMAL RANDOM VARIABLES.
C THE SIMULATION IS RUN 1000 TIMES AND THE ACHIEVED PROB. OF DETECTION
C (PD) IS PROBABLY THE BEST FOR THIS KIND OF SONOBUOY PATTERN.
C
C    THE ANALYTICAL ESTIMATIONS OF PROBABILITY OF DETECTION ARE COMPUTED
C BY THE SUBROUTINE "CONFET".
C
C    THE PROGRAM WAS WRITTEN IN VS FORTRAN, DEBUGGED AND EXECUTED ON
C THE IBM 3033 MAINFRAME, AT NPS, BY LCDR HARRY ATHANASOPOULOS, 1987.
C THE OUTPUT IS EDITED TO THE END OF THE PROGRAM.
C
C
C                         KEY TO VARIABLES
C                        ------------------
C
C
C      1.- X          : X-COORDINATES OF TARGET
C      2.- Y          : Y-      -"-          -"-
C      3.- SONOS      : NUMBER OF SONOBUOYS
C      4.- TRIALS     : TOTAL NUMBER OF TARGETS
C      5.- BINGO      : TOTAL NUMBER OF DETECTED TARGETS
C      6.- SIGMA      : STAND.DEVIATION OF THE TARGETS DISTRIBUTION
C      7.- ISEED      : INTEGER SEED FOR THE LNORM N(0,1) GENERATOR
C      8.- UX         : BIVARIATE N(0,25) TARGET X-COORDINATE
C      9.- UY         :    -"-       -"-      -"-  Y-COORDINATE
C     10.- RRR        : TARGET'S DISTANCE FROM ORIGIN
C     11.- DIST       : TARGET/DETECTING SONOBUOY DISTANCE
C
C
C
C                          THE PROGRAM
C                         =============
C
C
      DIMENSION RN(2),X(16),Y(16)
C----------------------------------------------------------------------
C  SONOBUOY COORDINATES FOR THE GIVEN PATTERN
C----------------------------------------------------------------------
      DATA X/5.,10.,30.,-15.,-30.,0.,0.,0.,0.,-10.,10.,-10.,10.,-10.,
     *10.,0./
      DATA Y/0.,0.,0.,0.,0.,10.,15.,20.,-5.,5.,5.,-20.,-20.,-10.,
     *-10.,-25./
C----------------------------------------------------------------------
C INPUT PARAMETERS, GIVEN BY THE DECISION MAKER, AND INITIALIZATION
C----------------------------------------------------------------------
      SONOS  =16.
      TRIALS =1000.
      SIGMA  =25.
```

```
      BINGO  =0.
      C1     =0.
      C2     =0.
      C3     =0.
      C4     =0.
C-----------------------------------------------------------------------
C  PROVIDE ANY INTEGER "SEED" FOR THE RANDOM NUMBER GENERATOR
C-----------------------------------------------------------------------
      ISEED  =87937
C-----------------------------------------------------------------------
C  BEGIN SIMULATION
C-----------------------------------------------------------------------
   20 DO 1 I=1,TRIALS
   10    CALL LNORM(ISEED,RN,2,1,0)
          UX=SIGMA*RN(1)
          UY=SIGMA*RN(2)
C-----------------------------------------------------------------------
C  TARGET APPEARANCE FREQUENCY CHECK INSIDE THE TARGET AREA
C-----------------------------------------------------------------------
      RRR=SQRT(UX**2+UY**2)
      IF(RRR.LE.25.) C1=C1+1
      IF(RRR.GT.25..AND.RRR.LE.50.) C2=C2+1
      IF(RRR.GT.50..AND.RRR.LE.75.) C3=C3+1
      IF(RRR.GT.75.) C4=C4+1
               DO 2 J=1,SONOS
                DIST=SQRT((UX-X(J))**2  + (UY-Y(J))**2)
C-----------------------------------------------------------------------
C  THIS CONDITION DEPENDS ON THE CHARACTERISTICS OF THE SONOBUOYS
C-----------------------------------------------------------------------
                IF((DIST.LE.2.).OR.(DIST.GE.30..AND.DIST.LE.33.))THEN
                  BINGO=BINGO+1
                  GO TO 1
                END IF
    2 CONTINUE
    1 CONTINUE
      PD=BINGO/TRIALS
      WRITE(9,70)
   70 FORMAT('           S I M U L A T I O N   R E S U L T S')
      WRITE(9,80)
   80 FORMAT('          ========================================',/)
      WRITE(9,85)
   85 FORMAT('  FOR THE GIVEN PATTERN,',//)
      WRITE(9,90) TRIALS,BINGO
   90 FORMAT('  NUMBER OF RANDOM TARGETS =',F8.0,', DETECTED =',F8.0)
      WRITE(9,100) PD
  100 FORMAT('  PROB. OF DETECTION WITH EXISTING PATTERN =',F7.3,////)
      WRITE(9,109)
  109 FORMAT('            A N A L Y T I C   R E S U L T S')
      WRITE(9,110)
  110 FORMAT('           ==================================',//)
      CALL CONFET(SIGMA,SONOS)
      STOP
      END
C
C***** END OF MAIN PROGRAM *****
C
C
C-----------------------------------------------------------------------
C   THIS SUBROUTINE COMPUTES ANALYTIC RESULTS
C-----------------------------------------------------------------------
C
       SUBROUTINE CONFET(SIGMA,SONOS)
C-----------------------------------------------------------------------
C  INITALIZATION OF SONOBUOY-DEPENDENT PARAMETERS (LETHAL RANGE)
C-----------------------------------------------------------------------
      PI = 3.14159
      CENTER = 2.
      OUT = 33.
      RIN = 30.
```

```
      AHAT = SONOS*PI*(CENTER**2)+SONOS*PI*(OUT**2-RIN**2)
      Z = AHAT/(2*PI*SIGMA**2)
C----------------------------------------------------------------------
C  ANALYTIC APPROXIMATION OF DETECTION PROBABILITY WITH UTTER OPTIMISM
C----------------------------------------------------------------------
      PDOPT = 1-EXP(-Z)
      WRITE(9,120)  PDOPT
  120 FORMAT('  PROB. OF DETECTION WITH UTTER OPTIMISM      = ',F6.4,//)
C----------------------------------------------------------------------
C  DETECTION PROBABILITY USING "CONFETTI APPROXIMATION #1"
C----------------------------------------------------------------------
      PDCON1 = (1-EXP(-SQRT(Z)))**2
      WRITE(9,121)  PDCON1
  121 FORMAT('  PROB. OF DETECTION FROM CONFETTI APPROX. #1 = ',F6.4,//)
C----------------------------------------------------------------------
C  DETECTION PROBABILITY USING "CONFETTI APPROXIMATION #2"
C----------------------------------------------------------------------
      PDCON2 = 1-((1+SQRT(2*Z))*EXP(-SQRT(2*Z)))
      WRITE(9,122)  PDCON2
  122 FORMAT('  PROB. OF DETECTION FROM CONFETTI APPROX. #2 = ',F6.4,//)
      RETURN
      END
C
C***** END OF PROGRAM *****
C
C
C
C
C                        OUTPUT FILE
C                       =============
C
C
C          S I M U L A T I O N   R E S U L T S
C         =======================================
C
C  FOR THE GIVEN PATTERN,
C
C
C  NUMBER OF RANDOM TARGETS =   1000., DETECTED =    664.
C  PROB. OF DETECTION WITH EXISTING PATTERN =  0.664
C
C
C
C
C            A N A L Y T I C   R E S U L T S
C           =================================
C
C
C  PROB. OF DETECTION WITH UTTER OPTIMISM      = 0.9154
C
C
C  PROB. OF DETECTION FROM CONFETTI APPROX. #1 = 0.6278
C
C
C  PROB. OF DETECTION FROM CONFETTI APPROX. #2 = 0.6510
C
C
C**********************************************************************
```

APPENDIX D

A WEAPONS EVALUATION PROBLEM

```
C                         DOCUMENTATION
C                         =============
C
C   THIS PROGRAM HELPS IN EVALUATING SIX AIRCRAFT GUN SYSTEMS, USING
C AIR-TO-AIR SIMULATED COMBAT DATA, PROVIDED BY THE NAVY; IT GIVES (PK).
C (PA) IS ASSUMED TO BE GREATER OR EQUAL TO .70.
C DATA FROM THE SIMULATION ARE IN A DATA DASE FILE CALLED "IN"
C
C   THE PROGRAM WAS WRITTEN IN VS FORTRAN, DEBUGGED AND EXECUTED ON
C THE IBM 3033 MAINFRAME, AT NPS, BY LCDR HARRY ATHANASOPOULOS, 1987.
C THE INPUT AND OUTPUT FILES ARE EDITED TO THE END OF THE PROGRAM.
C
C
C                       CODING OF ABBREVIATIONS
C                       -----------------------
C
C A    : AIRCRAFT AREA, AT MOMENT OF ENGAGEMENT
C AV   : VULNERABLE AIRCRAFT AREA DURING ENGAGEMENT
C PA   : PROB. OF OBTAINING FIRING POSITION, DURING ENGAGEMENT
C PH   : PROB. OF HITTING ENEMY AIRCRAFT, PER ROUND
C N    : NUMBER OF ROUNDS FIRED, PER ENGAGEMENT
C NN   : GUN SYSTEM COUNTER, ACCORDING TO INPUT SEQUENCE
C PKH  : PROB. OF KILL, GIVEN A HIT, PER ROUND
C PKR  : PROB. OF KILL, PER ROUND
C PK   : PROB. OF KILL, PROVIDED (N) ROUNDS WERE FIRED
C FIRE : NUMBER OF ROUNDS SO THAT (PK) IS GREATER OR EQUAL TO .65
C
C
C
C                           THE PROGRAM
C                           ===========
C
      OPEN(UNIT = 8,FILE = 'IN')
      OPEN(UNIT = 9,FILE = 'OUT')
C-----------------------------------------------------------------------
C  READ SIMULATION DATA FROM INPUT FILE
C-----------------------------------------------------------------------
      NN=1
   10 READ(8,*) A,AV,PA,PH,N
C-----------------------------------------------------------------------
C  CHECK FOR THE END OF INPUT FILE
C-----------------------------------------------------------------------
      IF(A .LT. 0.) GOTO 1
C-----------------------------------------------------------------------
C  INPUT ERROR TRAPPING
C-----------------------------------------------------------------------
      IF((PA .GT. 1.) .OR. (PA .LT. 0.)) GOTO 333
      IF((PH .GT. 1.) .OR. (PH .LT. 0.)) GOTO 334
C-----------------------------------------------------------------------
C  THESE ARE THE MATHEMATICAL EQUATIONS THAT WE NEED
C-----------------------------------------------------------------------
      PKH = AV/A
      PKR = PKH*PH
      PK = (1 - (1 - PKR) ** N) * PA
C-----------------------------------------------------------------------
C  CREATE THE OUTPUT FILE
C-----------------------------------------------------------------------
      WRITE(9,100) NN
  100 FORMAT('          R E S U L T S   FOR GUN SYSTEM NO.',I2)
      WRITE(9,*) '   ========================================='
      WRITE(9,*) ' '
```

```
      WRITE(9,*) ' '
      WRITE(9,*) ' INPUT VALUES (FOR THIS GUN SYSTEM)'
      WRITE(9,*) '--------------'
      WRITE(9,108) A
  108 FORMAT('   A = ',F6.3)
      WRITE(9,107) AV
  107 FORMAT('   AV= ',F6.3)
      WRITE(9,106) PA
  106 FORMAT('   PA= ',F6.3)
      WRITE(9,105) PH
  105 FORMAT('   PH= ',F6.3)
      WRITE(9,104) N
  104 FORMAT('   N = ',I6)
      WRITE(9,*) '--------------'
      WRITE(9,101) PK
  101 FORMAT('   PROBABILITY OF KILL (PK) WITH ABOVE N IS  ',F6.3)
      WRITE(9,*) '--------------'
      IF(PK .LT. .65) WRITE(9,*) '   NOTE:  PK <.650'
C-----------------------------------------------------------------
C  HOW MANY ROUNDS ARE NECESSARY FOR (PK) GREATER THAN .650?
C-----------------------------------------------------------------
      FIRE = 0
  222 FIRE = FIRE + 1
      PK = (1 - (1 - PKR) **FIRE )*PA
      IF(PK .GE. .650) GOTO 20
      GOTO 222
   20 CONTINUE
      IFIRE = FIRE
      WRITE(9,102) IFIRE
  102 FORMAT('        FOR PK >.650, ',I5,'  ROUNDS OF FIRE ARE NEEDED',/)
      WRITE(9,*) '*******************************************************'
      WRITE(9,*) ' '
      WRITE(9,*) ' '
      WRITE(9,*) ' '
      NN=NN+1
      GOTO 10
C-----------------------------------------------------------------
C  INPUT ERROR MESSAGES
C-----------------------------------------------------------------
  333 WRITE(9,*) ' GIVEN "PA" NOT A PROPABILITY, WRONG DATA'
  334 WRITE(9,*) ' GIVEN "PH" NOT A PROBABILITY, WRONG DATA'
      STOP
    1 WRITE(9,*) '*******************************************************'
      WRITE(9,*) ' END OF DATA'
      NN=NN-1
      WRITE(9,103) NN
  103 FORMAT(' THE ABOVE',I2, ' RESULTS CORRESPOND TO INPUT SYSTEMS')
      WRITE(9,*) '*******************************************************'
      STOP
      END
C
C     ***** END OF PROGRAM *****
C
C
C
C                         I N P U T   F I L E
C                        ====================
C
C
C
C  - THIS FILE CONTAINS SIMULATION AVERAGE DATA OF SIX AIRCRAFT GUN
C    SYSTEMS.
C  - SEE CODING OF PARAMETERS AT TOP OF THE ACTUAL PROGRAM.
C
C
C    12.5,  2.0,    .7 ,    .3 ,  26
C    18.5,  5.0,    .8 ,    .5 ,  20
C    10.0,  3.0,    .7 ,    .4 ,  30
C    08.0,  1.0,    .8 ,    .6 ,  10
C    15.3,  8.0,    .8 ,    .7 ,  18
```

```
C    20.0,  4.0,     .9 ,     .8 ,  12
C    -1.0,  0.0,    0.0 ,    0.0 ,   0
C    ================================
C     A   ,  AV ,    PA  ,   PH  ,  N
C    ================================
C
C
C
C
C
C                        O U T P U T   F I L E
C                       ======================
C
C
C        R E S U L T S    FOR GUN SYSTEM NO. 1
C   ================================================
C
C
C  INPUT VALUES (FOR THIS GUN SYSTEM)
C --------------
C  A = 12.500
C  AV=  2.000
C  PA=  0.700
C  PH=  0.300
C  N =     26
C --------------
C  PROBABILITY OF KILL (PK) WITH ABOVE N IS   0.505
C --------------
C   NOTE:  PK <.650
C      FOR PK >.650,    54  ROUNDS OF FIRE ARE NEEDED
C
C *****************************************************
C
C
C
C        R E S U L T S    FOR GUN SYSTEM NO. 2
C   ================================================
C
C
C  INPUT VALUES (FOR THIS GUN SYSTEM)
C --------------
C  A = 18.500
C  AV=  5.000
C  PA=  0.800
C  PH=  0.500
C  N =     20
C --------------
C  PROBABILITY OF KILL (PK) WITH ABOVE N IS   0.756
C --------------
C      FOR PK >.650,    12  ROUNDS OF FIRE ARE NEEDED
C
C *****************************************************
C
C
C
C        R E S U L T S    FOR GUN SYSTEM NO. 3
C   ================================================
C
C
C  INPUT VALUES (FOR THIS GUN SYSTEM)
C --------------
C  A = 10.000
C  AV=  3.000
C  PA=  0.700
C  PH=  0.400
C  N =     30
C --------------
C  PROBABILITY OF KILL (PK) WITH ABOVE N IS   0.685
C --------------
```

```
C      FOR PK >.650,    21  ROUNDS OF FIRE ARE NEEDED
C
C *****************************************************
C
C
C
C         R E S U L T S   FOR GUN SYSTEM NO. 4
C   ================================================
C
C
C  INPUT VALUES (FOR THIS GUN SYSTEM)
C --------------
C  A =  8.000
C  AV=  1.000
C  PA=  0.800
C  PH=  0.600
C  N =     10
C --------------
C  PROBABILITY OF KILL (PK) WITH ABOVE N IS   0.433
C --------------
C   NOTE:  PK <.650
C      FOR PK >.650,    22  ROUNDS OF FIRE ARE NEEDED
C
C *****************************************************
C
C
C
C         R E S U L T S   FOR GUN SYSTEM NO. 5
C   ================================================
C
C
C  INPUT VALUES (FOR THIS GUN SYSTEM)
C --------------
C  A = 15.300
C  AV=  8.000
C  PA=  0.800
C  PH=  0.700
C  N =     18
C --------------
C  PROBABILITY OF KILL (PK) WITH ABOVE N IS   0.800
C --------------
C      FOR PK >.650,     4  ROUNDS OF FIRE ARE NEEDED
C
C *****************************************************
C
C
C
C         R E S U L T S   FOR GUN SYSTEM NO. 6
C   ================================================
C
C
C  INPUT VALUES (FOR THIS GUN SYSTEM)
C --------------
C  A = 20.000
C  AV=  4.000
C  PA=  0.900
C  PH=  0.800
C  N =     12
C --------------
C  PROBABILITY OF KILL (PK) WITH ABOVE N IS   0.789
C --------------
C      FOR PK >.650,     8  ROUNDS OF FIRE ARE NEEDED
C
C
C
C
C *****************************************************
C  END OF DATA
C *****************************************************
```

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6.	Commodore A. Rouhotas HN 34, Marathonos Street Vrilissia Athens 152-35, Greece	1
7.	Captain G. Germanos HN 3, Daphnis Street Kastri, Nea Erythrea Athens, Greece	1
8.	A. J. Phelps CB 1, Woodsyre Sydenham Hill London SE26 6SS, UK	1
9.	CDR L. Kaloulis HN 10, Plythonos Gemistou Street Athens 176-71, Greece	1
10.	CDR J. C. Georgiades HN NAVILCO/HLO/OG 700, Robbins Ave. Philadelphia, Pennsylvania 19111	1
11.	CDR A. Grigoropoulos HN 12, Kallirrois Street Macriyanni Athens 117-43, Greece	1