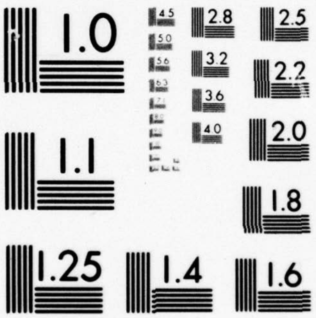
AD-A036 969   DECISIONS AND DESIGNS INC   MCLEAN VA   F/G 12/2
STEP-THROUGH SIMULATION: A METHOD FOR IMPLEMENTING DECISION ANA--ETC(U)
NOV 76   J W ULVILA, R W BROWN, L S RANDALL   N00014-75-C-0426
UNCLASSIFIED   TR-76-18   NL

| OF |
AD
A036969

END

DATE
FILMED
4-77


1.0
4.5
5.0
5.6
6.3
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

Step-Through Simulation:

A METHOD FOR IMPLEMENTING DECISION ANALYSIS

10
B.S.

J. W. Ulvila
R. V. Brown
L. S. Randall

DECISIONS and DESIGNS, INC.

OFFICE OF NAVAL RESEARCH
CONTRACT NUMBER N00014-75-C-0426
CONTRACT AUTHORITY IDENTIFICATION
NR 197-029 (455)

TECHNICAL REPORT 76-18

STEP-THROUGH SIMULATION:

A METHOD FOR IMPLEMENTING DECISION ANALYSIS

J.W. Ulvila
Harvard University
Graduate School of Business Administration

R.V. Brown
University College, London
and
Decisions and Designs, Inc.

L.S. Randall
Decisions and Designs, Inc.

Sponsored by

Office of Naval Research
Engineering Psychology Programs
Contract Number N00014-75-C-0426

November, 1976

DECISIONS AND DESIGNS, INC.
Suite 600, 8400 Westpark Drive
McLean, Virginia 22101
(703) 821-2828

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS
BEFORE COMPLETING FORM

⑭ 1. REPORT NUMBER
TR-76-18

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

⑥ 4. TITLE (*and Subtitle*)
STEP-THROUGH SIMULATION: A METHOD FOR IMPLEMENTING DECISION ANALYSIS.

⑨ 5. TYPE OF REPORT & PERIOD COVERED
Technical Report.

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(*s*)
J. W. Ulvila
R. V. Brown
L. S. Randall

⑩ Jacob W. Ulvila
Rex V. Brown
L. Scott Randall

8. CONTRACT OR GRANT NUMBER(*s*)
⑮ N00014-75-C-0426

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Decisions and Designs, Incorporated
8400 Westpark Drive
McLean, VA 22101

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
Office of Naval Research
800 N. Quincy Street
Arlington, VA 22217

⑪ 12. REPORT DATE
Nov[redacted], 1976

13. NUMBER OF PAGES
67

14. MONITORING AGENCY NAME & ADDRESS(*if different from Controlling Office*)
⑫ 64p.

15. SECURITY CLASS. (*of this report*)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (*of this Report*)
Approved for public release; distribution unlimited

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

18. SUPPLEMENTARY NOTES

19. KEY WORDS (*Continue on reverse side if necessary and identify by block number*)
Step-Through Monte Carlo Simulation
decision analysis
action selection
Modal Step-Through
extensive-tree model
sample path
decision node
event node

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

This report describes the initial development of the Step-Through variant of Monte Carlo simulation, a new procedure for implementing decision analysis or for training decision makers.

Like regular Monte Carlo simulation it involves sampling possible aftermaths of an initial action, and generating a distribution of outcome values for it. However, the detailed structure and/or assessments of the decision model are

→ next page

390664

elicited as called for in the execution of each trial. It therefore permits substantial economy of elicitation if there are few trials. The Step-Through procedure also offers economy of elicitation and calculation over a traditional extensive-tree decision-analytic model without requiring simplifications or aggregations in the model's conceptualization.

In addition to describing this procedure, this report illustrates its use in the context of a Navy task force commander's decision situation, describes a prototype interactive graphic computer implementation of this procedure, and presents the results of a preliminary test and evaluation of it.

SUMMARY

The standard form of decision analysis, typified by the rollback of an extensive decision tree, involves the complete definition and assessment of sequences of acts and events, from which a probability distribution of values and/or an expected utility for each initial option can be derived. When applied to real decision problems, however, it often results in models that are either too complex or too simple. The complex models are unmanageable to elicit. Simple models may call for a high degree of judgment aggregation (though the subject's judgment bears more usefully on the detailed texture of the problem) or, alternatively, simple models may require inappropriate simplifying assumptions.

Conventional Monte Carlo simulation substantially reduces the computational chore of the more complex structures, but not the elicitation requirements. The Step-Through variant of Monte Carlo simulation also seeks to maintain the structural form (and essence) of an extensive tree but drastically reduces the number of required elicitations as well as calculations.

Like conventional Monte Carlo simulation, the Step-Through variant uses a random sampling procedure to generate a sample of trials or paths through a decision tree, from which the probability distribution of all possible outcomes to (and values of) any given action or strategy is estimated. Unlike conventional Monte Carlo simulation, it does not require the user to define completely the more extensive tree that underlies it or to specify all the probabilities called for. Instead, each segment of the decision tree is specified only when and if required <u>for the trial in question</u>, including the listing of acts and events and the assessment of probabilities. Subsequent acts may be assigned according to a

preset strategy which is to be evaluated, or selected on-line by the subject, or even treated as an uncertain event to be sampled. The elicitation is thus on-line, dynamic, selective and, provided the trials are few in number, economical of effort. A special, limiting case is Modal Step-Through, where a single path is generated, and at each step the most likely sequel is selected; this is particularly easy to apply.

Nevertheless, many of the seemingly irreducible problems of eliciting complex act-event structures remain with Step-Through, which discourages absolute reliance on any complex personalist model (that is, a model of a specific subject's thinking) for action selection. Simpler models such as the direct-probability assessment of dimensions of value may generally be preferred unless the stakes involved are very high.

The main value of Step-Through may, indeed, be as an auxiliary decision aid. For example, a few trials can be run to sensitize the subject (decision maker) to the kind of consequences a decision may have. Then he may make the decision informally or make the assessments needed for a simpler decision-analytic model. Modal Step-Through is often sufficient for this purpose. Alternatively, Step-Through can be used for generalized training of decision makers, as a kind of war-game in which initial and subsequent acts are chosen by the trainee and other elicitations are provided by other players.

This paper describes the Step-Through variant, illustrates its use in a Navy task force commander's decision situation, describes a prototype interactive computer graphic implementation, and presents the results of preliminary tests of its viability. It consolidates and expands upon earlier developmental work on this topic performed under the sponsorship of the Office of Naval Research and the Rome Air Development Center.

CONTENTS

FIGURES

ACKNOWLEDGMENTS

The technical approach developed in this report stems from an idea suggested by Cameron R. Peterson in the course of a project to develop operational decision aids for naval task force commanders, for which he was the responsible DDI director. He and Rex V. Brown were primarily responsible for developing the idea into a usable tool. Jacob W. Ulvila carried out most of the testing activity under Brown's direction and took the major initiative in writing this report. Scott Randall developed the interactive computer-graphic software to implement the technique on which the appendix is based.

Much of the conceptual development and testing on the Operational Decision Aids project, was carried out for the Office of Naval Research and was monitored by Dr. M. A. Tolcott under ONR Contract No. N00014-74-C-0263. See Brown, Peterson et al. (1975). The interactive graphics were developed primarily under Rome Air Development Center Contract No. F30602-74-C-0225. The preparation of this report was carried out under ONR Contract No. N00014-75-C-0426.

1.0 INTRODUCTION TO STEP-THROUGH SIMULATION

1.1 Motivation for Step-Through Simulation

1.1.1. As a complete action selection device - In the standard, classical use of decision analysis to model a decision maker's action selection problem, the extensive-form tree, all relevant elements of the situation are modeled explicitly in a decision tree. That is, all of the decision maker's initial options and their subsequent event and action implications are displayed in a decision tree, a probability is assessed for the occurrence of each event, and a value is assigned to each path through the tree. On the basis of these assessments, each option can be evaluated by taking a weighted average value, by "rolling back" the tree.[1] It should be noted that there are many acceptable alternative formulations within this mold, differing, for example, in how finely events are defined and therefore how complex the tree is. For convenience, we will reserve the term "extensive tree" for the more complex formulations.

This use of decision analysis is conceptually very appealing, for it provides for the maximum amount of disaggregation of the problem into manageable sub-problems. However, in practice, an explicit model of all relevant elements of a decision problem often requires an unmanageably large and complex assessment task, sometimes involving millions of assessments. In addition, the computational demands of a complex extensive-form decision tree are very large.

---

[1] See Brown, Kahr, and Peterson (1974); Raiffa (1968); Schlaifer (1969); or Handbook for Decision Analysis (1973) for a fuller description of the classical use of decision analysis.

Variants of this classical paradigm have been sought in an attempt to overcome the computation and elicitation burdens of the complex extensive-form decision model. Some of these variants include: direct-value model, direct-probability model, and staged-tree model.[2]

The direct-value model is a very simple one that models the value of the initial options explicitly but considers uncertainties and subsequent action choices only implicitly. In a direct-value model, each option is evaluated along one or more dimensions of value, and a trade-off function is specified to allow the resulting values to be aggregated into a single index of attractiveness. Uncertainties and subsequent actions are taken into account implicitly in deciding the values of each immediate option. The direct-value model greatly reduces the amount of both elicitation and computation required by an extensive tree, at a cost, however, for the direct-value model often requires assessments that are very difficult to make. That is, by requiring evaluations that implicitly consider the uncertainties and subsequent actions, the direct-value model aggregates the entire path following an option. This procedure works well for fairly simple decision problems in which, although consideration of trade-offs is crucial, there are no critical uncertainties. However, in complex decision situations, this aggregation may lead to assessments that are grossly inaccurate because the implicit considerations are so difficult to make. The point is that everything which might occur after the action must somehow be reflected in the values assigned (one value for each criterion) to the action.

---

[2] See Brown, Hoblitzell, Peterson, and Ulvila (1974) for a fuller description of these variants.

Similar to the direct-value model in its simplicity is the direct-probability model, where probabilities are assessed explicitly for key uncertain events that directly contribute to the outcome. This variant only implicitly considers multiple-value criteria, subsequent action choices, and events that are informational rather than directly contributing to value. A direct probability model works well in simple decision situations in which uncertainty, rather than value, is the main consideration and determinant of a good decision. However, in complex decision situations, the direct-probability model, like the direct-value model, does not allow for the amount of disaggregation required to make accurate input assessments.

The staged-tree variant is representative of a class of variants that force the decision problem to take a special form. The staged-tree variant assumes that all of the relevant information in an extensive-tree model of a decision problem can be represented in a series of summary state descriptions. The decision tree can then be replaced by a concatenation of Markov models. This special form greatly reduces the complexity and computational burden of the extensive tree but at the expense of introducing stochastic independence assumptions that are not easily met in practice. In addition, the staged-tree and other related variants do not permit the convenient disaggregation that is permitted in the extensive-form tree.

All of the simplifications of the extensive form mentioned above are effective in reducing the number of elicitations and the amount of calculation needed in a large extensive-form model. However, none of these methods maintains a very desirable feature of extensive form, that of disaggregating a complex decision problem into a series of sub-problems that are easy to manage. One way to reduce the computational burden of the extensive-form analysis while maintaining its disaggregation is to use conventional Monte Carlo simulation to sample paths through an extensive tree, which has been completely specified, to obtain a distribution of end positions for each immediate action alternative. This method allows for the same degree of disaggregation as the extensive-form tree, but it also requires the same number and types of elicitations. Thus a gain is made only in the amount of computation required; the assessment burden is the same as that for an extensive-form tree.

The problem remains to find a modeling technique that allows for a reduction in the number of elicitations and the amount of calculation required by a complex extensive-form analysis but retains the disaggregation advantage that an extensive-form tree offers for complex decision situations. The Step-Through variant of Monte Carlo simulation approach appears to have these features.

1.1.2 As an auxiliary decision aid - In addition to providing a complete analysis of alternative options leading to a clear prescription for action, a desirable analytic tool may have other functions:

- To organize and sensitize a subject's perceptions of a decision problem so that he can more readily make an informal decision, or provide input to some other decision model. Some structured exploration of detailed possible sequels to a decision may make it easier to make broad aggregated assessments of major summary outcomes, as needed for a direct-probability model, and

- To train and/or evaluate a tactical decision maker by giving him vicarious experience in responding to a rapid succession of uncertain contingencies flowing from some initial action. War gaming has exactly this function, but its conventional forms often lack a satisfactory probabilistic mechanism.

1.2 Description of Step-Through Simulation

The logic of the Step-Through variant is essentially that of conventional Monte Carlo simulation. That is, Step-Through involves simulating paths through an implicit extensive-form tree in order to obtain a sample of endpoints for each initial option. Unlike conventional Monte Carlo simulation, however, Step-Through requires assessments of inputs as a trial progresses in an interactive procedure which alternates assessments with Monte Carlo sampling of events in chronological sequence, rather than a complete specification of all inputs in advance. In this manner, many of the tree paths that have a low probability of occurrence will never be sampled and thus will never need to be modeled.

A process diagram of the Step-Through procedure is shown in Figure 1-1. The procedure is begun by the decision maker's choosing an option from among those immediately available. Next, the following node in an implicit decision tree is defined. If this node is an event node, Monte Carlo simulation is used to choose a branch of the node, and this simulates a result at the node. If this node is an action choice node, however, the decision maker chooses the branch to follow. Nodes are processed in this manner until a complete path through the tree has been simulated. Then other paths are simulated, in a like manner, for the same option, thus generating a sample of endpoints for the action.

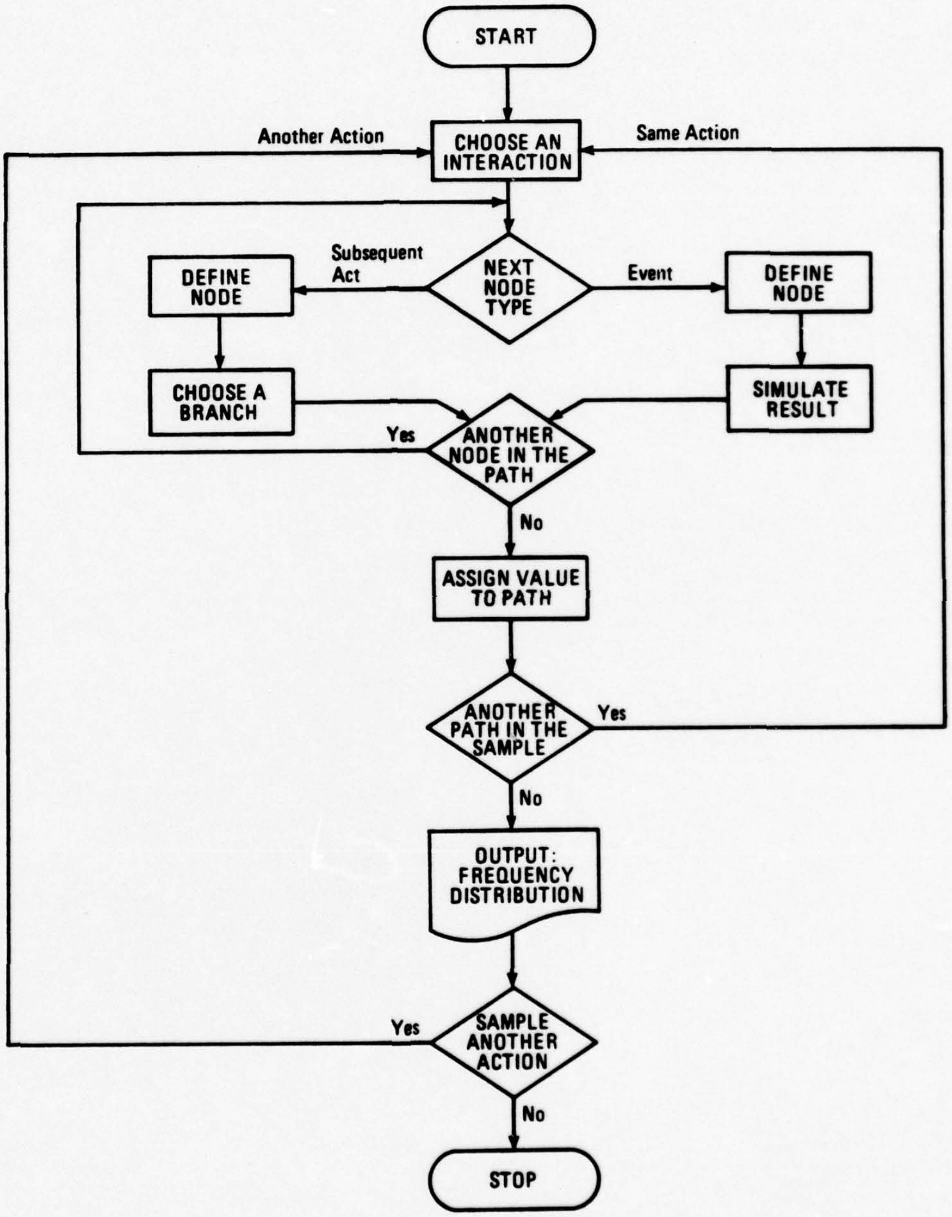


Figure 1-1

PROCESS DIAGRAM OF STEP-THROUGH SIMULATION

The same procedure is then repeated for each initial option. After paths have been sampled for all initial options and their endpoints valued, their frequency distributions of values are compared to determine the best choice. (The valuation may be direct, through the assignment of a single value to each path, or indirect, through the combination of multiple dimensions of value).

The resulting samples of endpoint values are interpretable in the same way as those for conventional Monte Carlo simulation. However, Step-Through offers a reduction of effort and a flexibility not available in conventional simulation: the total number of required assessments is fewer (since assessments are required for only the paths actually encountered in this simulation), and the structure of the tree itself can be developed as the trial progresses. At the analyst's option, subsequent acts can be consciously chosen as they occur, specified as elements of a predetermined strategy, or treated as uncertain events.

A special abbreviated form of Step-Through, which can be used as a preparation for the more general case (or indeed for some other form of decision analysis) is Modal Step-Through. For this, a single trial is generated for each initial action. However, instead of eliciting a complete probability distribution for each uncertain event called for and randomly sampling a value from it, the most probable, or modal, event is judgmentally selected. This procedure will not, of course, give any measure of uncertainty about the total value of an initial action; but it is very easy and inexpensive to do and may be most suggestive of the best way to proceed with the analysis, possibly by some technique other than full Step-Through. Modal Step-Through may also be very useful in training, or at least preparing, the subject for the elicitations he may be called upon to provide. For example, this form has occasionally been used to precede the direct-probability form of decision analysis, which appeared to benefit from having had the subject address, however briefly, the detailed texture of possible aftermaths to the initial actions.

Software for a prototype interactive graphic computer program to implement Step-Through is described in the Appendix to this report, together with instructions on how to use it.

1.3 Number of Trials Needed for Step-Through Simulation

As with other kinds of Monte Carlo simulation, the number of trials must be sufficient for the sample to adequately resemble the implicit population of paths from which it is drawn. However, the issue is particularly crucial here because of the exceptionally high variable cost per trial. More than a few trials will soon offset the savings in fixed cost compared with conventional Monte Carlo simulation.

It might be thought that the expected sampling error of estimates would be related to the length of the path; it might therefore be inferred that using Step-Through to model a decision problem with long paths requires an unreasonably large sample of paths. A closer examination, however, shows this concern to be unwarranted.

Since Step-Through is a procedure for drawing a random sample from a target population (in this case, the target population is the value of endpoints in a decision tree), the rules of error for sample statistics apply. These rules, however, state that the sampling errors of the statistics depend only on the type of sample (for instance, a random sample, a stratified sample, a systematic sample, and so forth), the sample size, and the underlying distribution of the target population. The sampling errors do not depend upon the complexity of the model used to represent the target population.[3] For example, in the language of classical inference, the standard error of a random sample from a normally distributed population is equal to the standard deviation of the population divided by the square root of the sample size. The standard deviation of the population, in this case the target variable, is the same whether the sample of size n is drawn by means of a single-tiered model (such as a direct probability model) or a many-tiered model of the same target variable (such as would be involved in an ambitious simulation). For personalist, or Bayesian, inference, an analogous argument can be made in terms of likelihood functions and priors. The general argument does not depend on the parent distribution's being normally distributed.

Thus, increasing the complexity of a model of a target variable does not, of itself, affect the distribution of that target variable it is attempting to model and therefore has no effect on the <u>sampling</u> error of estimates of the population's parameters.

This argument applies equally well to conventional Monte Carlo simulation, though it is by no means universally acknowledged by practitioners of that art, and we have not seen it presented in the technical literature.

Although greater model complexity does not call for a greater number of simulation trials, the <u>modeling</u> error inherent in a model of the target variable may be <u>reduced</u> by a more complex disaggregated model. (This is a primary

---

[3] A fuller discussion of sampling statistics is contained in Larson (1969), pp. 195-216.

motivation for using an extensive-tree analysis or Step-Through rather than a simple model.) Thus, increasing the number of steps in Step-Through can frequently offer a reduction in modeling error without affecting sampling error.

2.0 ILLUSTRATIVE APPLICATION OF STEP-THROUGH SIMULATION

The best way to explain the details of the Step-Through simulation technique is through an illustrative comparison of the technique with an extensive-tree model in an actual decision situation. The following sections present such a comparison in the setting of a Navy task force commander's decision problem, where he must decide whether to make a pre-emptive strike against an enemy airfield. First, the problem situation is described in some detail. Next, an extensive-tree model of the situation is presented and, finally, a Step-Through model of the same situation is explained.

The particular decision setting used in this illustration is based upon the one in which the Step-Through technique was first developed. While the initial application did not make full use of the power of the Step-Through technique, it did tentatively establish the feasibility of Step-Through simulation and point the way for its subsequent development and refinement.

2.1 Setting for a Pre-emptive Strike Decision

The following sections describe a realistic, but hypothetical, decision situation that might be faced by a U.S. Navy task force commander, designated as CTF Delta, who is operating under an air strike mission directive.[1]

2.1.1 Events leading to a decision - Orange and Purple are two traditionally mutually hostile minor powers who have agreed to, and lived for some time with, a peace agreement

---

[1] This scenario was written in support of the Office of Naval Research's Operational Decision Aids project and originally appeared in Brown, Hoblitzell et al. (1974), pp. 30-32.

that involves withdrawal by Orange from neutral territory previously occupied by her and a token presence in this area by Purple. Purple, with the support of Black, a major power, has gradually built up a force in this area and is now capable of launching a major attack against Orange, whom the U.S. supports.

Black has increased its naval operations in and near the coastal waters off Purple. Black forces in the area consist of one surface-to-surface anti-ship missile (SSM) group and two anti-submarine warfare (ASW) groups operating several hundred miles apart. In addition, Black surveillance/ intelligence vessels are known to be in the general area.

Task Force Delta, a carrier strike force of the U.S. fleet in the area, has been ordered to proceed from its present location to an objective area off the coast of Purple and to be prepared to provide support to Orange by interdicting pre-selected threat air fields and other targets in Purple. The Task Force is to proceed under full readiness conditions to avoid a confrontation with Black's naval forces, and to adopt a "wait-and-see" defensive policy until and unless it is threatened.

At the start of the scenario (T+0 hours), the strike authorization against the specified targets in Purple has not been received by the Commander, Task Force Delta (CTF Delta). Preliminary information regarding the possible strike mission against Purple has been received, and CTF Delta is preparing the mission plan. Initial estimates indicate that three days of strike operations will be required to accomplish the mission objectives.

The Task Force is composed of two carrier task groups: TG Delta One, which is proceeding east to the objective area and has been designated as the strike group; and TG Delta Two, which is proceeding south to rendezvous with TG Delta One at T+24 (hours) and has been designated the escort and force defense group.

Enroute to the rendezvous with TG Delta Two, one of Black's ASW groups is reported operating south of TG Delta One on an eastern course, and the Black's SSM group is reported east of TG Delta One on a northerly course. ASW A/C from the two task groups have reported contacts with two of Black's conventional submarines, but no contacts with Black's SSGN known to be operating with the Black's naval forces have been reported.

At T+24 the rendezvous is completed, and CTF Delta has received authorization for the strike mission against Purple. The Task Force is proceeding at high speed in order to arrive at the objective area and begin mission strikes at T+40. Black's SSM force has changed course and is pursuing the Task Force at high speed.

In addition to the anti-ship missile threat to the Task Force from Black's surface and sub-surface units, Black and Purple have 27 medium-range bombers and 20 long-range bombers at fields west of the objective area. Those aircraft constitute an air-to-surface missile threat as well as a conventional bombing threat to the U.S. task force. Planning information given to CTF Delta indicates a high probability of Black's intervention, ranging from harassment of the Task Force to a limited local naval engagement.

2.1.2 <u>The decision and its possible consequences</u> - The decision facing CTF Delta is whether to make an early strike, at time T+36, on the three bomber bases closest to the proposed operating area, rather than to strike later as planned, and if so, which of two defensive postures to adopt. The motivation of the early strike is primarily to reduce the potential air threat to the Task Force. However, this action has the disadvantage of reducing the surprise element in the attacks on the primary mission targets and could result in an earlier reaction by Purple, Black, or both.

The Commander is uncertain about the degree of hostile reaction to either this early strike or the planned mission strikes and the timing of that reaction. While he must be prepared to defend the Task Force against all possible levels of attack, he must carry out his primary mission in spite of any attacks on his forces and any resulting damage and losses which may occur. He must also be concerned that his initial and subsequent decisions remain within the constraints (rules of engagement) imposed by higher authority so that his actions do not unnecessarily precipitate a local naval war involving third parties. These considerations define the value dimensions for the outcomes of his decision: avoiding an engagement with Black, minimizing loss and damage sustained by the forces, and achieving success in accomplishing the primary mission.

Once into the execution phase of the mission, the Commander may be confronted with numerous decisions as the tactical situation evolves. Typical of these are:

- Make a pre-emptive strike against Black's SSM forces at the first indications of their reaction to either the early strike on bomber bases or the planned mission strikes, as opposed to the "defend-if-attacked" posture;

- In the event of an enemy reaction, continue mission air strike operations while defending the force, or concentrate all assets on task force defense and on attacking the enemy forces and resume mission strikes only after the threat has been reduced or eliminated; or

- Change the force disposition during an engagement as the threat and assets available to counter it change (and protection of damaged assets is indicated) or wait until the engagement is over to initiate SAR and salvage operations and reorganization of remaining force assets.

When the dust has settled on the incident, the main overall consequences by which the initial early strike decision will be regretted or upheld are: whether superpower Black has been drawn into the conflict, damage to U.S. forces and success of the mission.

2.2 Extensive-Tree Analysis of a Decision

As explained in Section 1.2 above, the Step-Through simulation procedure does not require the specification of a complete explicit extensive-tree model of the decision problem. However, in order to highlight the similarities and differences between the Step-Through and the extensive-tree techniques, an analysis of this decision situation will be presented first in the form of an extensive-tree model. Subsequently, in Section 2.3 below, the Step-Through procedure will be applied to the same decision problem.

In principle, it is possible to draw a very extensive tree of this decision situation, a very detailed description of all possible sequences of events and subsequent actions following each of the task force commander's (CTF Delta's) initial options. However, because such a tree would be too complex to draw in detail, it is represented in schematic form in Figure 2-1 (the branch definitions are given in Figure 2-2). Unless otherwise indicated by a dotted line, each branch of a node is followed by the next complete node, with the result that there are over a million paths through the complete tree. To complete an extensive-form analysis of this tree, it would be necessary to assess conditional probabilities at all of the event nodes encountered along each path, evaluate the attractiveness of each endpoint, and calculate an expected value for each option. Clearly, this is an unmanageable task, and it has not been done for this illustration.

However, the attractiveness or value of the endpoints was adequately captured by the outcome of three contributing events: U.S./Black engagement, engagement damage, and mission success.[2] Since there are a small number of combinations of these events and since their valuation is also used in the Step-Through model, this evaluation was performed, as presented in Figure 2-3. This figure shows the relative attractiveness of each possible outcome. The most preferable outcome, assigned a value of 100, is "complete mission success without an engagement with Black." The least preferred outcome, assigned a value of 0, is "U.S./Black engagement resulting in heavy damage to U.S. forces and an aborted mission." All other outcomes are of intermediate attractiveness and are assigned values between 0 and 100, as shown.

---

[2] It can thus be considered as an example of a "staged tree" referred to on page 3.

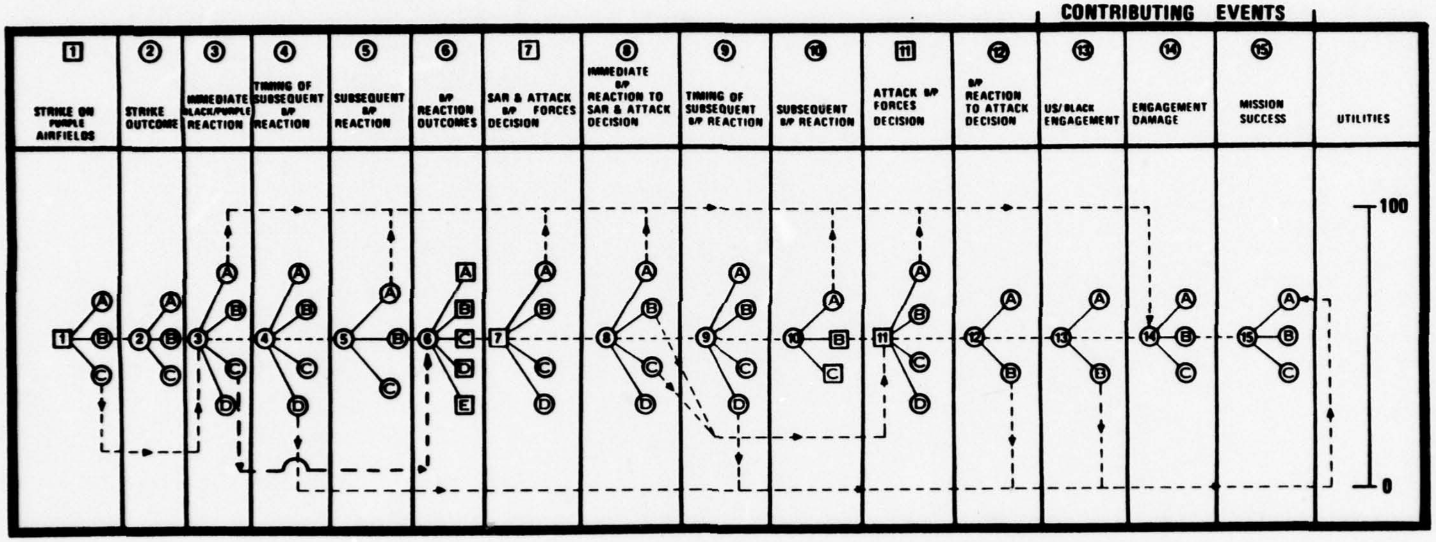


Figure 2-1

EXTENSIVE TREE

POINT	BRANCH	LABEL
1	Ⓐ	Pre-emptive strike (Purple Airbases) – normal T.F. defense posture
	Ⓑ	Pre-emptive strike – Increased T.F. defense posture
	Ⓒ	No pre-emptive strike – normal T.F. defense posture (proceed to launch point for strike @ T+40)
②	Ⓐ	Complete neutralization
	Ⓑ	Partial neutralization
	Ⓒ	Minimal or no damage
③	Ⓐ	Black–Purple attack on task force
	Ⓑ	Purple attack on task force
	Ⓒ	Purple attack on Picket DD's
	Ⓓ	No immediate military reaction
④	Ⓐ	Military reaction occurs on 3rd day
	Ⓑ	Military reaction occurs on 2nd day
	Ⓒ	Military reaction occurs late in first day (T+50)
	Ⓓ	No military reaction
⑤	Ⓐ	Black – Purple attack on task force
	Ⓑ	Purple attack on task force
	Ⓒ	Purple attack on Picket DD's
⑥	A	2 DD's sunk/out of action
	B	1 DD sunk/out of action; 1 damaged/still operable
	C	2 DD's damaged/still operable
	D	1 DD damaged/still operable
	E	No/minimum damage
7	Ⓐ	Immediate SAR and replacement operations
	Ⓑ	No immediate SAR or replacement operation
	Ⓒ	Attack Purple patrol boat base
	Ⓓ	No attack
⑧	Ⓐ	Black – Purple attack on task force
	Ⓑ	Purple attack on task force
	Ⓒ	Purple attack on SAR/replacement OPS and DD's
	Ⓓ	No further Black–Purple attack
⑨	Ⓐ	Military reaction occurs on 3rd day
	Ⓑ	Military reaction occurs on 2nd day
	Ⓒ	Military reaction occurs late in first day (T+50)
	Ⓓ	No military reaction
⑩	Ⓐ	Black-Purple attack on task force
	B	Purple attack on task force
	C	Purple attack on picket replacements
11	Ⓐ	Attack black missile ship force
	Ⓑ	Attack "F" class and OSA base
	Ⓒ	Attack patrol boat base
	Ⓓ	No attack
⑫	Ⓐ	Black attack on task force
	Ⓑ	No further black – purple attack
⑬	Ⓐ	U.S./Black engagement
	Ⓑ	No U.S./Black engagement
⑭	Ⓐ	Heavy damage to U.S. task force, light damage to Black Forces
	Ⓑ	Moderate damage to both U.S. and Black forces
	Ⓒ	Light damage to U.S. task force, Heavy damage to Black for
⑮	Ⓐ	Complete success
	Ⓑ	Partial success
	Ⓒ	Mission aborted

Figure 2-2

BRANCH DEFINITIONS FOR FIGURE 2-1

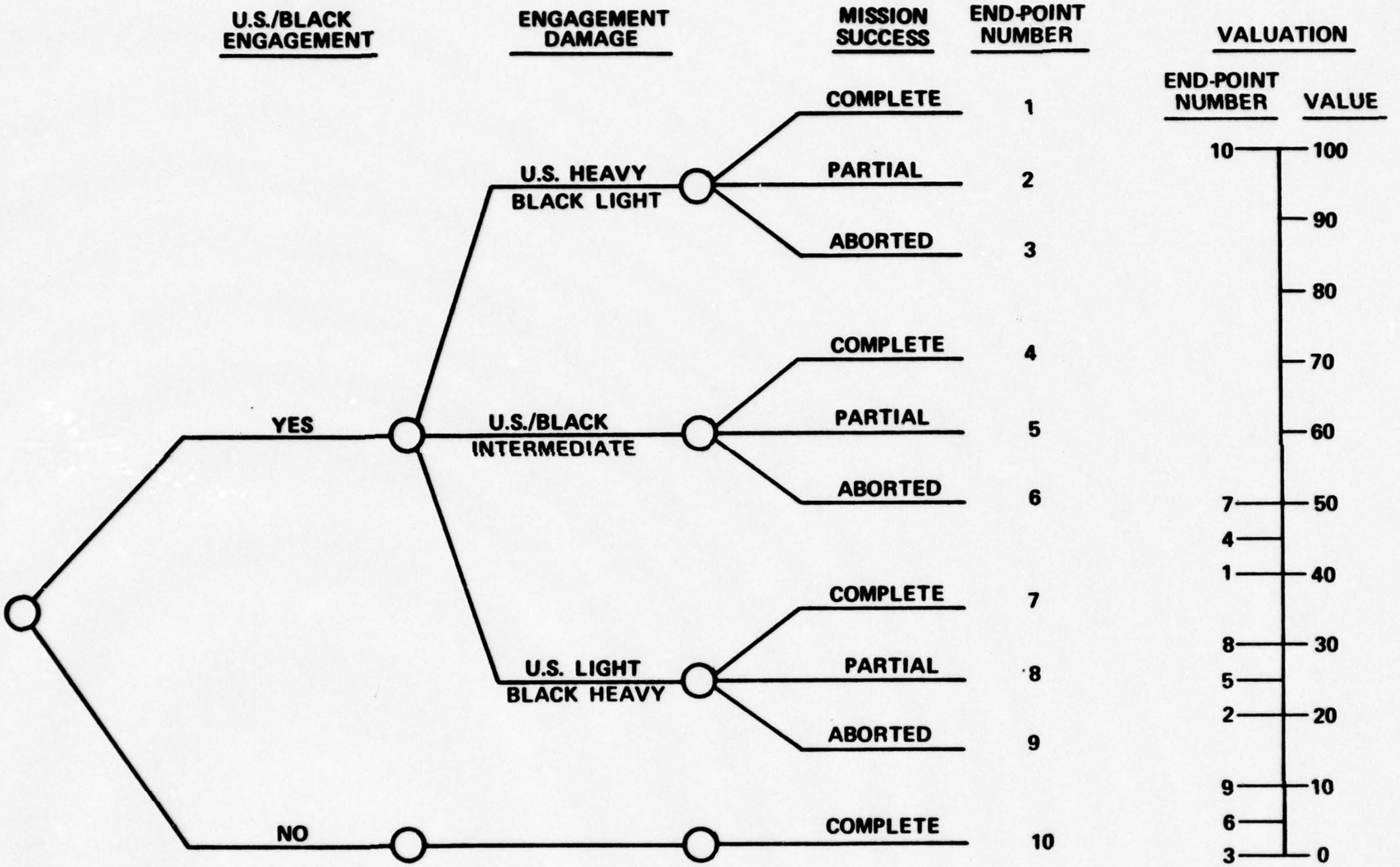


Figure 2-3

VALUATION OF CONTRIBUTING EVENTS

2.3 Step-Through Analysis of a Decision

The discussion below illustrates the use of Step-Through simulation to model CTF Delta's decision problem described above. As an aid to the reader, the correspondence between the Step-Through and the extensive tree analyses will be shown in some of the figures of this section. The accompanying discussions, however, will describe the Step-Through procedure as it would be carried out, without first providing a description of the underlying tree structure. The underlying structure is not provided first because Step-Through is used as an aid in structuring as well as evaluating a decision problem. Indeed, Step-Through may be used to set the stage for a subsequent extensive-tree analysis, not necessarily at the same level of detail.

Assume that prior to the beginning of the first Step-Through sequence, the outcome values for combinations of contributing events have been assessed, as given previously in Figure 2-3. The decision maker may now begin to evaluate his initial options by using Step-Through sequences. For instance, the decision maker may first wish to evaluate the alternative, "No preemptive strike (proceed to launch point for strike at T+40)."

If the decision maker selects this alternative to evaluate, he would then specify what events might follow such an action. As shown in Figure 2-4 (the simulation sequence is shown as a bold path in the extensive-tree diagram), he specified that Black or Purple might react with an attack against the U.S. task force. The decision maker or some other expert would then supply a probability distribution over the possible Black or Purple responses. Based on the assessed probability distribution, a result for

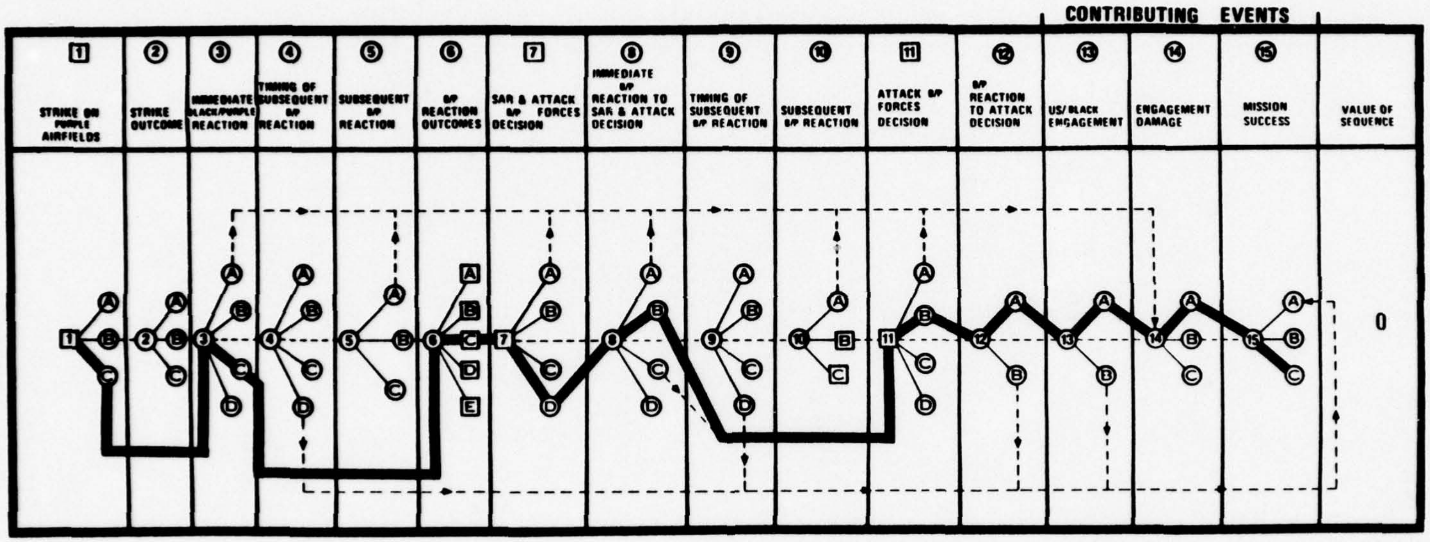


Figure 2-4

STEP-THROUGH SIMULATION SEQUENCE I

this node is simulated by using the Monte Carlo procedure.[3] In the illustrative sequence shown, the simulated result at this node is "Purple attacks U.S. picket ships." Next, the decision maker would describe the next act or event of importance, which, as shown in Figure 2-4, is the outcome of the Purple attack. This event node is then defined by indicating the possible results and their probabilities, and the Monte Carlo procedure would again simulate the result, in this case, that "two destroyers are damaged but still operable." Next, the decision maker would indicate that a decision is required on whether or not to engage in either replacement operations or an attack against Purple. Given the simulated situation, the decision maker might indicate that he would not engage in either replacement or attack actions. Note that this feature of Step-Through, that is, the decision maker chooses subsequent actions as they are encountered, is different from conventional Monte Carlo simulation in which subsequent actions are specified according to a decision rule. (However, it could have been treated the same if the choice were between complete strategies, rather than between initial options, or if the subsequent acts were treated as uncertain events.[4])

The Step-Through procedure continues in a similar manner, with the decision maker choosing subsequent acts and simulation determining the results of uncertain events, until the outcome is determined, in this case in terms of the contributing events and their values. The outcome of the first sequence, is shown in Figure 2-4: A U.S./Black engagement resulted in heavy damage to the U.S. and caused the

---

[3] An introductory-level description of the Monte Carlo procedure is presented in Schlaifer (1969), ch. 13.

[4] See Brown, 1975.

mission to be aborted. As indicated in Figure 2-4, this outcome is the worst possible, with a value of 0. Thus, the first trial path drawn for the action, "No pre-emptive strike, proceed to launch point for strike at T+40," has a value of 0. This single trial, however, yields very little information about this action. To gain useful information about the action, a representative sample of several trial paths through the tree must be drawn by repeating the process described above. Such a sample will result in a frequency distribution of value for the action such as that shown in Figure 2-5 for 20 sample paths beginning with the "No pre-emptive strike" action.

This frequency distribution can then be compared with frequency distributions obtained from Step-Through samples for the other actions to determine the preferable option. For example, Figure 2-6 shows possible frequency distributions that might be obtained by sampling 20 paths for each action. Such samples can be used as a basis for a decision. In this illustration, for instance, the action "Pre-emptive strike with increased defense" might be preferable because it has a much higher estimated mean and only a slightly higher estimated standard deviation than "No pre-emptive strike."[5] On the other hand, "Pre-emptive strike with normal defense" might be the least preferable alternative since it has both the lowest estimated mean and the highest estimated standard deviation.

In general, the length of the trial path and consequently the number of elicitations required in the trial

---

[5] The estimates in Figure 2-7 are the maximum likelihood estimate of the population mean and standard deviation for a normally distributed population. See Larson (1969), ch. 7, for a discussion of statistical estimation and the maximum likelihood method.

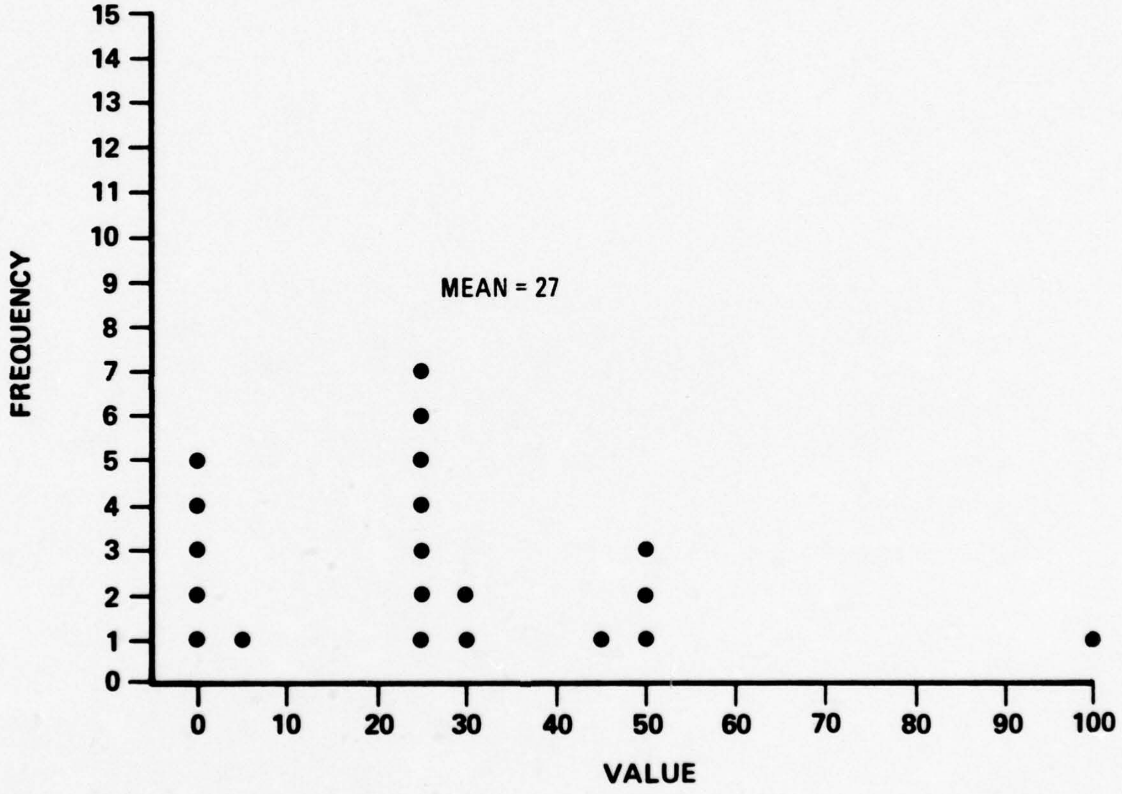


Figure 2-5

ILLUSTRATIVE SAMPLE OF VALUES FOR "NO PRE-EMPTIVE STRIKE"

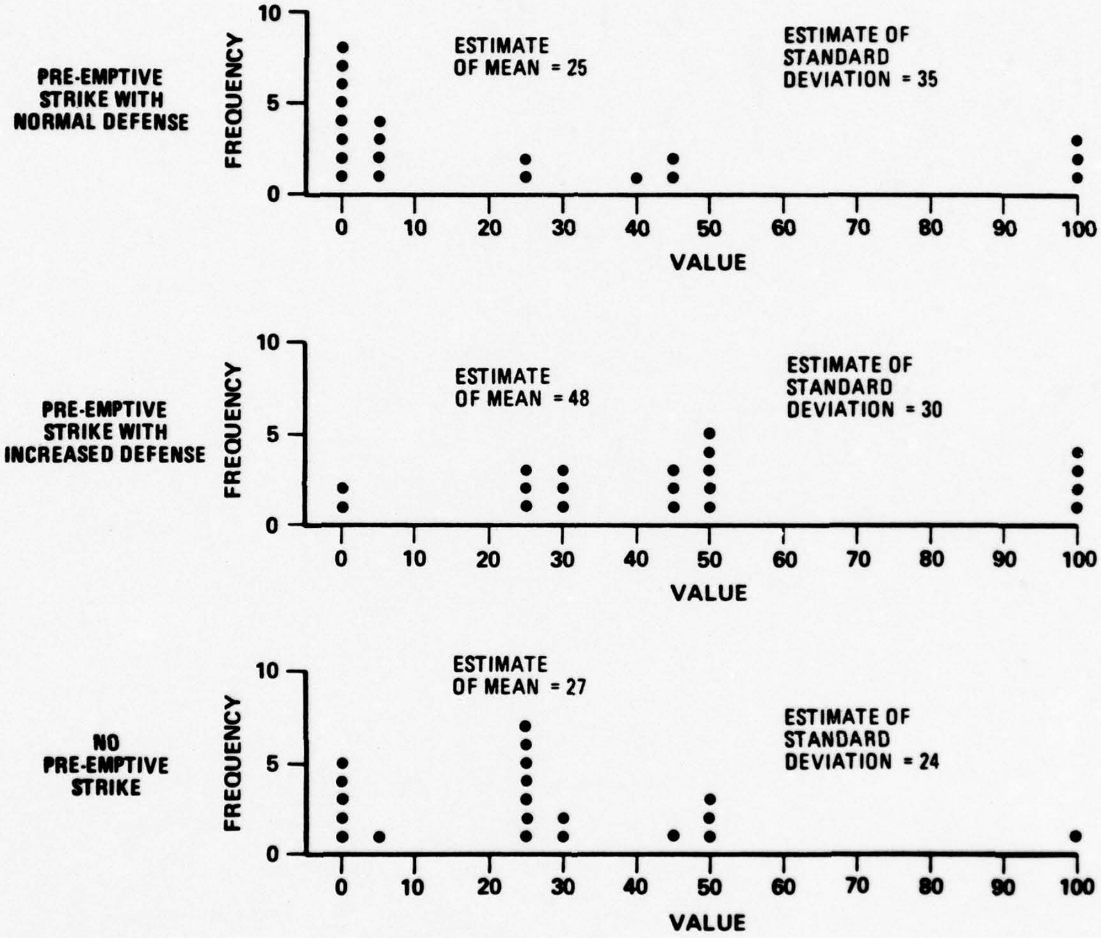


Figure 2-6

ILLUSTRATIVE SAMPLES OF VALUES FOR ALL ACTION ALTERNATIVES will vary from trial to trial. Figure 2-7 shows a trial path that is much shorter than the one illustrated in Figure 2-6.

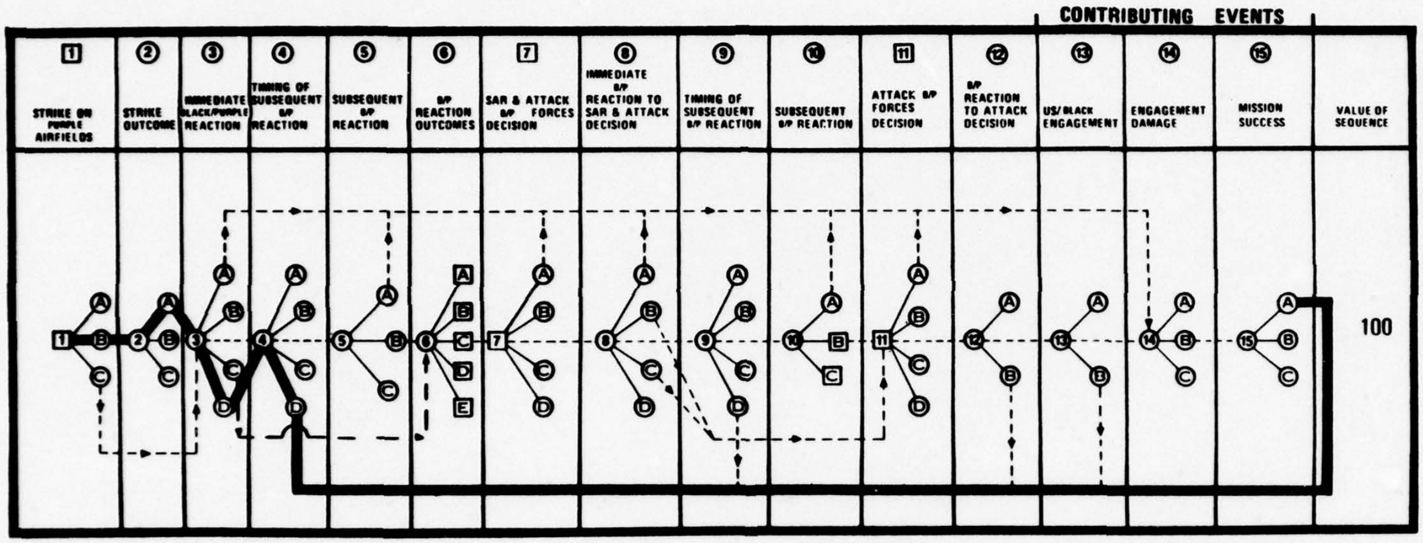


Figure 2-7

STEP-THROUGH SIMULATION SEQUENCE II

3.0 TESTING THE USEFULNESS OF STEP-THROUGH

Experience in developing the Step-Through variant promised to be useful in a variety of real decision situations where a complex decision model is required. However, some testing activity was needed to confirm this hypothesis. Specifically, the testing activity described below was undertaken to establish a preliminary determination of the elicitation and computational advantage if any of Step-Through over a complex extensive-tree analysis, to gain insights into the technique of implementing Step-Through, and to identify the strengths and weaknesses of the computer prototype (see Appendix A) in order to suggest software refinements.

3.1 Testing Approach

Since Step-Through is a new technological idea, it is probably most fruitfully tested by workshop trials, that is, informal reflections based upon trial applications of the methodology in an opportunistic sample of decision situations. This method of testing is not as complex or as rigorous as a controlled experiment and consequently does not produce results that are as definitive. However, at this early stage of development, useful insights can be obtained most economically through workshop trials. If the results of this testing activity indicate that Step-Through is a viable procedure, more controlled experimentation may be indicated for a later time.[1]

Five workshop trials using a variety of decision problems and decision makers were conducted. Problems included

---

[1] The interested reader can find a more complete discussion of the range of possible evaluation techniques and the reasons for choosing each in Brown and Watson (forthcoming).

military decisions of the type presented in Section 2.0 and personal career decisions. Subjects included trained decision analysts and military officers both with and without exposure to decision analysis techniques. The trials were carried out after various amounts of pre-modeling effort (structuring the sequence of acts and events, assigning values, and assessing probabilities). At one extreme, Step-Through was used as a first formal consideration of the problem, without any pre-modeling. At the other extreme, Step-Through was used to evaluate and refine a decision model that had already been substantially, although not completely, modeled. This pre-modeling included an elicitation of the complete schematic sequence of acts and events, an elicitation of an influence diagram describing the conditional nature of the probabilities, and an assignment of outcome values. At an intermediate level of pre-modeling, Step-Through was used after eliciting a modal path through the tree for each initial option, identifying the value criteria, and assigning values to outcomes.

3.2 Test Results

As mentioned above, test results were primarily sought to determine the elicitation and computational advantage, if any, of Step-Through over an extensive tree, to gain insights into the proper implementation techniques for Step-Through, and to identify necessary software refinements. These results were sought in order to establish conclusions on the viability of the Step-Through variant of decision analysis, the proper method of its application, and the proper direction for its future development.

The pilot testing results supported our initial assumption that Step-Through can offer a considerable economy of elicitation and computation effort over a complex extensive tree. The amount of advantage offered by Step-Through, however, was found to depend critically upon the proper implementation of the method, especially with respect to the proper amount of pre-modeling. That is, both too little and too much pre-modeling of a decision problem was found to affect adversely the advantage of Step-Through. When used with little or no pre-modeling, it produced models that were grossly inaccurate simplifications of the decision situation. On the other hand, a high degree of pre-modeling produced structurally sound models, but the pre-modeling itself required a large elicitation effort and thus reduced the advantage of Step-Through. When a moderate amount of pre-modeling was performed, however, a structurally sound model was obtained at a modest elicitation cost. Overall, when properly implemented, Step-Through was found to reduce the total elicitation and computational burden of an extensive-tree analysis of comparable complexity by over 50%. This advantage can be expected for moderately to highly complex decision models, that is, those containing ten or more tiers of nodes.

The workshop trials proved to be very useful in answering four implementation questions:

1. Should other forms of decision analysis be attempted before applying Step-Through?

2. How much does the decision maker need to be involved in a Step-Through modeling effort?

3. How much does a decision analyst need to be involved in a Step-Through modeling effort? and

4. How much pre-modeling should precede the Step-Through procedure?

The tests indicate that the Step-Through procedure is most effective when it is used after a moderate amount of pre-modeling. The pre-modeling should consist of an elicitation of a modal or most likely path through the tree for each immediate action alternative, an elicitation of the criteria of value in the decision situation, and an assignment of values to the possible contributing events. As mentioned above, Step-Through offers its greatest economy of elicitation and computation when a moderate amount of pre-modeling is performed. Further, our tests indicate that moderate pre-modeling helps to reduce the amount of confusion that the decision maker experiences during the Step-Through procedure, and this enables him to provide inputs that accurately reflect his perceptions of the decision situation.

The tests indicate that Step-Through should not be used as the first formal method of analyzing a decision problem. Step-Through was found to require a large commitment of resources in terms of monetary expense, a decision analyst's time, and the decision maker's time. Consequently, a Step-Through analysis can be justified only in decision situations that cannot be adequately addressed by less costly analytic techniques, such as a direct probability model.[2] Thus, it is prudent to attempt a less costly analysis before attempting to apply Step-Through, unless Step-Through with very few trials, or in its less expensive modal form, is used to prepare the way for another approach by sensitizing the subject's judgment.

The workshop trials indicate that the decision maker needs to be heavily involved. His heavy involvement increases

---

[2] For a discussion of how alternative decision analytic approaches compare on cost, precision and other measures of performance, see Brown and Ulvila (1976).

the chances that an accurate model will result and that the decision maker will understand the output of the model. With heavy involvement of the decision maker, Step-Through effectively highlights the key considerations of a decision problem in a way that facilitates their precise modeling and estimation. This results in an accurate model of the decision problem. Heavy involvement is also necessary to communicate the results of the model, that is, the probable consequences of selecting each initial option. In addition, the tests indicate that heavy involvement of the decision maker in Step-Through analysis serves an immediate training function by increasing his understanding of the decision situation. On the other hand, without heavy involvement of the decision maker, it is extremely difficult, if not impossible, to obtain a Step-Through model that accurately reflects the decision maker's perception of his problem. Moreover, it is very difficult to communicate the output of the model to the decision maker.

The workshop trials indicate that a decision analyst also needs to be heavily involved in the Step-Through modeling procedure to guide the decision maker through the sample paths and to provide an interpretation and explanation of the output. Otherwise, there is a high probability that a poor model and an inaccurate interpretation of its output will result.

With regard to the computerized version of Step-Through described in Appendix A, the workshop trials indicate that substantial modifications are necessary to bring the program to a final product stage. Most importantly, modifications must be made to streamline the operation and interaction of the program with the user. In Step-Through models that utilized the computer program, the structure of the model was often influenced by the requirements of the program.

This influence was in the direction of pressuring the user to define shorter paths and less complicated forks.

These are clearly undesirable features of the computer program; however, we feel that they can be overcome by modifying the software.

The current program strains the user's memory capacity by requiring him to remember the details of each trial path, including the sequence of acts and events modeled and the previous assessments of utilities and probabilities. The user can alleviate the strain by defining short paths in the model. Alternatively, a computer modification could relieve the strain by providing the user with a summary description of the path and by allowing him to backtrack in the path. The pressure to define simple forks is caused by the laborious procedure that is required by the program for fork definition. This pressure can be removed by a modification that streamlines the interactions necessary to define the forks.

The modifications mentioned above are intended to correct shortcomings in the program. Furthermore, the program would be more useful if it provided additional output, for example, a running estimate of the mean value and a measure of dispersion around the mean (such as the standard deviation, a central 90% credible interval, or another similar measure) in addition to the frequency distribution, separate frequency distribution displays for each immediate action alternative, and separate frequency distribution displays for each criterion of value.

4.0 CONCLUSIONS

Limited development, application, and testing allow only tentative conclusions about the usefulness of the Step-Through variant of Monte Carlo simulation for structuring a decision model, pruning a decision tree, and evaluating initial options. Because Step-Through offers elicitation economies over the extensive-tree variant, and because it retains the disaggregation properties of the extensive tree, Step-Through is a very effective procedure for developing an accurate structure of a complex decision situation. Because the Step-Through procedure effectively identifies the key parameters in a decision model, it is a useful procedure for pruning an extensive decision tree by eliminating superfluous branches. Because Step-Through offers elicitation and computational economies over an extensive tree and because Step-Through enables an accurate structure of a decision situation, it is a useful technique to evaluate initial options as a basis for choice among them.

The application and testing activity also revealed that Step-Through is a useful procedure for training decision makers for contingent situations. In particular, its ease of operation and limited demands, compared with conventional Monte Carlo simulation, enable a decision maker to simulate easily an uncertain future situation and to develop an understanding of the situation and a "feel" for the best response to it.

On the other hand, Step-Through does not appear to be a promising variant to use as an initial formal approach for modeling a decision situation, for evaluating subsequent acts in complete decision strategies, or for use without expert supervision. The workshop trials have shown that Step-Through requires a large commitment of resources and thus is justified only after simpler modeling techniques prove to be inadequate. In addition, Step-Through appears to produce over-simplified structures of complex decision models when no previous formal modeling is performed.

Since only a small fraction of the sample paths through the implicit decision tree will contain the same setting for subsequent acts, a Step-Through analysis to evaluate complete strategies requires a sample that is too large to be practical. Since the Step-Through procedure is fairly complicated and since the output of a Step-Through model is fairly difficult to interpret, a good Step-Through analysis requires a high degree of participation from both the decision maker and a trained decision analyst.

On the basis of testing, it appears that the prototype computer implementation of Step-Through must be modified before it is suitable for a production environment. In particular, its operation must be streamlined to remove the pressure on the user to define Step-Through models containing short paths and simple forks. In addition, the computer program can be enhanced by providing the user with additional output.

Finally, the testing that has been completed suggests that the viability of the Step-Through variant warrants further testing, development, and application, both in controlled experimental settings and in applications to real decision problems.

APPENDIX A

PROTOTYPE COMPUTER SOFTWARE IMPLEMENTATION[1]

A prototype interactive computer graphic software package has been developed to test the feasibility and usefulness of the Step-Through variant of Monte Carlo simulation. While a manual implementation of Step-Through is sufficient to yield some tentative insights into its conceptual feasibility and implementation, the manual procedure is tedious and time consuming, especially in such areas as performing the Monte Carlo procedure. A much more powerful realization of the concept can be effected by using a computer. In addition, interactive computer graphics offers a streamlined interface between the user and the machine. Thus, the interactive computer graphics program is expected to ease the user's computational tasks and keep his focus on the decision problem while the computer keeps track of the technicalities of the Step-Through procedure.

The following sections describe the key features of the "Step-Thru Monte Carlo Decision Analysis System" (MONTE), as it is implemented to run on the computer installation at Decisions and Designs, Incorporated. This installation consists of a PDP-11/40 minicomputer with a Vector General DD3 graphic display system. Once MONTE has been brought to execution, all interactions with the user occur via the

---

[1] The software described here was developed under a contract from the Rome Air Development Center, Griffiss Air Force Base, New York.

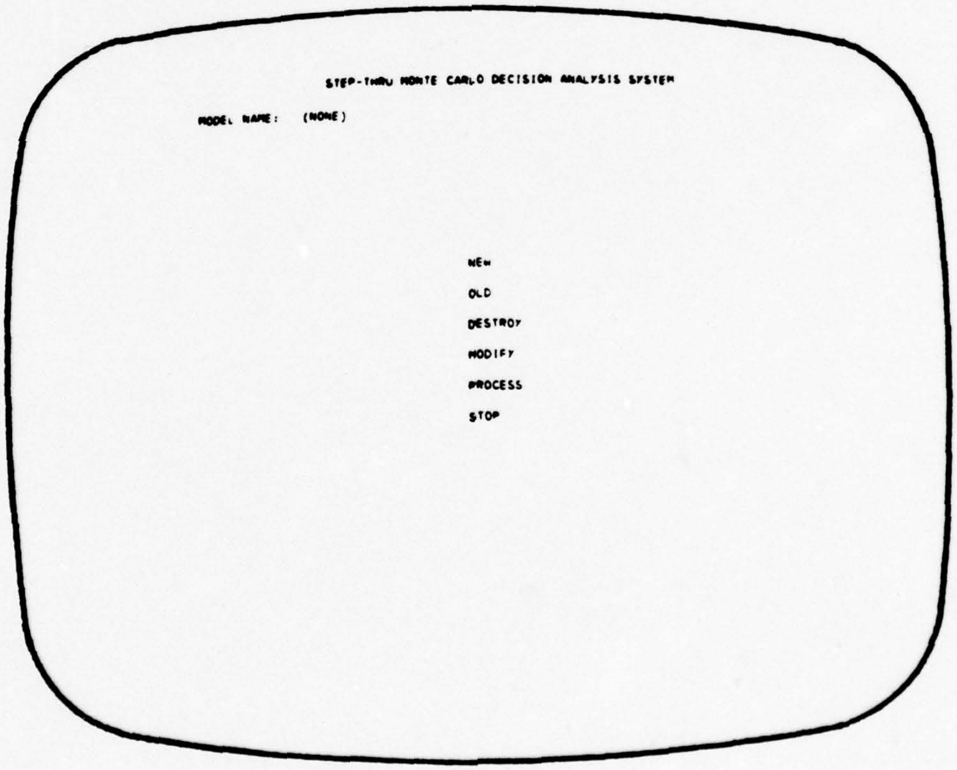
This section of the report is adapted from Randall and Barclay (1975) and contains descriptions of the most important features of the prototype computer program. For a more complete description of the program, including a description of the hardware configuration and program generation, the reader is referred to the original document.

display system. Except for unusual error conditions, all MONTE output appears on the display monitor. The figures contained in the following sections are the actual displays that appear on the monitor during the program's use.

It should be noted that the prototype software documented below has evolved under research conditions and that it has not yet been developed to the point where it is suitable for use in a normal production environment. Although every effort has been made to ensure that the software is error-free, certain aspects of the software may not be as robust as is desirable and necessary in a production program. For example, providing the program with invalid inputs may cause it to fail or to produce unpredictable results.

A.1 Beginning Program Execution

When execution begins, the display contains the image shown in Figure A-1. The user can select one of six options displayed by pointing at it with the light pen. When an item has been selected, it will blink. Selecting NEW allows the user to define a new model; selecting OLD allows him to retrieve a previously defined model. DESTROY permits the user to purge a model from the system. To make parametric or structural changes in an existing model, the user can select MODIFY. Selecting PROCESS initiates the Step-Through



STEP-THRU MONTE CARLO DECISION ANALYSIS SYSTEM

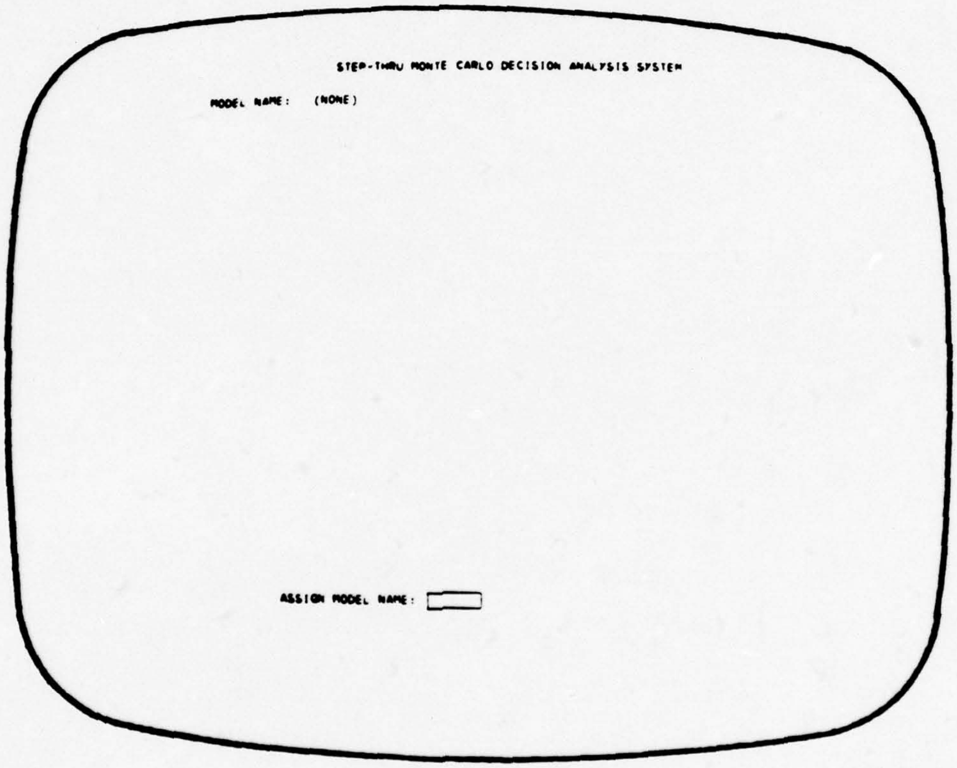
MODEL NAME: (NONE)

Figure A-1
MONITOR DISPLAY 1

procedure. Finally, the user can terminate execution by selecting STOP.

A.2 Model Definition

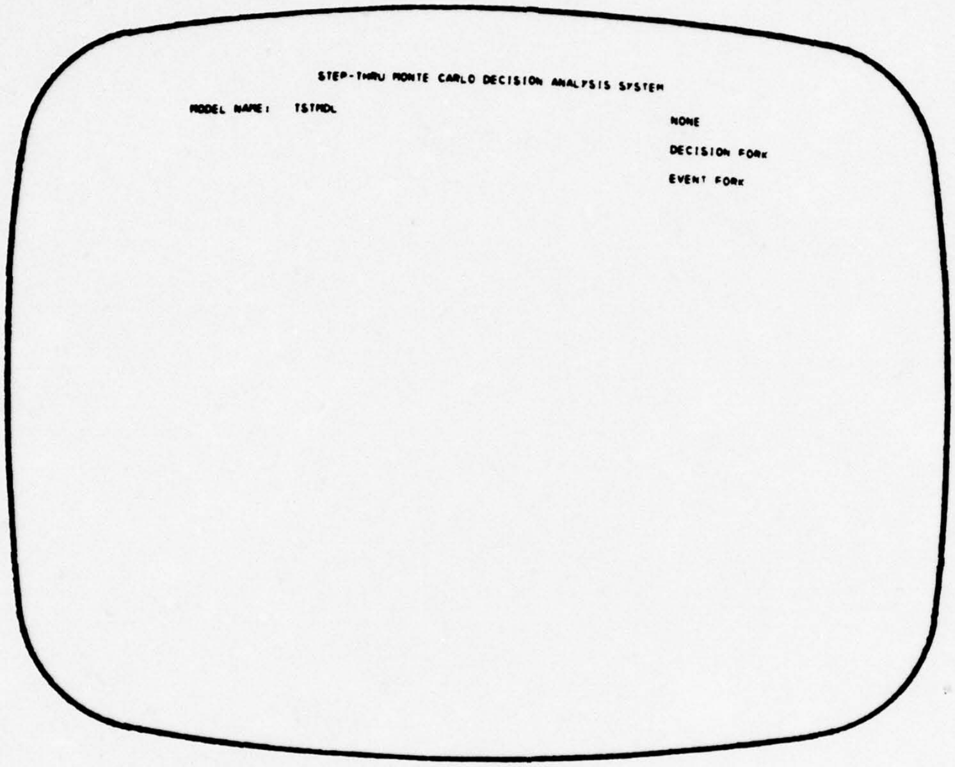
When the user selects NEW, the image of Figure A-2 appearing on the screen requests the user to assign a name to the new model. The user must enter the name via the display keyboard and terminate the entry by depressing the carriage return (CR) key.



```
STEP-THRU MONTE CARLO DECISION ANALYSIS SYSTEM
MODEL NAME:  (NONE)

ASSIGN MODEL NAME: 
```

Figure A-2
MONITOR DISPLAY 2

Once a model name, in this example, "TSTMDL," has been specified, MONTE will display the image of Figure A-3 on the screen. (The example model used in this section is the one used in Randall (1975) and thus does not correspond to the illustrative application of Step-Through given in Section 2 above.)

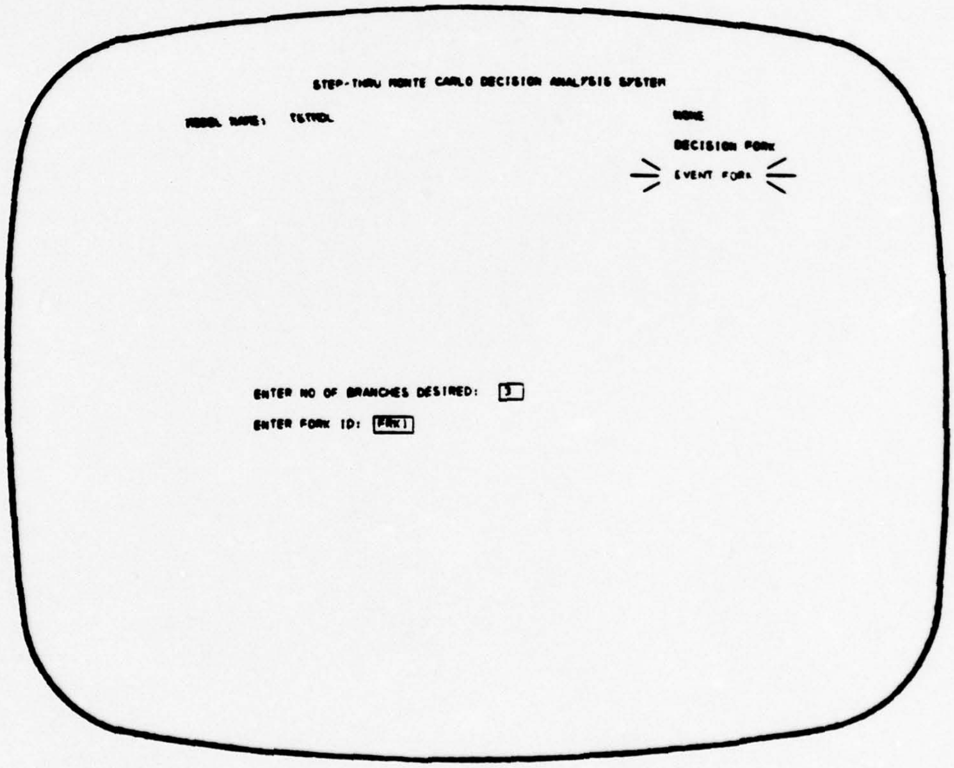


```
                    STEP-THRU MONTE CARLO DECISION ANALYSIS SYSTEM
MODEL NAME:    TSTMDL
                                                                  NONE

                                                                  DECISION FORK

                                                                  EVENT FORK
```

Figure A-3
MONITOR DISPLAY 3

A.3 Fork Definition

In order to define either an event fork or an action fork, the user must first select this item, by using the light pen, from the list in Figure A-3. After such a selection, MONTE will request a further description of the number of branches emanating from the fork and a four-character I.D. for identifying the fork, as depicted for an event fork in Figure A-4.



STEP-THRU MONTE CARLO DECISION ANALYSIS SYSTEM

MODEL NAME: TSTMDL

NONE

DECISION FORK

EVENT FORK

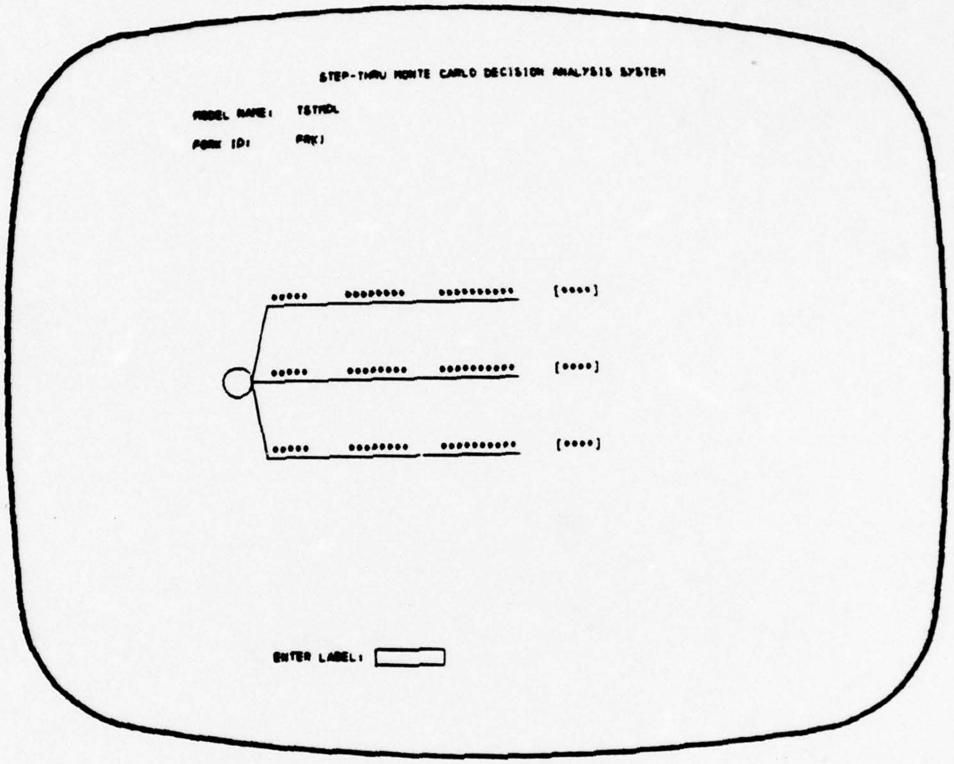
ENTER NO OF BRANCHES DESIRED: 3

ENTER FORK ID: FRK1

Figure A-4

MONITOR DISPLAY 4

After receiving responses to these requests, MONTE will display a fork with the number of branches and of the type requested, as shown in Figure A-5.



STEP-THRU MONTE CARLO DECISION ANALYSIS SYSTEM

MODEL NAME: TSTMDL

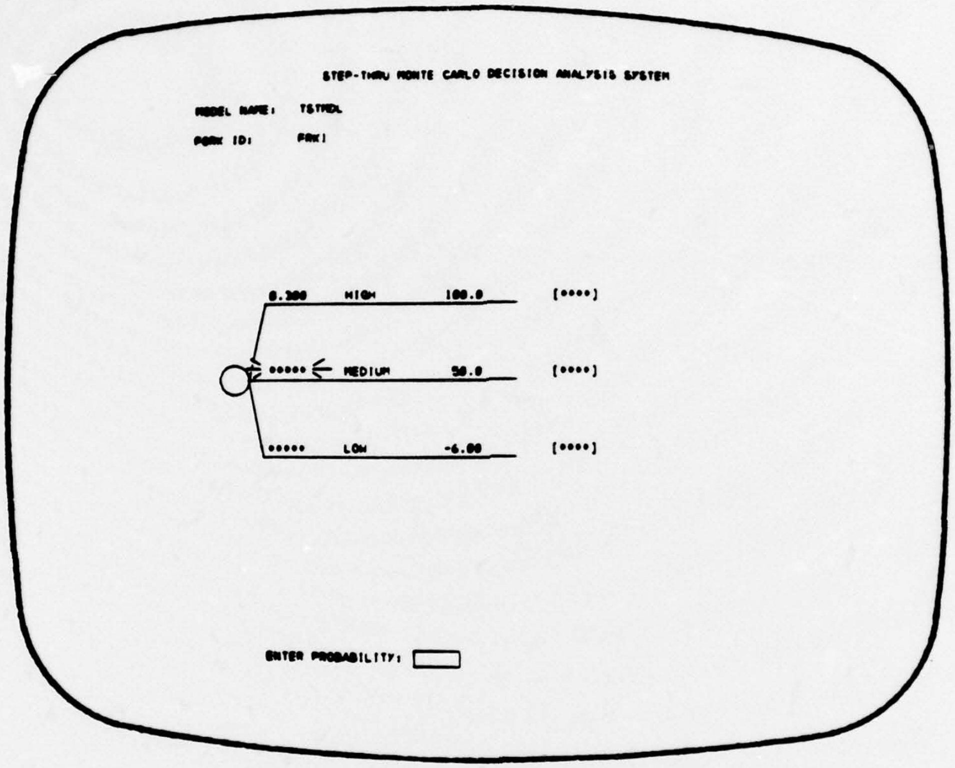
FORK ID: FRK1

ENTER LABEL:

Figure A-5

MONITOR DISPLAY 5

MONTE will then allow the user to specify a value for all or some of the parameters associated with the fork. The parameters of an event fork, which are shown as asterisks in Figure A-5, are, from left to right: branch probability, branch label, branch utility, and I.D. of the fork following the branch (which we will subsequently reference as the "branch link"). MONTE will cause each parameter field to flash in turn and will request an input of the appropriate type, as shown in Figure A-6. The user can specify branch links in advance, or he can wait until the fork is processed and then specify only the link that is required as a result of the simulation. The latter option was used in the illustration of Section 2.2 above.

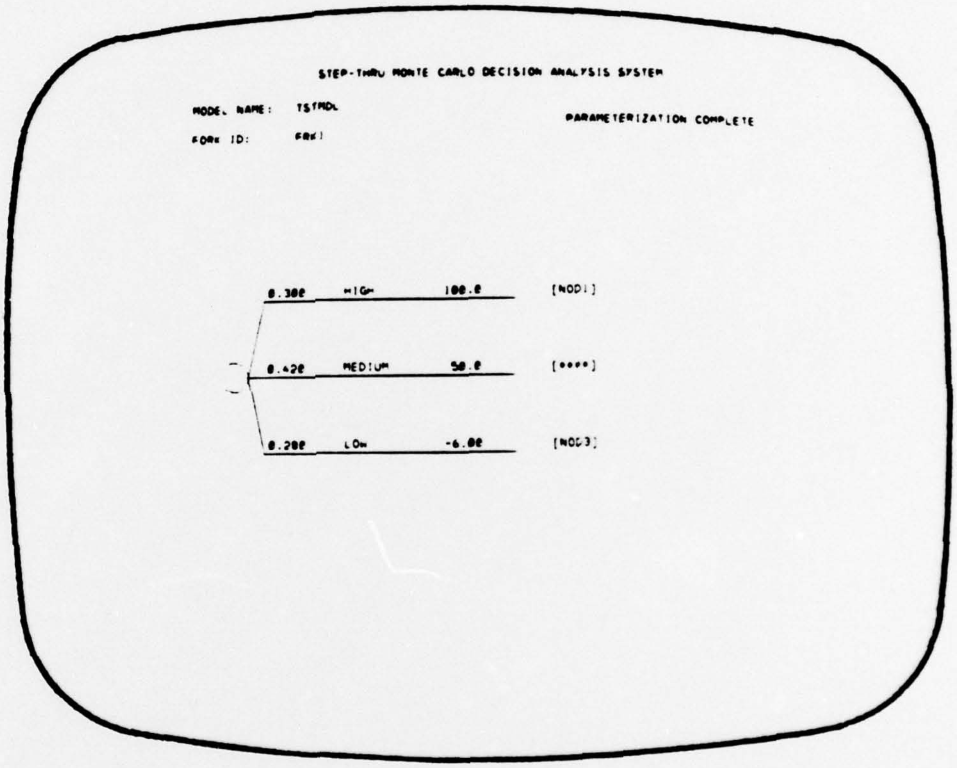


```
STEP-THRU MONTE CARLO DECISION ANALYSIS SYSTEM

MODEL NAME:   TSTMDL
FORK ID:      FRK1

   0.300     HIGH          100.0         [****]

   *****  <- MEDIUM         50.0         [****]

   *****     LOW           -6.00         [****]

ENTER PROBABILITY: ☐
```

Figure A-6
MONITOR DISPLAY 6

A.4 Parameter Changes

After cycling through all parameter fields, MONTE provides the user an opportunity to change or correct any parameter, as in Figure A-7. He can select a parameter to be changed by pointing at it with the light pen.



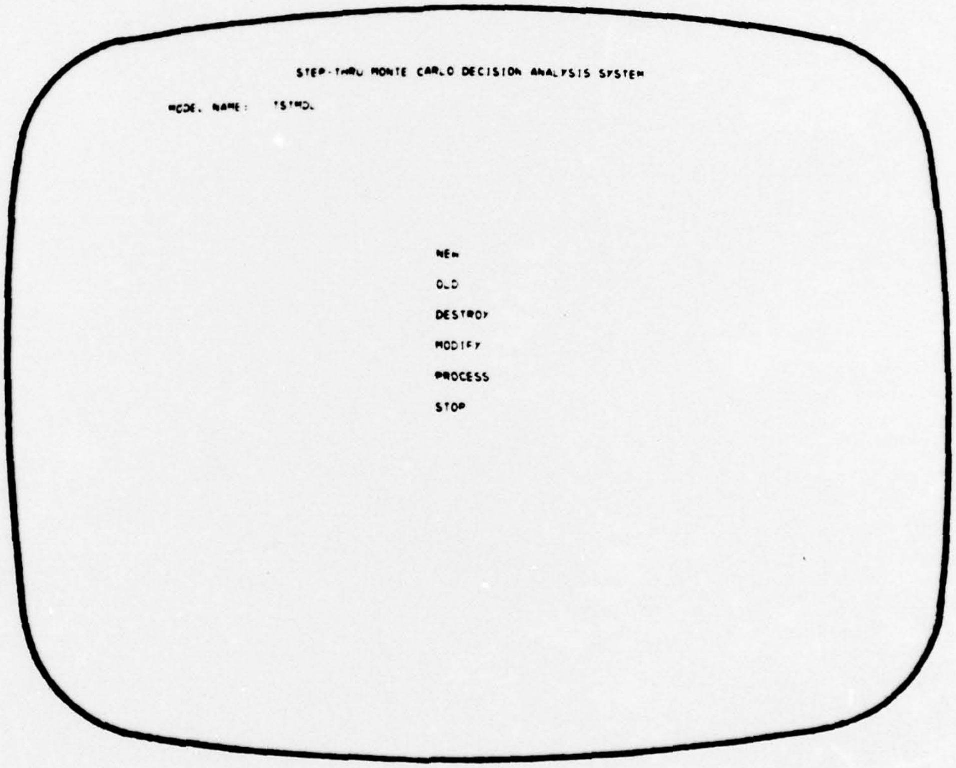
```
STEP-THRU MONTE CARLO DECISION ANALYSIS SYSTEM

MODEL NAME:   TSTMDL                         PARAMETERIZATION COMPLETE
FORK ID:      FRK1

          0.300     HIGH        100.0        [NOD1]

          0.420     MEDIUM       50.0        [****]

          0.280     LOW         -6.00        [NOD3]
```

Figure A-7
MONITOR DISPLAY 7

When a parameter has been selected, it will flash, and MONTE will request a value of the appropriate type, as in the initial request for parameters. When all desired changes, if any, have been made, the user can point the light pen at PARAMETERIZATION

COMPLETE in Figure A-7, and the fork definition will be complete. The image of Figure A-3 will reappear on the screen, and the user may define another fork. (A decision fork is similar in appearance to an event fork except that a square replaces the circle at the left of the fork, and the decision fork has no branch probabilities.)

When the user has defined all the forks he wishes, he may select NONE; the model definition will terminate at this point and the image of Figure A-8 will appear.



STEP-THRU MONTE CARLO DECISION ANALYSIS SYSTEM

MODEL NAME: TSTMDL

Figure A-8
MONITOR DISPLAY 8

A.5 Step-Through Processing

The user activates the Step-Through process by pointing the light pen at PROCESS in the option list of Figure A-8. This instruction causes MONTE to display the immediate action choice fork on the screen, as shown in Figure A-9.

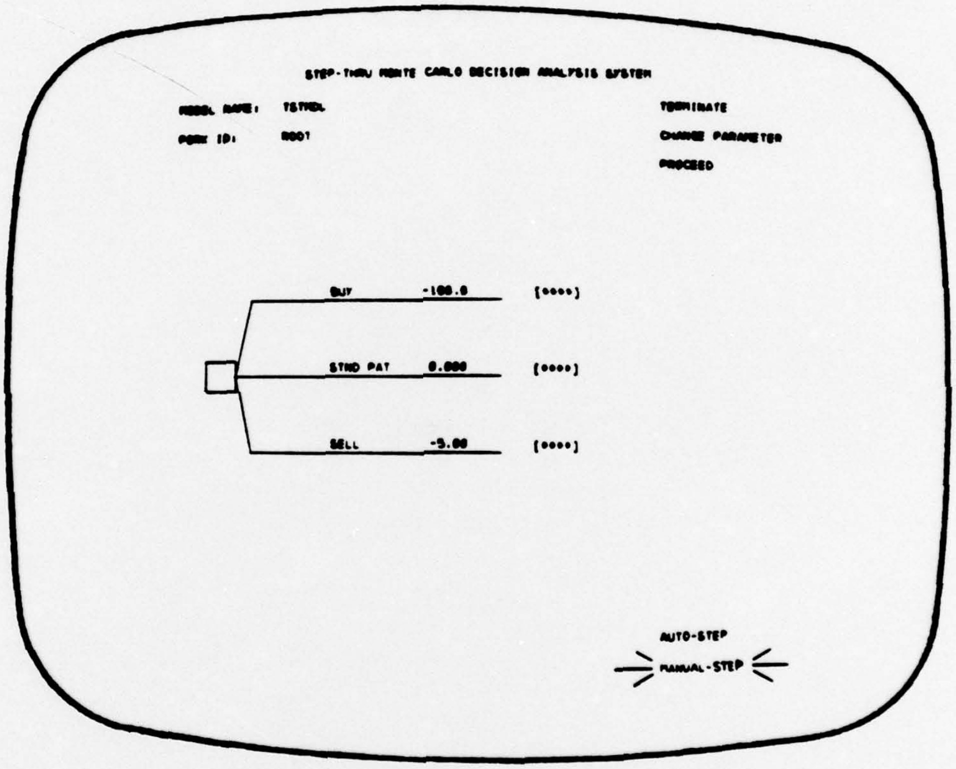
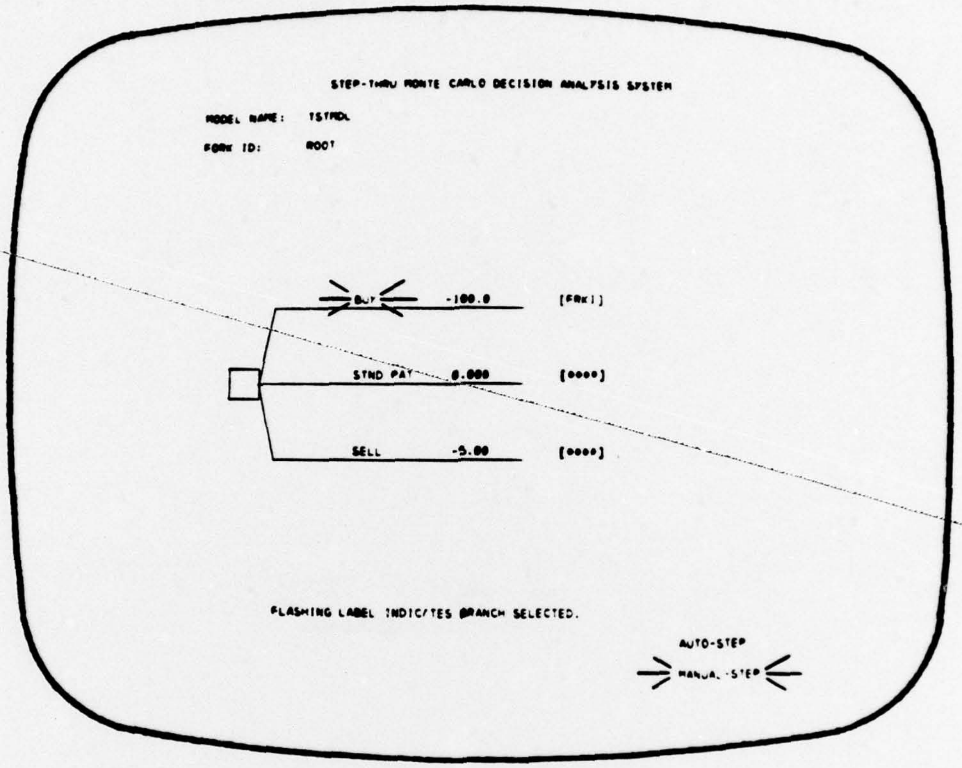


Figure A-9
MONITOR DISPLAY 9

The first step in the trial path through the decision tree is activated by pointing at PROCEED and then at the action whose path is to be sampled. (If the user does not wish to proceed, he can either change the parameters of the fork or terminate the process by pointing at the appropriate item in the option list of Figure A-9.) MONTE then responds by causing the branch label to flash and by informing the user that the corresponding branch has been chosen, as shown in Figure A-10.



STEP-THRU MONTE CARLO DECISION ANALYSIS SYSTEM

MODEL NAME: TSTMDL

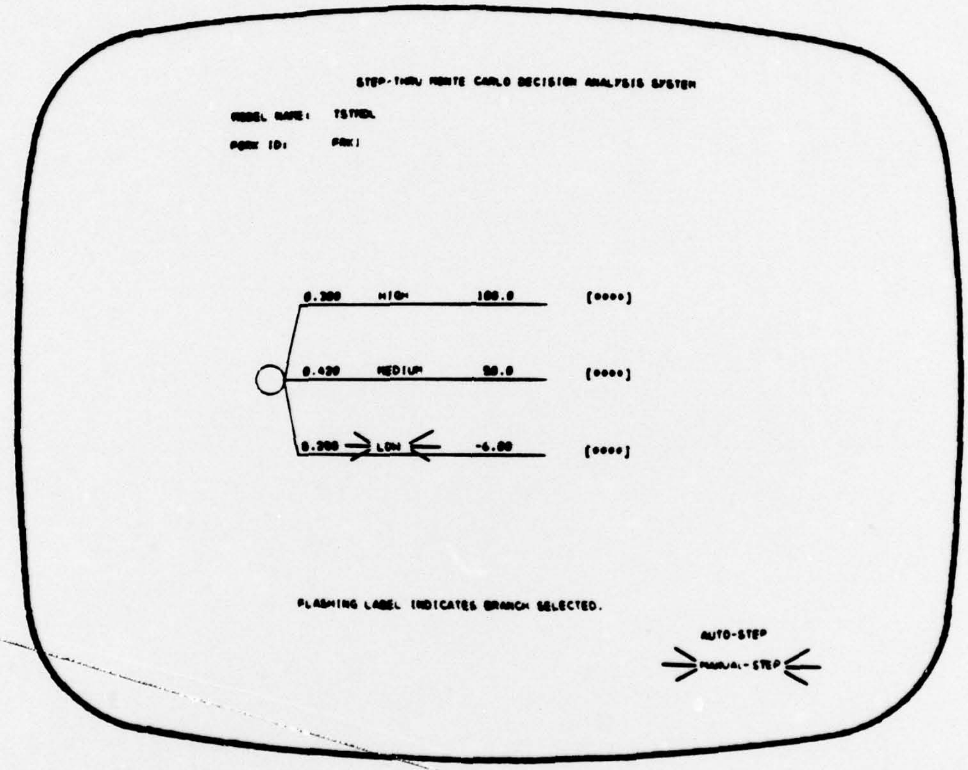
FORK ID: ROOT

FLASHING LABEL INDICATES BRANCH SELECTED.

Figure A-10
MONITOR DISPLAY 10

MONTE records the value of the branch utility, asks the user to specify the branch link (in this case the branch link is "FRK1"), and asks the user to define the next fork along the path by using the procedure described in Section A.3 above. The user then points at PROCEED to continue the path sample. (Alternatively, the user can specify branch links and subsequent branch definitions in advance. In this case, MONTE will automatically recall and display the next fork in the sample path.)

If the following fork is an event fork, then MONTE uses a random number generator to select a branch on the basis of the probabilities assigned to the various fork branches. MONTE then informs the user of the branch chosen, such as the choice of "LOW" shown in Figure A-11 for the event fork FRK1.

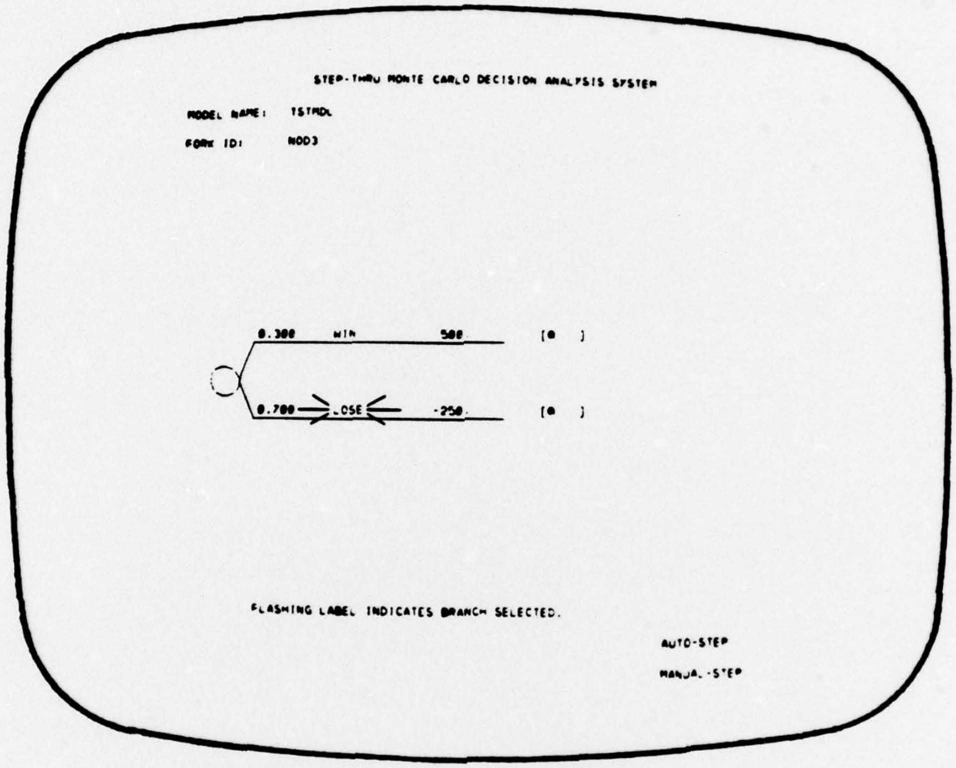


```
STEP-THRU MONTE CARLO DECISION ANALYSIS SYSTEM

MODEL NAME:   TSTMDL
FORK ID:      FRK1

0.300   HIGH     100.0   [****]
0.420   MEDIUM    50.0   [****]
0.280   LOW      -6.00   [****]

FLASHING LABEL INDICATES BRANCH SELECTED.
```

Figure A-11
MONITOR DISPLAY 11

Again, MONTE accumulates the value of the branch chosen and asks the user to define the next fork in the sample path.

This process repeats until the user indicates the end of the path by entering the symbol "@" as the name of the branch link, as shown in Figure A-12. At this point, a single trial path has been completed, and the user can begin another one.



STEP-THRU MONTE CARLO DECISION ANALYSIS SYSTEM

MODEL NAME: TSTMDL

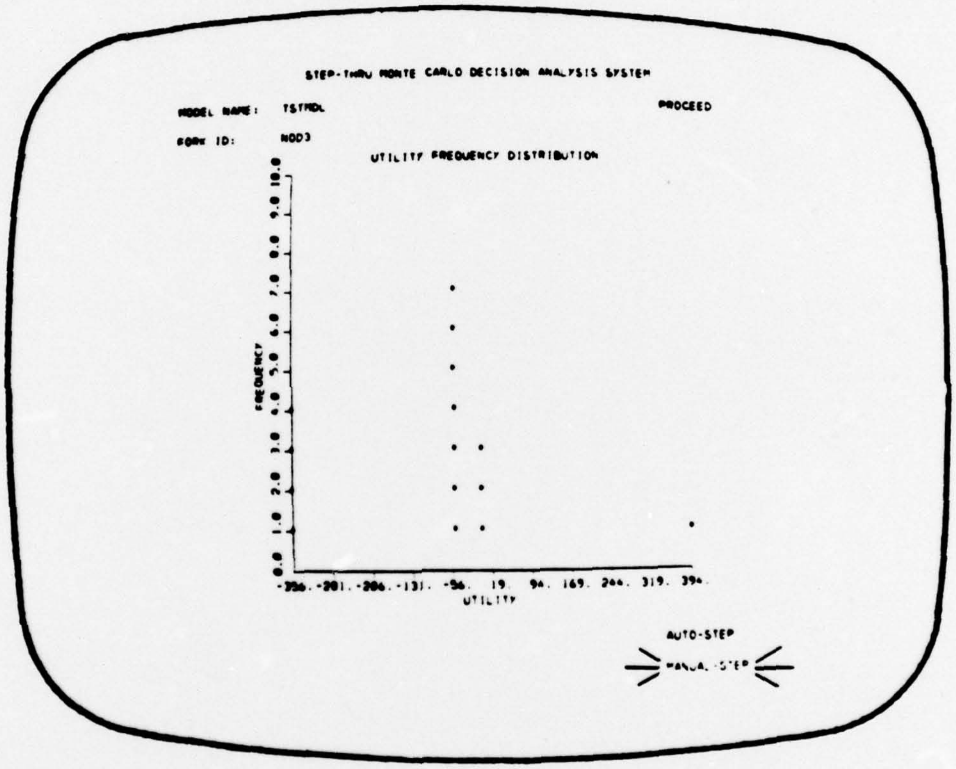
FORK ID: NOD3

FLASHING LABEL INDICATES BRANCH SELECTED.

Figure A-12
MONITOR DISPLAY 12

A.6 Result Display

After each trial path, MONTE displays the complete sample results in the form of a frequency distribution. Figure A-13 shows such a frequency distribution for a sample of 11 trial paths. Each star on the plot represents one trial path through



STEP-THRU MONTE CARLO DECISION ANALYSIS SYSTEM

MODEL NAME: TSTMDL

FORK ID: NOD3

Figure A-13
MONITOR DISPLAY 13

the tree. The abscissa of a star corresponds to the cumulative utility of the path of the trial that it represents. The ordinate corresponds to the number of trials that have resulted in the same cumulative utility. A sample of paths for all of the initial options can be used as a basis for choosing among them, as explained in Section 2.2 above.

A.7 Other Features

The foregoing sections have explained the major features of the computer program but have omitted the discussions of how to modify a parameter of a fork (for example, changing the probabilities on branches of an event fork), retrieve a model that had been previously defined, purge a model from the system, modify an existing model, and automatically process a pre-defined model (without indicating PROCEED at each step). These topics are not essential to the basic understanding of the Step-Through variant or its computer implementation, but may be of interest to a reader who plans to use the computer program. The interested reader can find a discussion of these topics in Randall and Barclay (1975).

REFERENCES

Brown, R.V. Modeling Subsequent Acts for Decision Analysis. Technical Report 75-1. McLean, Va.: Decisions and Designs, Inc., January 1975.

_____; Hoblitzell, C.M.; Peterson, C.R.; and Ulvila, J.W. Decision Analysis as an Element in an Operational Decision Aiding System. Technical Report 74-2. McLean, Va.: Decisions and Designs, Inc., September 1974.

_____; Kahr, A.S.; and Peterson, C.R. Decision Analysis for the Manager. New York: Holt, Rinehart and Winston, 1974.

_____; Peterson, C.R.; Shawcross, W.H.; and Ulvila, J.W. Decision Analysis as an Element in an Operational Decision Aiding System (Phase II). Technical Report 75-13. McLean, Va.: Decisions and Designs, Inc., November 1975.

_____, and Ulvila, J.W. Selecting Analytic Approaches for Decision Situations: A Matching of Taxonomies. Technical Report 76-10. McLean, Va.: Decisions and Designs, Inc., October 1976.

_____, and Watson S.R. Testing Procedures in the Design of Management Systems: Some Methodological Reflections. Technical report. McLean, Va.: Decisions and Designs, Inc., forthcoming.

Handbook for Decision Analysis. McLean, Va.: Decisions and Designs, Inc., 1973.

Larson, H.J. Introduction to Probability Theory and Statistical Inference. New York: John Wiley & Sons, 1969.

Raiffa, Howard. Decision Analysis. Reading, Mass.: Addison-Wesley, 1968.

Randall, L.S., and Barclay, S. Step-Thru Monte Carlo Decision Analysis System Program Documentation. Vol. I: Program Description. McLean, Va.: Decisions and Designs, Inc., August 1975.

Schlaifer, Robert. Analysis of Decisions Under Uncertainty. New York: McGraw-Hill, 1969.

TECHNICAL REPORTS DISTRIBUTION LIST

CODE 455

Director, Engineering Psychology
Programs, Code 455 (5 cys)
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217

Defense Documentation Center (12 cys)
Cameron Station
Alexandria, VA 22314

Lt. Col. Henry L. Taylor, USAF
OAD(E&LS) ODDR&E
Pentagon, RM 3D129
Washington, DC 20301

CDR Richard Schlaff
Office of Assistant Secretary of
Defense (Intelligence), Pentagon
Washington, DC 20301

Dr. Robert Young
Director, Human Resources Research
Advanced Research Projects Agency
1400 Wilson Boulevard
Arlington, VA 22209

Human Factors Plans, OP987P7
Office of the Chief of Naval
Operations
Department of the Navy
Washington, DC 20350

Personnel Logistics Plans, OP987P10
Office of the Chief of Naval
Operations
Department of the Navy
Washington, DC 20350

Dr. A.L. Slafkosky
Scientific Advisor
Commandant of the Marine Corps
Code RD-1
Washington, DC 20380

Office of Naval Research (6 cys)
International Programs
Code 102IP
800 North Quincy Street
Arlington, VA 22217

Fleet Analysis and Support Division,
Code 230
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217

Naval Analysis Programs, Code 431
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217

Operations Research Program, Code 434
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217

Statistics and Probability Program,
Code 436
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217

Information Systems Program, Code 437
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217

Director, ONR Branch Office
ATTN: Dr. J. Lester
495 Summer Street
Boston, MA 02210

Director, ONR Branch Office
ATTN: Dr. C. Davis
536 South Clark Street
Chicago, IL 60605

Director, ONR Branch Office
ATTN: Dr. E. Gloye
1030 East Green Street
Pasadena, CA 91106

Dr. M. Bertin
Office of Naval Research
Scientific Liaison Group
American Embassy - Room A-407
APO San Francisco 96503

Director, Naval Research Laboratory
(6 cys)
Technical Information Division
Code 2627
Washington, DC 20375

Mr. John Hill
Naval Research Laboratory
Code 5707.40
Washington, DC 20375

CDR Paul Nelson
Naval Medical R&D Command
Code 44
Naval Medical Center
Bethesda, MD 20014

Navy Personnel Research and
Development Center
Management Support Department,
Code 210
San Diego, CA 92152

Dr. Fred Muckler
Navy Personnel Research and
Development Center
Manned Systems Design, Code 311
San Diego, CA 92152

LCDR O'Bar, Code 305
Navy Personnel Research and
Development Center
San Diego, CA 92152

Dr. Alfred F. Smode
Training Analysis & Evaluation Group
Naval Training Equipment Center
Code N-OOT
Orlando, FL 32813

Dr. Gary Poock
Operations Research Department
Naval Postgraduate School
Monterey, CA 93940

Mr. J. Barber
Headquarters DA, DAPE-PBR
Washington, DC 20546

Dr. Joseph Zeidner
Director, Organization and Systems
Research Laboratory
U.S. Army Research Institute
1300 Wilson Boulevard
Arlington, VA 22209

Dr. Edgar M. Johnson
Organizations & Systems Research Lab
U.S. Army Research Lab
1300 Wilson Boulevard
Arlington, VA 22209

U.S. Air Force Office of Scientific
Research
Life Sciences Directorate, NL
Bolling Air Force Base
Washington, DC 20332

Dr. Donald A. Topmiller
Chief, Systems Effect. Branch
Human Engineering Division
Wright Patterson AFB, OH 45433

Dr. Jesse Orlansky
Institute for Defense Analyses
400 Army-Navy Drive
Arlington, VA 22202

Dr. Robert R. Mackie
Human Factors Research, Inc.
Santa Barbara Research Park
6780 Cortona Drive
Goleta, CA 93017

Director, Human Factors Wing
Defense & Civil Institute of
Environmental Medicine
Post Office Box 2000
Downsville, Toronto, Ontario
Canada

Dr. A.D. Baddeley
Director, Applied Psychology Unit
Medical Research Council
15 Chaucer Road
Cambridge, CB2 2EF, England

Dr. William A. McClelland
Human Resources Research Office
300 N. Washington Street
Alexandria, VA 22314

Defense Contract Administrative
Services Management Area
Attention: Mr. K. Gerasim
300 Joppa Road
Towson, MD 21204

Director, Naval Research
Laboratory (6 cys)
Technical Information Division
Code 2629
Washington, DC 20375

SUPPLEMENTAL DISTRIBUTION LIST

CODE 455

Dr. Marshall A. Narva
Army Research Institute for
Behavioral & Social Sciences
Room 236, 1300 Wilson Boulevard
Arlington, VA 22209

Major David Dianich
DSMS
Building 202
Fort Belvoir, VA 22060

Dr. Paul Slovic
Oregon Research Institute
Post Office Box 3196
Eugene, OR 97403

Dr. Amos Freedy
Perceptronics, Inc.
6271 Variel Avenue
Woodland Hills, CA 91364

Dr. A.C. Miller III
Stanford Research Institute
Decision Analysis Group
Menlo Park, CA 94025

Mr. Victor Rowney
Stanford Research Institute
Naval Warfare Research Center
Menlo Park, CA 94025

Dr. R.A. Howard
Stanford University
Stanford, CA 94305

Dr. Ward Edwards
Director, Social Science Research
Institute
University of Southern California
Los Angeles, CA 90007

Dr. Lee Roy Beach
Department of Psychology
University of Washington
Seattle, WA 98195

Mr. Frank Moses
U.S. Army Research Institute
1300 Wilson Boulevard
Arlington, VA 22209

Robert G. Gough, Major, USAF
Associate Professor
Department of Economics, Geography and
Management
USAF Academy, CO 80840

Dr. T. Owen Jacobs
P.O. Box 3122
Ft. Leavenworth, KS 66027