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DECISION THEORY RESEARCH

Clinton W. Kelly, III, et al

Decisions and Designs, Incorporated

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Report describes research and investigation in decision theory and computer aids for decision analysis, and case study applications of decision theory. Summaries are presented on advanced decision theoretic concepts including procedures for incorporating multiple dimensions of value in a single measure of utility, improving the structure of decision models, identi-		

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ifying cross cultural differences in the perception of uncertainty and optimizing the amount of information disclosure during bargaining. Several case study applications investigated uses of decision analysis for assessment and forecasting, resource allocation, multi-dimensional evaluation, policy formulation and implementation, and negotiation modeling. Developments in decision-aiding computer methods including interactive computer graphics are reported. Progress in updating a handbook for decision analysis and the results of a workshop on perceptions of the military balance are reported.

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1.0 INTRODUCTION

1.1 Background

This is the fourth interim technical report under Office of Naval Research Contract N00014-73-C-0149, describing progress in decision theory research and related applications during the period 1 March 1974 through 31 January 1975.

Unlike Technical Progress Report No. 3¹, which included several detailed technical reports, this report presents descriptions, discussions, and results of the work in summary form. A reference to individual technical reports is made in each of the sections of this report, where appropriate. In this way, a concise and factual discussion of technical findings and accomplishments during the period is presented, and source guidance is provided to those who may desire a complete, detailed understanding of the accomplishments.

The decision theory work, which was sponsored by the Defense Advanced Research Projects Agency, was carried out in basic research, case studies, computer support, a perceptions conference, and maintenance of a handbook for decision analysis, as described below.

In addition to the decision theory effort under ARPA sponsorship, four practical applications closely related to the ARPA-sponsored research, which were carried out under separate contracts with other agencies, are described in Section 4.0.

1.2 Basic Research

Basic research covers tasks which contribute to fundamental academic disciplines such as psychology, mathematical logic, systems analysis, and organizational behavior as well as to specific DoD interests. Typically, they require further development before they can be directly applied to DoD problems.

Section 2.0 contains a digest of the basic research areas addressed. These areas include:

- o Multi-Attributed Decision Analysis (Section 2.1),
- o Modeling Subsequent Acts for Decision Analysis (Section 2.2),

¹ "Decision Theory Research," Technical Progress Report No. 3, Decisions and Designs, Inc., to Defense Advanced Research Projects Agency under Contract N00014-73-C-0149.

- o Cross Cultural Study of Uncertainty (Section 2.3), and
- o Unilateral Disclosure (Section 2.4).

1.3 Case Studies and Other Applications

A key step in the development, evaluation, user adaptation and ultimately institutionalization of decision analysis tools is the conduct of pilot applications. It appears that the most promising mode for developing pilot applications is through active consulting on a live problem. It is felt that pilot applications developed through case studies will help assure realistic constraints on the development of technology and provide a basis for generalization of the technology to other situations.

Section 3.0 contains abstracts of case studies sponsored by ARPA that cover a wide range of high interest DoD problem areas. The area of Assessment and Forecasting is addressed in Section 3.3 (Predicting NATO Response to Impending Attack). The area of Resource Allocation is addressed in Section 3.7 (Allocating Funds for Research). Evaluation is addressed in Section 3.4 (Net Strategic Capabilities Model) and Section 3.5 (Multi-Attribute Utility Analysis in Arms Treaty Negotiation). Policy Formulation and Implementation is addressed in Section 3.1 (Evaluating Foreign Policy Alternatives for Saudi Arabia) and Section 3.2 (COCOM Study-Export Controls on Sales of Computers to Soviet Bloc). Negotiation is addressed in Section 3.6 (Use of Decision Theory for Analysis of U.S. Treaty Negotiations Positions).

Other applications of decision analysis techniques (not sponsored by ARPA) are presented in Section 4.0. These applications involve the area of Evaluation and include:

- o Design-to-Price EW--Contractor Selection (Section 4.1),
- o Requirements Tradeoff Analysis for the World Wide Military Command and Control System (WWMCCS) (Section 4.2),
- o Value of Intelligence Information for Decision Making (Section 4.3), and
- o Quantitative Estimates for a Major Weapon System, Aircraft Carriers, Using Decision Theoretic Analysis (Section 4.4).

1.4 Computer Support

Computer support is viewed as a means to facilitate the adaptation of decision analytic or other tools to the operating needs of the intended user. Such facilitation may require computers to perform tedious calculation or to otherwise streamline the man-model interface.

Several areas of computer support were investigated, including a survey of Computer Programs to Aid Decision Analysis (Section 5.1), Development of Interactive Computer Graphics Techniques (Section 5.2), and Application and Modification of CTREE, a particular decision analysis computer program (Section 5.3).

1.5 Perception Conference

Because of recent interest in the role of perceptions of the military balance in the decision making and planning processes within the Department of Defense, two workshops have been conducted. Results of the first workshop, to survey existing studies and hypotheses, and the second workshop, to solicit observations and suggestions of senior decision makers and planners, are reported in Sections 6.2 and 6.3.

1.6 Handbook for Decision Analysis

Section 7.0 describes a proposed revision to DDI's Handbook for Decision Analysis.

2.0 BASIC RESEARCH DIGEST

2.1 Multi-Attributed Decision Analysis

2.1.1 Purpose - Many options are available to the decision analyst faced with the problem of analyzing decisions whose consequences are to be evaluated by multiple criteria. The purpose of this study is to clarify the options and provide some guidance on when they should be exercised.

2.1.2 Approach - On the basis of prior experience in the analysis of multi-attributed decisions in government and business, systematic insights have been developed into the elements of this problem. In conjunction with analysis of literature in the field, a review of options for assigning values to multi-attributed objectives will be systematically made and each option evaluated in the context of a limited number of decision problems in the areas of defense, foreign policy and business.

2.1.3 Findings - An analysis of problems and alternate approaches is complete. One finding of the analysis¹ is that the use of reference gambles to evaluate utility functions over individual dimensions of value or over vectors of value is not as promising as the use of a direct rating procedure. Another finding is that the complexity of the utility scale is related to the length of time devoted to the analysis. Specifically, with a short analysis time, the analyses tended to involve simple probability relationships but required complex, multi-attributed utility scales. On the other hand, a long analysis time produced analyses that involved complex probability relationships but simple utility scales. A further finding indicated that the use of utility scales which involve exhaustive lists of dimensions combined by a formula (e.g., a weighted sum) runs a serious risk of failing to account for all dimensions of importance. In addition, the use of this procedure may also fail to correctly model interrelationships among value dimensions. Both of these risks are greatly reduced by holistic assessment of un-decomposed consequences. Another finding indicated that the precise definition of individual scales and the techniques used to elicit value comparisons among scales are the issues that most urgently require additional research (see Section 3.2.3 of this report).

The development of the analysis in the context of two specific cases is substantially complete and will constitute the second part of a two-part report.

¹ Brown, R.V. and Hatch, J.E., "Toward a Field-Tested Methodology for Multi-Attributed Decision Analysis, Part A - The Problem and Options," unpublished paper, 1974.

2.2 Modeling Subsequent Acts for Decision Analysis

2.2.1 Purpose - In standard decision analysis, acts subsequent to the initial choice (for example, after seeking information) are usually treated as perfectly predictable, conditional on uncertainties explicitly modeled. Decision trees are "rolled back" treating the act with the highest conditional expected utility as certain to occur (e.g., in preposterior analysis). This depends on strong and often unrealistic assumptions, notably that the decider's conditioning information has been "sufficiently" modeled. As a result, evaluation of initial options is often seriously distorted (for example by undervaluing information seeking strategies). The culprit is as much the choice of model as any correctable deficiency in implementation.

There is a pressing need to develop alternative models, which avoid some of the practical difficulties of preposterior analysis in handling subsequent acts.

2.2.2 Approach - Some possible modeling approaches are considered where, for example, subsequent acts are:

- (1) treated as events (with probabilities conditioned on partial information), and
- (2) not explicitly modeled, but terminal event or value probabilities are conditioned directly on partial information.

Modeling options are discussed in the context of substantial applied experience. .

2.2.3 Findings - A major implication is that the current state of the art of decision analysis as routinely implemented by many practitioners is seriously deficient and often gives rise to unsound recommendations. For example, initial options to defer action or gather new information are often seriously undervalued because only some of the ensuing information possibilities on which subsequent acts are conditioned are modeled. It is critical that the modeling does not make unrealistically constrictive assumptions about how subsequent acts will be chosen or the information on which they will be based.

Among the approaches considered, standard preposterior analysis, even if correctly implemented, tends to be too cumbersome or too difficult to elicit. Treating subsequent acts as events seems indicated where those acts

are a critical element in the problem (e.g., where the analysis includes information seeking or delaying initial options). Direct conditioning of value or terminal events on initial options or on conditioning events appears to be indicated in all other cases. The results of this study are incorporated in a recent technical report².

2.3 Cross Cultural Study of Uncertainty

2.3.1 Purpose - The main purpose of this study is to achieve a better understanding of cross cultural differences in the perception of probability. Specifically, it is aimed at identifying interpersonal differences that are due to culture and those that are not. It also explores the psychological mechanisms related to the differences. The results of this research, along with some of the tools and techniques developed in carrying it out, will advance the technology of decision analysis, while the findings themselves should contribute to cognitive theory and the theories of culture.

2.3.2 Approach - A three year program of research is envisaged which will proceed in a number of overlapping stages:

- o Literature review
- o Discussions with relevant experts
- o Observational and clinical studies to screen and generate hypotheses
- o Develop measuring instruments using interactive computer programs
- o Formal experiments
- o Reporting and feedback

2.3.3 Findings - The planning phase was begun in October of 1974 and the initial stages of research are underway at present. The first report is due June 1975.

2.4 Unilateral Disclosure

2.4.1 Purpose - In any bargaining situation, participants are faced with decisions regarding the kinds of information that should or should not be revealed to other parties. The purpose of the present effort is to categorize various negotiation conflicts in terms of their game-theoretic aspects and, within each resulting category, to provide optimal rules for the unilateral disclosure of various kinds of information.

2 "Modeling Subsequent Acts for Decision Analysis," Technical Report No. 75-1, Decisions and Designs, Inc., to Defense Advanced Research Projects Agency under contract N00014-73-C-0149.

2.4.2 Approach - The principal target of this research is strategy formulation for international negotiations. The kinds of information that will be evaluated as candidates for disclosure include values associated with levels of the various dimensions of the negotiations, trade-offs among these dimensions, and probabilities of relevant events.

The approach employs a combination of literature review, analysis of case studies, and a theoretical formulation and analysis based upon the theories of games and decisions.

3.0 CASE STUDY ABSTRACTS

3.1 Evaluating Foreign Policy Alternatives for Saudi Arabia

3.1.1 Abstract - Decisions and Designs, Incorporated worked with staff members at the National Security Council to evaluate three possible negotiation strategies toward Saudi Arabia aimed at securing a stable expanding supply of oil. A flexible decision model was developed. Implementation of the study was interrupted by the Yom Kippur War.

3.1.2 Background and approach - A staff group at the National Security Council was interested in evaluating alternative possible agreements with Saudi Arabia aimed at insuring the continued availability of Saudi oil and increased production to meet world demand. The main task was to model a key aide's perception of the problem, augmented by expert judgment from economists, Mideast and oil experts, for example, with the CIA. Work on this project was funded by Rome Air Development Center and ARPA.

The analysis produced a flexible decision model and used it to evaluate three sharply different negotiating strategies toward Saudi Arabia. A "Base" option involving no change in U.S.-Mideast policies was compared to an extreme option that involved maximum accommodation of Saudi interests and an intermediate option that reflected a moderate change in U.S. policy. It is important to note that the choice of options in a policy analysis such as this may exert a great influence on the final decision (much greater than in other areas of decision making). The foregoing options comprise a preliminary set which, it was anticipated, would be refined after an initial decision analysis.

This model evaluated the impact of the various negotiating postures on Saudi oil supply, and also considered the associated political and economic costs and gains to the U.S. Specifically, it explored the impact of an agreement on balance of payments, the way Western Europe and Japan would perceive a U.S.-Saudi agreement, the impact an agreement would have on U.S.-Israeli relations and the pro-Israeli sentiment in the U.S., and finally, the effect an agreement would have on other oil producers. Various sub-models were used to elicit predictive and value judgments at differing levels of complexity and aggregation. Where different evaluation and/or probability approaches were inconsistent, those inconsistencies were resolved in consultation with the various input assessors.

On the basis of the judgmental inputs, both the extreme and intermediate options were preferred to the base option by a large margin, and the intermediate option was slightly preferred to the extreme one. Specifically, the large favorable impacts of both agreements on the availability of Saudi oil and on balance of payments was not offset by their unfavorable impact on allied goodwill and pro-Israeli sentiment. This caused both agreements to be preferred to no agreement. The large difference in unfavorable impact of the two agreements on pro-Israeli sentiment caused the intermediate option to be preferred to the extreme one.

3.1.3 Implications - The National Security Council staff obtained a better appreciation of the implications of alternative perceptions of consequences and attitudes towards them (for example, pro-Israeli sentiment). An explicit statement of generalized government values such as the rate of equivalence between GNP, federal budget dollars, and balance of payments dollars was generated which can be used in other national policy studies of this type.

The implementation of the findings of the study was interrupted by the 1973 Yom Kippur War and by the transfer of the staff involved at the National Security Council.

A classified technical report¹ which describes the work is available. An unclassified version was presented at the 1973 Decision Analysis Conference in Los Angeles. Numerous briefings have been made, for example, to the Senior Seminar at the Foreign Affairs Institute.

A new technique was developed for simplifying prediction of interrelated continuous variables (in this case, volume and price of oil). This technique involved judgmentally dividing the price-volume space into regions, using isopreference contours, and then assessing a representative point for each region using indifference judgment. Other insights into the handling of value dimensions which were interrelated in terms of probability and/or utility were gained.

¹ "Decision Theoretic Procedures for Intelligence," Section IV, RADC-TR-73-406, Rome Air Development Center.

3.2 COCOM Study - Export Controls on Sales of Computers to Soviet Bloc

3.2.1 Abstract - The Chairman of the Council on International Economic Policy was responsible for making a recommendation to the President on the level of embargo for computers sold to the Soviet Bloc. A decision model was used to analyze the action implications of the vast amounts of data and opinion which was in the hands of the Council. A report on the analysis was submitted to the President along with a recommendation consistent with its findings.

3.2.2 Background and approach - In May of 1973 an interagency study group was set up by the Assistant to the President on National Security Affairs to review U.S. policy on the sales or licensing of data processing equipment, technology and software to Communist countries. The study, chaired by the Council on International Economic Policy, (CIEP), focused particular attention on the criteria to be used by Government departments in judging export applications and on tracing the consequences to the U.S. of continuing, tightening or relaxing COCOM list procedures. COCOM is an international coordinating committee representing the major Western powers and Japan, charged with controlling the export of computers and other items on a strategic list to communist countries. Computers are classified as being above or below an easy access line according to a number of criteria of "effective computer power," the primary criterion being processing data rate. An "easy access line" is chosen which slows down, but does not prevent, the export of computers above it and generally confers a significant, but not critical, competitive advantage to the sale of computers below it.

Toward the end of the study, it became apparent that a decision model would help organize data and expertise gathered during the course of the study, as they related to major options open to COCOM. The model was used initially to address the question of where to set the easy access line for commercial computers exported to the Soviet Bloc, with the thought that it might eventually be used to address other options.

Six representative COCOM policy options on commercial computer sales to the Soviet Bloc were evaluated in terms of U.S. interests. Expert judgments were elicited in quantitative form from experts in the business, intelligence and policy-making communities.

These judgments were combined within a decision analytic model to calculate an expected value for each policy option. Each of the six options was defined in terms of the relative ease of Soviet access to various levels of Western commercial computer equipment and technology. The current option in effect (Option 1) generally limits "easy access" to computers with a processing data rate (PDR) less than 8 million bits per second (mbps) and places restrictions on auxiliary commerce such as OEM sales, peripherals, and test equipment. At Option 6 the Soviets would have "easy access" to all major computer systems regardless of their PDR and almost all restriction on auxiliary commerce would be removed.

The value of each policy option to the U.S. was examined in terms of: (1) Computer sales -- potential gains from Soviet Bloc trade; (2) COCOM response -- possible reaction of our COCOM partners; (3) Other non-military impacts -- economic, technological, political gain or loss; (4) Military threat -- national security risk. These values were expressed in billions of dollars of equivalent U.S. export sales.

U.S. computer sales (with foreign-based sales given half-weight compared with U.S. exports) are relatively constant through Option 3, then increase thereafter to Option 6 as the Soviet market shifts in favor of the more powerful U.S. computers. However, Option 6 has a sales impact of only \$0.1 billion more than Option 1 in 1975. The response of COCOM allies is most favorable at Option 3 (as a gesture toward the liberalization of East-West trade) and least favorable at Option 6 (where they suffer most competitively vis-a-vis the U.S.). The difference is valued at the equivalent of \$1.0 billion in exports.

Other non-military impacts and military threats were similarly evaluated, and the four value functions were summed to obtain a total value function. Option 3, which involved granting easy access to computers with a PDR of up to 32 mbps and partially relaxing restrictions on software, peripherals and test equipment, showed a clear net advantage over other options. It was valued at half a billion equivalent export dollars above the status quo.

The relative value of these options was not materially affected by modifying each of the inputs within plausible ranges. Unless political factors excluded from the analysis strongly favored other options, Option 3 was

clearly preferred. The relatively small value differences which appeared between options considered in this study may indicate that options other than those considered, such as an "absolute" embargo, as opposed to an "easy access" line, are more critical to the U.S.

3.2.3 Implications - The ultimate recommendation of CIEP to the President on this issue was consistent with and apparently influenced by the decision analysis. The study served to highlight certain relationships, notably the dominating impact of one factor - COCOM response. A further application of the technique has been discussed, involving a similar study on behalf of CIEP to evaluate alternative international agricultural policies. A report² (classified SECRET) has been given limited distribution by the Council to appropriate government agencies and briefings were made to small groups.

The study showed that decision analytic models can be used as effective vehicles for coordinating expertise residing in numerous individuals, for facilitating the task of a policy maker in deducing the implications of that expertise, and possibly in communicating and validating a recommendation to third parties. In addition to this general finding, some specific technical insights were also obtained. In particular, this study pointed out the problem area of alternative utility model designs.

On one hand, a utility model may be very disaggregated. Such a model must explicitly consider:

1. The importance of each individual measure of value as a whole (e.g., the importance of Allied Goodwill compared to that of Military Threat, without regard to how the alternative options may impact on each dimension),
2. The ultimate potential for impact on each measure (e.g., if the Allied Goodwill was judged in (1) above to be the most important measure but, if in addition, there is no way that anything can possibly affect Allied Goodwill, then its ultimate potential is zero), and

² "Computer Sale to the Soviet Bloc (U)," Technical Report 73-4, Decisions and Designs, Incorporated, to the Council on International Economic Policy, under Defense Advanced Research Projects Agency and Office of Naval Research sponsorship, Contract N00014-73-C-0149.

3. The fraction of the potential impact that is obtained by each specific option.

On the other hand, the model may be very aggregated. This type of model may:

1. Assign values on each measure of value, of 0 and 100 to the worst and best outcome possibilities that might result (locating other possibilities in between), and
2. Require explicit consideration of a "swing weight" for each 100 point swing (i.e., an elicitation of the value of the "swing" between the worst and best possibilities on one scale compared to the value of the "swing" between the worst and best possibilities on the other scales).

Indications are that it is difficult to extract the required elicitations for both models, but there are also specific problems peculiar to each model. In particular, there is a risk in the aggregated model that the assessor will disregard some important components (since this model requires implicit handling of components that are explicitly addressed in the disaggregated model). The disaggregated model, however, is often very cumbersome to use. In addition, it is difficult to attach meaningful scales to each value measure (e.g., it is difficult to define exactly what is meant by relative value of Allied Goodwill as a whole compared to the value of Military Threat as a whole). These topics are also addressed by the Multi-Attribute Decision Analysis report described in Section 2.1.

3.3 Predicting NATO Response to Impending Attack

3.3.1 Abstract - A "rational" decision analysis model was used to provide military planners with new descriptive insights into the NATO decision process in the face of an impending Warsaw Pact attack. It suggested a more general methodology for improved forecasts involving NATO and other organizational decision processes.

3.3.2 Background and approach - This analysis was performed for SAGA, the Studies, Analysis and Gaming Agency of the Office of the Joint Chiefs of Staff, OJCS, with a primary focus on assessing NATO readiness as it bears on mutual balanced force reduction proposals.

The central question posed in the study is: "If the Warsaw Pact were to attack at the end of a thirty-day mobilization cycle, at what point in time after the Pact begins to mobilize would NATO go into a state of reinforced alert?"

A major part of the study involved developing, with the aid of decision analysis techniques, a quantitative model of the dynamic decision making processes of SACEUR. This model quantified: inputs of probabilities and predictions based on a plausible sequence of incoming intelligence information; and value judgments, for example, relating to possible relative troop strength at the time of attack. The output of the model, an indication of a point in time when SACEUR would opt for NATO mobilization, was then combined with experienced assessments of North Atlantic Council (NAC) organization delays to arrive at a prediction when NATO would actually mobilize.

3.3.3 Implications - The study alerted SAGA staff to the fact that forecasts of NATO mobilization actions are critically sensitive not just to the diagnostic value of incoming intelligence but also to SACEUR's value judgment of the relative costs of a false alarm versus being unprepared at attack. The methodology developed may have value as a means for giving knowledgeable military planners new insights into NATO decision processes that could impact on MBFR and similar assessments of interest to U.S. General Purpose Force planning. A proposal for follow-on research has been solicited by SAGA. A derivative research task on the modeling of bureaucratic processes is to be proposed to ARPA. An unclassified report³ has been published and numerous briefings have been given to military and technical groups.

This study developed techniques for modeling "subsequent acts" (see 2.2 above) and identified important areas for further research, notably the modeling of bureaucratic processes to relax the assumption of an organization being a single rational actor. That is, the usual form of decision analysis assumes the existence of a single decision maker whose decision problem is modeled. This case study identified a need for the development of a technique to model the bureaucratic processes of an organization.

³ "The Timeliness of NATO Response to an Impending Warsaw Pact Attack," Technical Report 74-1, Decisions and Designs, Inc. to Defense Advanced Research Projects Agency under contract N00014-73-C-0149.

3.4 Net Strategic Capabilities Model

3.4.1 Abstract - A strategic capabilities model has been constructed which develops the relative potential capabilities for the strategic weapon systems of two nations from the individual offensive and defensive systems in the force. The model and computer program capture the entire problem at a high level of aggregation and permit rapid assessment of the changes in capability caused by varying any of the significant performance and technological indices for the systems. Thus, analyses of the effect of future technology, consideration of alternative strategic arms negotiating postures, and similar assessments can be performed with economy and speed.

3.4.2 Background and approach - Some of the most critical decisions facing the Department of Defense are in the area of strategic arms. These decisions range from unilateral decisions about research and development, procurement, operations, and policy to bilateral decisions leading to SALT negotiations and treaties. The strategic arms problem involves both a large number of variables and complex interactions. Consequently, attempts to come to a better understanding of the problem with respect to both unilateral and bilateral decisions has resulted in a range of simplistic models or even equations that investigate a portion of the problem (e.g., Tsipis, Aosta, "The Calculus of Nuclear Counterforce", Technology Review, October/November, 1974; pages 34-47) to vastly complex war game simulations that require large amounts of time to program and run.

It frequently turns out that in decision analytic models, both unilateral and bilateral decisions can be most efficiently constructed by beginning with a very coarse-grained structure of the problem and then successively evolving to a more fine-grained structure as a result of sensitivity tests of the model. Consequently a coarse-grained strategic capability model was constructed with the intent that it capture the entire problem at a high level of aggregation.

The strategic capabilities model can be described by the flow chart in Figure 3.4.1 below:

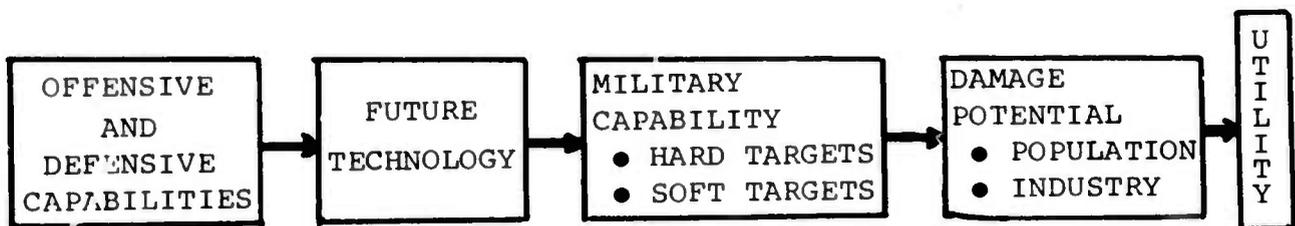


Figure 3.4-1

The description of offensive and defensive capability combined with assumptions about targeting is modified by forecasts about the impact of future technology which leads to indices of military capability for both the U.S. and U.S.S.R. against hard targets and against soft targets. These assessments of military capabilities are then converted into measures of damage potential for both population and industry. These assessments of military capability and damage potential are then assessed in terms of assumed utility for both countries. At the current stage, the capabilities portion of the model, i.e., that portion beginning with offensive and defensive capabilities and ending with damage potential, is now available in an interactive graphic mode on the DDI ADP 11/40 computer. Relative potential capabilities of alternative strategic forces can rapidly be determined in an interactive manner by the use of this capabilities model and computer program.

Relative potential capability is not necessarily a measure of absolute military capability. To develop a true military capability would require consideration of alternative targets, targeting concepts, retargeting capability, command and control, doctrine, strategy and specific objectives. The DDI capabilities model uses a single target complex and one targeting concept, i.e., all counterforce targets with equal priority on a preempt strike and the largest population and industrial centers, to effect the greatest possible damage on a retaliatory strike. Targets are not prioritized and no capability exists, with the current program, to determine relative potential capability for less than an all-out massive nuclear exchange.

Nonetheless, considerable flexibility is available through the DDI capabilities model and computer program to assess relative potential capabilities of various forces by changing:

- o kinds of weapons systems
- o numbers of different systems
- o numbers of weapons or carriers within systems
- o numbers of re-entry vehicles
- o warhead yield
- o C.E.P.
- o weapon system reliability
- o weapon system survivability
- o alert, airborne or at sea quantities
- o penetrability
- o defensive technology
- o percent of force or system used or withheld.

The above items can be varied individually or in almost any combination desired, for one or more weapon systems, in the U.S., U.S.S.R. or both forces. The same

variation need not be employed to both forces, e.g., one can trade off numbers of bombers and percent on alert for U.S. forces against numbers of missiles for U.S.S.R. forces and within seconds determine the changed relative capabilities of both. Each set of new relative capabilities is displayed to the analyst or decision maker in the form shown in Figure 3.4.2 below:

	U.S.	U.S.S.R.
Preempt Relative Capability		
Retaliatory Relative Capability		

Figure 3.4-2

Note that any change in the performance or numbers of any weapon system for either the U.S. or U.S.S.R., changes both countries relative potential capability, expressed in terms of a preempt (first strike or disarming) capability and a retaliatory (assured defense) capability. This relative potential capability is computed and displayed on the graphics display in a matter of seconds.

3.4.3 Implications - While this model has been designed primarily as a tool for technology assessment with respect to strategic capabilities, it should prove that it is potentially useful in a wide variety of contexts ranging from decision analyses of research and development or production decisions to utility of analyses of SALT negotiations. This rather simplistic model, together with an interactive capability, make it ideally suitable for quick response--first approximations at answers to a wide variety of questions. After this screening process, those problems that appear to warrant further investigation can be subjected to more detailed analysis.

Construction of this capabilities/utility model of strategic arms has highlighted an important research issue that is generally relevant for the construction of models. What is an appropriate level of aggregation? Two opposing tendencies are popular; and in the extreme, both are most certainly wrong. One is to build highly complex simulations of an important problem, and the other is to treat a problem at an entirely intuitive level. Unfortunately, there is little interaction between the two approaches. Simulations are typically so complex that there is little opportunity for intuition to become educated. Principles should be developed that would guide the construction of models at an intermediate level of aggregation--with assumptions at a sufficiently low level to be justifiable and at a sufficiently high level to be understood in relation to the conclusion of the model. In the immediate future, the results obtained from this model will be compared with those of more complex simulations.

3.5 Multi-Attribute Utility Analysis in Arms Treaty Negotiation

3.5.1 Abstract - A multi-attribute utility model was developed which can handle the attributes of strategic weapon systems and the issues in a two-party arms negotiation. The model was used to develop procedures permitting the explicit consideration of trade-offs among several issues simultaneously and reduce the outcomes to a Pareto-optimal set of issues. A major problem for the study was whether the operational and technical characteristics of the offensive and defensive weapons were adequate as utility determinants; i.e., was an accurate, objective view of the military balance sufficient to propel a negotiation along toward a Pareto-optimal solution? Also, more knowledge of how the parties perceive the strategic balance, and its affect on utility, was thought necessary. Preliminary conclusions are that issues other than weapon qualitative characteristics, providing greater differential utilities, would bilaterally increase the bargaining potential in the negotiation, and also that perceptions are of significant importance.

3.5.2 Background and approach - A negotiation problem exists whenever two parties have divergent goals, yet each is sufficiently interested in achieving an agreement that they are willing to compromise those goals to some degree. If the negotiations involve a single issue, and the parties are of somewhat comparable bargaining strength, a compromise strategy often prevails. Both parties adjust their positions and perceive the equity of the outcome in terms of payment made and value received.

a time rarely results in an optimal agreement. The balance is easily tipped in favor of the stronger side, which can win more on all issues, not only those most important to it. This complexity is characteristic of the issues involved in negotiating the international control of nuclear weapons. As an alternative to the issue-by-issue bargaining process, which often results in sub-optimal treaty packages, the application of utility analysis permits simultaneous consideration of a number of issues to determine which of the possible treaties will result in each party conceding least on those objectives it values most highly. As applied in this study, the methodology of utility analysis seems especially appropriate to this particular negotiation problem since it 1) helps to identify the most important issues and eliminate others; 2) illustrates more precisely the relative significance of those issues as perceived by both parties; and 3) provides the means of assessing both the objective and subjective components of all issues, in order to determine trade-off possibilities.

Once the utility of given issues has been established, it should then be possible to interrelate those issues and evaluate the possible tradeoffs among them in terms of the net benefit accruing to each party. The ultimate goal of the negotiation process is an agreement equally satisfying to the parties involved, and this aim can only be achieved if each side wins relatively more on those issues it considers most important. It follows logically that the parties should be more willing to make concessions on issues less relevant to their particular interests. Utility analysis, by examining all issues in terms of their relative utility to each side, could widen the scope of the bargaining process and enhance the respective positions of the parties.

The first step in the utility analysis procedure is to identify the most important issues, define them precisely, and establish a quantified upper and lower limit for each. The worth to each side of the various possible positions on the treaty issues can be represented in terms of utility functions. The value of a possible treaty can then be calculated using a multi-dimensional combination of the utility functions for the different issues. A utility function gives the utility or worth to a party of any position on an issue, defined over a particular range. In its simplest form it is assumed that each party has a different utility function for each of the issues, and that these are relatively independent; that is, the utility to be derived from a position on one issue or dimension does not depend on the utility to be derived from the position on another. The assessors are then questioned to determine if the independence assumption is valid. (Research has found⁴, however, that even in cases where independence does not hold, the linear, additive model is still very powerful and the error involved in using such a model is quite small.)

⁴ Fischer, Gregory W., "Four Methods for Assessing Multi-Attribute Utilities," University of Michigan Doctoral Dissertation, 1972.

By isolating the most salient issues, a specific bargaining range for each may be postulated, a feature which promotes a structured, orderly negotiation process. The methodology allows each party, after determining which issues are most important to it, to adopt a more liberal position on the issues viewed as less useful in terms of its own interests. At the same time, each side has the opportunity to win more on those issues it considers most important.

In general there will be a continuum of treaties, corresponding to different relative bargaining strengths, in which the proportion of the total utility to be given to party A is varied from zero to 100%. The treaties described in this way are called Pareto-optimal treaties because they have the following property: It is impossible to increase the utility to one side without decreasing the utility to the other side. The continuum of points representing these treaties can be conveniently represented on a graph in which the Pareto-optimal treaties form a curve. All of the Pareto-optimal treaties, including the one in which both sides receive an equal amount of utility, fall on this curve.

3.5.3 Implications - This analysis essentially yielded a "zero sum game," which means that along the Pareto-optimal boundary, any change which resulted in increased utility for one side brought about an almost equivalent decrease in utility for the other side. It is possible that this zero sum game is the outcome of an analysis that treats military balance as an objective rather than a perceptive process. The analysis assumed that both parties have a good understanding of the perception of military balance, that this "good understanding" can be calculated in a relatively objective manner and would therefore be very similar for both sides. Consequently, the analysis failed to capture the essence of perception (at least for purposes of negotiation); it failed to show where the two sides view the balance differently.

It may be that the analysis was deficient in terms of revealing differences in perception because military balance was considered only with respect to military interests. This discounts the fact that each party has considerably more at stake in the area of strategic arms. For this reason, a second analysis was conducted, and this included not only military concerns, but also economic (such as cost of consumer goods) and political (such as foreign influence and the opinion of Third World countries) interests.

The utility analysis procedure as applied in the first analysis can be used effectively "behind-the-scenes" in order to facilitate negotiations between the parties. It can also be used unilaterally by one of the parties after a bargaining session to update assumptions about the other side and to alter its negotiating position in order to maintain an equivalent utility while increasing utility for the other side.

The results of the first analysis, however, indicated that the utility analysis methodology was appropriate at the objective level but failed to incorporate the perceptive differences existing between the parties. The Pareto-optimal curve generated by this analysis appeared to be unacceptable in that the range of possible treaty outcomes clearly did not maximize utility for either party. There are no "preferred" treaty packages (those that would increase the utility for one side without detriment to the other side) since they would fall above this curve, and by definition, the curve itself fixes the upper limit of utility.

In the second analysis, the bargaining range was expanded to include other significant areas of impact which would offer additional trade-offs; and this generated a more satisfactory Pareto-optimal curve, i.e., one that increased the utility to both sides of a set of possible treaty outcomes. It is this second model which has the potential, in practical application, to promote more effective negotiating techniques and to improve the quality of the resultant agreements.

The outcomes of the analyses conducted in this study imply certain research problems that are presently being examined, and these are threefold:

The first, and perhaps the most significant research consideration involves the methodology itself. The study demonstrates that utility analysis can be effectively applied in negotiations, and that the methodology provides the flexibility needed to incorporate in the bargaining process other impact areas or dimensions of interest that would provide additional tradeoffs.

The outcome of the original analysis indicated obvious deficiencies; therefore the issues and goals were broadened by increasing the number of differential interests in the subsequent analysis. The second approach involved a hypothetical utility analysis with dimensions of strategic capability similar to those used in the original analysis. For convenience, the dimensions of capability were constrained to co-vary for both sides jointly; that is, the parties were subject to the same limit on megatonnage, number of re-entry vehicles, etc. Then, as a function of these dimensions of strategic capability, a multi-attribute utility function was constructed for each side. The attributes included military, economic and political interests, and the dimensions of capability were evaluated separately in terms of these three interests for each side. The relative importance of these interests was also assessed.

The Pareto-optimal curve generated by this second analysis differs from those generated by the initial analysis in many respects. First, it is not possible for any treaty to yield 100% utility to either party. This is due to the assumption that the three dimensions of interest conflict internally; that is, changes in a capability that result in an improvement for military interests tend to result in a detriment for economic interests.

Another difference is that not only does the constraint prevent both sides from achieving 100% utility, but in addition, if either side approaches 100% of the utility resulting from a treaty, there is a tendency for the joint utility to decrease sharply, resulting in an envelope that falls off toward an origin of zero utility for both sides. This latter effect occurs because certain of the interests for both parties are positively correlated. For example, an increase on the limit of military capability along an expensive dimension hurts both sides from an economic standpoint.

The important result, of course, is that the Pareto-optimal curve generated by the second analysis is far more attractive than that resulting from the first analysis in that it is now possible to find sets of treaties that should be perceived as relatively attractive to both parties when the perception of attractiveness is measured along economic and political as well as military dimensions.

Since the Pareto-optimal treaties were found by maximizing the total utility for particular constraints, it is impossible for any treaty to lie above and to the right of the Pareto-optimal curve. On the other hand, an infinite number of treaties will fall to the left and below the curve, but all of these treaties are dominated. This means that 1) one can increase the utility to party A without decreasing the utility to party B by moving to the right, or 2) one can increase the utility to party B without decreasing the utility to party A by moving up, or 3) one can increase the utility to both parties by moving up and to the right.

It would appear then that the Pareto-optimal boundary could be moved toward the upper right-hand corner by including additional dimensions of interest, especially if those dimensions are positively correlated across both parties. Furthermore, it should be possible to move that boundary even further toward the upper right-hand corner by adding issues as well as interests. If a military treaty were expanded to include economic and/or political issues, it should be possible to effect changes in issues where party A can gain more than it costs party B to make certain other concessions in which party B gains more than party A loses.

The second research concern involves the implementation of utility analysis procedures in negotiation situations. The analyses described above suggest the appropriateness of the methodology for negotiations as well as the benefits to be realized by the parties involved. The type of compromise facilitated by utility analysis should result in more durable treaties that enhance the overall interests of the parties. Yet it seems to be contrary to the general attitude evident in international negotiations, where the focus appears to be more and more constrained to single issues of increasingly narrow scope. Therefore, major research efforts will be directed toward establishing the validity and thereby encouraging the application of the foregoing analytical approach to negotiations.

Finally, research efforts will be focused on optimization procedures, i.e., the techniques used to find the Pareto-optimal curve after utility functions have been assessed, which are currently rather coarse. They now require system intervention and technical assistance from analysts. The use of these Paretian tools would be considerably enhanced by the development of improved optimization routines.

3.6 Use of Decision Theory for Analysis of U.S. Treaty Negotiations Positions

3.6.1 Abstract - Many feel that an issue-by-issue U.S. negotiation strategy on a treaty dealing with such complex issues as the international control of nuclear energy could result in a situation unfavorable to the U.S. DDI is developing a technique to evaluate complete treaties and guide strategies for improving upon suboptimal treaties.

3.6.2 Background and approach - The United States, and presumably other foreign countries, is considering the need for new and additional nuclear treaties and agreements to limit testing, provide for peaceful uses of nuclear energy, safeguard the environment, and limit further nuclear weapon proliferation. Due to the complexity of the nuclear energy problem in general, and the potential concerns, the value of a "whole treaty" approach that identifies all of the relevant issues, dimensions of value and uncertainties assumes even greater significance.

The objective is to develop and test a technique for evaluating and suggesting improvement to treaties concerning international nuclear energy related issues. The first task is to develop a method for identifying issues of importance to negotiation parties and national and international goals against which possible treaties

can be compared. The next task is to construct hypothetical treaties of interest to nations and power elements within nations and select the best ones as benchmarks against which others can be tested.

A decision analytic approach (called Paretian analysis) is used to identify target treaties that would significantly improve the state of the world from the U.S. point of view. The approach involves finding those treaties which are superior to all others in that no further improvement can be made to one nation without hurting another.

3.6.3 Implications - Initial experience suggests the methodology can identify treaty issues that are much more important to one side than the other, thus providing a base for negotiation. Examples include verification procedures, environmental standards, and nuclear services to non-nuclear countries. It is expected that the results will provide benchmarks against which the potential for future negotiations can be evaluated as well as avenues for improving upon a broad spectra of international agreements and protocols. The next step is to review results with representatives of U.S. departments and agencies who normally participate in this phase of U.S. policy making. Assuming they are interested, parameter estimates from substantive experts can be applied to actual negotiation analysis.

Methodologically, the research has advanced the state of art in Paretian analysis by permitting treaty evaluation against individual criteria such as impact on the actual military, economic and political balance among nations, and impact on perceptions of other nations.

Currently, the model will handle only two nations, and research is needed to expand the model to deal with more than two nations at a time.

Since nations may be involved in negotiating a number of different agreements at the same time, work is also required to interrelate the impact of different negotiations, or of one potential treaty upon another. In this way, it may be possible to identify combined treaties that would be superior to any that could be developed alone.

3.7 Allocation of Decision Analysis Resources

3.7.1 Abstract - A system has been developed for optimally allocating funds for decision analysis research and for evaluating proposals. The system has general applicability. It can be applied to the allocation of research resources and the evaluation of research proposals in many disciplines. It is not uniquely applicable to the area of decision analysis research chosen for this study.

3.7.2 Approach - Possible areas for research on decision analysis are subdivided into topics. A reference research program is evaluated where each such topic is considered to have a standard input of research resources, and the output, in terms of the clients' interests (e.g., DoD), is evaluated either directly or via a submodel which considers how the standard subprojects impact on client areas of interest and the relative importance of those areas. The impact of research resources, greater or less than the standard input, is evaluated by means of an assessed "response curve" from which an optimum allocation of resources between topic areas can be routinely reduced.

3.7.3 Implications - A multipart computer program has been developed which allows specific evaluations to be made in the context of allocating program funds and evaluating specific research projects submitted as proposals. A technical report⁵ is close to completion. A discussion of theoretical approaches was included in the previous progress report⁶ to ARPA.

⁵ "Allocation of Decision Analysis Resources," Technical Report 75-3, Decisions and Designs, Inc., to Defense Advanced Research Projects Agency under contract N00014-73-C-0149.

⁶ "Decision Theory Research," Technical Progress Report No. 3, Section 2.1, Decisions and Designs, Inc., to Defense Advanced Research Projects Agency under contract N00014-73-C-0149.

4.0 OTHER APPLICATIONS OF DECISION ANALYSIS REFLECTING ARPA-SPONSORED RESEARCH

The studies reported upon in the following four sections of this progress report were not performed under the basic contract. The Defense Advanced Research Projects Agency and Office of Naval Research neither funded nor sponsored them. However, as was noted earlier in paragraphs 1.1 and 1.5, the four studies which follow are based in part upon the results of the ARPA/ONR research effort and serve to enhance an understanding of the research accomplishments during the reporting period.

4.1 Design-to-Price EW - Contractors Selection

4.1.1 Abstract - A multi-attribute utility model was used to quantify user preferences and relate these preferences to system technical characteristics in a design-to-price electronic warfare (EW) system procurement¹. The contractors receiving lowest indices of military value, in terms of end-user preferences, were eliminated early in the evaluation and then several iterations of the model were used to reduce the number of contractors to the two who are now building prototype systems. The actual choice of contractors by the Navy was based on the model's output, and the model is now being adapted to other Naval procurement tasks.

4.1.2 Background and approach - Massive cost overruns in the procurement of weapon systems have lead the Department of Defense to use a new procurement concept called Design-to-Price. Traditionally, a service set detailed specifications or specific requirements for a weapon system and then invited qualified contractors to bid on these well-defined systems. Assuming that all contractors were qualified to build a system, the one submitting the lowest bid most often would win the contract. Consequently, the contracting officer's job was relatively straightforward; that is, to select the qualified contractor with the lowest dollar bid. The design-to-price concept is being tried out as an alternative procurement approach, where the requiring service defines the requirement in extremely broad terms. One variant is to simply provide a set of scenarios in which the system will be used and then invite each of the contractors to use his own ingenuity in designing a system that will, within some pre-determined fixed price, perform optimally within the scenarios.

¹ This study was performed for the Naval Electronic Systems Command, Navy Department, Washington, D. C.

Design-to-price has changed the criteria and weights that procuring activities use in contractor selection. Instead of giving heavy preference to that contractor with the lowest dollar bid, as before, the task is now to select that contractor whose system offers the most value in terms of end-user preferences.

The purpose of this project was to use concepts from multi-attribute utility analysis, which had been developed under previous ARPA sponsorship, to aid in the selection of contractors proposing on a design-to-price procurement. Specifically, the Navy had narrowed the field to six potential contractors who were proposing to build a family of electronic warfare suites. The objective of this study was to develop an evaluation model which could be used as an aid in selecting two contractors who would build prototype systems.

The first step in the construction of the evaluation model was to use a hierarchical goal fabric analysis to successively decompose higher-level operational goals into sub-goals and to relate the degree to which the performance of systems proposed by each contractor, measured with respect to a number of technical system characteristics, would satisfy these sub-goals. The goal fabric had four levels: The first level specified the scenarios with respect to which the evaluation was to be conducted. Four basic scenarios describing an independent ship operation, an open sea task force level operation, underway replenishment and amphibious operations were used initially. Later, these were varied to produce a total of eight scenarios which were incorporated in the final model. The second level in the goal fabric described the four functions of jamming, decoying, deceiving and providing inputs to various ships weapon systems that an EW suite should perform. Each of these major functions was then described in terms of a number of properties or sub-functions in the third level of the goal fabric. For example, to execute the decoy function, an EW system must be available, i.e., not down for repairs; it must sense an incoming cruise missile, react within a specified time period and be capable of ejecting a chaff cloud to decoy the missile away from the target used. The fourth level of the goal fabric identified those technical system characteristics which were necessary to perform each sub-function. A small abstract of the total goal fabric is shown in Figure 4.1-1 below.

Note that implicit in the goal fabric are the dependency relations both within and across levels.

After completing the goal fabric, the next step was to have Navy experts assess the utility of varying each technical characteristic with respect to accomplishing each of the related sub-functions. These utilities were scaled from 0 to 1.0 or 100% and were assessed using the properties of a perfect EW suite to establish the 100% anchor point. Thus, the output of the model valued each candidate system relative to a perfect EW system rather

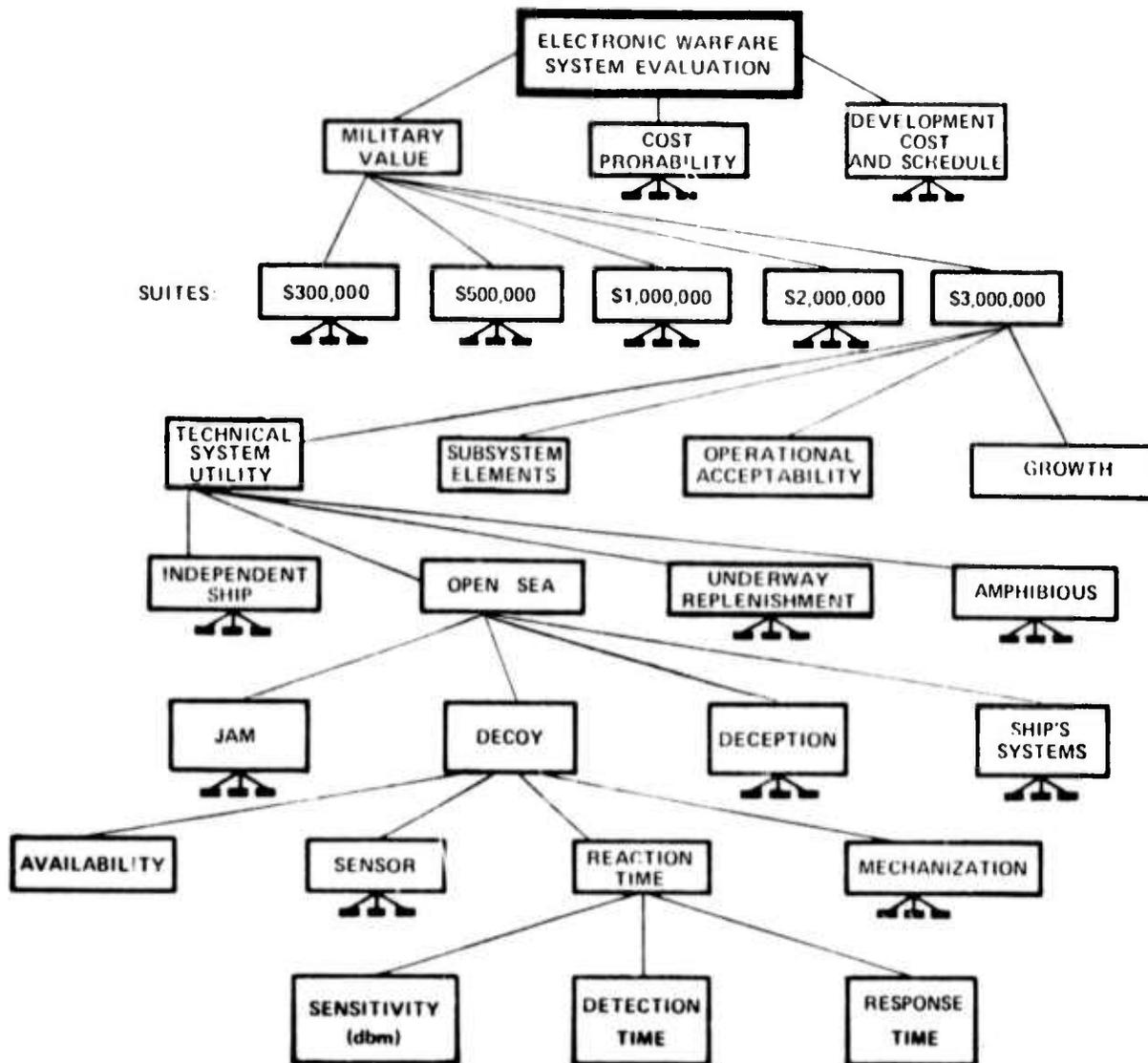


Figure 4.1-1

than describing it's utility in terms of an absolute measure. Each of these utility functions was derived from experts who interpreted results from analytical studies and integrated them with operational experience. Examples of these utility functions are included in Figure 4.1-2 below.

The last step in the analysis consisted of assigning importance weights to each function, sub-function and technical characteristic and then validating and modifying the resultant model as appropriate, using data available on current EW suites.

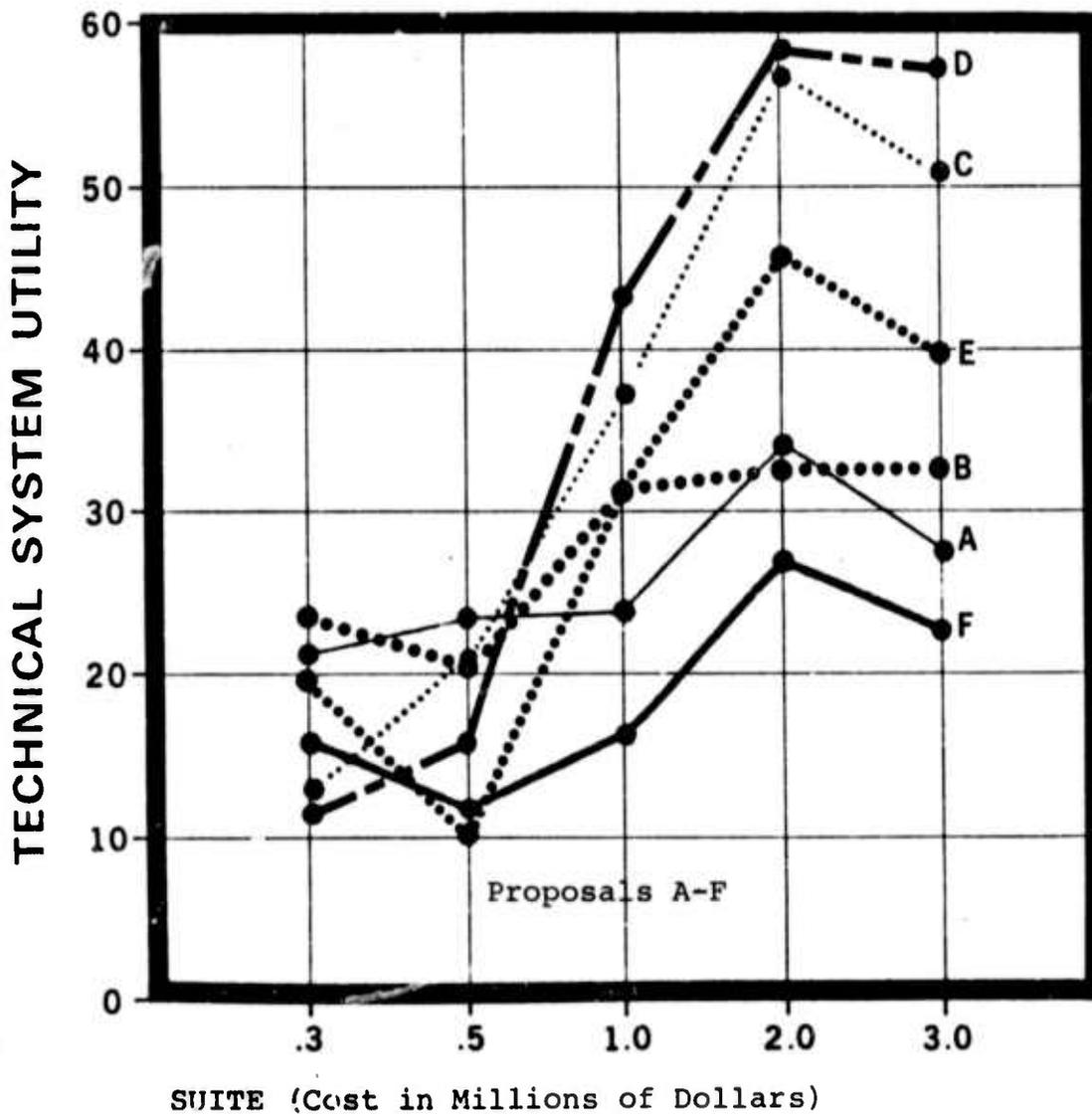


Figure 4.1-2

4.1.3 Implications - The multi-attribute utility model was used as the core of the actual Navy evaluation. The contractors receiving lowest indexes of military value were eliminated early and then several iterations of the model were used to reduce the number of contractors to the two who are now building prototype systems. It is the Navy's intention to modify the model and use it to evaluate these prototypes and to select the final contractor.

Although successful in a specific context, broader application of the techniques is restricted by the necessity to develop a totally new model for each new application. Research is needed to develop principles for structuring multi-attribute utility models. These are principles which would specify:

- (1) The nature of the variables to be included in the model;
- (2) Their level in the hierarchy; and
- (3) Combination rules - that is, should utilities be combined in an additive or a multiplicative fashion.

Illustrations of general design principles include the use of the "top down" modeling approach, which tends to insure that all of the major variables are included and that the detail of structure within a variable is commensurate with its importance. Another potential principle is that dependent variables should be subordinate to the variables they depend upon. For example, if the relative importance of different functions of a system depend upon the scenario in which the system operates, then those functions should be subordinate to the set of scenarios upon which they depend. Finally, most designers of multi-attribute utility models have tended to use additive, in preference to multiplicative, combination rules. This likely represents a propensity to start with the simplest possible combination rule and then move into more complex rules only when forced to do so. One set of multiplicative rules was used in the design-to-price model described above in a case where the utility of the system went to zero if the utility of any component went to zero. Research is required to identify circumstances under which other combination rules are more appropriate.

A second important problem for the development of multi-attribute utility models concerns the assessment

of importance weights. There is a tendency for respondents to focus on the universal importance of functions, whereas the utility model requires importance weights dependent upon the specific ranges of the conditioning variables in the hierarchy. Research is needed to find ways to overcome this bias.

A third problem concerns the selection of scenarios to be included in the model. Scenarios can be highly concrete and specific, but it is important to insure that the sample scenarios are indeed both representative of the population of possible scenarios and that they discriminate among the alternatives being chosen. This suggests that a stratified sampling procedure would be useful in the process of constructing or selecting scenarios. Stratification would occur by first specifying scenarios that maximally discriminate among the alternatives being evaluated and then assigning relative likelihoods to the scenarios so that they may be weighted in accordance with their probability of occurrence.

A final problem concerns the development of procedures for carrying out sensitivity analyses. The model described above contained, we believe, more dimensions than were actually necessary to discriminate among the proposed systems. A capability to rapidly identify the most important dimensions could substantially reduce the effort required to elicit utility functions (some 1500 were included in the model) over the technical characteristics. Recent research work on the importance of weights in additive utility models, carried out by the Oregon Research Institute, offers the outline of a possible approach.

4.2 Requirements Tradeoff Analysis for the World Wide Military Command and Control System (WWMCCS)

4.2.1 Abstract - A hierarchical multi-attribute utility model, based upon research carried out under ARPA sponsorship, is being developed for use by the WWMCCS architect to carry out tradeoffs among requirements for the purpose of constructing architecture which maximize benefit within varying cost constraints.

4.2.2 Background and approach - The World Wide Military Command and Control System (WWMCCS) is an example of a class of hierarchical command and control systems. Requirements are currently being established for the purpose of guiding the development of an architecture. The problem is that requirements are typically stated as absolutes. If

requirements are treated as absolutes, then the design objective must be to satisfy those requirements regardless of cost. Although this philosophy is rarely carried to extremes, and compromises are most often reached between requirements on the one hand and cost of achieving those requirements on the other, it is a fact that the explicit statement of requirements in absolute terms may often result in systems that are badly over-designed. Over-design is subtle and very difficult to detect. The reason is that over-design is an economic rather than an engineering concept. Assessment of over-design requires simultaneous consideration of both performance and resource consequences. Its essence resides not in the mere fact that more performance may be proposed than is necessary, but rather in the fact that whatever additional performance (over and above some minimum set) is proposed may not warrant expending whatever additional resources are required to achieve that additional performance. On economic grounds, it may be preferable to accept lesser performance or even to accept zero performance; that is, abandon the project and expend the saved resources on some other project entirely. If, however, the requirements are described in terms of utility functions over measurable dimensions of performance, then the likelihood of over-design is decreased because a design objective which maximizes the benefit-to-cost ratio can now be adopted.

The objective of this project is to develop a multi-attribute utility model designed to assess tradeoffs among requirements for the purpose of constructing the WWMCCS architecture. It is intended that this model provide for evaluation with respect to a number of scenarios ranging from nuclear war to day-to-day operations in the absence of crises.

The approach being followed is based on constructing a hierarchical multi-attribute utility model, similar to that described in Section 4.1 above, to obtain organizational utilities over measurable system characteristics.

² This study was performed for IBM Corporation in support of the Electronic Systems Division, Air Force Systems Command, L.G. Hanscom AFB, Bedford, Mass.

With this approach the utility for the organization is seen as a function of the goal structure of the organization. It is assumed that the organization has a single superordinate goal which it attempts to maximize in its decisions. Very often this goal is difficult to label or characterize verbally, and is ordinarily defined implicitly by the structure and relationships among the goals immediately below it. For example, a company might wish to maximize long-run return on investment, volume of production, and share of the market. Each of these goals is to some extent incompatible, and its importance to the achievement of the superordinate goal determines its weight in the utility hierarchy. Each goal has in turn subgoals, until a level of detail is reached at which it is relatively easy to assess the contribution of various alternative policies with respect to the lowest level subgoals. The advantage of this system is that, by maximizing the weighted utility, the system insures that the alternative chosen will maximize the contribution to the superordinate goal.

4.2.3 Implications - The model is being developed and no definitive quantitative results are available. However, at a conceptual level, by explicitly addressing tradeoffs and treating requirements as utility functions rather than as points on dimensions, the model gives indications of greatly facilitating communication between the group responsible for generating requirements and the group responsible for generating architectures.

The effort involves a number of research issues. The approach described above requires the explicit assessment of utility functions over measurable performance dimensions. A general problem associated with this and other evaluation projects is that it is seldom obvious how adequate the utility model employed has been in evaluating the outcomes. Two commonly used models are the multiple linear regression (MLR) model and the multi-attribute utility (MAU) model. The assumption most often made in the application of the MLR model is that a decision maker is using an implicit evaluation model when he chooses or ranks alternatives, and that this model contains a good deal of error. Thus, by stripping away this error statistically, the underlying consistent evaluation function may be approximated. The trouble with this approach is that the criterion for this model is the behavior of the decision maker, and there may be information which the decision maker would like to use, but does not

use and therefore does not exhibit it in his decision making behavior. Thus, although studies on bootstrapping have shown that the consistent model inferred from decision making behavior using a MLR model often improves on the performance of the decision maker himself, it seems entirely reasonable that if the information he would like to use could be included, and used consistently, the performance achieved would be even better.

The multi-attribute utility model attempts to do just that; it uses all the information that the decision maker would like to use, and is using in making his evaluation. The problem here is that the MAU model is itself a criterion; it is a specification of the preferences of the evaluator, and as there are no disputing tastes, it is the final statement about how outcomes are to be evaluated. Yet there is error in the process -- in the assessment of the utility scales, in the structuring of the dimensions, the rule for combination and the selection of dimensions to be included or excluded. How is the evaluator to judge whether the utilities of values produced by the model differ significantly from what he truly believes? The complexity of the process has led him to use a model in the first place, so it is difficult for him to compare his intuitions with the output, and it might be that the insensitivities in his intuitions make him unable to discriminate quantities which are important.

This is particularly important in many applications where, for the purchaser to be able to allocate his funds in an optimum fashion, he must be able not only to rank order the alternatives, but also to determine how much better one is than another. Thus, in many cases he needs to be sure that the output of whatever evaluation model he is using is accurate.

A second problem, related to the one above, is that of utility assessment. Broadly stated, the problem is that a utility function is a representation of an individual or an organization's preferences, and since the criteria for accuracy in that representation are buried within him, it is difficult to determine whether the method used to obtain the assessments is a good one or not. In the realm of probabilities this problem has been attacked using two methods, consistency and veridicality. In the first case, the laws of probability require a variety of relationships to hold among probability assessments, regardless of their values; and in the second case,

experience with a known data generator for a sufficient period of time should produce probabilities which are in good agreement with the true probabilities.

In the case of the utility assessment, consistency measures may be the only method open; it seems difficult to experimentally manipulate an individual's values to correspond to some predetermined form. Thus, before research can be run to discover which of several alternative utility assessment procedures is best, research must be conducted to determine which kinds of consistency measurements are psychologically meaningful in the determination of utility accuracy. This research would have two benefits. It would provide the basis for investigation of utility assessment procedures, and it would also provide the decision maker in a practical application with a means of evaluating his particular utility assessments.

With respect to utility assessment, research needs to be carried out to determine the circumstances under which one procedure for assessing organizational utility might be preferable to another. For example, in addition to the procedure described above, one of the current methods for assessing the utilities of an organization is to have each of the different groups or individuals assess his utility functions for each of the dimensions, together with the weights for combining them, and then to combine these weighted utility functions using weights related to the power or importance of the groups.

Alternatively, an organizational utility function may be assessed by treating each of the interested parties in the organization as a side in a multilateral treaty negotiation. Thus, the evaluation of alternative organizational policies can be carried out as though the problem were to arrive at a mutually satisfactory compromise. The advantage of an organizational utility arrived at in this way is that the interaction among the various parties' utility functions will in general be nonlinear, and an explicit negotiation model brings these nonlinearities into the evaluation in a relatively straightforward way. In addition, many alternatives need not be considered as possible solutions, since they will be dominated by other alternatives.

These methods are only a few of the possible organizational utility assessment techniques which might be used in place of the simplifying assumption of a rational unitary decision maker. Research needs to be conducted to determine the effectiveness of each of these assessment techniques and the improvement they yield over the rational unitary decision maker model.

4.3 Value of Information for Decision

4.3.1 Abstract - Under this ongoing project³, decision models have been developed which assess the value of intelligence information for high-level policy decisions. These models show how U.S. policies, actions, and the uncertainties associated with the reactions by affected parties, and the characteristics of the political, economic, scientific, and military environments interact in decision situations which are affected by the information available.

4.3.2 Background and approach - Military intelligence is important for U.S. decisions, but it is expensive. Although it is important to decision makers, it may be the case that it is not collected and produced in such a way as to maximize its benefit.

Secretary Schlesinger has stated that "The consumer frequently fails to specify his product needs for the producer; the producer, uncertain about eventual demands, encourages the collector to provide data without selectivity or priority; and the collector emphasizes quantity rather than quality". There is substantial slippage in the collector's understanding of the needs of the producer of intelligence and in the producer's understanding of the needs of the user, that is, the ultimate decision maker.

The ultimate objective is to improve the utility of information available from intelligence sources in the national decision making process. This requires analysis of both the national decision making process and the intelligence production and collection processes. The analysis concentrates on ways of identifying the intelligence needs based upon the value of the intelligence to the user. Methods and procedures that the intelligence planner and analyst employ can then be developed. Although an independent effort, the analysis and results must interface with the Critical Near Term Defense Intelligence Objectives (CNTDIO) System of the Defense Intelligence Agency.

A number of decision models have been constructed which relate intelligence uncertainties to the outcome of key defense decisions. Decision makers or their surrogates evaluated the relative importance of possible decision outcomes and intelligence analysts assessed the impact which changes in intelligence collection would have on their ability to forecast the occurrence of intelligence uncertainties which could affect the outcome of the decisions. A dollar value was then assigned to filling each intelligence deficiency or to each collection system being evaluated.

³ This study is being performed for the Defense Intelligence Agency, Department of Defense, Washington, D.C. under a contract with the Defense Nuclear Agency, Alexandria, Virginia.

The current analysis has proceeded according to the following steps:

1. Select defense-related problem areas, based upon current U.S. interest or involvement.
2. Prepare models relating possible defense decisions to important information gaps.
3. Refine the decision-intelligence models through discussion, elicitation and assessment techniques by working with decision makers and intelligence analysts.
4. Develop a multi-attribute utility model for measuring the dollar value of each outcome in terms of U.S. military, economic, and political interests.
5. Compute the expected value for each of the decision options, for both current and perfect information states, to establish an upper bound on the value of information.
6. Step 5 assumes the simplified model of a rational, unitary decision maker. The final step is to adjust the value of information by assessing its probable actual impact on the decision making process.

4.3.3 Implications - A practical procedure for the purpose of assessing the value of intelligence to decision makers should enhance the functions of collection and production.

The initial applications of decision analysis to value of information provides strong indications that it offers a contribution of the understanding of the value-of-information problem. However, these applications have highlighted the following deficiencies which could severely restrict applicability of the methodology:

1. Application of the methodology required input from intelligence analysts and decision makers. Currently, the models are so complex that a great deal of time is required. This consideration is especially important since it is the user's or decision maker's time rather than the analyst's time which is required for most of the input in the model. Several research developments suggest that a considerable reduction in structural complexity can be achieved without sacrificing quality. One possibility is to use Markov principles and attempt to stage or coalesce the decision tree whenever appropriate. This may be accomplished

by constructing a dummy variable for any level of the decision tree such that all succeeding assessments depend only upon the level of the dummy variable. The number of required assessments will then grow as an additive function of the number of stages rather than a geometric function of the size of the tree. Another principle for simplifying the assessment process is to make detailed models for analyses of a few of the assessments needed and then to use the conclusions of those side models as anchor points for direct judgments of the remaining assessments. This technique can be applied to the assessments of probability, utility, or even to the direct value of information. Although these procedures have proven to be useful, a comprehensive examination should focus on general principles for simplifying value-of-information models.

2. A standard model calculates the value of information as equal to the difference between the expected value of the primary decisions with the information and without the information. A systematically conservative bias can be expected, however, in that it is very difficult to identify all primary decisions for which the information is relevant at the time of the analysis. Furthermore, information may have value for other than primary decisions. For example, order of battle information about Eastern Europe may have value, not only because of the information itself, but, in addition, that information implies a capability to obtain such information in the future and hence insures a capability for off-site verification. In addition, information may have value in terms of alerting one to the need that a decision must be made and also may be useful in generating options among which to choose. The point is that intelligence may serve a variety of purposes and research is needed for the development of principles that will insure that models do not explicitly exclude any of these purposes.

4.4 Quantitative Estimates for a Major Weapon System, Aircraft Carriers, Using Decision Theoretic Analysis

4.4.1 Abstract - A preliminary decision theoretic model for the estimation of total aircraft carrier inventory requirements has been developed⁴. The analysis develops requirements from basic national policy and objectives as they can be supported by aircraft carrier missions on a global scale. Basic scenarios are used in the model, for major areas of the world which have cohesive geographical, political, economic and military significance. A prioritized, probabilistic utility assessment is made, not only at the optimal (or minimal risk) level of carrier forces, but also with regard to the degradation in satisfying national objectives anticipated with fewer carriers or with alternative but less capable aviation platforms. Work is proceeding on force mixes using alternative aviation platforms and cost-benefit analysis. This effort should show whether the decision theoretic model being developed will have potential for analyses of force mixes eventually involving the major sea- and land-based weapon systems.

4.4.2 Background and approach - Since 1960, force-level requirements have been developed by the Defense Department based on specific force planning guidance. This guidance limited the scope of the final analyses to the detailed examination of specific scenarios related to U.S. interests in no more than two major geographical areas and one or more of the most likely contingencies in those major areas. A force level which appeared adequate, with reasonable risk, to meet this guidance was assumed, in effect, to be adequate world-wide; it was presumably adequate to handle conflicts and crises anywhere, to provide deterrence, and to support all commitments and national objectives of the United States. It was recognized that the analyses were made independently, without explicit interaction with world-wide events, and that events would never develop exactly as postulated. Nevertheless, the limitations were necessary to reduce the amount of analytical work to manageable proportions.

The number of studies now available constitute an impressive body of analytical results, each covering a limited situation. Also, a great deal more was learned about the capabilities of major weapon systems, such as the aircraft carrier, and about the value of their application throughout the world. With this wealth of information, a

4 This study is being performed for the Office of the Chief of Naval Operations (OP-558), Navy Department, Washington, D.C.

different approach suggests itself -- a probabilistic analysis of a significant number of the contingency situations which are historically known to evolve from the political, economic, and military environment throughout the world. This kind of analysis would permit the application of decision theory rules, optimization routines, and sensitivity analyses, for example, and would be a valuable adjunct in the decision making process.

The national resources at stake in the aircraft carrier program decision which must be made in the near future are sufficient to justify special analytical measures. A new nuclear aircraft carrier, CVN-71, is programmed for acquisition funding in FY 1978, with long-lead components funded in FY 1977. The Navy Department plans call for construction of an aircraft carrier in alternate years thereafter. The Carrier Programs Office (OP-55B) is engaged in requirements analysis and justification of the program, and has employed Decisions and Designs, Incorporated to develop decision analytic methods for estimating aircraft carrier requirements and measures of the utility of alternative force mixes.

The primary task is to develop aircraft carrier requirements based explicitly upon U.S. policy and objectives-- political, economic, and military. One step in attaining that objective is to evaluate the impact of the number and mix of aircraft carriers upon U.S. world-wide interest in all areas of the world, including the interests of our allies and all other significant factors. Specifically, what is the function that relates number and mix of aircraft carriers to the utility that those carriers provide to U.S. interests? The objective is to assess that functional relationship.

Work was initiated by Decisions and Designs, Incorporated early in January 1975. An analysis is being developed which is comprised of the following steps:

- o The different areas of the world, such as the Mediterranean and Western Pacific, are prioritized according to the degree to which aircraft carriers can be expected to contribute to meeting national objectives. The prioritization is based upon at least three factors -- the relative degree of U.S. interest in the area, the degree to which aircraft carriers can impact upon U.S. interests if called upon, and the probability that they will be called upon to do so.
- o The development and prioritization of generic scenarios in each of the areas. These scenarios

include both nuclear and conventional warfare, both serious and mild crises, and the maintenance of U.S. objectives -- freedom of the seas and projection of forces. The prioritization of scenarios, like the prioritization of the areas, is based upon the magnitude of U.S. interests impacted by the scenario, the degree to which aircraft carriers can impact upon those interests, and the probability that they will be called upon to do so.

- o The next step is to establish carrier requirements within scenarios. Classically, a requirement is considered a point assessment, but such a procedure is patently inappropriate. It is critically important not only to assess the number of carriers required to satisfy 100% of the carrier related needs within a scenario, but also to assess the degree to which those needs will be impaired by a reduced number of carriers. Therefore, a statement of a requirement, within a scenario, can be construed as a curve rather than a point -- a utility curve that describes the degree to which the utility of aircraft carriers decreases as a function of reducing the number of carriers from the maximum number required to satisfy the need to zero carriers.
- o The final step is to develop an allocation of aircraft carriers to different areas of the world. This allocation is based upon an optimization routine that assigns each increase in the number of carriers in inventory to different areas according to all three functions described above; the relative priority of the area, the relative priority within the area, and the requirement curve describing the degree to which carriers contribute to prioritized U.S. policy within each area.

The output of these four steps provides a function that relates the utility of U.S. policy of satisfying carrier-related requirements around the world as a function of the number of carriers in the Naval inventory.

4.4.3 Implications - This ongoing analysis has potential practical impact in three areas. First of all it will influence the scheduling of CVN-71; i.e., exactly when, as a function of its prioritized requirement, will the next nuclear aircraft carrier be produced. Secondly, the result of the analysis can influence the long-range mix of

aircraft carriers. Will they continue to be produced according to the maxim that all carriers must be nuclear and the larger the better, or will a mix be developed that is sensitive to the requirements of carriers based upon high and low threat areas and also areas which provide a ready versus an almost nonexistent supply of petroleum. Finally, a successful implementation of the proposed analysis has the potential for providing a generalized method for explicitly relating weapons requirements to policy. It may be possible for such documents as the JSOP to be modified in such a way that they actually provide explicit linkages between U.S. policy and statements of weapons requirements.

The analysis also has some research implications, based upon the work thus far. In this case, the most critical needs are to provide an acceptable methodology, and to develop procedures that will make the necessary subjectivity of analyses such as this more respectable. The three basic forms of input -- the prioritization of areas of the world, the prioritization of scenarios, and the requirement curve within scenarios -- necessarily require expert judgments of operational experts. These are experts who understand the role of carriers within scenarios and experts who understand the relative importance of U.S. policy interests in different areas. This process introduces subjectivity and operational expertise at a much higher level than is typical in simulations of war games that are frequently used to evaluate systems. It must be the case that operationally qualified experts are capable of making and encoding such subjective judgments into analyses. The research problem is not only to develop better procedures for assessing such subjective judgments, but also to develop ways in which those judgements can be respectable and accepted by users.

Beyond the involvement of the current study with sea-based aviation platforms, from large nuclear carriers to VSTOL support ships, there is a strong indication that the analysis can be more broadly applied. Further investigation of the methodology being developed, using mixes of naval aviation and non-aviation platforms, ground forces, and land-based air forces, can evolve significant decision aids.

5.0 COMPUTER SUPPORT

5.1 Computer Programs to Aid Decision Analysis

5.1.1 Background - During the past few years, a number of computer programs have been developed to ease the computational burden involved in decision analysis problems. The computer programs, however, have been done by a large number of independent developers with little cooperation among developers. Furthermore, although decision analysis practitioners have expressed an interest in learning about developments in computer-aided decision analysis, no studies have been previously undertaken to catalogue the various programs that have been developed.

5.1.2 Objective - The objective of this study is two-fold. First, the study is designed to produce a useful guide for decision analysis practitioners who wish to utilize available computer software in their work. In this regard, the study provides a user-oriented description of the design features of various programs. Secondly, the study is intended to provide a loose statement on the state-of-the-art in computer applications of decision analysis techniques. In this regard, descriptions of programs that are strictly developmental or are for internal use only are surveyed as well as those that are commercially available.

5.1.3 Approach - Since this study is essentially one of data gathering, organization and evaluation, the approach employed a literature review and a large number of personal interviews.

5.1.4 Implications - The computer programs that have been developed to aid in decision analysis can be functionally grouped into four classifications:

- a. Decision tree roll-back programs
- b. Probability and utility programs
- c. Modeling languages
- d. Other special-purpose programs

A technical report¹ has been published which provides a detailed description of each program within the groups in terms of its availability, cost, mode of use (e.g., interactive or batch), and extent of previous use. In addition, the report indicates programs that represent the state-of-the-art in various areas.

In addition to providing a statement on the state-of-the-art in computer programs for decision analysis and a useful guide to the use of existing programs, this study also identifies important areas for future improvement in the technology.

¹ "An Impressionistic Survey of Computer Programs for Decision Analysis," Technical Report 75-2, Decisions and Designs, Inc.

5.2 Development of Interactive Computer Graphics Techniques

5.2.1 Objective - To develop an interactive computer graphics capability to aid intelligence analysts and decision makers in making probabilistic forecasts and assessments.

5.2.2 General approach - Previous research has shown it is critical for the intelligence analyst/decision maker to understand the structure of the analysis, manipulate the details of the analysis, and ensure continuity and completeness in his thought processes.

In this research effort, DDI is studying and evaluating alternative interactive computer graphics techniques to aid the analyst/decision maker in graphically structuring each analytic problem, reducing the time and complexity of alternative computations necessary to arrive at an optimum solution/decision. The effort also considers the ability of the techniques to facilitate the "sensitivity analysis" (interactively changing parameters and noting single and combined results) which is vital to the analyst's confidence in the final results.

5.2.3 Interim technical results - A prototype interactive computer graphics program has been developed by DDI for structuring the analysis of intelligence estimates of technological parameters for strategic nuclear weapons. This program allows an intelligence analyst, using the interactive computer graphics display, to vary the hypothetical technological parameters of both the offensive weapon systems and the defensive systems, and computes the resultant effect on strategic capabilities. The system includes the capability to vary the probabilities for technological change, providing the analyst with assessments which are useful in establishing credibility over any desired distributions.

In addition to the obvious direct benefits which can accrue from the use of this program, its formulation has led to the development of generalized tools and techniques which can be used to minimize programming efforts for future application systems. In particular, this system contains a generalized "virtual table" component which reduces the programming effort required for displaying tables of information on the screen; it frees the system developer from the arduous tasks of table layout and formatting, and automatically compensates for tables exceeding the physical dimensions of the screen by allowing such tables to be translated up or down and left or right under a "window," via the light pen, so that the entire table can be viewed (a portion at a time).

It also provides a table update feature, which allows the end user to select table elements with the light pen and then to modify their values. The developer need specify only the text of desired labels, the values to be displayed, and a few parameters, such as character size, the desired width of table columns, and whether table elements are to be modifiable. With this tool, the programming effort required for displaying tables can be reduced by 90 percent or more.

The intelligence analyst is continually faced with probability assessments concerning categorical events, or events which lie along a continuum. DDI has developed interactive computer programs to assist in the assessment of both kinds of probabilities. These programs provide feedback to the analyst quickly enough to assist him in the assessment process and allow revision of the various inputs on the basis of feedback in real time.

The first program implements a proper scoring rule tool for the calibration of the analyst engaged in the assessment of the probabilities of categorical events. Calibration is essentially the process of adjusting an assessor's probability report so that it agrees with his internal degree of certainty. This process assists the probability assessor in developing both understanding of the concepts of probability and confidence in his ability to make assessments.

A proper scoring rule is a system of feedback which has the unique mathematical property that the total score is maximized if the assessor assigns a probability representing his true degree of certainty. Saying it another way, he can minimize his penalty score only by reporting his true assessed probability.

A probability assessor can use a proper scoring rule as a tool in the following way: The assessor can be given a series of questions for each of which he indicates the answer he believes correct, together with the probability that his answer is the correct one. He can then receive feedback in the form of the correct answer and the score he received, under the proper scoring rule, for being either correct or incorrect with the probability he assigned.

DDI has implemented a proper scoring rule program on its interactive computer system, permitting the user to proceed rapidly through the sequence of questions and to receive a more meaningful form of feedback than could be provided using paper and pencil.

A second program implements a method for the direct assessment of probabilities of events that lie along a continuum. The method requires the analyst to assess values initially such that the probability is equal that the true value falls within each of two, three, or four intervals on the continuum. The interactive computer graphics screen accepts input about indifference judgments, shows graphs of the implied cumulative distributions, allows revision based on feedback and produces new feedback. During or upon completion of the iterative assessment procedure the system can differentiate the cumulative distributions and show graphically the resulting probability density function. This form of presentation is more readily interpreted than the cumulative distribution by many users of the information.

The capabilities of the prototype interactive computer graphics program are described in further detail in the appendices to an interim technical report² which was published in December 1974.

5.3 Application and Modification of CTREE

5.3.1 Objective - CTREE is a computer programming language designed to simplify the task of analyzing complex decision diagrams. The language was developed for ARPA by the Decision Analysis Group of the Stanford Research Institute (SRI). DDI is presently employing CTREE for DIA in the analysis of some complex problems concerning the values to be placed on various kinds of intelligence.

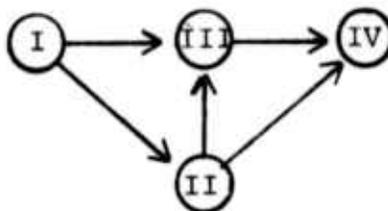
In addition to this specific practical goal, DDI is exploring, in collaboration with SRI, further advances in decision-analytic software designed to be analyst-compatible and capable of implementation on a computer-graphics system.

5.3.2 Approach - Modification of CTREE is being accomplished by the writing (in FORTRAN and CTREE) of some general programs and subroutines to enable a user to bypass the rather complex task of programming each decision problem in CTREE. These general programs should permit the solution

2 "Graphics Interactive System for Decision Theoretic Analysis," First Technical Report (ARPA), Decisions and Designs, Incorporated, to Rome Air Development Center under Contract F30602-74-C-0225.

of most problems without resorting to any programming, and require only that the user use a simple, specially formatted data file. In this data file, it is only necessary to specify the linkages of an influence diagram and the numerical probabilities and values for the problem at hand. This method of specifying the diagram structure via the structure of a relatively simple influence diagram marks a major simplification in the analysis of complex decision problems.

The influence diagram associated with a particular decision (or probability) diagram amounts to a specification of the assessment dependencies in the decision diagram. The assessments at the fourth node, for example, might depend only on the paths taken at the second and third nodes, but not on the path at the first node. Assuming that all other assessments are conditional on all previous nodes, the influence diagram could be drawn as follows:



The arrows in the figure indicate that the outcome at one node (tail of arrow) must be specified before the conditional assessment at another node (head of arrow) can be made.

5.3.3 Findings - The new software to permit the automatic generation and analysis of decision diagrams from the specification of an influence diagram has been developed and is undergoing testing and refinement. Practical applications are being achieved in our previously mentioned work for DIA.

6.0 PERCEPTION CONFERENCE

6.0 WORKSHOP ON PERCEPTIONS OF THE MILITARY BALANCE

6.1 Background

During the first quarter of Fiscal Year 1975, the Defense Advanced Research Projects Agency (ARPA) Technology Assessments Office (TAO) indicated its intention to sponsor several workshops on the role of perceptions of the military balance in the decision-making and planning processes within the Department of Defense (DoD). ARPA TAO's interests in this subject were based upon:

- o The increasing number of references to the actual or potential impact of perceptions of the military balance upon the decision-making and planning processes in the highest echelons of the Departments of Defense and State.
- o Questions by the Director of Net Assessment in the Office of the Secretary of Defense (OSD) as to whether or not something more can/should be done with respect to assessing, integrating and institutionalizing perceptions of the military balance in the national security decision-making and planning processes.

Subsequently, two workshops on perceptions of the military balance were conducted for ARPA TAO. The first workshop was conducted by the RAND Corporation in Santa Monica on August 26-27, 1974, and the second (which is the principal subject of Section 6.0) was conducted by Decisions and Designs, Incorporated, in Arlington, Virginia, on January 27-28, 1975.

6.2 The First Workshop

6.2.1 Objectives and proceedings - The stated aim of the first workshop was "to survey existing studies and hypotheses concerning the factors, variables, and events that affect perceptions...from the standpoint of different disciplines, literatures, countries, and cultures."¹ In this context and as indicated in Table 1, the participants in the first workshop and the papers presented reflected a fairly broad spectrum of disciplines and interests. The papers served as the basis for a wide-ranging discussion among the participants of the workshop on the characteristics of perceptions, on hypotheses concerning the factors which influence perceptions, and on some ideas for pursuing research related to these hypotheses.

1 "Perceptions of the Military Balance: Report of a Workshop August 26-27, 1974" (draft), RAND Working Note WN 8875-ARPA October 1974.

<u>Subject</u>	<u>Author/Institution</u>
• "Elite Perceptions of the Military Balance"	Dr. Daniel Lerner, Massachusetts Institute of Technology (MIT)
• "The Distortion of Theories by Intimate Processes"	Dr. Lionel Tiger, Rutgers University
• "How International Communication Affects Perceptions of the Military Balance"	Dr. Ithiel de Sola Pool, MIT
• "A Psychoanalytic Orientation on Perceptions"	Dr. Nathan Leites, RAND Consultant
• "Survey Research and Perceptions of the Military Balance"	Mr. Albert H. Cantril, Consultant
• "Perception and 'Reality'"	Mr. Albert H. Cantril
• "Perceptions of the Military Balance--The Case of Japan"	Mr. Paul F. Langer, RAND
• "Perceptions of Military Power"	Dr. Herbert Goldhammer, RAND
• "Chinese Perceptions of the Soviet-American Balance"	Dr. Michael Pillsbury, RAND
• "Perceptions of the Military Balance: Some Models and Anecdotes"	Dr. Charles Wolf, Jr., RAND
• "Symbolic Processes in Perceptions of International Power Relations"	Dr. Murray Edelman, University of Wisconsin

Table 1. Papers Presented during the First Workshop

6.2.2 Results - The proceedings and results of the first workshop are summarized in a RAND report¹ which identifies the following interesting hypotheses pertaining to the factors that appear to influence perceptions of the military balance:

- o Discrete, dramatic, individual events, such as the Cuban missile crisis or the launching of Sputnik
- o Clustered events; "for example, the effect of Sputnik may have been magnified because it was part of a series of events that included the Soviet Union's first thermonuclear test and its success in suppressing dissension in Hungary
- o Military deployments; for example, the frequency or intensity of naval patrols, changes in basing posture, and removal of forward-based nuclear weapons
- o Internal debate and self-perception within the U.S. on defense matters, especially authoritative views of relative military effectiveness expressed in such policy documents as the Defense Secretary's annual posture statement

¹ Ibid.

- o Policy preferences of elites in third countries
- o Composition of military forces
- o Nuclear weapons, particularly with respect to certain physical attributes
- o Wartime experiences of a nation's senior military officers with respect to military forces, weapon systems, and their effectiveness.

Some ideas with regard to methods for pursuing research related to the foregoing hypotheses were also identified in the RAND report and may be briefly described as follows:

- o Description of information networks; i.e., descriptive studies of those information sources which reach and are accredited by particular foreign leaders and elites
- o A comparative study of selected military publications which would provide a descriptive and comparative analysis of certain recurring and generally reputable sources of information about the military balance, such as the regular publications of the International Institute for Strategic Studies, the Brookings Institution, and Jane's
- o Periodic surveys and in-depth interviews that are timed in relation to particular public events or a sequence of noteworthy events, particularly those that are specifically designed to deal with changes in opinion
- o Case studies of particular crises, such as the Middle East war of 1973, the Cuban missile episode of 1962, and the Czechoslovakian invasion of 1969.

6.3 The Second Workshop

6.3.1 Objectives and planning - Given the exploratory nature and results of the first workshop, the overall aim of the second workshop was to solicit the observations and suggestions of senior decision-makers and planners with respect to:

- o The influence of perceptions of the military balance on the decision-making and planning processes within DoD, and other Agencies of the Federal Government
- o Additional perceptions-related research which could make significant contributions to the decision-making processes within DoD and which would appear to offer

the greatest opportunities in terms of institutionalizing the results of the research in the national security decision-making and planning processes.

In this context, the participants in--as well as the agenda which were developed by Decisions and Designs, Incorporated for--the second workshop are identified in Table 2 and 3, respectively. As may be noted, the majority of the participants are in the user category; i.e., senior decision-makers or planners.

<u>Individual</u>	<u>Position and/or Agency</u>
● Mr. Edward C. Aldridge	Deputy Assistant Secretary of Defense (DASD) for Strategic Programs, Office of the Assistant Secretary of Defense for Program Analysis and Evaluation (OASD PAE)
● Dr. Graham T. Allison	Professor of Political Science, Harvard University
● Dr. John K. Beling ¹	Assistant Director (Net Technical Assessment), Office of the Director of Defense Research and Engineering (ODDR&E)
● Dr. Lewis M. Branscomb ²	Chief Scientist, International Business Machines (IBM)
● Dr. Donald Brennan ¹	Hudson Institute
● Mr. Fritz W. Ermarth	Office of Strategic Research, Central Intelligence Agency (CIA)
● General Andrew J. Goodpaster	Former Supreme Allied Commander, Europe
● The Honorable Robert W. Komer	Workshop Chairman, RAND
● Mr. Andrew W. Marshall	Director of Net Assessment, Office of the Secretary of Defense
● Mr. Brooks McClure ¹	Office of the DASD for Policy Plans and National Security Council (NSC) Affairs, Office of the Assistant Secretary of Defense for International Security Affairs (OASD ISA)
● Mr. Rex D. Minckler	Workshop Manager, Decisions and Designs, Incorporated
● The Honorable Paul H. Nitze ¹	Former Deputy Secretary of Defense
● Dr. Cameron R. Peterson ¹	Decisions & Designs, Incorporated
● Mr. Gene H. Porter ¹	Director of the Naval Forces Division, OASD PAE
● Mr. Franklin P. Shaw ¹	DASD (Regional Programs), OASD PAE
● Lt. Gen. Ray B. Sitton ¹	J-3, Office of the Joint Chiefs of Staff
● Maj. Gen. William Y. Smith	DASD for Policy Plans and NSC Affairs, OASD ISA
● Mr. Gerald D. Sullivan	Workshop Sponsor, Technology Assessments Office, ARPA
● Dr. James P. Wade ²	Director, Department of Defense (DoD) SALT Task Force, OASD ISA
● Mr. John Whitman ¹	Soviet Specialist, CIA
● Dr. Charles Wolf ¹	Head, Economics Department, RAND
● Mr. Gregory R. Woods ¹	Director of the European Division, OASD PAE
● Mr. Melvin O. Wright ¹	Vice President and Director, Reynolds Securities, Incorporated
● Dr. Robert A. Young ¹	Human Resources Research Office, APRA
<u>Footnotes:</u>	
¹ Participated in the Workshop only on January 27	
² Participated in the Workshop only on January 28	

Table 2. A List of the Participants in the Second Workshop

<u>Subject</u>	<u>Individual (Agency)</u>
<u>January 27</u>	
<ul style="list-style-type: none"> • Introductory remarks, guidelines, and definitions 	Hon. Robert Komer (RAND)
<ul style="list-style-type: none"> • A summary of the highlights and results of the first workshop 	Dr. Charles Wolf (RAND)
<ul style="list-style-type: none"> • Observations on how perceptions are currently used in the decision-making processes of the Federal Government and how they might be used more effectively in the national security decision-making and planning processes 	Dr. Graham Allison (Harvard)
<ul style="list-style-type: none"> • A concept for the development of a methodology for quantitative assessment of the utility of the elements involved in perceptions of the military balance 	Dr. Cameron Peterson (Decisions and Designs, Inc.)
<ul style="list-style-type: none"> • Difficulties in identifying/defining the dimensions/factors that constitute perceptions on other than a case-by-case basis 	Dr. Donald Brennan (Hudson Institute)
<ul style="list-style-type: none"> • A general overview of Soviet perceptions from the point of view of the U.S. Intelligence Community 	Mr. Fritz Ermarth (CIA)
<ul style="list-style-type: none"> • Real-world observations on the impact of foreign perceptions in the decision-making and planning processes in multi-national corporations 	Mr. Melvin Wright (Reynolds Securities, Inc.)
<ul style="list-style-type: none"> • Real-world observations on the impact of perceptions of the military balance in the decision-making and planning processes within the Department of Defense (DoD) 	Gen. Andrew Goodpaster Hon. Paul Nitze
<u>January 28</u>	
<ul style="list-style-type: none"> • A brief summary of recent and on-going perceptions-related research 	Mr. Andrew Marshall (Office of the Secretary of Defense) Mr. Gerald Sullivan (ARPA TAO)
<ul style="list-style-type: none"> • A general discussion of what additional research on perceptions of the military balance could make significant contributions to the decision-making and planning within DoD 	All participants

Table 3. The Agenda for the Second Workshop

6.3.2 Proceedings and results - Presentation and discussion of the subjects listed in Table 3 generated a number of significant observations and suggestions by the senior decision-makers and planners present with respect to:

- o The characteristics of perceptions of the military balance
- o The influence of perceptions on national security decision-making and planning processes

- o The pros and cons of a more methodological assessment and integration of perceptions of the military balance in the decision-making and planning processes of DoD and the State Department. As may be noted in Table 3, some observations of the impact of foreign perceptions on the decision-making and planning processes in multi-national corporations were also injected into the discussion
- o Additional perceptions-related research which could make significant contributions to the decision-making and planning processes within DoD
- o Means of institutionalizing the results of perceptions-related research in the national security decision-making and planning processes.

The observations and suggestions of the participants in the second workshop are summarized in a report by Decisions and Designs, Incorporated,¹ which highlights:

- o Principal, recurring themes and issues
- o Areas of apparent consensus and divergence
- o Suggested subjects or areas for new and additional research
- o Suggested means of implementing/institutionalizing the results of the research.

Although there was general consensus among the participants in the workshop with regard to the importance of perceptions in the national security decision-making and planning processes, there was a significant range of opinions on just what can/should be done to assess and integrate perceptions in the decision-making and planning processes of DoD and the Department of State. However, as a minimum, it was the consensus that efforts to sensitize current and potential decision-makers and planners to the phenomenology associated with perceptions should be continued and expanded. Obviously, this might be accomplished in a number of ways, some of which could involve:

- o The preparation and suitable dissemination of a series of case studies; in particular, case studies reflecting the perceptions-related experiences of senior decision-makers

¹ "The Proceedings and Results of a Workshop on Perceptions of the Military Balance" (draft), by Rex D. Minckler, February 28, 1975.

- o Planning and conducting appropriate seminars on the subject for senior decision-makers and planners
- o The preparation and presentation of a suitable block of instructions or seminars on the subject at the senior Military Service Colleges and, possibly, at the Service Academies.

A sample of other significant observations and suggestions, which are contained in the report but which do not necessarily reflect a consensus, is as follows:

- o Although accurate perceptions of the strategic military balance are considered to be very important in the decision-making and planning processes, perceptions of the overall political, economic, technological, and military balance are even more important. In other words, perceptions of the military balance should be considered in the decision-making and planning processes, but only in conjunction with perceptions of the economic and technological, and, in particular, the political balance so as to provide a perception of the overall/net balance
- o Perceptions and "realities" tend to converge over time so that inaccurate or misleading perceptions are difficult to maintain on a long-term basis, but since the "agenda" of world problems keep changing, perceptions and "realities" may never have time to converge. In this context, "dis-information" (e.g., information that is disseminated with the intent to mislead) could have significant effects in times of crisis, but "dis-information" must be very carefully prepared and may have a very short life, once disseminated
- o In the realm of uncertainties with respect to military power or balance, quantitative indicators dominate qualitative indicators. However, although there may be some 200-300 variables involved in assessing perceptions of the military balance, it would appear to be possible to develop a methodology and/or model by means of which overall estimates of the military balance, though somewhat gross, may be generated.

6.3.3 Implementation - Although the foregoing Decision and Designs, Incorporated, and RAND reports on the two workshops do contain a number of worthwhile observations and suggestions by distinguished representatives of both the decision-making/planning and academic/research communities, the actual dissemination and implementation of these suggestions rests initially with ARPA and OSD, and ultimately, with the Military Services themselves.

7.0 HANDBOOK FOR DECISION ANALYSIS

7.1 Handbook Preparation

7.1.1 First printing - Sixteen chapters of a user-oriented Handbook for Decision Analysis^{1,2} were prepared and distributed late in 1973. The decision theory content was based in part upon work previously accomplished under the present ARPA-sponsored contract, N00014-73-C-0149. This work has been described in earlier Technical Progress Reports^{3,4}.

7.2 Handbook Revision

7.2.1 Objective - An improved finalized version of the Handbook for Decision Analysis will be produced which incorporates the improvements and errata identified during use of the initial printed version.

7.2.2 Approach - The foreword in each chapter of the initial version of the Handbook contained a solicitation for corrections, comments, and suggestions for improvement, to be used in the production of a revision in the future.

This approach provided little in the way of useful inputs. Therefore, in October 1974, a questionnaire was developed and sent to each of the original Handbook recipients in an attempt to elicit more useful inputs to the proposed revision.

7.2.3 Results - As of the end of this reporting period, about 25% of the nearly 150 handbook recipients have responded. Of these responses, nearly half have contained useful inputs to the proposed revision. The result has been the identification of a requirement for several new chapters, and significant revisions of some of the original chapters in order to provide a more comprehensive and cohesive coverage of the subject matter.

7.2.4 Future tasks - Prepare an outline of the revised Handbook in consultation with key Handbook users and coordinate with the Defense Advanced Research Projects Agency and Office of Naval Research for approval. A

- 1 Handbook for Decision Analysis, Decisions and Designs, Incorporated, October 1973
- 2 Handbook for Decision Analysis (Preliminary), Defense Intelligence School, October 1973
- 3 "Decision Theory Research", Technical Progress Report No. 2, Decisions and Designs, Incorporated, to Defense Advanced Research Projects Agency under Contract N00014-73-C-0149 (CONF.)
- 4 "Decision Theory Research", Technical Progress Report No. 3, Decisions and Designs, Incorporated, to Defense Advanced Research Projects Agency under Contract N00014-73-C-0149.

need has been substantiated for a new introductory chapter which discusses the role of decision analysis in relation to other approaches. Also, it is desirable to include case study material which will be of practical value in highlighting various technical issues which are treated in a more abstract and theoretical manner in the Handbook which is now in use.

The final task is to prepare the new Handbook for Decision Analysis for publication. Publication will follow approval of the outline, and the necessary reviews and approval of the manuscript by the Defense Advanced Research Projects Agency and the Office of Naval Research.