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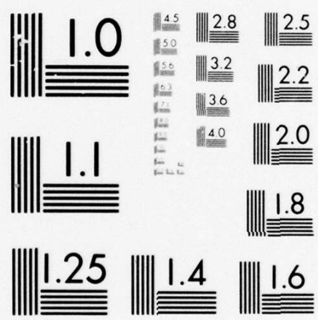

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DEFENSE SYSTEMS MANAGEMENT SCHOOL

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Program Management Course

Student Study Program

DECISION THEORY
AND THE
VALUE OF INFORMATION
STUDY REPORT
PMC 73-2

Kenneth S. Herberger
Lieutenant Colonel USA

November 1973

Fort Belvoir, Virginia 22060

HERBERGER

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DEFENSE SYSTEMS MANAGEMENT SCHOOL

STUDY TITLE:

Decision Theory and the Value of Information

STUDY PROBLEM/QUESTION: Information requirements exert significant impact on the cost of weapon systems. A technique to evaluate the value of information would be desirable to determine the commitment of resources to its collection and development.

STUDY REPORT ABSTRACT:

The continuing need for additional information to support the decision making process has exerted a significant impact on the costs of weapons system acquisition. A technique to evaluate the potential contribution of additional information to the decision making process is presented. Decision theory techniques to include decision trees, probability assessment, identification and quantification of dimensions to evaluate the outcomes as a result of a decision are proposed as a systematic approach to evaluate the potential value of additional information. The need to integrate this concept with other management tools will contribute to the allocation of organization resources to the collection of additional information.

KEY WORDS: MANAGEMENT CONCEPTS DECISION THEORY DISCOUNTING INFORMATION SYSTEMS

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DECISION THEORY AND THE VALUE OF INFORMATION

An Executive Summary
of a
Study Report

Kenneth S. Herberger
Lieutenant Colonel USA

November 1973

Defense Systems Management School
Program Management Course
Class 73-2
Fort Belvoir, Virginia 22060

Executive Summary

The purpose of this paper is to illustrate the application of Decision Theory techniques to the evaluation of information requirements.

The Department of Defense has recognized the impact of information requirements upon the acquisition cost of weapon systems. Publication of DOD Directive 5000.19 provides specific criteria to be used in determining either new information requirements or the continuation of existing information requirements. While much emphasis has been placed upon management personnel to reduce information requirements, there has been little guidance to assist in the accomplishment of this task.

This paper presents a broad outline of the major elements of decision theory which can be used to evaluate the potential merit of collecting additional information in support of decision making. It is not the intent of the author that this methodology be embraced with blind faith. Rather that managers at all levels become acquainted with the systematic approach to problem definition and resolution which this paper recommends.

The mythical ZULU SYSTEM (ZS) is used to illustrate the application of this technique to a decision problem. The ZS illustrates how the potential value of information can be estimated by comparing the result of the decision made without information against the end result of the same decision made with additional information.

There are many factors which bear upon the collection of information, some of which are not addressed by this paper. If this paper will cause management personnel to evaluate the potential payoff against the hazzards of not collecting additional information then it has served its purpose.

DECISION THEORY
AND THE
VALUE OF INFORMATION

STUDY REPORT

Presented to the Faculty
of the
Defense Systems Management School
in Partial Fulfillment of the
Program Management Course
Class 73-2

by
Kenneth S. Herberger
Lieutenant Colonel USA

November 1973

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CONTENTS

SECTION I

Introduction

The impact of the cost of information requirements upon the acquisition costs of major weapon systems has been an issue of concern to the Department of Defense for a significant period of time. In 1962 it was estimated that between forty to sixty percent of the cost of major weapon systems was attributable to data and documentation in all of its forms.[1] The issuance of recent Department of Defense Directives indicate that there is a continuing concern as to the impact of information costs and the anticipated benefits as a result of its collection.

> "Two major factors will be considered prior to the imposition of a new or continuation of existing information requirements: the cost of obtaining the information in relation to its use, and the penalties and risks associated with not having the information".[2]

The above excerpt provides sound criteria to be used in assessing the merits of collecting information, but there is little in the way of guidance as to how it should be implemented.

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1. ____________ Principles and Applications of Value Engineering Training Guide, Department of Defense, Washington, D.C. pp. 6-16. (undated)

2. ____________ Department of Defense Directive 5000.19, Department of Defense, Washington, D.C., June 1971, p. 3.

The methods for allocating the costs associated with the collection and processing of information alone are an area of study which would accommodate many differing points of view. As an example there are few organizations which expense the research time and efforts of the many people required to support the numerous conferences and reviews which are conducted prior to high level decision meetings held within the Department of Defense. Yet each of these collection efforts is accomplished in support of collecting, processing, and evaluating information to be provided to the principals of the decision meeting. The thrust of this paper however, will not be directed towards the mechanics of collecting the costs associated with information requirements, though it is a worthy undertaking.

The purpose of this paper is to illustrate the application of decision theory techniques as a systematic approach to the selection of alternatives, and the determination of the value of related outcomes. The use of this approach will provide the decision maker with a measure of the consequence of his decision and consequently a basis for evaluating the impact of making a decision without additional information. The decision theory technique will then be used to illustrate how the expected value of information could be developed, and thereby provide the decision maker with a yardstick against which to allocate resources to the acquisition of additional information.

It is acknowledged that there are some areas of management for which there are accurate decision rules and standards which can be used for control of the operations of an organization. This situation is more normally found at the lower levels of management, but is seldom the case in middle or upper level management. A review of the decision making process at the higher levels of management will reveal a preponderance of decisions which are required for unforeseen problems, which rely to a high degree upon the application of the subjective judgment of the decision maker. The unpredictable and unstructured nature of high level decision making process dictates that a systematic approach be used to evaluate the need for additional information in order to assist in the selection of the best alternative.

The rationale of this paper proposes the use of probability, expected value, decision diagrams, subjective values in an integrated effort to assess the possible outcomes of a decision and subsequently the expected value of information related to the decision under consideration. Application of this technique will benefit the decision maker in that it will enhance problem definition and assessment. The use of decision theory facilitates the examination of complex problems by reducing them to a series of less complex and consequently more manageable decisions. Those who have participated in managerial decisions where there were elements of uncertainty will readily agree that the identification and treatment of areas of uncertainty significantly contributes to the decision making process.

The generalized concept and its primary elements are described in the second section of the paper. Subsequent sections of the paper use the decision problem for the mythical ZULU SYSTEM to illustrate the application of the methodology.

The following summary of the ZULU SYSTEM acquisition effort is appropriate to enable the reader to appreciate the role of decision theory in the selection of alternatives and the evaluation of the expected worth of information. The ZULU SYSTEM had completed research and development acceptance testing (RDAT) in April of 1972. (Point A of Figure 1)
At that time it appeared that there was a reasonable degree of success for the development of a producible ZULU SYSTEM. The series of tests accomplished as a result of the decision at point "B" were to measure the system performance in an environment and manner similar to that in which it would be deployed. As illustrated later in the paper the results of the test are incorporated into the initial probabilities of a producible/nonproducible system through the application of Baye's Theorm. The paper then addresses the use of dimensions to evaluate and quantify the possible outcomes. Quantification of the possible outcomes is then reevaluated in the event additional information were collected. Comparison of the alternatives provides a yardstick for gauging the potential worth of additional information.

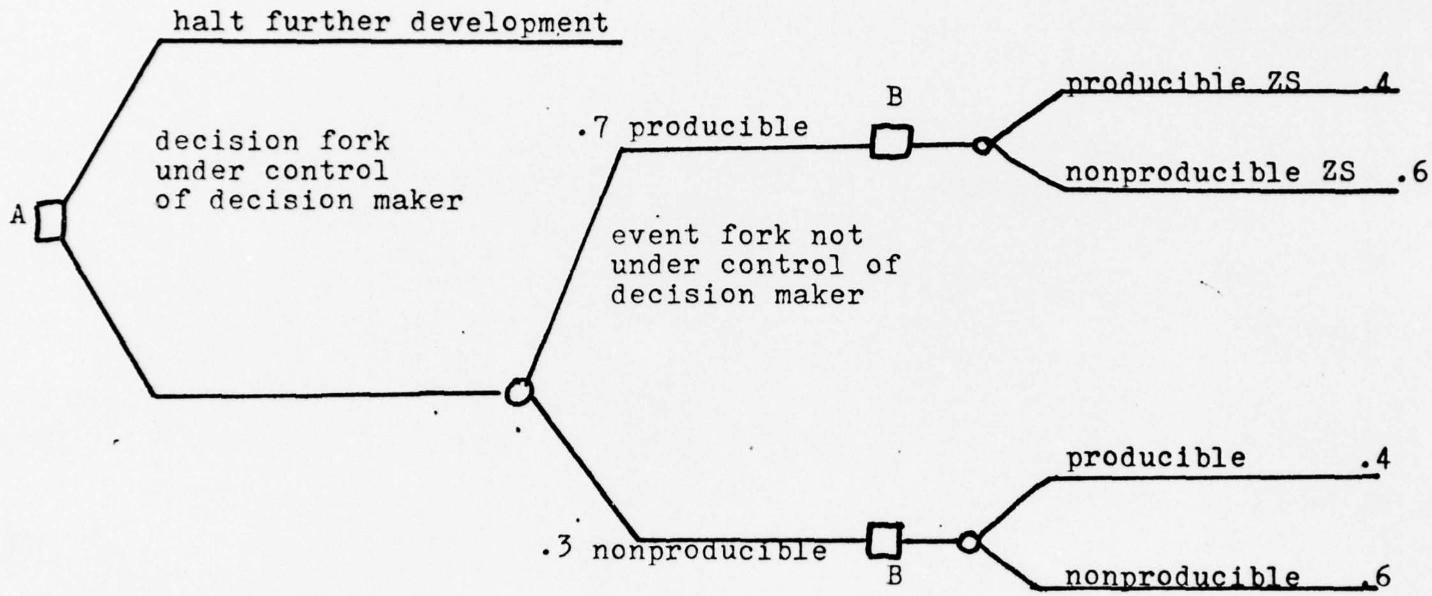

Figure 1: Condensed representation of ZULU SYSTEM (ZS) activities from completion of RDAT to Aug 72. (Test conducted as a result of act "B" evaluated the capability of the ZS to satisfy the system specification).

SECTION II

Decision Theory

The application of decision theory techniques provides a systematic approach for the analysis of the possible outcomes of a decision problem. It does not provide the decision maker with the exact results for his decision but it brings into focus the elements of uncertainty and allows the introduction of prior experience and knowledge in the assessment of the various alternatives. Once the possible outcomes have been evaluated and quantified it is then possible to gain a measure of the expected value which additional information could contribute to the selection of the possible alternatives. The expected value of the outcomes with information is compared against the expected value of the outcomes without information. The difference between the outcomes is the maximum which the decision maker should be willing to pay for the additional information. This will be demonstrated using the ZULU weapon system in Section V of this paper.

The elements of decision theory and their general relationship are illustrated by Figure 2. The decision tree provides an effective means for the graphical representation of the decision under consideration and the various outcomes for completion of the project. The square blocks represent acts over which the decision maker has control, that is he can select which path to take. The circles represent event forks which are not under his control. Though only two paths are illustrated there are normally many possible paths. The reduction to the two paths does not invalidate the theory as they can be treated as the representation of the average for the possible outcomes. The decimal figures on each of the event forks represent the probability of the outcome with which it is associated. The methods for obtaining the probabilities and the impact which they may have on the possible selection of the alternatives will be addressed in the following section. Through the application of backward induction the probabilities are applied against the terminal values of their related outcome.[3] By this method the average value is computed for each event fork. It is assumed that the decision maker would select that alternative which would yield the highest probable outcome.

The terminal value for each of the outcomes is computed by means of the value assigned to each dimension associated with the specific outcome. The critical impact which the assignment of the dimensional values have upon the selection of the alternatives cannot be over emphasized. Problems and techniques used to obtain the values ascribed to the dimensions are addressed in Section IV of this paper.

3. Raiffa, Howard, Decision Analysis, Addison-Wesley, Menlo Park, California 1970, for a more comprehensive discussion of backward induction, p. 23.

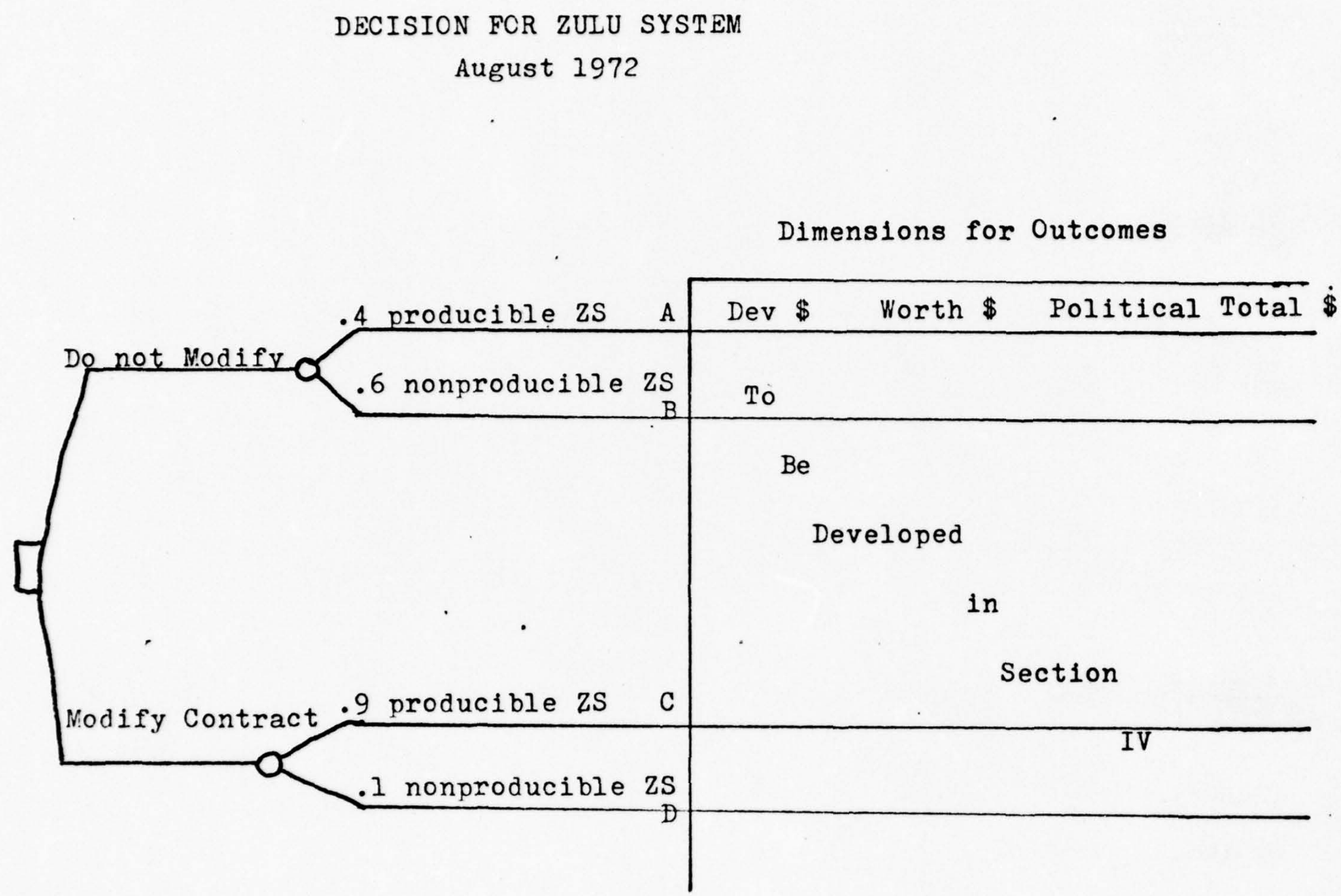

Figure 2: Graphic Representation of Decision Theory concept for Selection of an Alternative. (To modify or not modify the development contract)

It should be noted that the probability of developing a producible ZS is not the same as the original probability assessed after completion of RDAT in April 1972, but includes the impact of the information obtained as a result of testing conducted after testing of the original probable outcomes. The methodfor obtaining these probabilities as well as those for the relative success of the contract if modified will be discussed in detail in the following section.

SECTION III

Probability Assessments

The application of the concept of probability in everyday activities should facilitate understanding of its application to decision theory. In applying probability to the selection of alternatives it is imperative that consideration be given to the method by which the probability was obtained and the impact which variations of the probability would have upon the outcome.

In some cases the probability is the result of observations made over a period of time, or accumulated as a result of test efforts. The original assessment for obtaining a producible ZS in April of 1972 was .7. As a result of the test effort this probability was revised by application of Bayes'Theorm. This theorm maintains that the validity of a hypothesis can be operated upon by applying the result of test datum against the original hypothesis based upon the likelihood ratio. "The likelihood ratio is the number of times more likely it would be to observe the data if one hypothesis were true than the other were true."[4] This appears in symbolic notation as

$$\frac{P(H_1/D)}{P(H_2/D)} = \frac{P(D/H_1) \times P(H_1)}{P(D/H_2) \times P(H_2)}$$ (Where D indicates the data was observed)

This theorm was used to develop the revised probabilities in Figure 3b, wherein the original estimate of a producible system

4. Petersen, Cameron R. et al, Introduction to Decision Analysis A Case Study, Defense Intelligence School, Washington, D.C., August 1973, p. 31.

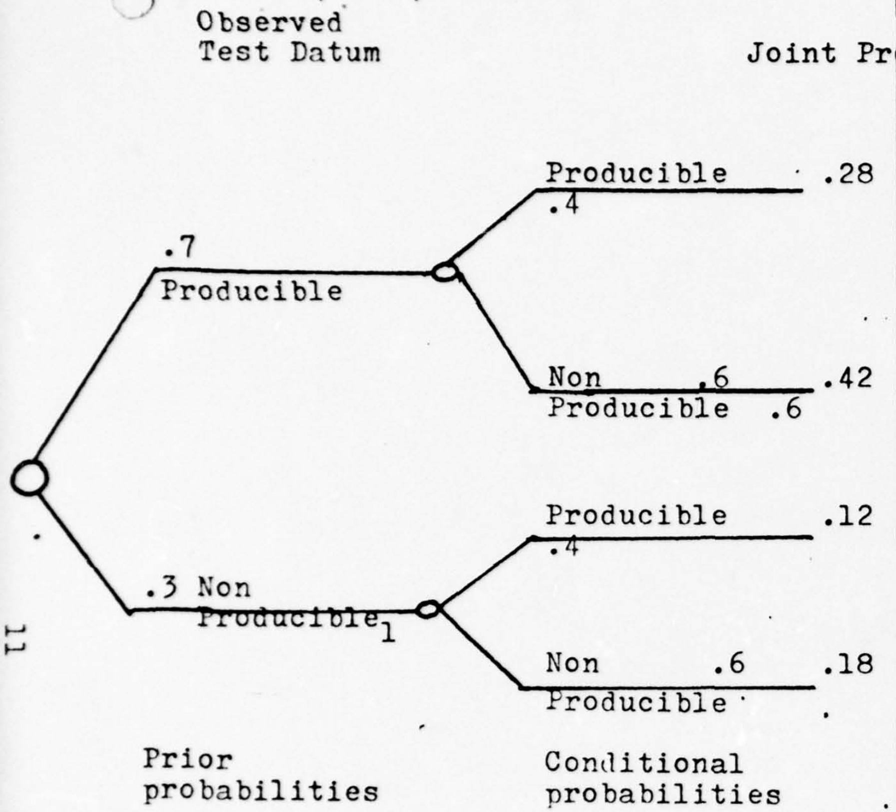

Figure 3a: Prior and conditional probabilities.

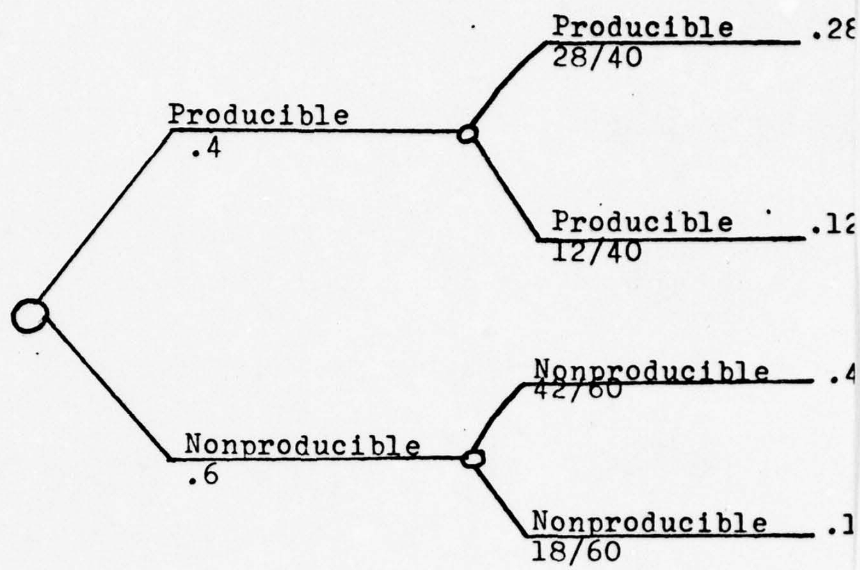

Figure 3b: Posterior probabilities (after results of Act B test effort)

was revised as a result of the subsequent test efforts and analysis of the collected data. The prior probabilities and their associated conditional probabilities are indicated in Figure 3a. Applying Bayes' Theorm the flipped tree with the revised posterior probabilities were developed and are displayed in Figure 3b.[5]

It is not always possible to obtain possibilities by means of actual measurement. In the event the decision was made to modify the contract it was estimated that there was a .9 chance that the effort would result in a producible ZS. This assessment was developed based upon the evaluation of the experts within the program office. Though it was a subjective value it had as its basis for assignment the previous experience in similar situations. There are those who may argue that there is no room for the use of subject assessments of this nature but they are offset by those who advocate the integration of the intuitive judgement of the human being. "We must not place reliance exclusively on brute force methods, but must also attempt to simulate the gestalt approach which the human uses, and which he uses on so many problems with a not inconsiderable degree of success."[6]

The impact which varying the probability assessments are normally tested by means of a sensitivity analysis. This will

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5. Raiffa, Howard, Decision Analysis, Addison-Wesley, Menlo Park, California, 1970, for a more comprehensive discussion of Bayes' Theorm and its proof. p. 17.

6. Machel, Robert E., Information and Decision Processes, McGraw Hill Book Co., New York, 1960, p. 6.

provide the decision maker with a feel as to the relationship between the probability assignment and the outcomes.

SECTION IV

Dimensions

The last major element of this technique which needs to be examined in closer detail is the means by which the terminal values are quantified for each of the outcomes. Initially it may appear that this would be a straight forward mathematical exercise, however, it often requires the assistance of an expert in the case of complicated decision analysis. The role of the expert is to assist the decision maker by asking those questions which will aid the decision maker in his visualization of the possible outcomes and the attributes which can be assigned to quantify these outcomes. As previously indicated there were three dimensions identified for the ZS. These were the development cost, expected worth, and the political dimensions. Each of these dimensions exert a varying degree of influence throughout the organization levels. Figure 4 illustrates the relationship of these dimensions to the organizational level with the least important at the bottom.

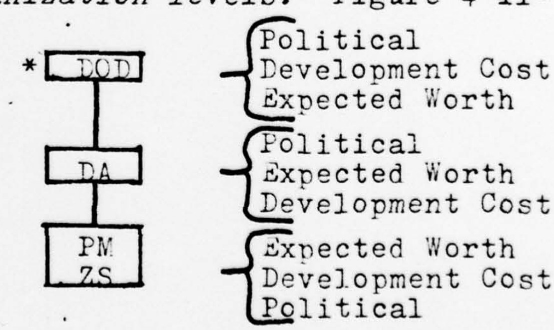


Figure 4: Dimension relationship to organizational level. *Indicates decision authority.

It is appropriate that this relationship be understood in order to appreciate why some decisions which are made at higher levels of authority appear to be of a questionable nature.

The first dimension to be quantified was the developmental costs for each of the outcomes. This was accomplished by examining the cost estimates and assigning them against the appropriate outcome. The variance in developmental costs for a producible ZS and a nonproducible ZS was attributable to a penalty clause which obligated the government in the event there was no production decision. The difference between the modified and unmodified contract was due also to the increased capability which the system would have based upon the revised specification. These values are indicated on Figure 6.

The second dimension to be evaluated was the expected worth. This was accomplished by means of a panel of experts using the delphi technique. A group of 15 experts throughout the military service provided their estimate as to how the proposed ZS systems would contribute to the combat effectiveness of the military forces. In addition to their comments they were required to assign a dollar value figure based upon the expected force configuration and deployment of the system. This data was then reviewed and a second set of questionnairs was dispatched to each of the original respondents. Though they did not know the other participants they wereprovided with information as to the median value, the range and standard deviation of the estimates for the group. The results of this iterative process are also displayed in Figure 6.

Quantification of the political dimension was more involved than either of the others. The reason for difficulty in assigning a value to the political aspect can be attributed to the many factors which must be considered and the transformation from a raw figure to a dollar equivalent. The steps which were taken in this process were to initially rank the political ramification of each of the outcomes in their order of relative merit. The results of this ranking are displayed in Figure 5. Once the ranking had been accomplished it was necessary to ascertain the degree of political impact of the outcomes relative to each other. This was facilitiated by using a scale from 1 to 100 and placing the best political outcome at a value of 100 and the worst at a value of 1. It was then necessary to translate this relationship into a dollar base equivalent in order to incorporate the political dimension into the terminal value for each of the outcomes.

To obtain this value for the ZS the first question was to establish a relationship between the political impact and the expected worth if a system were successfully developed. After this relationship was determined it was essential that a neutral or zero point be assigned to the 1 to 100 scale. The subsequent expansion of this scale to an equivalent dollar value is recorded in Figure 6.

To ascertain the impact which varying the dimensional values may have on the outcome of alternatives and consequently the "selection" made by the decision maker it is essential that a sensitivity analysis be conducted on those values which rely more heavily upon the use of subjective reasoning.

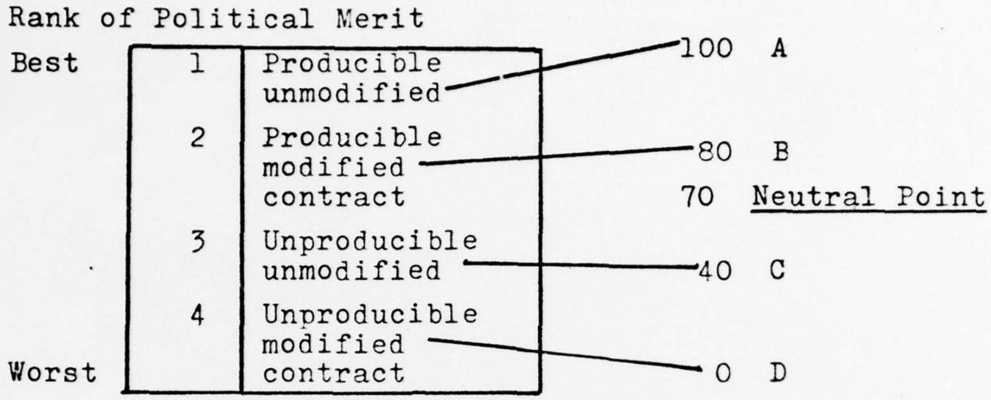


Figure 5: Quantification of Political dimension.

NOTE: Political aspect twice as important as development costs as viewed by DOD (the decision maker).

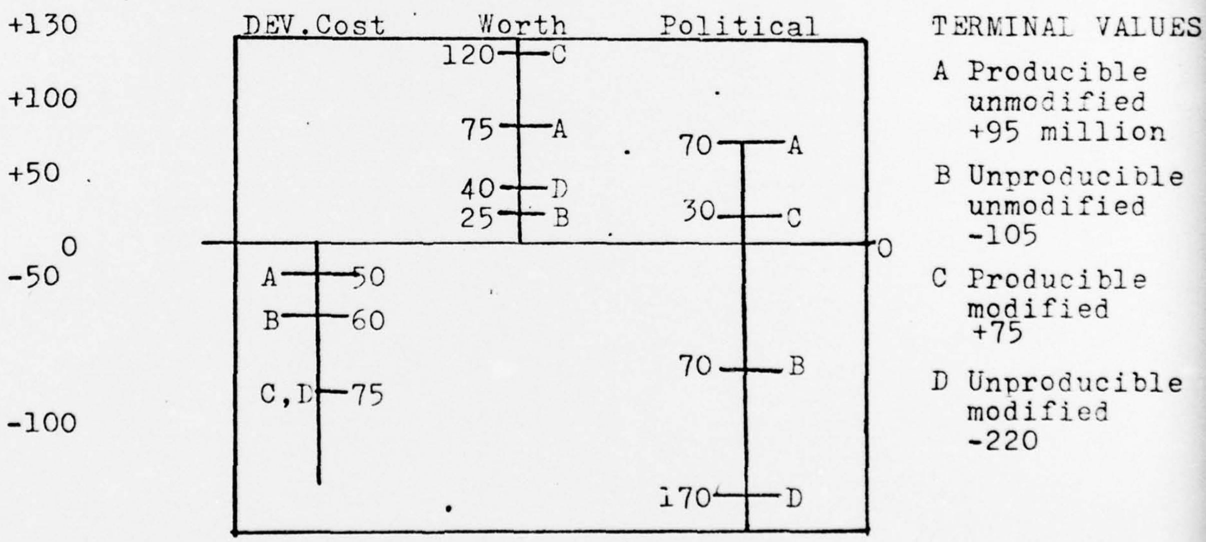


Figure 6: Translation of political rank to dollar equivalents - (millions of dollars).

SECTION V

<u>Value of Information</u>

The preceeding section in addition to illustrating the application of the major elements of decision theory technique as applied to the assessment of possible alternatives also generat the basic information required to compute the expected value for the two alternatives of the ZS which were under consideration. Figure 7 is a condensation of this information.

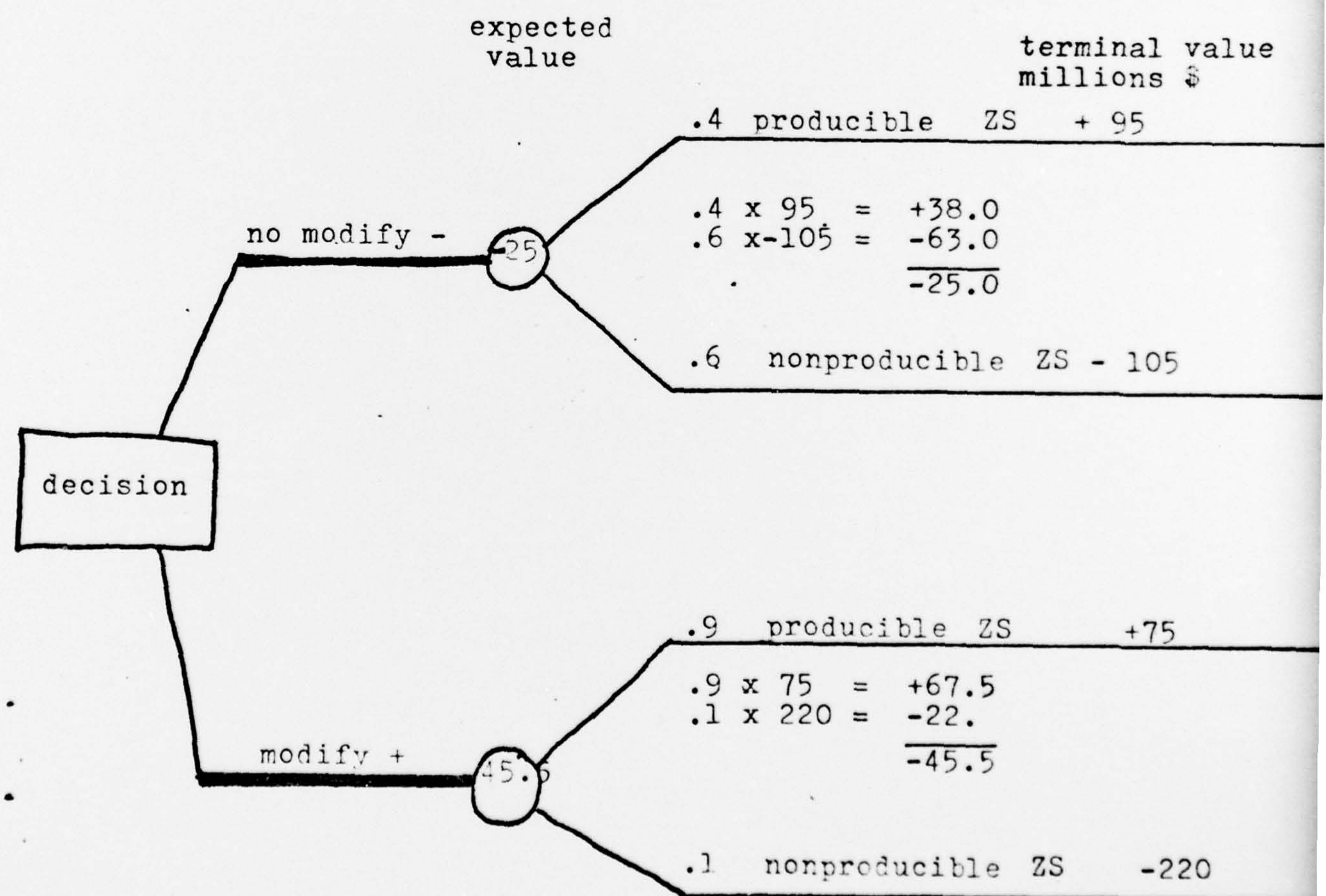


Figure 7: Computation of expected values.

The expected values are the algebric sums of the possible outcomes for each of the alternatives. With the information which is presently available it would appear that the best alternative to be selected is to modify the contract. The question which now must be addressed is should more information be obtained and how much should be paid for it.

For purposes of this paper the term information is used in its broadest possible sense. It may include the feedback from a test, the results of a review conference, or some other effort directed towards the collection and processing of data which would contribute to the selection of an improved alternative. To illustrate the method for assessing the value of information it is assumed that the results of purchasing information could lead to a 50/50 chance of providing favorable information. Figure 8 represents the decision problem which must be considered by the decision maker as to the collection or purchase of additional information prior to the selection of the alternative to modify the contract or continue as planned.

Based upon the results of the analysis of the expected value of the possible outcomes without information the expected value of the outcome without additional information is shown in Figure 7. In order to establish the value of the outcomes in the event additional information is purchased it is necessary

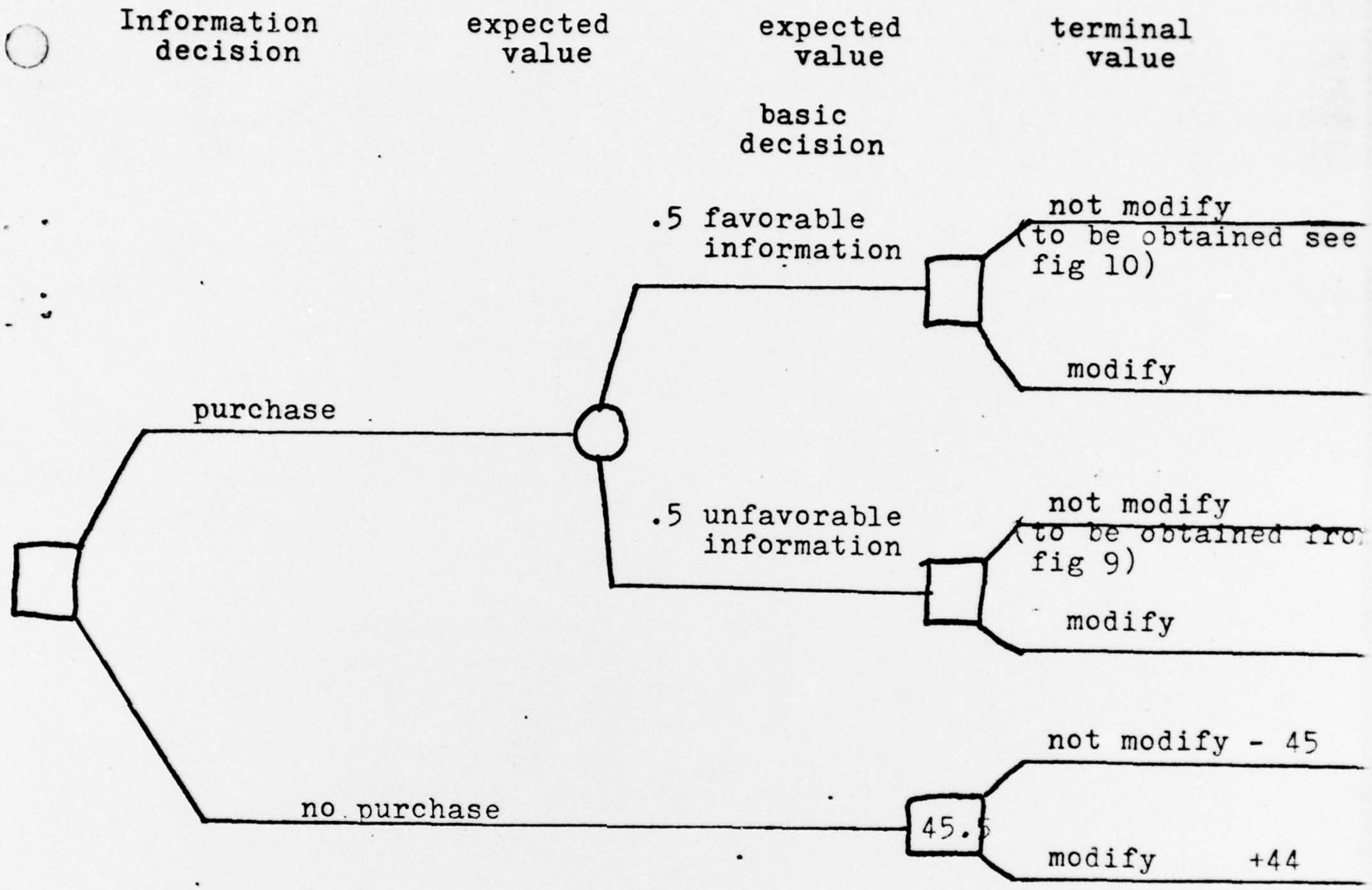


Figure 8: Information diagram.

to consider the effect which such additional information would have upon the various outcomes. This is accomplished by the application of Bayes' Theorm. The computation of the revised probabilities for the development of a producible ZS are illustrated in Figure 9 given unfavorable information.

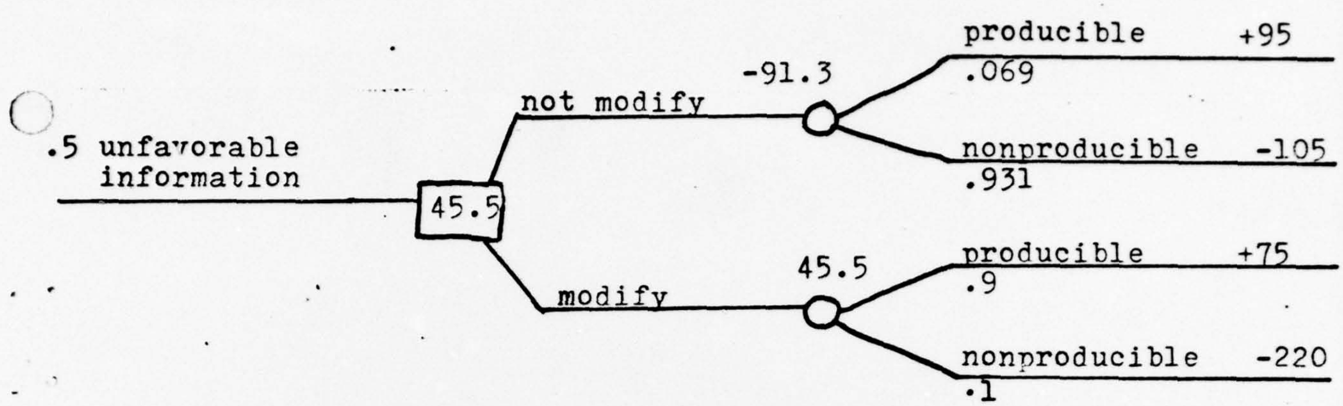


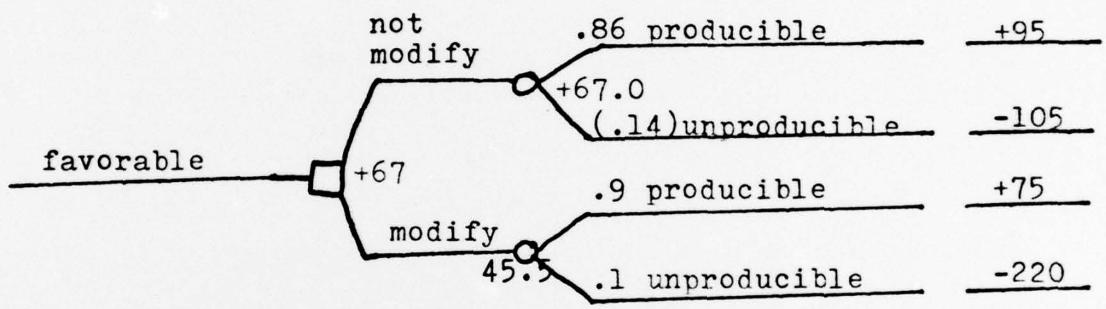
Figure 9: Computation of expected value given unfavorable information.

Based upon passed observations the impact of unfavorable information has confirmed that a producible system was attainable with a probability of .1, under the existing contract. The availability of this information had no appreciable impact upon the probability of attaining a producible system in the event the contract was modified. The following computations using Bayes'Theorm illustrates the revision of the probability for obtaining a producible system provided that unfavorable information was obtained.

P(prod)	-	.4	X	.1	-	.04	$\frac{1.0}{.58}$ x .04 = .069
P(unprod)	-	.6		.9	-	.54	$\frac{1.0}{.58}$ x .54 = .931

To obtain the adjusted posterior probabilities the sum of the nominator and denominator is divided into one(1). This factor is used to multiple the nominator and denominator. The revised probabilities for a producible ZS are indicated on Figure 9.

In a similar fashion the probability of obtaining a producible ZS in the event favorable information were obtained for the present contract was .9. Additional information had no impact upon the probability of a producible system in the event the contract was modified. The results of this information are displayed in Figure 10.



Applying Bayes Theorm

$$\frac{P(prod)}{P(unprod)} - \frac{.4}{.6} \times \frac{.9}{.1} - \frac{.36}{.06} \qquad \frac{1.0}{.42} \times .36 = .86$$

$$\frac{1.0}{.42} \times .06 = .14$$

Figure 10: Computation of expected value given favorable information.

The reevaluation of the possible outcomes as a result of additional information was applied to the terminal values and resulted in the revised expected values for the basic decision as indicated in Figure 11, given that favorable or unfavorable information was obtained respectively.

Since there was no assurance that the information which was obtained as a result of the additional studies or conferences would be favorable or unfavorable it was decided that each outcome would be accorded an equal chance of occurrence (50/50).

These percentages were used to operate upon the expected values as indicated in Figure 11 and were averaged out to arrive at the expected value for the purchase of information as indicated in Figure 12.

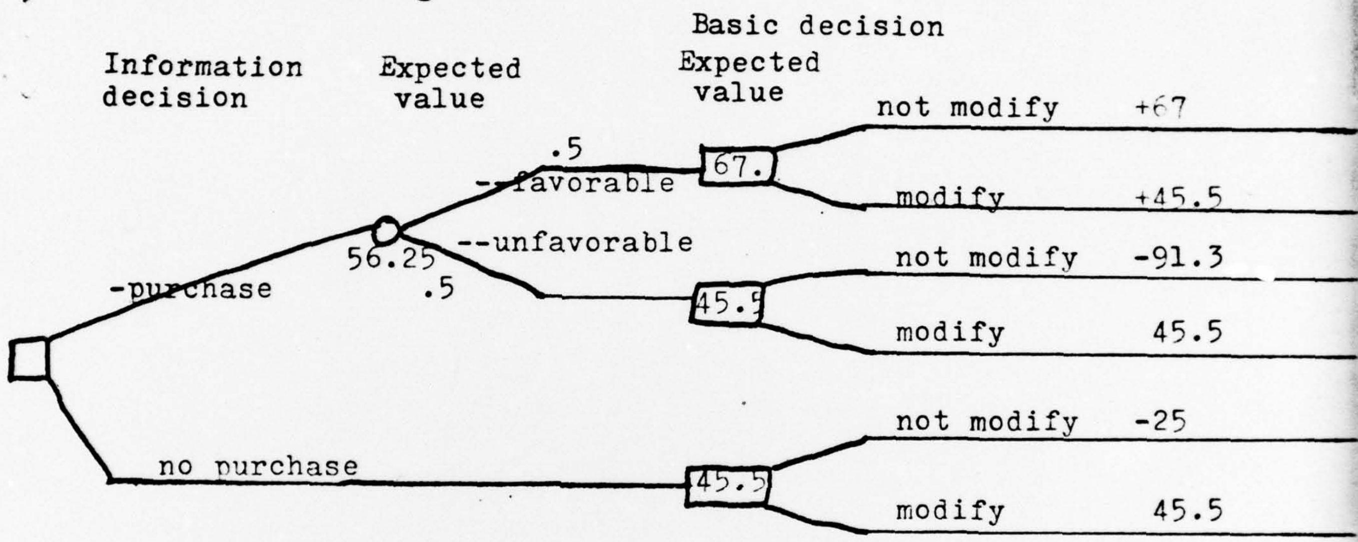


Figure 11: Computation of expected values.

As a result of the calculations the expected value if information was purchased was found to be 56.25 million dollars. The difference between the value of the alternatives is a measure of the expected difference in the ultimate outcome as a result of the purchase of information. Since this value is greater than that which was obtained without information - the maximum expected contribution which such additional information could provide is the difference between the expected values or 10.75 million dollars.

The need to subject an analysis of this type to a sensitivity test cannot be over emphasized. Variation of the dimension values or the probabilities over a range until such time as the outcomes change would provide the decision maker with a feel as to how much change his decision could stand before it should be subjected to a more thorough analysis.

Conclusions

The need for additional information in support of the decision making process is an unending quest. The luxury of total information cannot be supported in this era of increased emphasis upon costs. Information requirements exert a significant force upon the acquisition cost of weapon systems.

The high level decision making process incorporates the judgment and intuition of senior managers. This is often necessary due to the increased uncertainties and unknowns involved in such decisions. The application of decision theory techniques in such cases can provide a major contribution to resolution of the decision under consideration. Decision theory techniques facilitate problem definition and assessment by providing a systematic framework within which the possible alternatives are evaluated. The use of dimensions to develop a terminal value for each of the possible outcomes is the basis for comparing the results with information as opposed to those without information.

Decision theory techniques can be applied to evaluate the potential value of additional information. When integrated with the other tools of management decision theory techniques will contribute to improved allocation of organization resources to the accumulation of information.

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