



COGNITIVE SYSTEMS LABORATORY

**PROGRESS TOWARD A GOAL-DIRECTED
DECISION SUPPORT SYSTEM**

**JOSEPH SALEH
JIN KIM**

**ANTONIO LEAL
JUDEA PEARL**

PROGRESS TOWARD A GOAL-DIRECTED DECISION SUPPORT SYSTEM

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by

J. Saleh

A. Leal

J. Kim

J. Pearl

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1.0. ORGANIZATIONAL DESIGN FOR A GOAL-DIRECTED DECISION SUPPORT SYSTEM

1.1. Model Structure

The decision support system aids the decision maker through computer interaction by structuring his decision problem and eliciting informational values associated with his perception of the problem environment. The system is "goal-directed" [1] in the sense that, unlike the decision-tree structure, the information supplied by the user is evoked and guided by explicit references to the objectives which need be accomplished and the means by which they may be attained. Figure 1-1 shows the model structure and the components relevant to attaining the goal. The main components are the following:

- (1) Goal - the major objective of the decision maker.
- (2) Subgoals - the "goal dimensions" or detailed items that combine to form the overall goal.
- (3) Actions - the action strategies that are open to the decision maker for accomplishing a particular subgoal.
- (4) Modes - the possible methods of performing each action.
- (5) Preconditions - those states of nature or the environment that must exist before a particular (action) mode can be implemented.

The structure should be thought of as a "tree". Thus, the goal is divided into many subgoals, each subgoal has a number of possible actions that could accomplish it, each action has a number of ways (modes) it can be performed, and each mode has a number of preconditions that must be completed. Once the preconditions are specified, they lead directly to new subgoals. That is, the subgoal of completing the specific precondition that allows actions to be taken, etc. The structure can then be repeated.

Cross-relationships can also exist in the structure. For example, it is possible for one action to do "double duty". A single action may have a

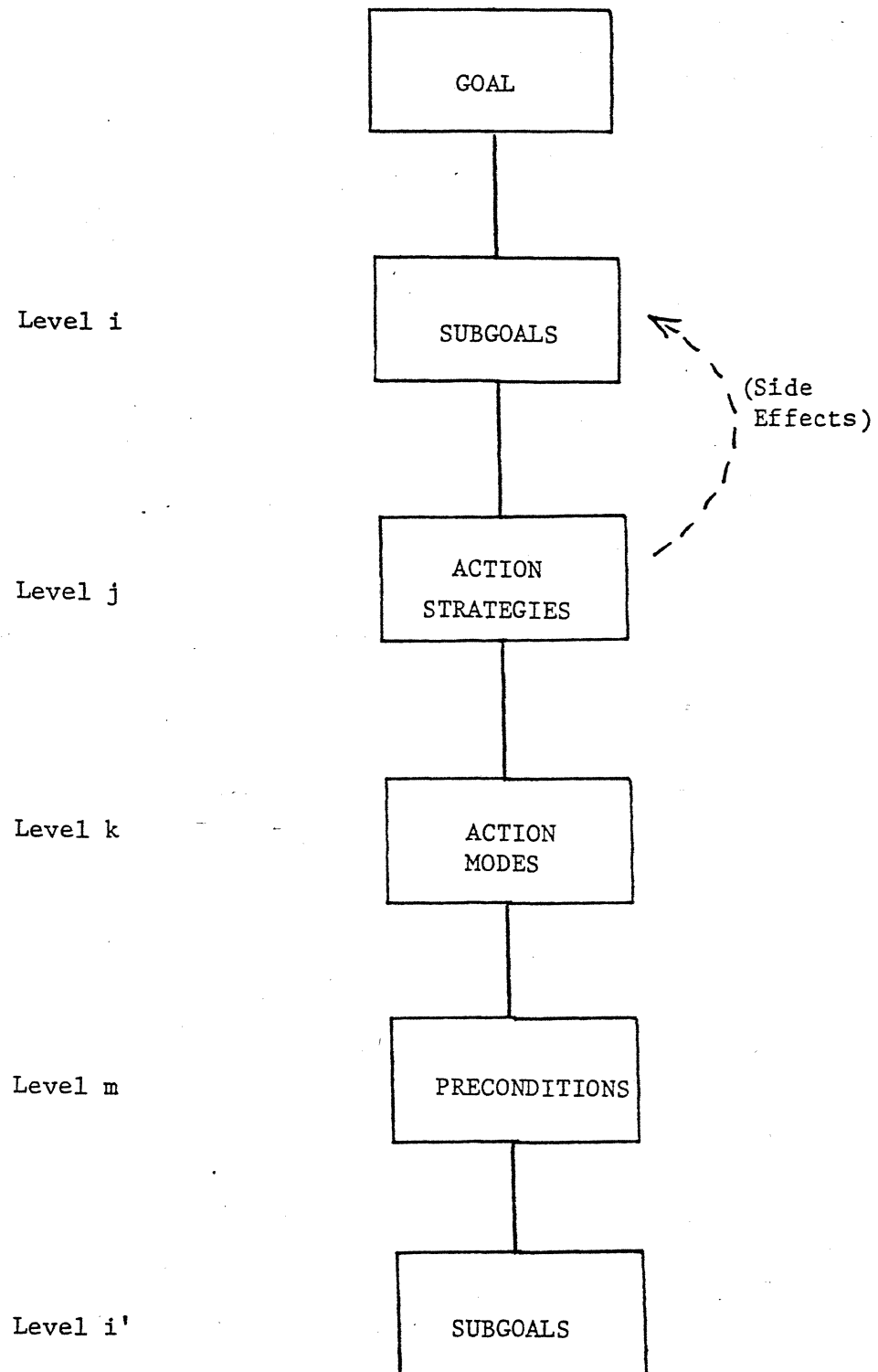


Figure 1-1. Model Structure

beneficial or adverse effect on a subgoal to which it is not directly connected. (Thus, the structure is more properly called a "graph" rather than a tree.) These cross-relationships must be elicited from the decision maker and will affect the recommendations given by the system.

The following sections outline each of the above components in detail including the required informational values and algorithms for aggregating them. The structure "levels" have been indexed for purposes of referencing the various values and parameters.

1.2. The Major Goal

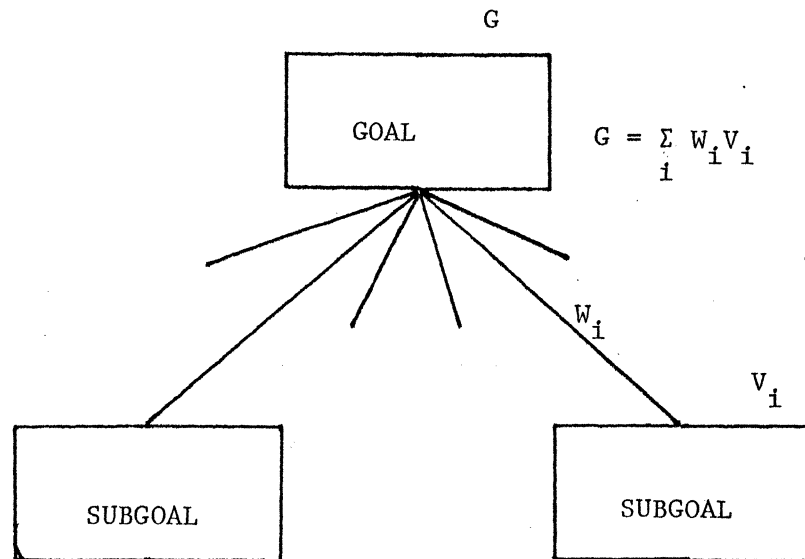
The decision maker will usually state the major goal in terms of a particular state of affairs that he desires. The overall goal has an associated value G ($0 \leq G \leq 1$) that captures the decision maker's accomplishment of the goal to different levels of satisfaction. It is the task of the decision support system to maximize this value. The value of G need not be 0 at the beginning of the elicitation session, that is, a portion of the goal may already be attained. The value $G=0$ will reflect a pessimistic state of affairs and $G=1$ an optimistic situation, conveniently chosen by the user for references purposes.

1.3. Subgoals

With the major goal stated, it is now necessary to explore in detail the goal dimensions, or "subgoals". The subgoals are simply the components that combine to form the overall goal. The subgoals may either be desired dimensions or adverse dimensions (hopes and concerns). Adverse dimensions are those whose elimination supports goal attainment. The subgoals should completely describe the major goal in such a way that if all desired dimensions were fulfilled to their utmost level and all adverse dimensions were reduced to their lowest possible level, the goal would be achieved completely.

Figure 1-2 shows the structure of the major goal in terms of its subgoals.

Level i



G Goal Value $0 \leq G \leq 1$

W_i Subgoal Weight (importance) $0 < W_i < 1$ $\sum_i W_i = 1$

V_i Subgoal Value (Level of Attainment) $0 \leq V_i \leq 1$

Figure 1-2. Goal Structure

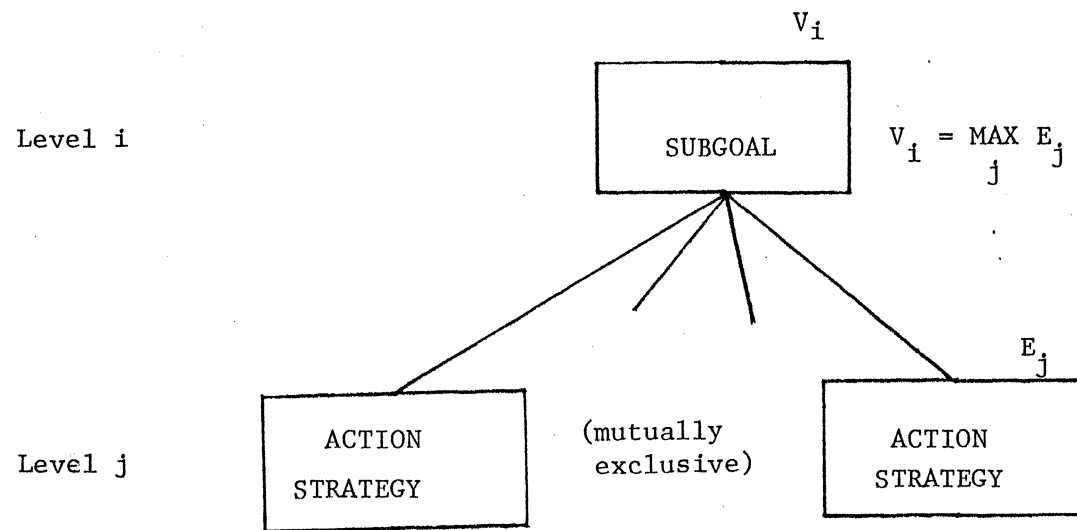
The relation between the major goal and the subgoals is represented by two numbers associated with each subgoal: value and weight. The value V_i ($0 \leq V_i \leq 1$) of subgoal i is the degree to which it has been achieved. (This parallels to the value G for the goal.) The weight W_i ($0 \leq W_i \leq 1$) for subgoal i is a measure of its importance relative to the other subgoals. The decision maker is instructed to estimate the degree to which the accomplishment of the subgoal adds to the satisfaction of the major goal. The weights are constrained to sum to 1 ($\sum_i W_i = 1$).

The goal value G is obtained from the subgoal values and weights by a linear combination ($G = \sum_i W_i V_i$). Thus, the subgoal structure corresponds to a linear multi-attribute model.

1.4. Actions

After the list of specific subgoals has been established, the decision support system begins elicitation of actions. For each subgoal, the decision maker is asked to think of possible actions that would cause the desired subgoals to be achieved (attained) or the adverse subgoals to be eliminated (reduced). More than one action may be listed. However, each action should have the capacity, by itself, to affect the subgoal, and they should be mutually exclusive.

Actions are divided into two levels: action "strategies" and action "modes". An action strategy is a statement of a plan or a short description of what is to be done. An action mode is a more detailed specification of the method for accomplishing the action strategy. An action mode may be thought of as simply a "subaction". Figure 1-3 shows a subgoal with a number of supporting action strategies. Each action strategy has an associated "effectiveness" measure E_j ($0 \leq E_j \leq 1$), which indicates the level of subgoal attainment to be expected if action strategy j were executed. The value V_i of the subgoal is the maximum of the supporting action strategies ($V_i = \max_j E_j$) representing the



V_i Subgoal Value $0 \leq V_i \leq 1$

E_j Action Strategy Effectiveness $0 \leq E_j \leq 1$

Figure 1-3. Subgoal Structure

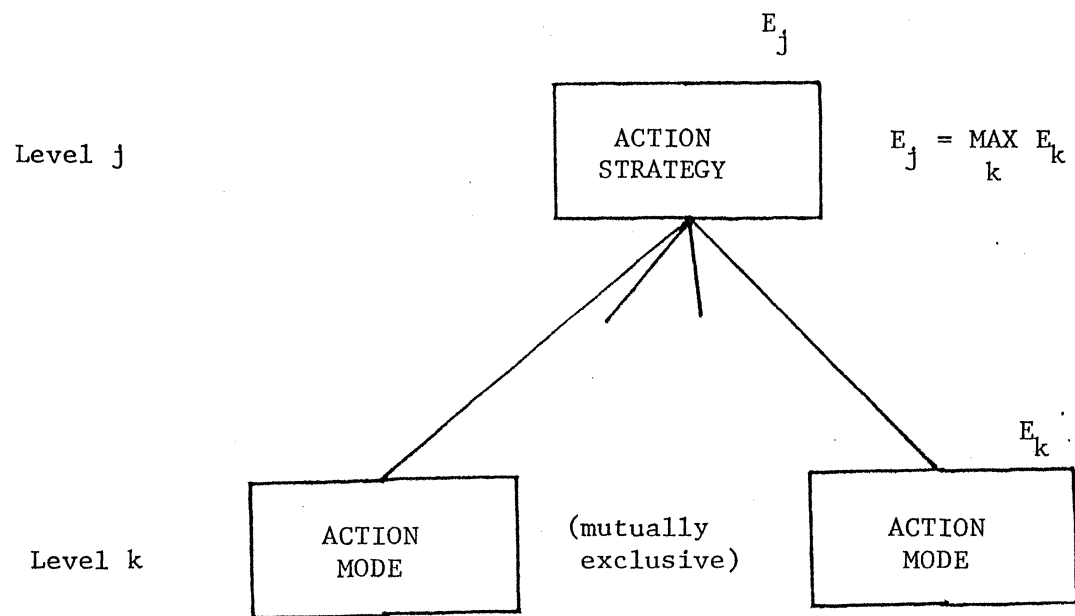
option of selecting that action strategy which produces the highest subgoal attainment.

Figure 1-4 shows the action strategy structure composed of supporting action modes. The action mode effectiveness E_k ($0 \leq E_k \leq 1$) is the amount that the corresponding mode affects the success of the action strategy. Again, the (locally) best action mode is the one with the highest value ($E_j = \text{MAX}_k E_k$). It may not always be necessary to subdivide every action strategy into action modes. If the action strategy can only be implemented in one way, the mode level is not needed. The benefit of characterizing action by a two-level structure lies in the fact that many properties of the various modes (e.g., preconditions) would be identical to all modes of a particular strategy. This would enable us to store these common sets of properties in the description of the parent strategy, thus saving the storage and elicitation time otherwise consumed by duplication.

1.5. Preconditions

A "precondition" is a state of nature or the environment that must exist before an action mode (or strategy) can be implemented effectively. Precondition satisfaction need not be an "all or nothing" requirement. The effectiveness E_k of an action mode may be proportional in some way to the level of attainment (completion) of the precondition state. Each precondition is characterized by a measure of completion L_m ($0 \leq L_m \leq 1$). This measure is used to calculate the effectiveness of the corresponding action mode. Since all of the preconditions should be completed before the effectiveness of the action mode can be fully realized, the mode effectiveness should be based on the normalized product of the supporting precondition completion levels.

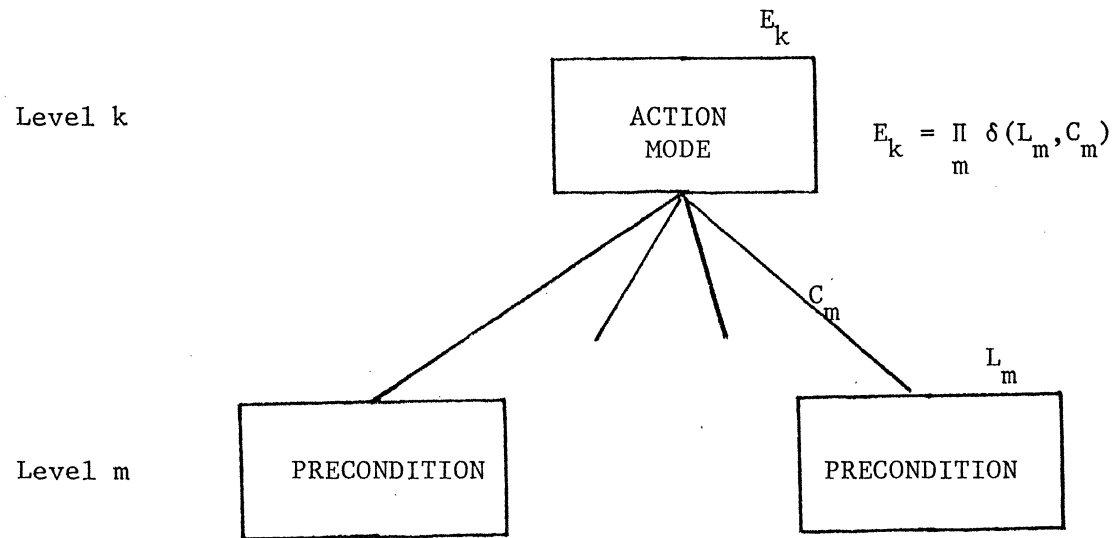
A second measure associated with each precondition is its "criticality" threshold C_m ($0 \leq C_m \leq 1$). The criticality is a threshold on the completion level of the precondition below which the effectiveness of the corresponding action



E_j Action Strategy Effectiveness $0 \leq E_j \leq 1$

E_k Action Mode Effectiveness $0 \leq E_k \leq 1$

Figure 1-4. Action Strategy Structure



E_k Action Mode Effectiveness $0 \leq E_k \leq 1$

L_m Precondition Attainment (Completion) Level $0 \leq L_m \leq 1$

C_m Criticality Threshold $0 \leq C_m \leq 1$

$\delta(L_m, C_m)$ Criticality Function $0 \leq \delta \leq 1$

Figure 1-5. Action Mode Structure

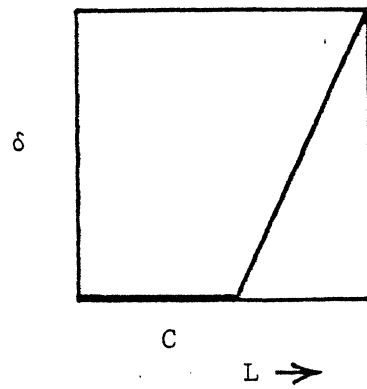
mode is nullified. A threshold of 0 means that the action mode can be executed (to some degree of effectiveness) even if the precondition exists at its minimum level of attainment. A threshold of 1 means that the mode cannot be implemented (or has 0 effectiveness) unless the precondition is fully satisfied.

There can be a number of possible relationships between the precondition completion level and the effectiveness of the supported mode. If this relationship is called δ , the "criticality function", it may be expressed in terms of a graph within the interval $[0,1]$. Figure 1-6 shows the chosen δ functions. It expresses the relationship between the precondition completion level L_m , its criticality C_m , and the degree to which it enables the action mode to be executed. Once the function is determined, the overall effectiveness of the action mode can be obtained by taking the normalized product of the criticality functions of each of the connecting preconditions.

1.6. States

There are two types of preconditions: controllable and uncontrollable. A "controllable" precondition means that the level of its completion is either known or can be controlled directly. An "uncontrollable" precondition is one whose current level of attainment is both uncertain and not directly adjustable. For example, in the context of business decision making, the user may consider the action mode "lower prices by 10 percent" as a potential action for achieving the subgoal "capture a larger share of the market". The effectiveness of this action depends (among other factors) on the variables "competitor's prices" and "buyers' price awareness". The latter can be controlled via advertisement while the former must be treated as an uncertain variable not subject to one's direct control or scrutiny. Figure 1-7 shows these two situations and the formulas for determining the precondition level.

At the point below a precondition, the decision structure repeats with



$$\delta = \begin{cases} 0 & \text{if } L < C \\ \frac{L-C}{1-C} & \text{if } L \geq C \end{cases}$$

L = Precondition Completion Level

C = Criticality Threshold

Figure 1-6. Criticality Function

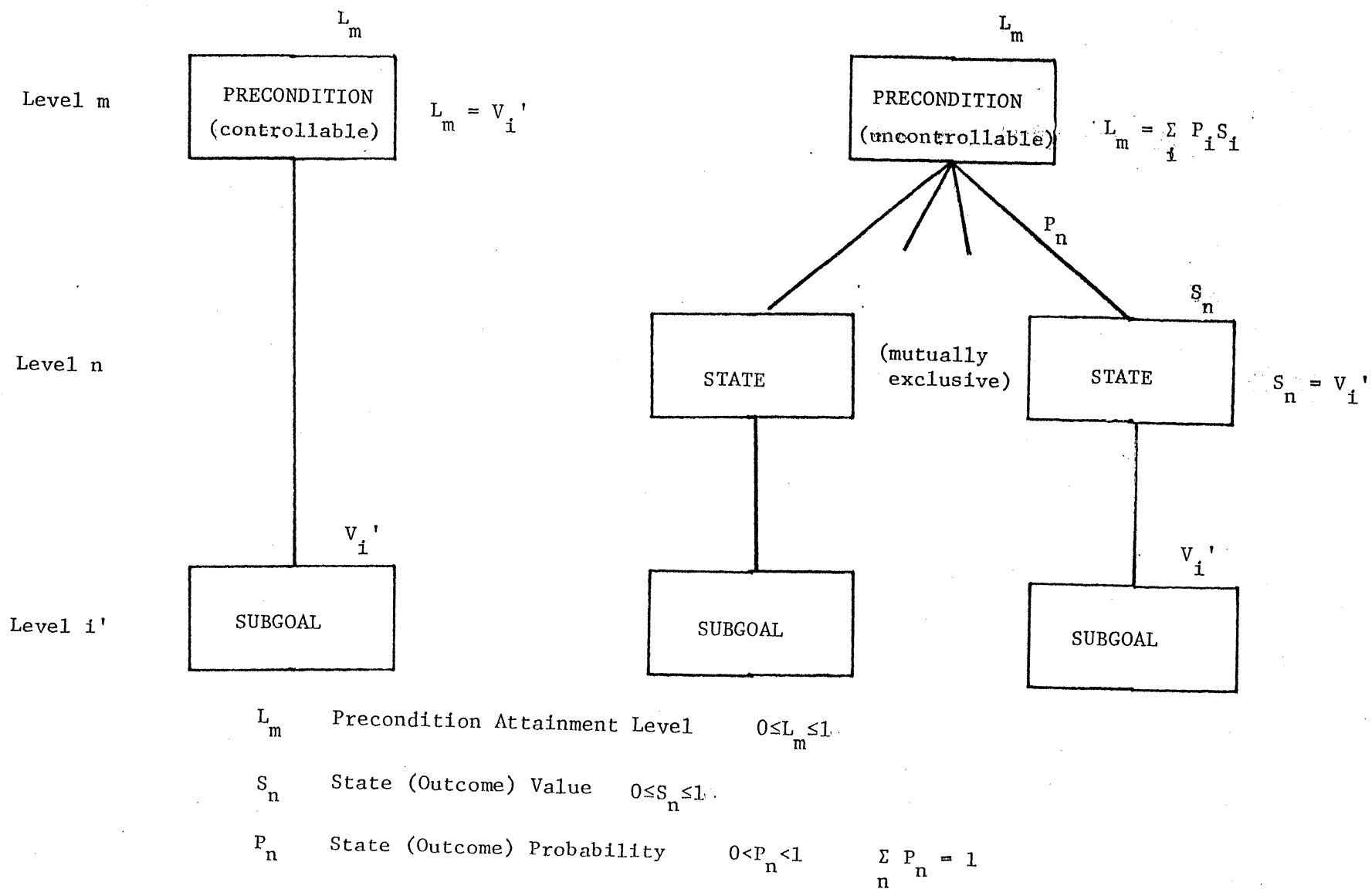


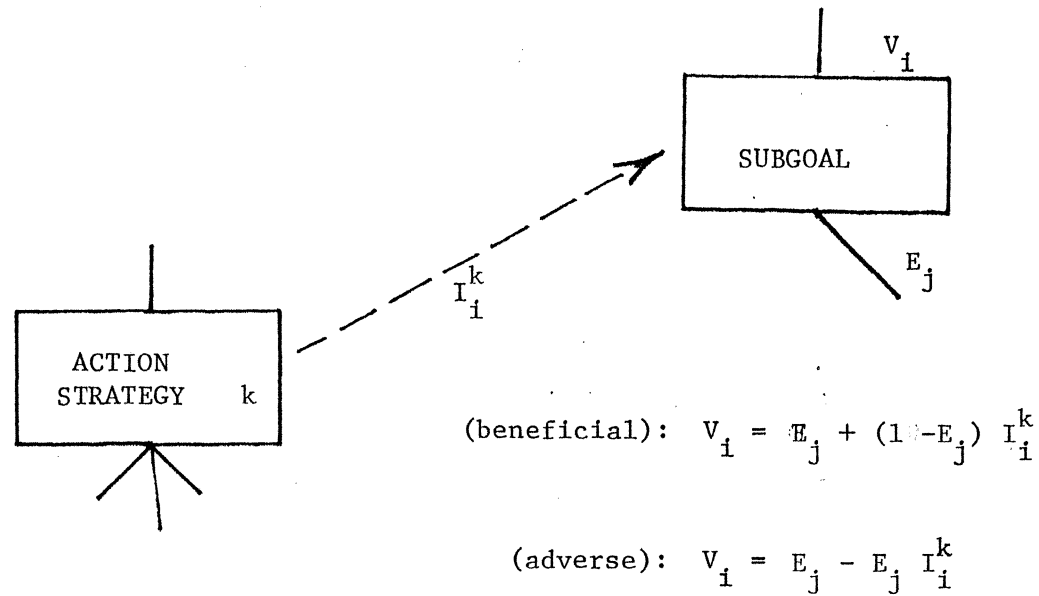
Figure 1-7. Precondition Structure

new subgoals. The new subgoal refers to the possible methods which can be used to satisfy the corresponding precondition. This may involve another entire structure including action strategies, action modes, further preconditions, etc.

The level of completion of a controllable precondition is simply equal to the level of attainment of its corresponding subgoal which states the need to satisfy that precondition. They are, in effect, the same thing. However, an uncontrollable precondition is linked to the possible states of the environment that, is known, would allow a precise value to be placed on the level of attainment. This situation corresponds to an "event" in a decision tree. Each state can be assigned a value and a probability of occurrence. The criticality level $\delta (L_{mn}, C_m)$ is connected with a level of precondition completion L_{mn} which would occur if the state S_n were to exist. The criticality δ_m of an uncontrolled precondition is the expected value of the criticality function induced by the various states: $\delta_m = \sum_n \delta (L_{mn}, C_m) P_n$.

1.7. Side Effects of Actions on Subgoals

It may happen that the execution of a particular action has a beneficial or adverse effect on a subgoal to which it is not directly connected. The decision system asks if any such effects are present and elicits an impact measure for the relationship. Figure 1-8 shows the side effects of an action j on a subgoal i . The "remote" impact I_j^r must be elicited and is considered to be the amount ($0 < I_j^r \leq 1$) that the action, if implemented, will increase or decrease the level of attainment of the affected subgoal. Assume that the subgoal attainment level has already reached a value V_i (between 0 and 1) as a result of action j directly connected to it. The remote action k will modify V_i in one of two different ways. If the remote action has a beneficial effect on the subgoal, the remote action k will increase V_i to $V_i' = V_i + (1 - V_i) I_i^k$.

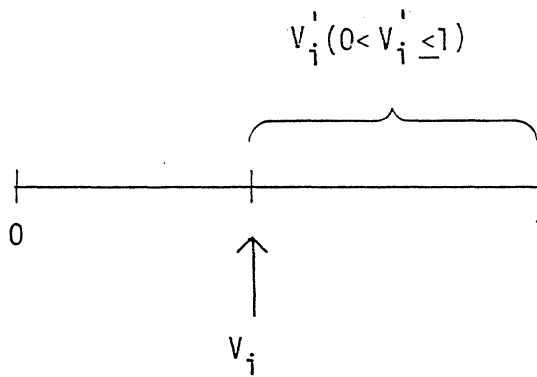


V_i Subgoal Value $0 \leq V_i \leq 1$

E_j Action Strategy Effectiveness $0 \leq E_j \leq 1$

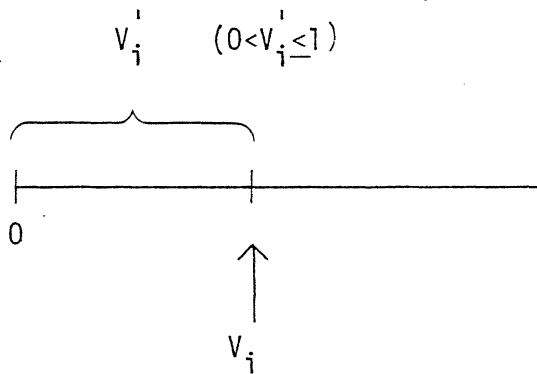
I_i^k Impact of Remote Action Strategy on Subgoal $0 \leq I_i^k \leq 1$

Figure 1-8. Side Effects of Actions on Subgoals



In other words, a value of $I_i^k = 0$ will not change V_i ; a value of $I_i^k = 1$ will cause the subgoal to reach its full attainment level, $V_i = 1$.

If the remote action has an adverse effect on the subgoal, the remote impact measure will lower the subgoal attainment level V_i to $V_i' = V_i - V_i I_i^k$.



A remote adverse impact of 0 will not change the current subgoal value V_i . A remote adverse impact of 1 will cause the subgoal to receive an attainment level of 0.

It may happen that there is more than one action affecting the same subgoal remotely. In such a case, each of the remote impact measures are applied successively (in any order) to obtain the change in V_i .

2.0. OPTIMIZATION

2.1. Motivation

One of the major effects required in employing a goal-directed system is the identification of the optimal feasible action plan whose implementation results in the highest level of attainment for the major goal; a feasible action plan is a sequence of action combinations, one for each level of the goal-directed graph. The identification process requires assessment of all feasible action combinations. Had the assessment of a plausible action combination been derivable from a linear aggregation of individual actions composing each action combination, the complexity of the optimization effort of a goal-directed graph with n actions would have been of the same order as n . However, since side-effects are aggregated with direct effects according to a multiplicative model, the effect of each individual action depends on the action combination in which it appears. Therefore, rather than independent actions, feasible action combinations must be assessed in their entirety resulting in a much higher complexity. For instance, for a graph with n actions clustered in k classes of m mutually exclusive actions $(a_1^1 \dots a_m^1) \dots (a_1^k \dots a_m^k)$, where $n = mk$, the number of plausible action combinations subject to optimization is $(m)^k$. If the value of G had to be calculated separately for each action combination, the evaluation effort would be prohibitively long.

During interview sessions, the optimization procedure is executed frequently. Each time a recommendation is requested the optimization must be performed. Additionally, it should be invoked each time a node is considered for expansion. As the number of actions in a goal-directed graph increases, the time required for optimization increases rapidly. Even during early stages of the interview, the optimization process may take a major portion of the processing time. In a larger goal-directed graph, the optimization process may take minutes. Therefore,

employment of the exact and exhaustive optimization process will be unacceptable. A local optimization procedure has been developed and simulated to investigate the effect of different starting points as well as the accuracy of the results. An optimization procedure based on first order approximation of side effect has also been developed. These subjects are covered in the following section.

2.2. Local Optimization

The local optimization procedure is based on the assumption that at any optimization instance the locally most effective actions from all groups of mutually exclusive actions, except one, remain fixed. The problem then becomes one of finding the most effective action from the remaining group. This action (together with those from the other groups) will then be chosen as the new starting point for further optimization. The process will then be iterated.

While the complexity of exhaustive optimization increases exponentially with n , the complexity of each iteration cycle of the local optimization is of the same order as n .

This saving in complexity is accomplished at the expense of the quality of the resultant plan. The method may fail to identify the global optimal action combination, therefore, resulting in a suboptimal plan. The amount of inaccuracy depends on the choice of the starting actions. A simulation program has been written to identify effective choices for starting points. The results of that simulation are presented in the next section. The accuracy of the optimization procedure may be enhanced by applying more than one iteration, however, as in most nonlinear problems of this kind, there is no guarantee that the process will ultimately converge.

2.3. Simulation Results

The local optimization procedure was simulated to identify an effective choice of the starting actions. Four alternative starting actions were defined.

Since each action is characterized by two factors, its direct effect and its associated side effects, the four alternative choices for starting action were defined as follows. Among the four choices, only alternative four represents an actual action already in the goal-directed graph. The other choices represent virtual actions substituting the actual actions in the graph.

- (1) Direct effect equal to the average of the direct effects of all actions emerging from the same subgoal, side effects all equal to zero.
- (2) Direct effect equal to the average of the direct effects of all actions emerging from the same subgoal, side effects all equal to the average of all side-effects initiated from the group is represents (directed towards the same target subgoals).
- (3) Direct effect equal to the maximum of the direct effects of all actions emerging from the same subgoal, side effects all equal to zero.
- (4) Direct effect equal to the maximum of the direct effects of all actions emerging from the same subgoal, side effects equal to the side effect of the action with large direct effect.

A simulation was run to test the four alternative choices for the starting action. A dynamic single level goal-directed graph was structured. The weight, direct effects and side effects were defined by random variables between zero and one such that all possible permutations of small, medium, and large effects and side effects be generated (small: 0-0.33, medium: 0.33-0.66, large: 0.66-1).

At each simulation step, the optimal action combination was selected by an exhaustive search. The selection criteria were as follows.

Let $\underline{\alpha} = (\alpha_1, \dots, \alpha_k)$ be an action plan which consists of k actions, where k equals the number of subgoals. According to the rollback formula, the level

of attainment of the major goal, $V_G(\underline{\alpha})$ becomes:

$$V_G(\underline{\alpha}) = \sum_{i=1}^k W_i E(\alpha_i) \prod_{\substack{j=1 \\ j \neq i}}^k [1 - S(\alpha_i, j)]$$

where

$E(\alpha_i)$ = direct effect of action α_i .

$S(\alpha_i, j)$ = side effect of action α_i on subgoal j .

With this convention, the selection criteria becomes:

$$\underline{\alpha}_{opt} = \underset{\substack{\text{all feasible} \\ \text{action combinations} \\ \underline{\alpha}_j}}{\text{Max}^{-1}} [V_G(\underline{\alpha}_j)]$$

The selection of the optimal action plan, in each simulation step, was followed by selection of the action plans using the local optimization procedure and based on each of the four alternative starting action choices. For each subgoal, a starting action was constructed according to the alternative choices. Then the local optimal action under each subgoal i , L_i , was calculated as:

$$L_i = \underset{j}{\text{Max}^{-1}} [V_G(H_1, \dots, H_{i-1}, \alpha_{ij}, H_{i+1}, \dots, H_k)]$$

where the α_{ij} 's are actions under subgoal i , and H_i is the starting actions for subgoal i . The local optimal action plan then was defined by:

$$\hat{\underline{\alpha}}_{opt} = (L_1, \dots, L_k)$$

The degree of merit of each starting action choice was calculated according to the following formula:

$$d(\underline{\alpha}) = \frac{V_G(\underline{\alpha}) - V_G(\text{Worst Action Combination})}{V_G(\text{Optimal Action Combination}) - V_G(\text{Worst Action Combination})}$$

$d(\underline{\alpha})$ is inversely proportional to the degree of suboptimality of the action plan. The value of $d(\underline{\alpha})$ ranges between zero and one, one representing an optimal plan.

The simulation results are portrayed in Figures 2-1, 2-2, 2-3, and 2-4 for the alternative choices 1, 2, 3, and 4, respectively. Comparison of the results indicates that alternative 3 is superior to the other three alternatives.

To investigate the performance of the local optimization procedure in multi-level goal-directed graphs, a simulation of a graph with sixteen actions appearing in two different levels was performed. The same three ranges (small: 0-0.33, medium: 0.33-0.66, and large: 0.66-1) were used for the value of the random variables. To calculate the rollback values, in this case, we need not only to define virtual actions, as in the single-level case, but also we must present virtual subgoals. The virtual subgoals are used to reduce some subgraphs to linear structures; therefore, fixing the subgraph values to the values of the virtual actions and subgoals on the linear structure. For example, the subgraph emerging from subgoal S_2 in Figure 2-5 is reduced to the corresponding linear structures in Figure 2-6. With this reduction, the value of actions under the subgoal S_1 are calculated under the assumption that virtual actions H_2 and H_{22} occur under S_2 .

The process of deriving Figure 2-6 from Figure 2-5 is outlined in Figure 2-7. First, virtual actions are constructed for the bottom level actions, as described for the one level graph (conversion of a to b). Then, using the value of virtual actions, the lower level subgoals values are calculated (b). The next step requires calculation of the first level actions effectiveness. At this point, there is a need to assume a fixed value for the level of attainment

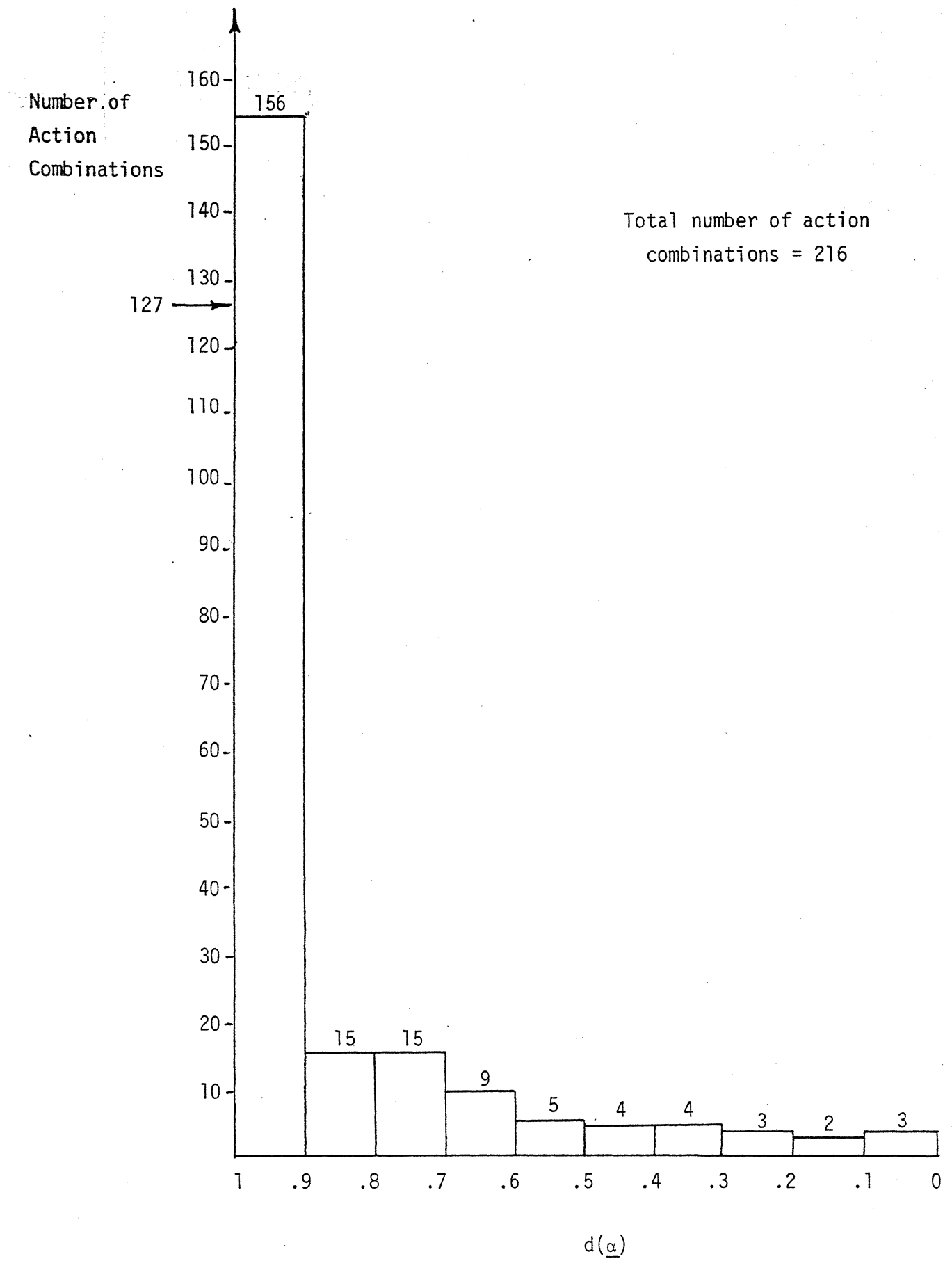


Figure 2-1. Simulation Result for the First Alternative Fixed Action

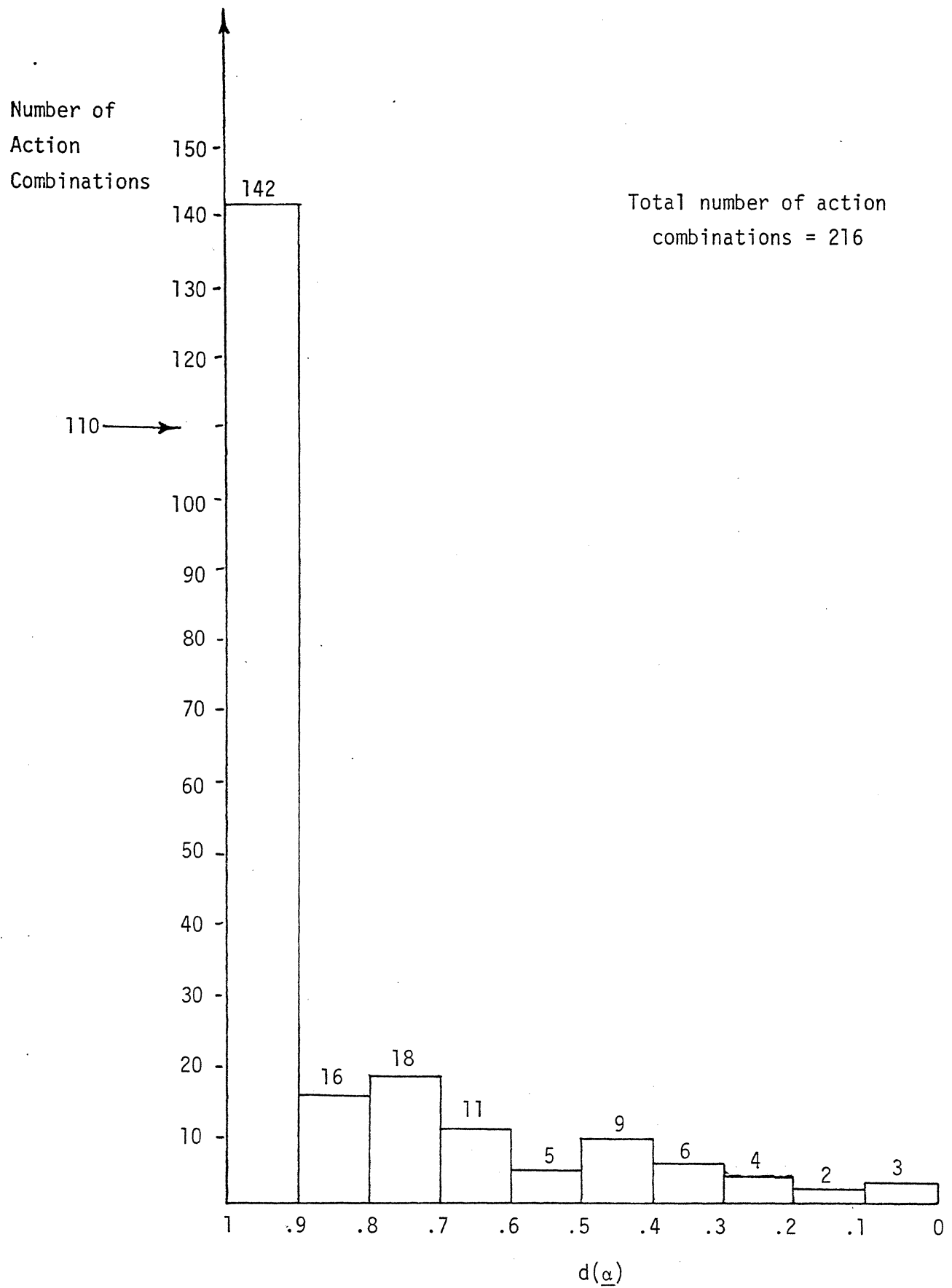


Figure 2-2. Simulation Result for the Second Alternative Fixed Action

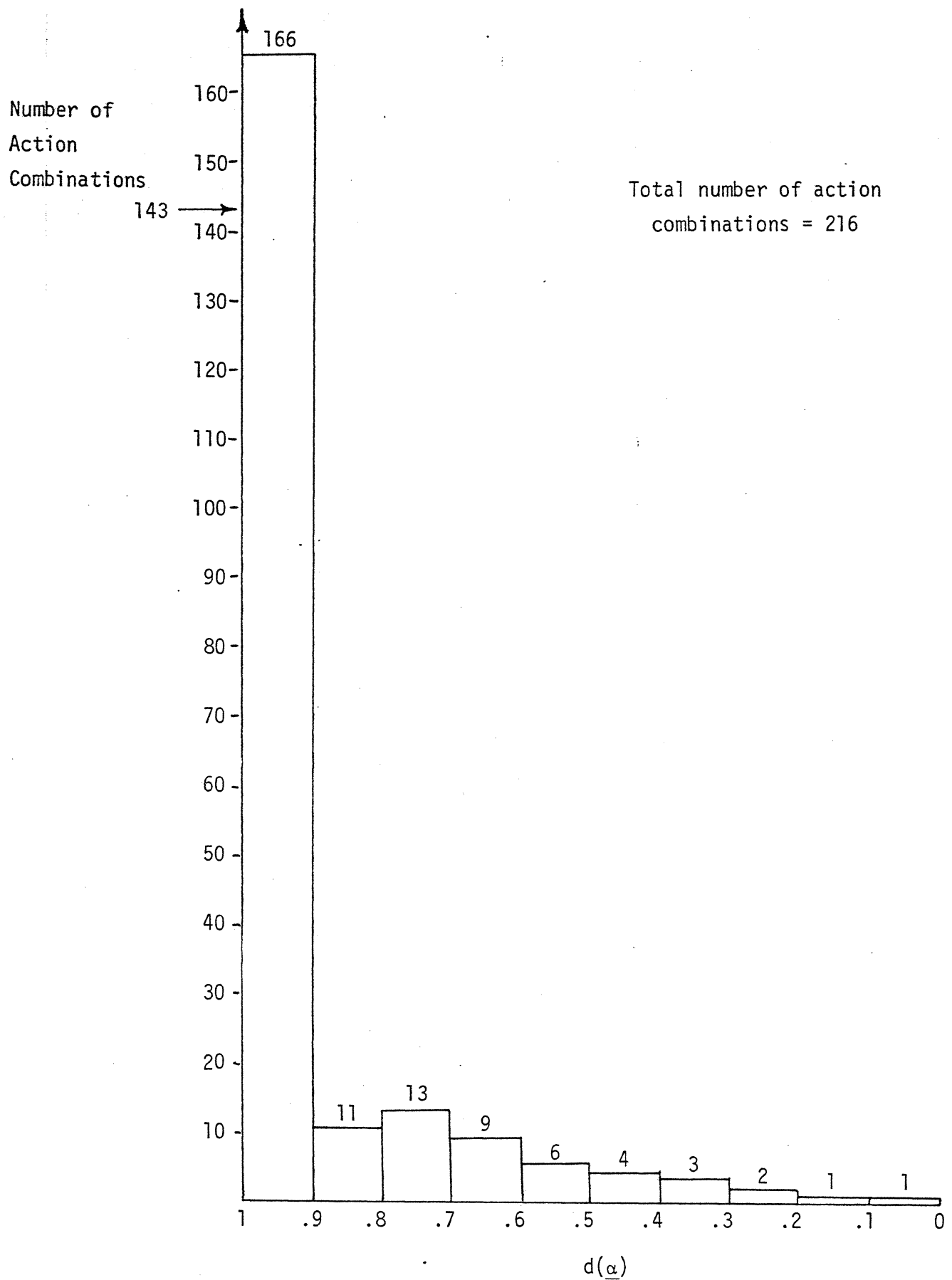


Figure 2-3. Simulation Result for the Third Alternative Fixed Action

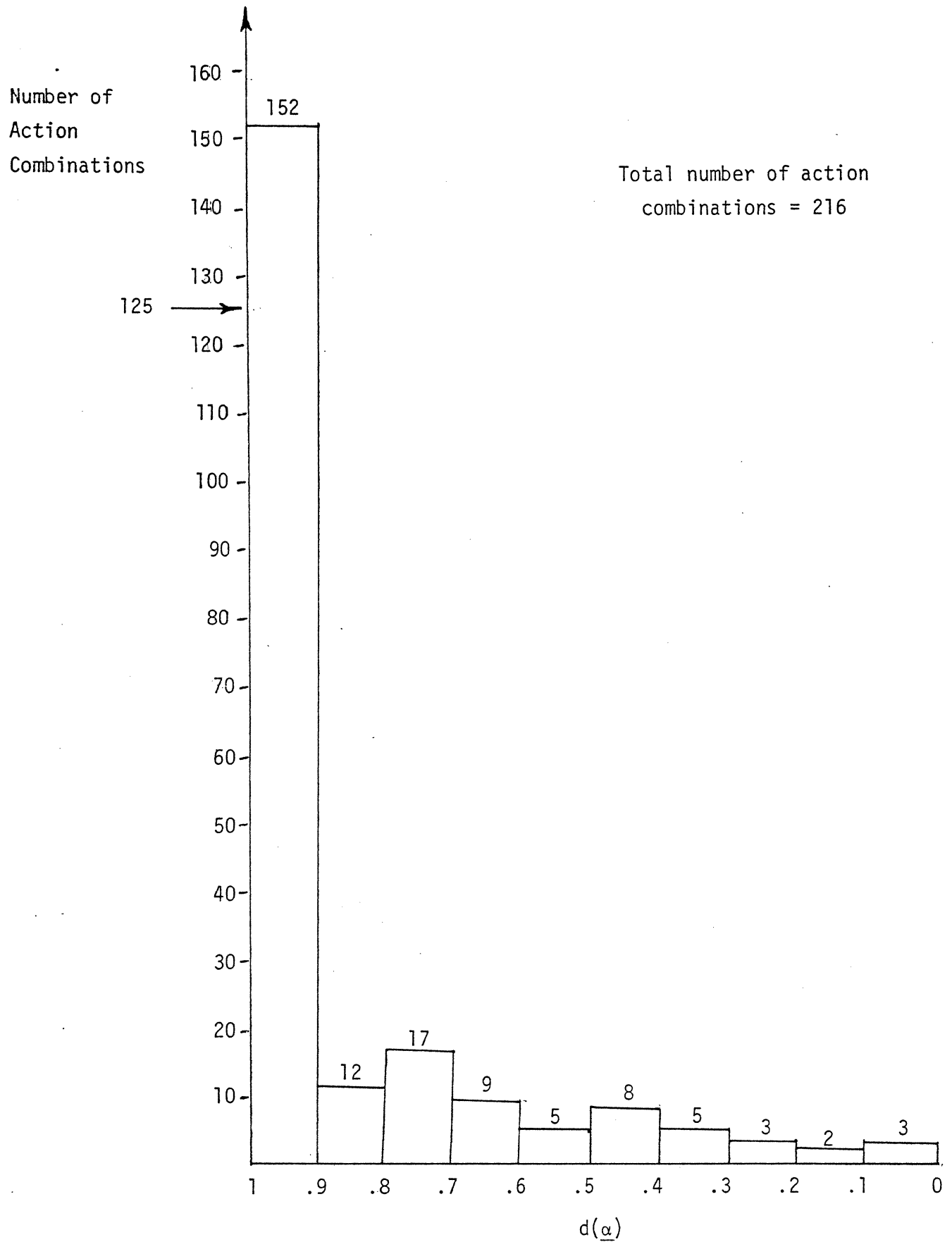


Figure 2-4. Simulation Result for the Fourth Alternative Fixed Action

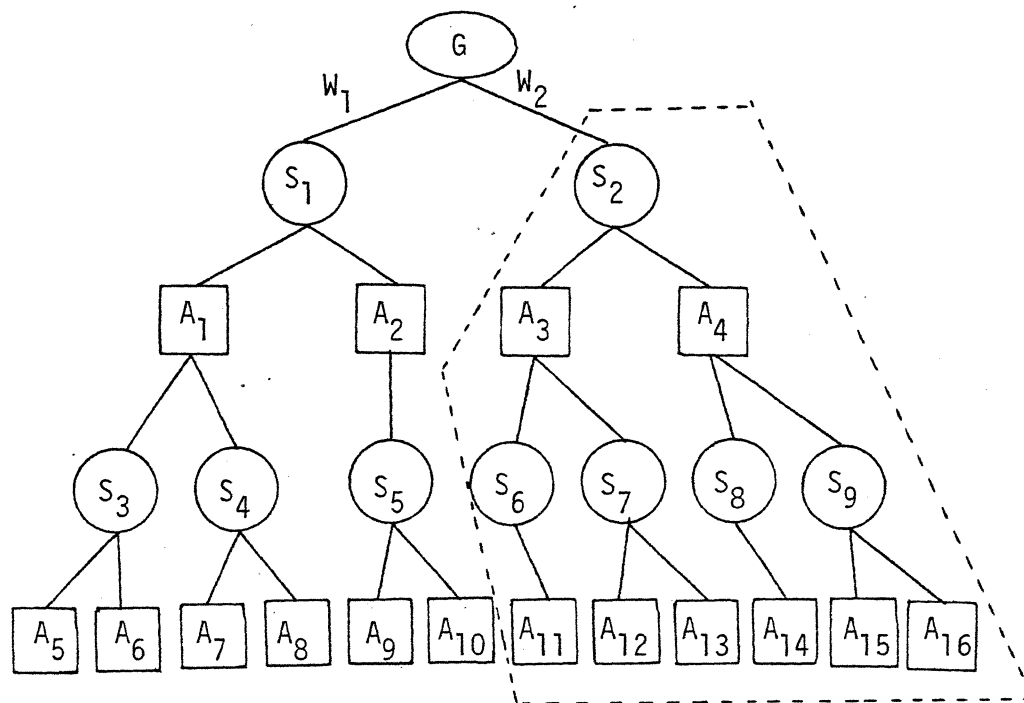


Figure 2-5. A Sample Two-Level Goal-Directed Graph
(Side Effects Are Not Shown on the Graph for Simplicity)

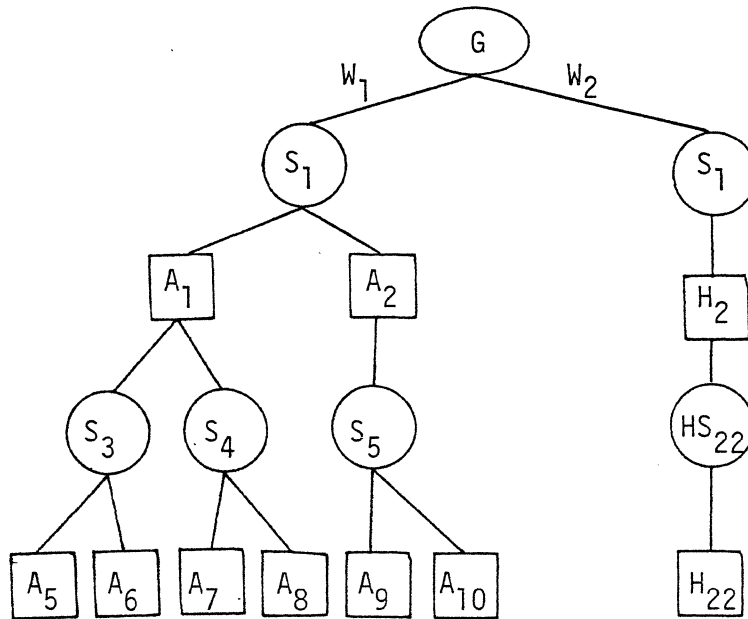
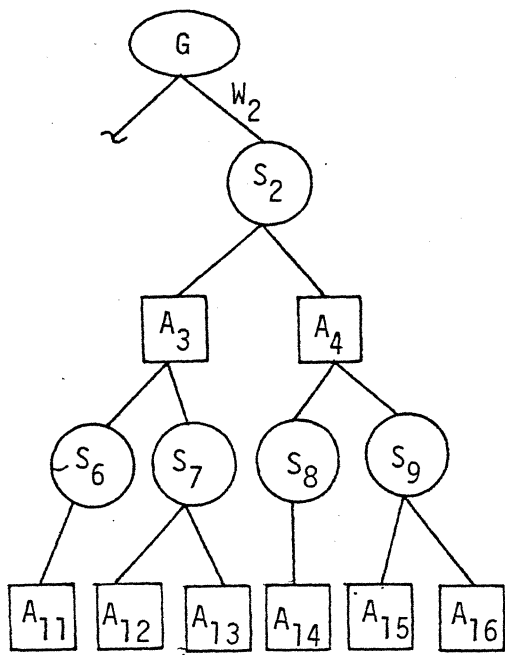
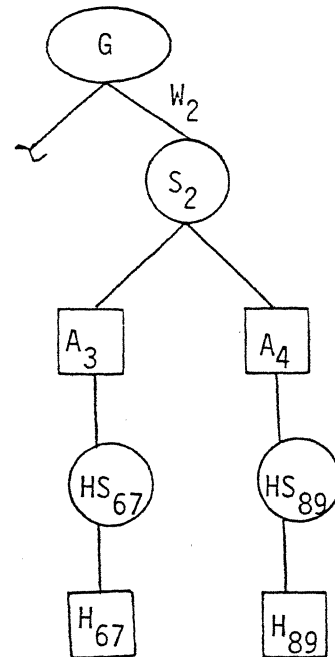
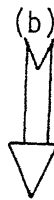
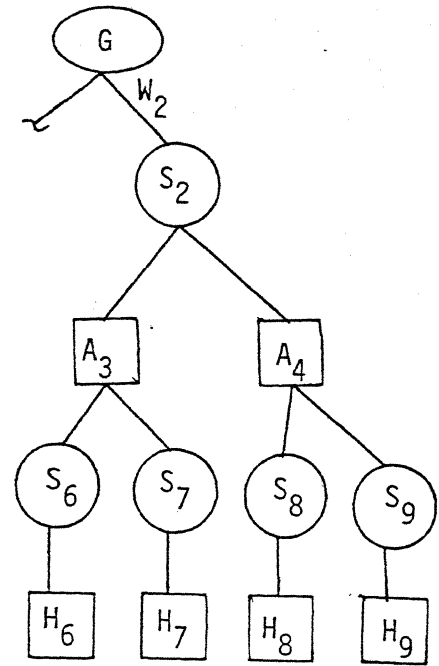
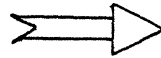


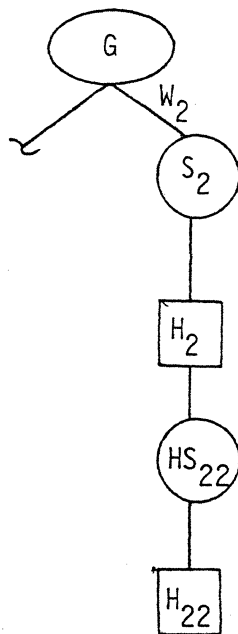
Figure 2-6. Goal-Directed Graph Reduction for Identifying
Local Optimal Action Under S_1



(a)



(c)



(d)

Figure 2-7. Graph Conversion Process

of the lower level subgoals. The values of subgoals, emerging from a common action, are fixed at the value equal to the product of the values of the original subgoals (conversion of b to c). This is equivalent to the exact calculation under the assumption of δ -functions all straight lines emerging from the origin with a 45 degree slope. The process can be shown on the graph by replacing the subgoals with a virtual subgoal by the calculated value. Note that during the simulation, since the values of the higher level actions were being generated by a random variable, there was no need to calculate the value of the virtual subgoals. Therefore, the simulation was not based on assuming any particular δ -function. The virtual subgoals are used to facilitate aggregation of side effects. The side effects of the new virtual actions (H_{67} and H_{89} in Figure 2-7) are calculated as follows (conversion of c to d):

$$S(H_N) = 1 - \prod_{i=1}^k [1 - S(H_{oi})]$$

where H_N is combined virtual action and the H_{oi} 's are virtual actions being combined.

By repeating the process, the graph of Figure 2-5 is converted to the one of Figure 2-6. Then local optimal action plans are calculated in the manner defined earlier. As in the case of one level graphs, the result in here also confirmed the superiority of the third fixed action alternative. Since the execution time for the simulation, in this case, was very long, the result was limited to only eight points which does not provide enough data for constructing meaningful bar charts.

2.4. Optimization Based on First Order Approximation of Side Effects

The required optimization can also be substantially reduced if the impact of side effects of actions on the degree of attainment of other subgoals would combine additively. Our choice of the multiplicative model instead was based on

the belief that people perceive the side effect of an action to depend on the degree of effectiveness of other actions taken simultaneously. For example, the major goal of realizing a healthy economy may be perceived, in a particular case, to be attainable by maintaining high employment and low inflation (Figure 2-8). Among other actions "subsidizing businesses" and "reducing business and inventory taxes" are proposed as alternative means to cause an increase in employment, while "increasing interest rate" and "reducing public expenditures" are viewed as ways to lower inflation. According to this model, although "increasing interest rate" enhances the level of attainment of "low inflation", its implementation has an adverse effect on the other subgoal "high employment". Here, the degree of the adverse effect is more naturally expressed by the percentage reduction in the effectiveness of the subgoal. In the example of Figure 2-8, "increasing interest rate" has a side effect, reducing the level of attainment of the subgoal "high employment" by 30 percent.

According to this model, if the degree of effectiveness of the action selected under the first subgoal is E_1 and the adverse impact of the action selected under the second subgoal with respect to the first subgoal is E_2^1 (Figure 2-9), then the level of attainment of the first subgoal (V_1) will be:

$$V_1 = E_1 - E_1 \cdot E_2^1 = E_1 (1 - E_2^1)$$

Since the required optimization effort in such a model is very high, the possibility of reducing it by employing a first order additive approximation has been investigated.

As shown in Figure 2-10, the line L represents the multiplicative model $V_1 = E_1 (1 - E_2^1)$ while the dotted line represents the additive approximation. It is parallel to the line $V_1 = E_1$ drawn from a representative point (\bar{E}_1) on L. The additive model is expressed by:

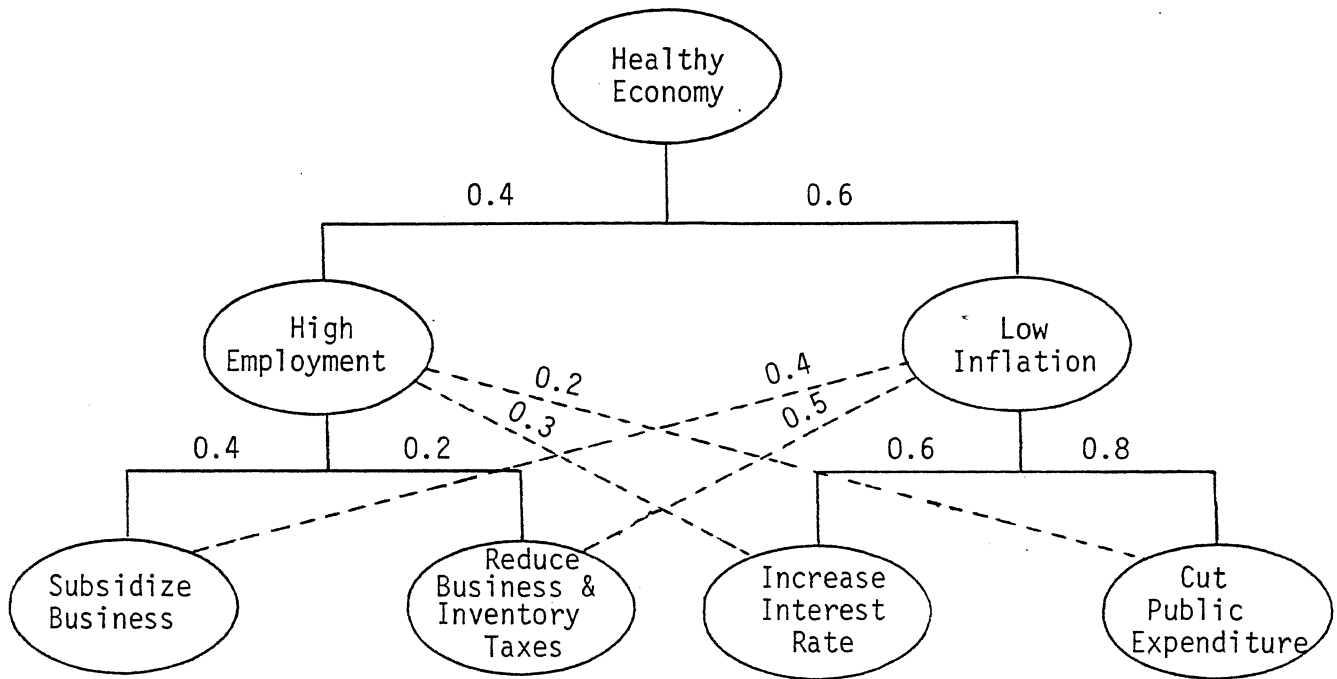


Figure 2-8. A Sample Goal-Directed Graph

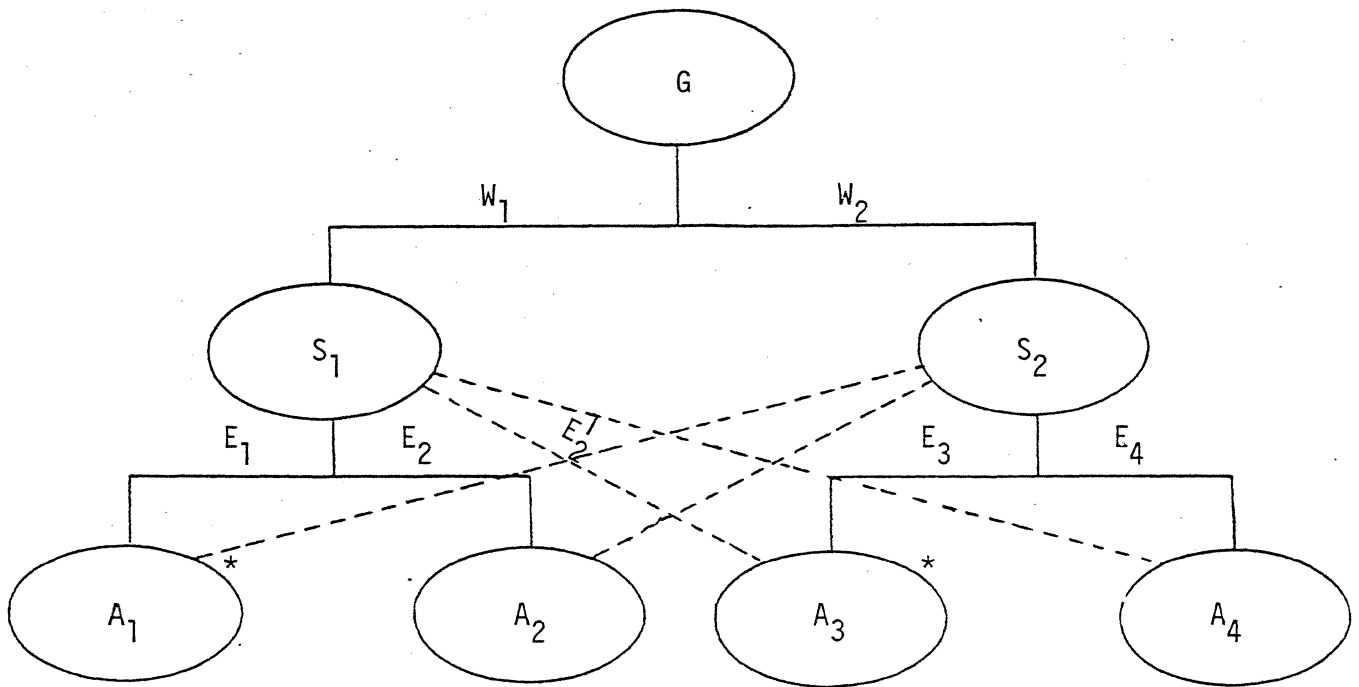


Figure 2-9. Structure of the Sample Goal-Directed Graph

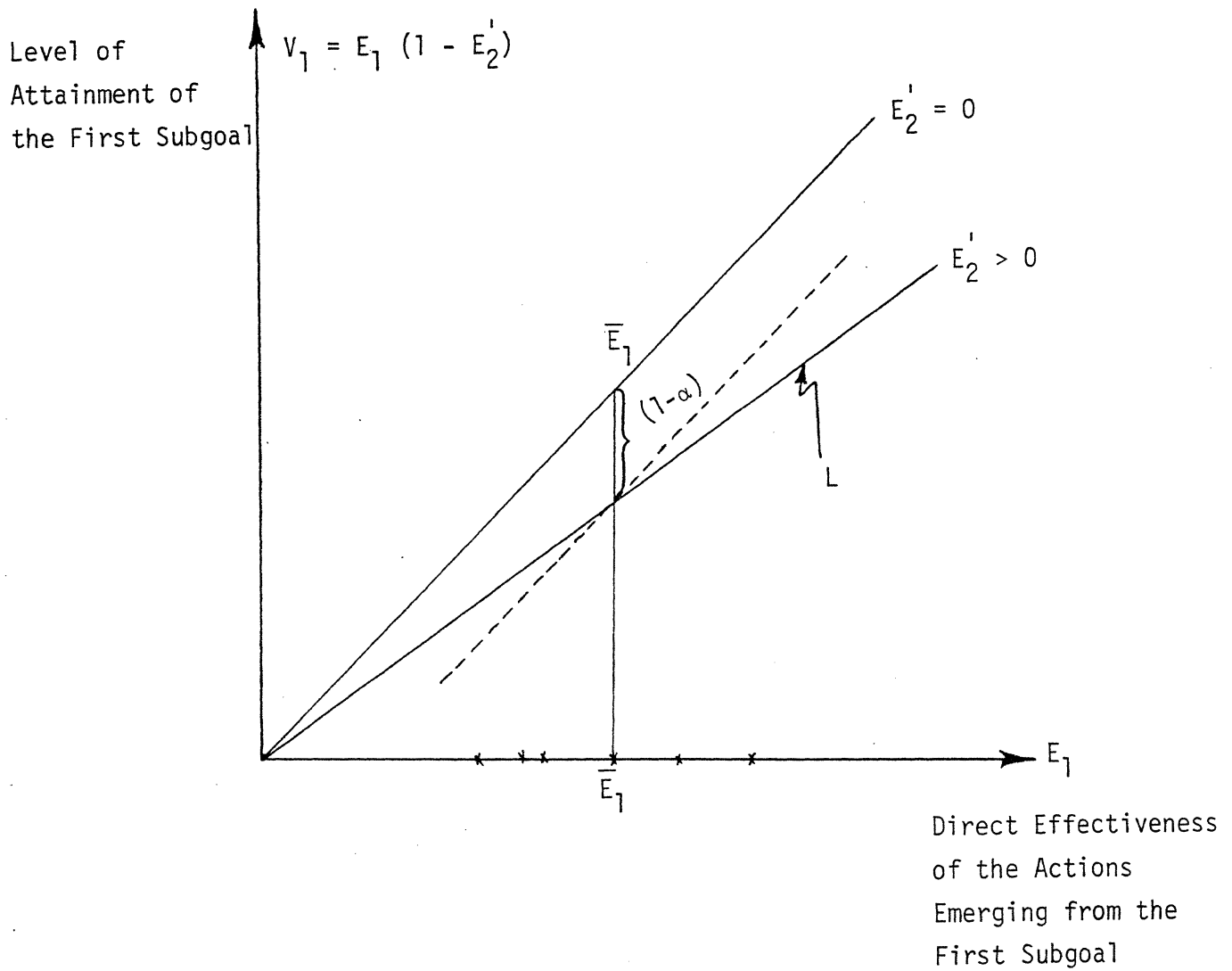


Figure 2-10. First Order Linear Approximation Model for Side Effects

$$V_1 = E_1 - (1 - \alpha)$$

where $\alpha = 1 - \bar{E}_1 E_2^1$

The accuracy of the model also depends on the selection of the representative point \bar{E}_1 , and would increase when \bar{E}_1 is chosen close to the effectiveness of the action which will be ultimately chosen.

Since the chosen action remains unknown at the time the additive model is constructed, we chose \bar{E}_1 to be the weighted average of the effectiveness of the actions under the given subgoal. Since the likelihood of eventually choosing an action increases with its effectiveness, we chose the normalized effectiveness as the weight associated with this action.

The accuracy of the model also depends on the magnitude of the side effects. For sufficiently small side effects, the model provides an adequate representation. If E_2^1 and E_3^1 are side effects of the actions emerging from other subgoals, then according to the exact model:

$$\begin{aligned} V_1 &= E_1 (1 - E_2^1) (1 - E_3^1) \\ &= E_1 (1 - E_2^1 - E_3^1 + E_2^1 E_3^1) \end{aligned}$$

With E_2^1 and E_3^1 sufficiently small we have:

$$V_1 \cong E_1 (1 - E_2^1 - E_3^1)$$

which confirms with the linear model.

The additive model results in a substantial reduction of the required optimization effort since, for a single level graph, the optimal action combination can be identified in one single iteration.

3.0. DIALOGUE MANAGEMENT

3.1. Motivation

The purpose of constructing a goal-directed graph is to provide a means for estimating the relative value of alternative ways of accomplishing the major goal, while providing aiding in generation of those alternatives. The degree of attainment of the major goal provided by each alternative action plan (strategy) is computed by assessing values of different graph elements and then rolling these values back through the graph. The rollback value that is obtained for degree of attainment of the major goal provided by each alternative action plan (strategy) is then a measure of the utility of that action plan (strategy).

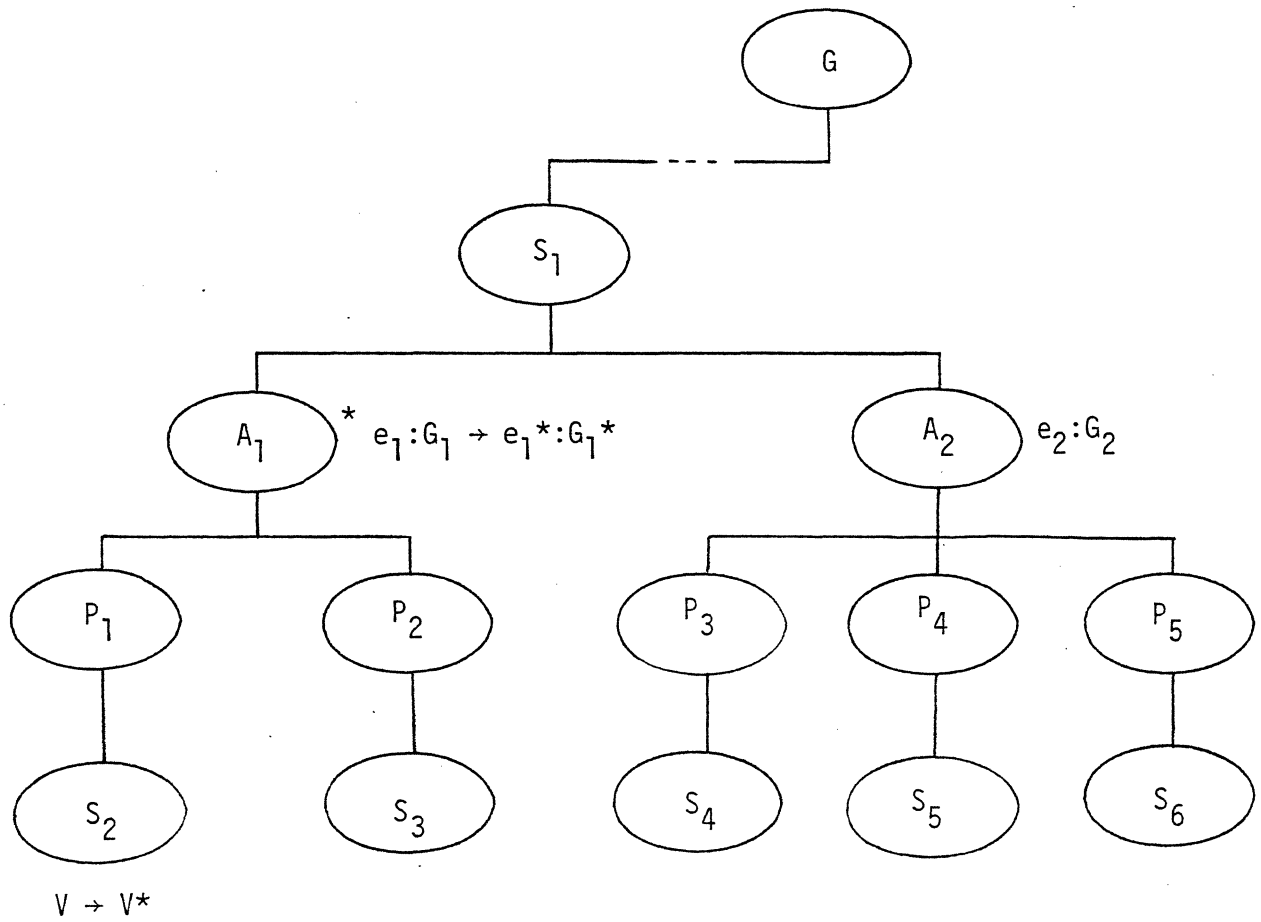
Beside aiding in generation of richer sets of alternative action plans, the time consuming effort of a goal-directed graph construction is justified by the belief that the utilities computed by rolling back the goal-directed graph are more valid estimates than those which would be produced through direct elicitation of the utilities of each alternative action plan. Suppose, however, that at each subgoal node the decision maker is asked, prior to the construction of the complete goal-directed graph, to provide assessments of the maximum degree of attainment a specific subgoal would achieve if the complete goal-directed graph were developed and solved. This assessment is expected to be generated on the basis of the knowledge and experience of the decision maker concerning similar issues. However, since he is uncertain about these degrees and is incapable of mentally manipulating the knowledge he possesses, the assessments could not be provided as an exact point estimate; they rather have to be defined as random variables in the form of probability distributions. The value of resolving the uncertainty regarding the rollback value of each alternative action plan could then be computed using the standard value of information calculation of decision analysis (see Merkhofer, et al., 1977). Since

constructing the complete goal-directed graph would be instrumental in resolving this uncertainty, the value computed for resolving uncertainty on the rollback value for a given subgoal can be interpreted as the expected value of further analysis along the path emerging from the subgoal. The value of analysis concept can then be used to guide the expansion of a goal-directed graph structure by selecting for expansion the node with the highest value of analysis.

A value of analysis can be assigned to each terminal subgoal node in a goal-directed graph structure which reflects the worth of focusing attention on the problem of planning the implementation of this subgoal. As an example, consider the incomplete goal-directed graph presented in Figure 3-1. This graph is considered incomplete since it is recognized by the user that the levels of attainment of the terminal subgoals (i.e., S_2 , S_3 , S_4 , and S_5) are uncertain, thus requiring further analysis.

An incomplete goal-directed graph such as the one presented in Figure 3-1 and the values assigned to its nodes are only approximations to the complete graph. The decision maker approximates the degrees of attainment of terminal subgoals by mentally manipulating alternative plans which may lead to its realization. Although the decision maker is uncertain about what the rollback values corresponding to the terminal subgoals would have been, were the graph expanded completely, he may be able to quantify his uncertainty by specifying a range or a distribution for that value. The terminal subgoals in the simplified graph that have the greatest need for expansion are those nodes for which the value of resolving the current uncertainty on true rollback value is the highest. Thus, the value of analysis concept can be used to recommend nodes in an existing goal-directed graph expansion.

The process of structuring a goal-directed graph proceeds as follows. First, an estimate for the uncertainty in the provisional value of each terminal



- v: the provisional value of the subgoal
- v*: the true value of the subgoal would be resulted by complete analysis of the subgoal
- y: denotes already satisfied preconditions

Figure 3-1. An Incomplete Goal-Directed Graph

subgoal node is elicited from the decision maker. Then, based on the elicited estimates, the value of analysis for each terminal subgoal is calculated. Finally, the subgoal with the highest value of analysis will be selected for expansion.

3.2. Calculation of Expected Value of Analysis

When the decision maker estimates the provisional value (V) of a specific subgoal (e.g., terminal subgoal S_2 in Figure 3-1), he crudely considers a set of relevant actions and their associated modes and preconditions, then he derives his assessment of the provisional value based on the level of attainment of the subgoal provided by the set of actions. Therefore, in absence of a deeper analysis of the subgoal, the decision maker believes that he will be able to implement the set of actions leading to a level of attainment roughly equal to V , for the subgoal.

Based on the above assumption, the expected value of analysis (EVA) for a terminal subgoal is defined as following:

$$EVA = E_{V^*} [G(V^*, V^*) - G(V, V^*)]$$

where $E_{V^*}(\cdot)$ stands for the expected value with respect to the random variable V^* , and V and V^* designate the provisional value and the true value of the level of attainment of the subgoal, respectively; $G(V_1, V_2)$ denotes the level of attainment of the major goal assuming that actions are selected believing that V_1 is the degree of attainment of the subgoal, while in reality V_2 is its true value.

3.2.1. EVA Assuming Linear Propagation Rule

Two different situations are conducted for: (1) the terminal subgoal, for which the value of analysis is being calculated, is a successor of an action belonging to the action strategy so far recognized as the most effective one,

and (2) the terminal subgoal is not a successor of any action belonging to the most effective action strategy. Each of the two possibilities are analyzed in the following.

CASE 1: The terminal subgoal, subject to value of analysis calculation, is a successor of a most effective local action.

In this case the action remains a part of most effective action strategy unless the true value, V^* , is sufficiently low to make another action, emerging from the same parent subgoal, become relatively more effective (i.e., resulting higher G). Since only the effectiveness of the most effective action is subject to change, the most likely candidate for becoming more effective is the presently second most effective action emerging from the same subgoal. If we denote the values associated to the most effective action by subscript 1 and those associated to the second most effective action by subscript 2, then the amount by which the provisional value, V , must change to cause a switch in the most effective action ($\Delta < 0$) will be:

$$\Delta = \frac{G_2(V, V^*) - G_1(V, V^*)}{w}$$

where w is the slope of the linear path weight function which expresses the relationship between the subgoal and the major goal. The value of w will be computed by nested multiplication of the individual propagation coefficients along the path from the subgoal to the major goal.

Changes in the level of attainment of the major goal (ΔG) due to variation in an action (which itself leads to further analysis) is equal to:

$$\Delta G = G(V^*, V^*) - G(V, V^*) \quad -$$

Since the true value, V^* , is a random variable, there is a probability, P , of V^* being small enough to result in a switch in the most effective local action:

$$P = \text{Prob. } [V^* < V + \Delta]$$

With the above conventions, the expected value of analysis is calculated as:

$$\text{EVA} = (1 - P) E [\Delta G \mid V^* \geq V + \Delta] + PE [\Delta G \mid V^* < V + \Delta]$$

However, if $V^* \geq V + \Delta$ the most effective local action remains the same. Therefore, there will be no change in the level of attainment of the major goal.

Consequently:

$$E[\Delta G \mid V^* \geq V + \Delta] = 0$$

Thus:

$$\text{EVA} = PE[\Delta G \mid V^* < V + \Delta]$$

(ΔG varies like $w \cdot V$ with w being a gross approximation to the ratio $\frac{d\Delta G(V)}{dV}$ for a limited range of operation dV). Assuming linear propagation rule, we can write:

$$\Delta G = w(V + \Delta) - wV^* = w(V + \Delta - V^*)$$

Therefore:

$$\begin{aligned} \text{EVA} &= PW E[(V + \Delta - V^* \mid V^* < V + \Delta)] \\ &= PW (V + \Delta - m) \end{aligned}$$

where:

$$m = E[V^* \mid V^* < V + \Delta]$$

CASE 2: The terminal subgoal, subject to value of analysis calculation, is not a successor of a most effective local action.

In this case, to cause a switch of the most effective local action, the true value, V^* , must be such that it results in a degree of attainment for the major goal sufficiently large to cause the corresponding action to become the most effective. If we denote the values associated to the most effective local action by subscript 1 and those associated to the subgoal under consideration by subscript 3, then the amount by which the provisional value, V , must change in order to cause a switch in the most effective action ($\Delta > 0$) will be:

$$\Delta = \frac{G_1(V, V^*) - G_3(V, V^*)}{w}$$

where w and V^* have the same conventions described previously. Here, also, the true value, V^* , is a random variable, with a probability, q , being small enough to result in a switch in the most effective action:

$$q = \text{Prob. } [V^* > V + \Delta]$$

Therefore, the value of analysis for the subgoal is calculated as:

$$\text{EVA} = qE[\Delta G \mid V^* > V + \Delta] + (1 - q) E[\Delta G \mid V^* \leq V + \Delta]$$

However, if $V^* \leq V + \Delta$, there will be no switch in the most effective local action. Therefore, the level of attainment of the major goal remains the same. Consequently:

$$E[\Delta G \mid V^* \leq V + \Delta] = 0$$

Thus:

$$\text{EVA} = qE[\Delta G \mid V^* > V + \Delta]$$

Under the assumption of linear propagation rule, we can write:

$$\Delta G = w(V + \Delta) - wV^* = w(V + \Delta - V^*)$$

Therefore:

$$\begin{aligned} EVA &= qwE[(V + \Delta - V^*) \mid V^* > V + \Delta] \\ &= qw(V + \Delta - n) \end{aligned}$$

where:

$$n = E[V^* \mid V^* > V + \Delta]$$

3.2.2. Calculation of Δ

Due to characteristics of the δ -functions used in the propagation of the impact of preconditions and the use of the Max-function in the calculation of the level of attainment of subgoals based on the effectiveness of actions, the exact relationship between the subgoal and the major goal can be described by a piecewise linear function. Examples of piecewise linear functions governing the propagation rules in a goal-directed graph are shown in Figure 3-2.

In Figure 3-2, the value of analysis of a terminal subgoal (S_4) is being examined. The side effects of actions on the path leading to this terminal subgoal (i.e., out of A_3) are not affected by variations in its value. Side effects are activated only when the corresponding action is chosen as a result of possessing the maximum value on its mutually exclusive set. Thus, the side effects of A_3 do not contribute to variations of $G(V^*)$.

With this understanding, the direct effect E_3 of action A_3 , as a function of all possible values V_4 of its successor subgoal S_4 , can be drawn as shown in Figure 3-2. The resulting variation in the level of completion of precondition P_3 is the same as the variation in V_4 . In this case, action A_3 has only one precondition (P_3), so its effectiveness varies according to the corresponding δ -function (δ_3). The level of attainment V_3 of the predecessor subgoal S_3 is equal to the maximum of the direct effects of actions A_3 and A_4 (i.e., E_3 and E_4) multiplied by the product of the side effects I_3 of all actions impacting V_3 (i.e., coming in from outside). Since it is assumed that all other subgoals

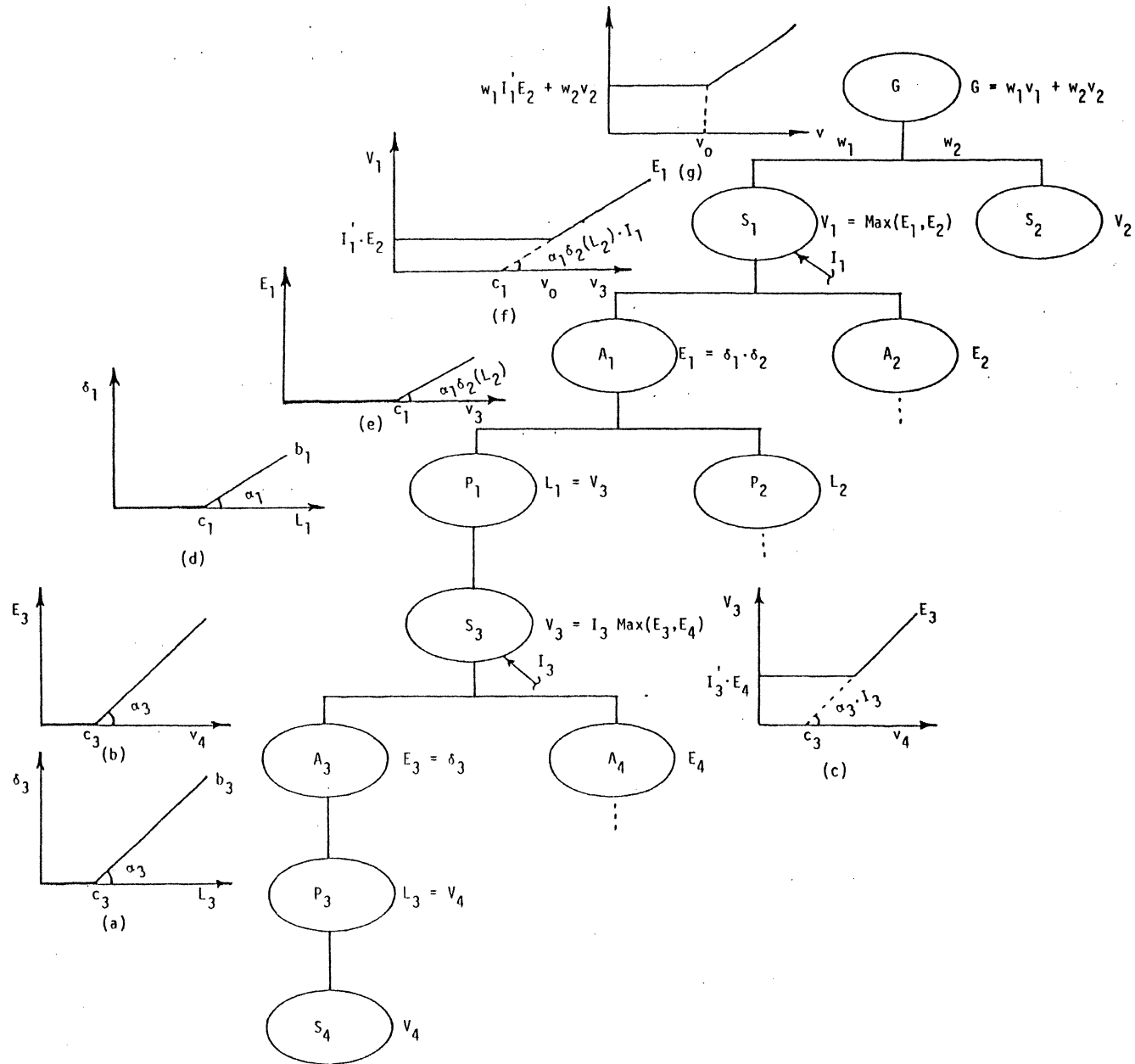


Figure 3-2. Propagation of Piecewise Linear Functions in a Goal-Directed Graph

in the graph except S_4 remain constant, the direct effect of action A_4 is constant and equal to E_4 . Therefore, V_3 as a function of V_4 can be plotted as in Figure 3-2. For small values of V_4 (which result in small values of E_3) the Max-function selects E_4 which, after multiplication by I_3 (the product of side effects of remote actions on S_3), yields the value V_3 . As V_4 increases, V_3 remains constant until the value of V_4 becomes sufficiently large to cause $E_3 > E_4$. From this point on, the value of V_3 will be equal to $E_3 \cdot I_3$. Since E_3 with respect to V_4 has a linear relationship with slope α_3 , the relationship between V_3 and V_4 , from the angular point on, will be linear with slope $\alpha_3 \cdot I_3$.

The graph V_3 versus V_4 summarized the variations in the level of attainment of a subgoal with respect to the variations in the level of attainment of a successor subgoal located at one level lower, in the goal-directed graph. In the same manner, the variations in the level of attainment of the subgoal S_1 (V_1), with respect to variations in V_3 , can be calculated and drawn for one subgoal-level higher in the graph. The only difference is that the action A_1 has more than one precondition (P_1 and P_2). Therefore, the value of its direct effect is the result of the product of the δ -function corresponding to preconditions P_1 and P_2 ($\delta_1 \cdot \delta_2$). However, since the values of other subgoals remain constant, the level of completion L_2 of precondition P_2 remains constant. Therefore, $\delta_2(L_2)$ will be a constant number modifying the function δ_1 as a multiplicative factor. Thus, E_1 versus V_3 will be of the same form as δ_1 with only the slope changed from α_1 to $\alpha_1 \cdot \delta_2(L_2)$. The Max-function used in computing the value of V_1 , and the product of side effects of actions impacting S_1 , then have the same effects as described earlier, therefore, resulting in a V_1 function versus V_3 as shown in Figure 3-2.

The propagation rule at each subgoal-level is in the form of canonical functions y_1 and y_2 shown in Figure 3-3. Each terminal subgoal is thus related

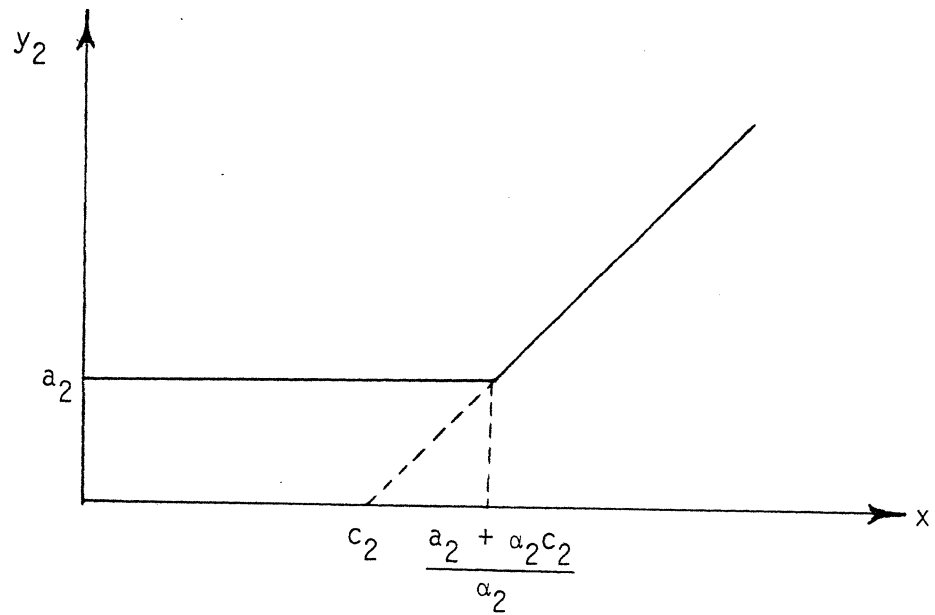
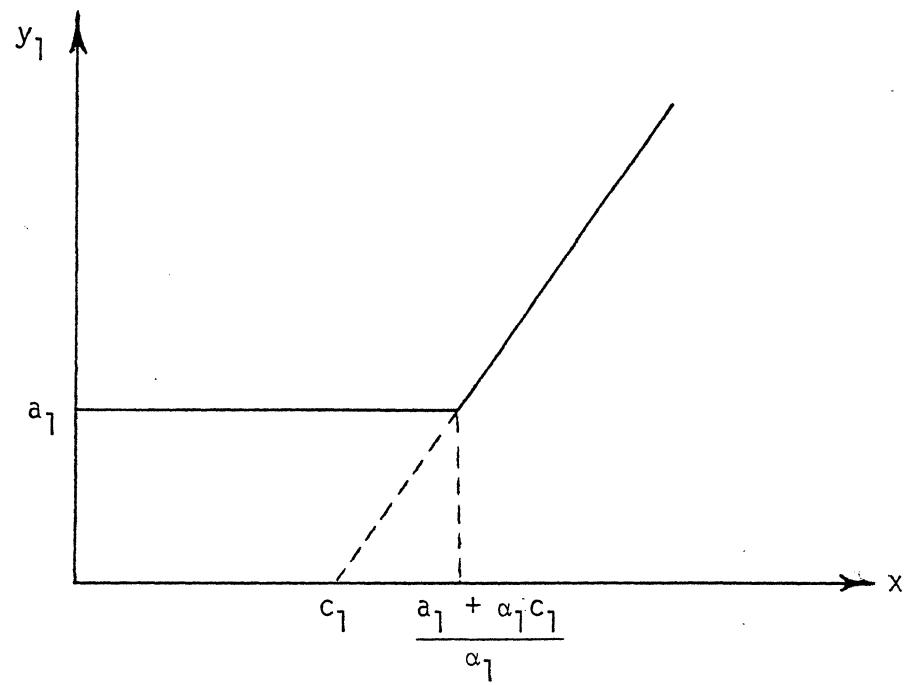


Figure 3-3. Two Typical Propagation Functions, y_1 and y_2 ,
Representing Different Subgoal Levels
of Goal-Directed Graphs

to the major goal through a path defined by the cascading series of functions of the same form. The calculation process can be systematically simplified using the fact that the cascade of two such functions will result in a continued function of the same form. To show this, consider functions y_1 and y_2 in Figure 3-3.

$$\text{If } n \leq \frac{a_2 + \alpha_2 c_2}{\alpha_2} = \frac{a_2}{\alpha_2} + c_2, \text{ then we have } y_2 = a_2.$$

$$\text{Therefore, either } a_2 \leq \frac{a_1 + \alpha_1 c_1}{\alpha_1} \text{ which results in } y_1 = a_1$$

$$\text{or } a_2 > \frac{a_1 + \alpha_1 c_1}{\alpha_1} \text{ which results in } y_1 = \alpha_1(a_2 - c_1).$$

$$\text{If } n > \frac{a_2 + \alpha_2 c_2}{\alpha_2} = \frac{a_2}{\alpha_2} + c_2, \text{ then we have } y_2 = \alpha_2(x - c_2).$$

$$\text{Therefore, either } \alpha_2(x - c_2) \leq \frac{a_1 + \alpha_1 c_1}{\alpha_1}, \text{ that is } x \geq \frac{a_1}{\alpha_1 \alpha_2} + \frac{c_1}{\alpha_2} + c_2$$

$$\text{which results in } y_1 = a_1$$

$$\text{or } \alpha_2(n - c_2) \geq \frac{a_1 + \alpha_1 c_1}{\alpha_1}, \text{ that is } x \geq \frac{a_1}{\alpha_1 \alpha_2} + \frac{c_1}{\alpha_2} + c_2$$

$$\text{which results in } y_1 = \alpha_1[\alpha_2(x - c_2) - c_1]$$

$$= \alpha_1 \alpha_2 x - \alpha_1 \alpha_2 c_2 - \alpha_1 c_1$$

Therefore, the cascade of the two functions, y_1 and y_2 , will be of the same form and equal to the one in Figure 3-4 if $\frac{a_2}{\alpha_2} + c_2 \leq \frac{a_1}{\alpha_1 \alpha_2} + \frac{c_1}{\alpha_2} + c_2$, that is if

$$a_2 \leq \frac{a_1}{\alpha_1} + c_1; \text{ or the one in Figure 3-5 if } \frac{a_2}{\alpha_2} + c_2 \geq \frac{a_1}{\alpha_1 \alpha_2} + \frac{c_1}{\alpha_2} + c_2, \text{ that is if}$$

$a_2 \geq \frac{a_1}{\alpha_1} + c_1$. Thus, after definition of the propagation functions of all subgoal-levels on the path from the terminal subgoal in question to the major goal (G),

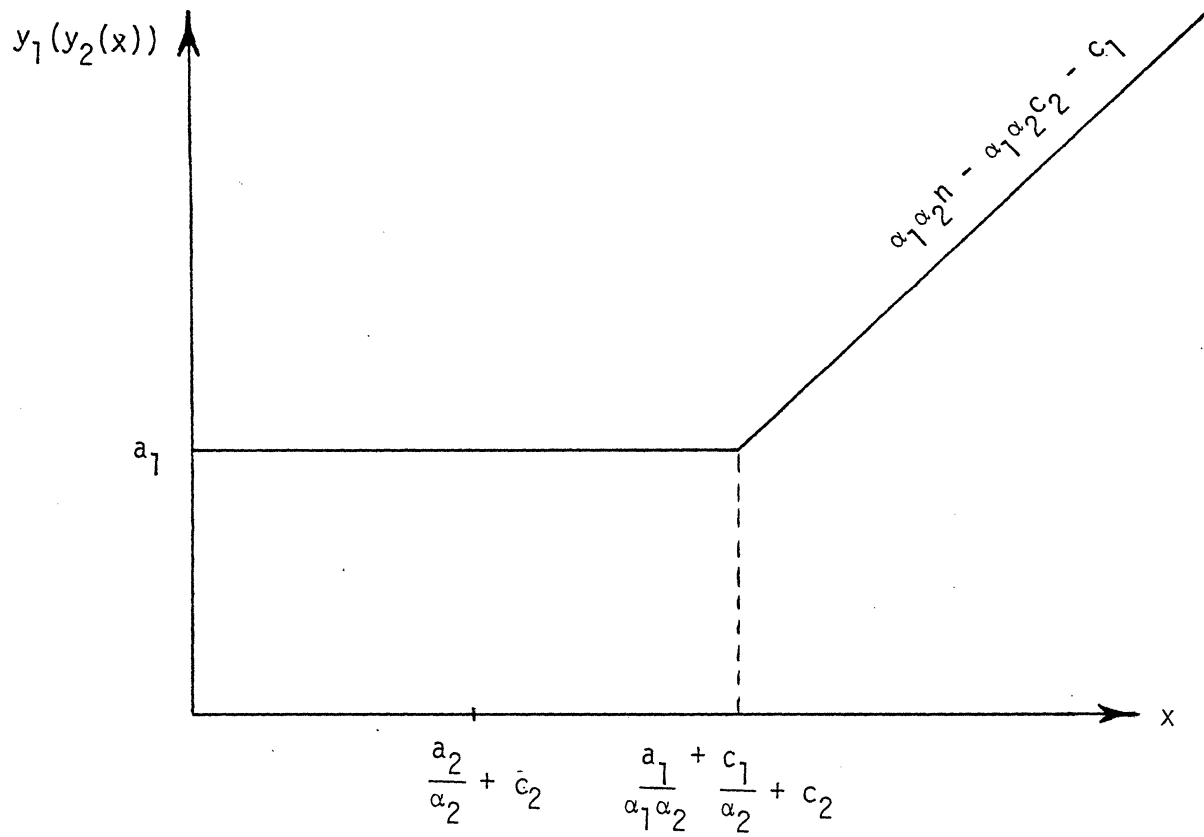


Figure 3-4. Cascade of the Two Propagation Functions,

$$y_1 \text{ and } y_2, \text{ if } a_2 \leq \frac{a_1}{\alpha_1} + c_1$$

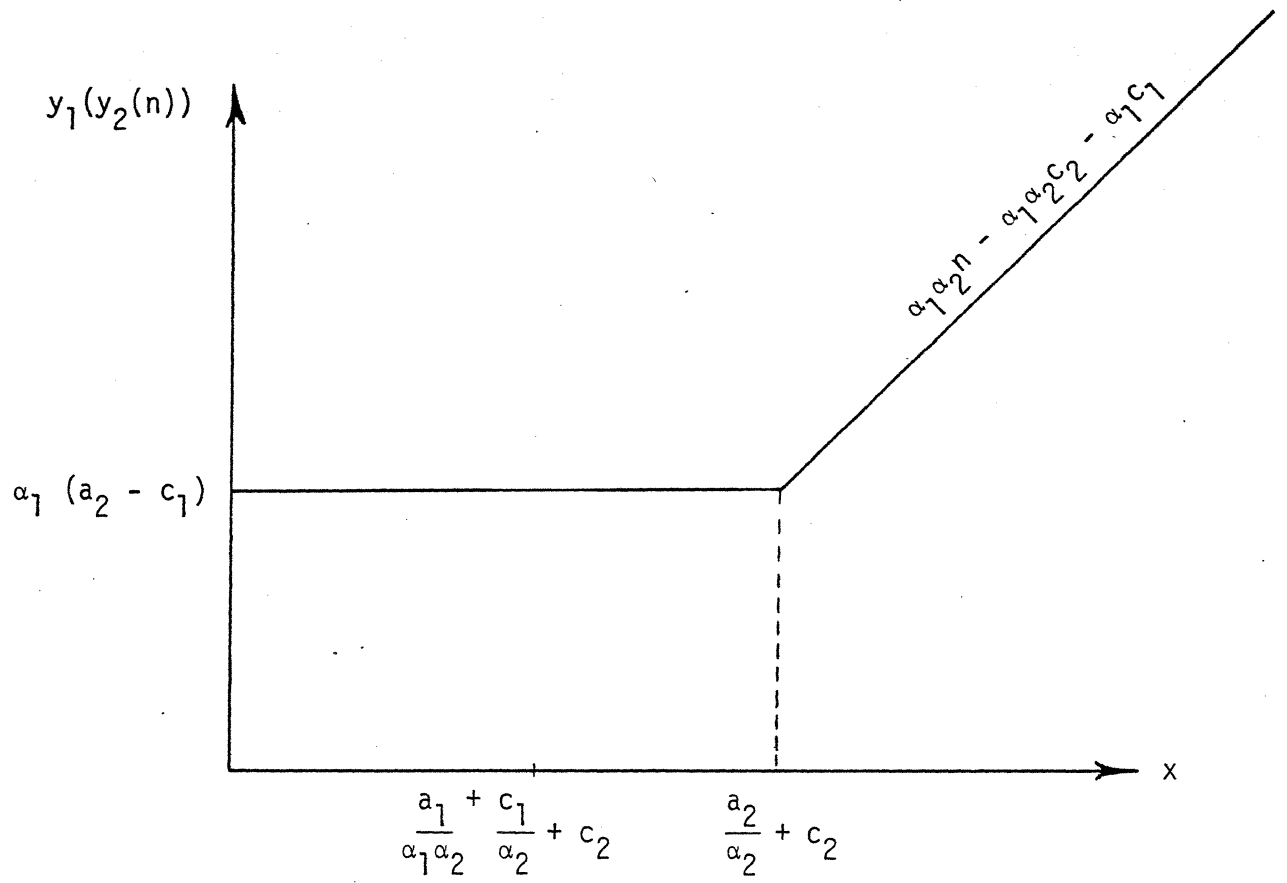


Figure 3-5. Cascade of the Two Propagation Functions,

$$y_1 \text{ and } y_2, \text{ if } a_2 \geq \frac{a_1}{\alpha_1} + c_1$$

the propagation functions along the path can be cascaded recursively, to express the exact relationship between the major goal and the terminal subgoal. At the highest level the resulting cascaded propagation function will be modified multiplicatively by the weight of the corresponding subgoal (e.g., w_1 in Figure 3-2) and additively by the weighted impact of other subgoals (e.g., $w_2 v_2$).

The value of Δ is derived directly from the modified propagation function. The point on the abscissa (Figure 3-6) corresponding to the function angular point (V_0) is equal to $V + \Delta$. Therefore subtracting the provisional value V , yields $\Delta = V_0 - V$. An example of a calculation of Δ in a cascaded path is shown in Figure 3-6.

3.2.3. Vector Representation of Propagation Function

The canonical function (Figure 3-7) can be represented by a three element vector, $\begin{pmatrix} a \\ b \\ \alpha \end{pmatrix}$; where a is equal to the constant level, $b = \frac{a + \alpha c}{\alpha}$ is the point on abscissa corresponding to the angular point, and α is the slope after the angular point. Using this vector, four operators can be defined to be used in propagating the three coefficients, completely describing the propagation function, along the path to the major goal. The four operators sufficient for this purpose are: (1) aggregation, (2) maximum, (3) cascade, and (4) summation.

The "Aggregation" operator is used for three purposes: (1) to aggregate the impact of the preconditions on the effectiveness of the corresponding predecessor action, (2) to aggregate the impact of side effects and the direct effect of actions on the level of attainment of the corresponding predecessor subgoal, and (3) to aggregate the impact of a subgoal on the major goal with its corresponding weight. The aggregation operation takes a canonical function and a number of constants and results in another canonical function. The constant, d , is a degenerate form of a canonical function expressible by $\begin{pmatrix} d \\ 0 \\ 0 \end{pmatrix}$. (Actually, the second element b can be arbitrarily any number between zero

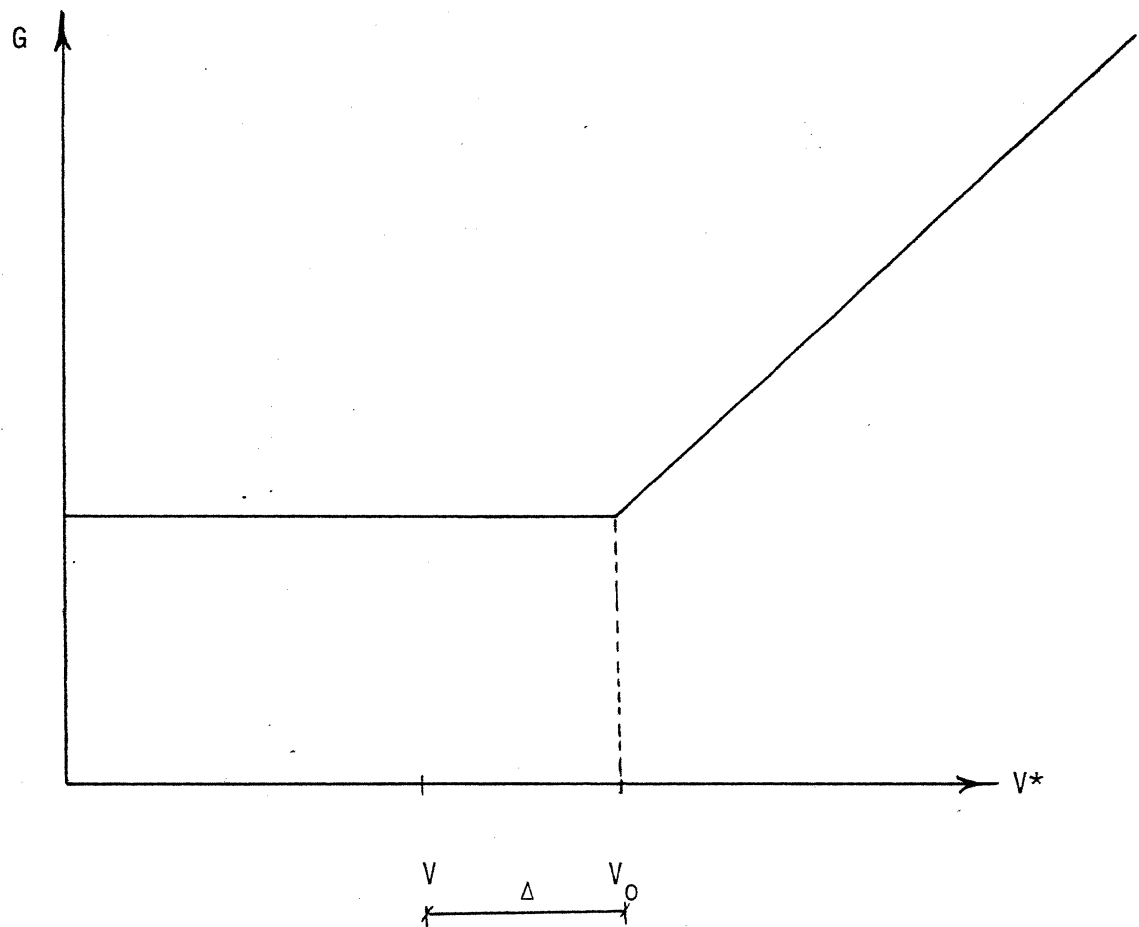


Figure 3-6. Derivation of Δ From Cascaded Propagation Function

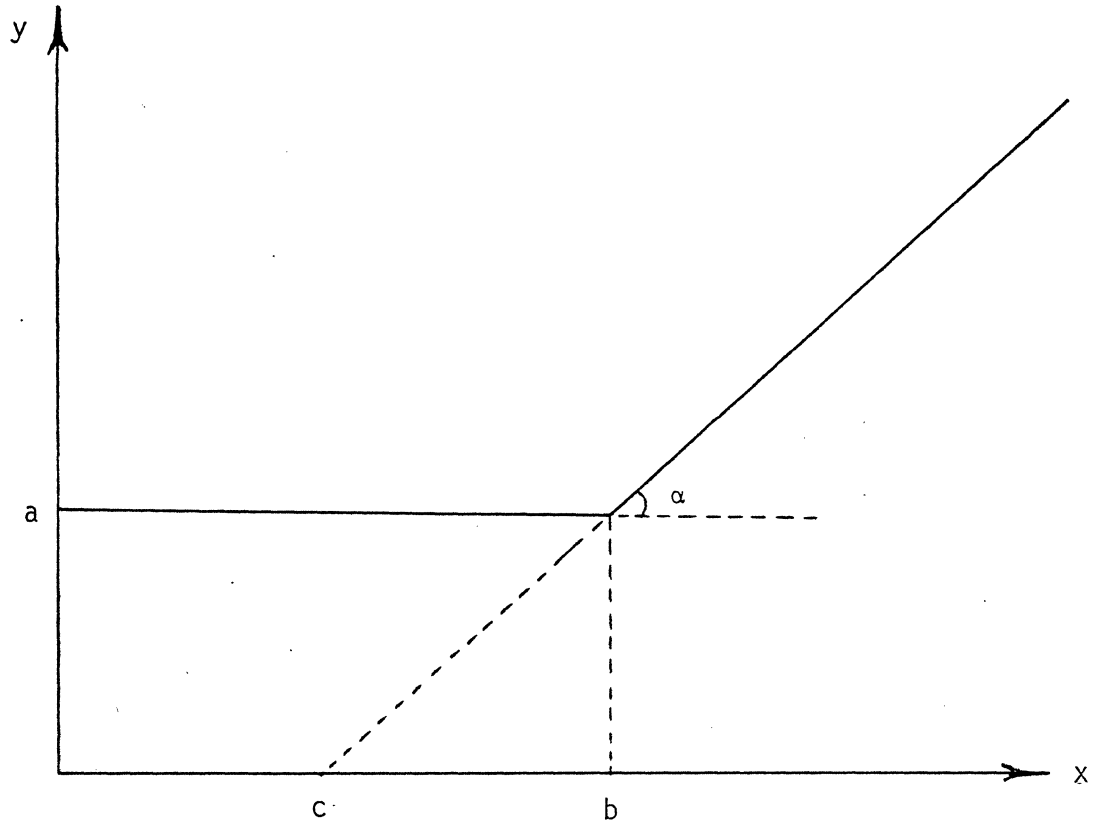


Figure 3-7. Representation of the Canonical Function by the Vector $\begin{pmatrix} a \\ b \\ \alpha \end{pmatrix}$

and one). The range and domain of the aggregation operator belongs to the set of canonical functions. The Aggregation operator is denoted by Π :

$$\Pi \rightarrow \left[\begin{pmatrix} d_1 \\ 0 \\ 0 \end{pmatrix}, \begin{pmatrix} d_2 \\ 0 \\ 0 \end{pmatrix}, \dots, \begin{pmatrix} d_i \\ 0 \\ 0 \end{pmatrix}, \dots, \begin{pmatrix} d_n \\ 0 \\ 0 \end{pmatrix}, \begin{pmatrix} a \\ b \\ \alpha \end{pmatrix} \right] = \begin{pmatrix} a & \Pi & d_i \\ & i & \\ & b & \\ \alpha & \Pi & d_i \\ & i & \end{pmatrix}$$

The "Maximum" operator is used to express the level of attainment of subgoals based on the effectiveness of the corresponding actions. Since the effectiveness of all actions except one remain constant, the maximum operator works on a canonical function and a number of constants and results in another canonical function. The Maximum operator is denoted by Max :

$$\text{Max} \rightarrow \left[\begin{pmatrix} d_1 \\ 0 \\ 0 \end{pmatrix}, \begin{pmatrix} d_2 \\ 0 \\ 0 \end{pmatrix}, \dots, \begin{pmatrix} d_i \\ 0 \\ 0 \end{pmatrix}, \dots, \begin{pmatrix} d_n \\ 0 \\ 0 \end{pmatrix}, \begin{pmatrix} a \\ b \\ \alpha \end{pmatrix} \right] = \begin{cases} \begin{pmatrix} \text{Max } d_i \\ \frac{\text{Max } d_i + \alpha b - a}{\alpha} \\ \alpha \end{pmatrix} & \text{if } a \leq \text{Max } d_i \\ \begin{pmatrix} a \\ b \\ \alpha \end{pmatrix} & \text{if } a > \text{Max } d_i \end{cases}$$

Once the propagation functions of all subgoal levels have been expressed in the form of vectors representing canonical functions, the "Cascade" operator is used to combine the functions along the path to the major goal. This binary operator takes two canonical functions and results in the cascading of the two functions which is also in canonical form. Since $f_1(f_2(x))$ is not equal to $f_2(f_1(x))$, the order of the arguments in a cascade operation is significant. If the vectors $\begin{pmatrix} a_1 \\ b_1 \\ \alpha_1 \end{pmatrix}$ and $\begin{pmatrix} a_2 \\ b_2 \\ \alpha_2 \end{pmatrix}$ represent the canonical functions $f_1(x)$ and $f_2(x)$,

then, using \uparrow to denote cascade operation $f_1(f_2(x))$, we have:

$$\begin{pmatrix} a_1 \\ b_1 \\ \alpha_1 \end{pmatrix} \uparrow \begin{pmatrix} a_1 \\ b_2 \\ \alpha_2 \end{pmatrix} = \begin{cases} \begin{pmatrix} a_1 \\ 1/\alpha_2 (b_1 - a_2) + b_2 \\ \alpha_1 \alpha_2 \end{pmatrix} & \text{if } a_2 \leq b_1 \\ \begin{pmatrix} \alpha_1 (a_2 - b_1) + a_1 \\ b_2 \\ \alpha_1 \alpha_2 \end{pmatrix} & \text{if } a_2 \geq b_1 \end{cases}$$

The "Summation" operator is used at the highest level of the goal-directed graph to add the impact of other first-level subgoals to the impact of the one under consideration with the varying level of attainment. (Since the level of attainment of all terminal subgoals, except one, remains constant, all other first-level subgoals will be also constant). This operator takes a canonical function and a number of constants and results in another canonical function. The summation operator is denoted by Σ :

$$\Sigma \left[\begin{pmatrix} d_1 \\ 0 \\ 0 \end{pmatrix}, \begin{pmatrix} d_2 \\ 0 \\ 0 \end{pmatrix}, \dots, \begin{pmatrix} d_i \\ 0 \\ 0 \end{pmatrix}, \dots, \begin{pmatrix} d_n \\ 0 \\ 0 \end{pmatrix}, \begin{pmatrix} a \\ b \\ \alpha \end{pmatrix} \right] = \begin{pmatrix} a + \Sigma d_i \\ b \\ \alpha \end{pmatrix}$$

Since constants are also special cases of canonical functions, both the range and the domain of the four operators are canonical functions. Therefore, the set of canonical functions is closed under the four operations.

The four operators are used to propagate the canonical functions represented in vector format. However, since the second element of the final resulting vector corresponds to the angular point and is equal to $V + \Delta$, these operators can be considered as means of propagating Δ .

3.2.4. Δ Algorithm

In summary, the algorithm for calculating Δ is as follows:

Step 1: Identify the number of subgoal levels (n) from the subgoal in question to the major goal. (e.g., $n = 3$ for S_4 in Figure 3-2).

Step 2: Calculate the vector representing the subgoal level ($n-1$) propagation function as:

$$\begin{pmatrix} a_{n-1} \\ b_{n-1} \\ \vdots \\ \alpha_{n-1} \end{pmatrix} = \begin{pmatrix} I \cdot \text{Max } E_i \\ \frac{(1-c)\text{Max } E_i + c \cdot \pi \delta_i(L_i)}{\pi \delta_i(L_i)} \\ \frac{I \cdot \pi \delta_i(L_i)}{1-c} \end{pmatrix}$$

where:

$\begin{pmatrix} 0 \\ c \\ 1/c \end{pmatrix}$ represent the δ -function of the parent precondition with respect to the terminal subgoal in question.

$\delta_i(L_i)$'s are the values of other sister-preconditions calculated at completion levels L_i equal to the mid-point of the range of level attainment of the corresponding subgoals.

E_i 's are the effectiveness of all the actions sister to the immediate predecessor action of the subgoal in question.

I is the product of all side effects impacting the parent subgoal at one level higher.

Step 3: For i ($n-2 \geq i \geq 1$) in descending order, find the vector relating the parent subgoal at level i to the subgoal in question recursively: If the propagation function at subgoal level i is

represented by $\begin{pmatrix} a_i \\ b_i \\ \alpha_i \end{pmatrix}$ and the vector relating the parent subgoal level $i-1$ to the subgoal in question is represented by $\begin{pmatrix} a_n^{i-1} \\ b_n^{i-1} \\ \alpha_n^{i-1} \end{pmatrix}$, then:

$$\begin{pmatrix} a_n^i \\ b_n^i \\ \alpha_n^i \end{pmatrix} = \begin{pmatrix} a_i \\ b_i \\ \alpha_i \end{pmatrix} + \begin{pmatrix} a_n^{i-1} \\ b_n^{i-1} \\ \alpha_n^{i-1} \end{pmatrix}$$

The vector relating the parent subgoal at level $n-1$ to the subgoal in question is:

$$\begin{pmatrix} a_n^{n-1} \\ b_n^{n-1} \\ \alpha_n^{n-1} \end{pmatrix} = \begin{pmatrix} a_{n-1} \\ b_{n-1} \\ \alpha_{n-1} \end{pmatrix}$$

Step 4: Calculate the vector relating the major goal to the subgoal in question:

$$\begin{pmatrix} a \\ b \\ \alpha \end{pmatrix} = \sum_j \left\{ \sum_{i \neq j} w_i v_i \Rightarrow \left[I_j w_j, \begin{pmatrix} a_n^i \\ b_n^i \\ \alpha_n^i \end{pmatrix} \right] \right\}$$

where:

I_j - the product of all side effects impacting the parent subgoal at the first level.

w_j - the weight of the parent subgoal at the first level.

w_i 's - the weights of other subgoals at the first level.

v_i - the level of attainment of other subgoals at the first level based on all other terminal subgoals being maintained at a level equal to the midpoint of the elicited range.

Step 5: b represents $v + \Delta$. Therefore calculate Δ as:

$$\Delta = b - v$$

where v is the midpoint of the elicited range of level of attainment for the subgoal in question.

Δ is then used in the value of analysis formulas as described in Section 3.2.1.

At this point in order to apply the formula for EVA, one still needs to calculate the parameter w (the path weight parameter). However, difficulties in estimating w , combined with several shortcomings of the EVA criterion led us to select an alternative criterion which requires only the calculation of Δ . This alternative will be discussed in the next section.

3.3. An Alternative to the Expected Value of Analysis

Problems may arise in case of assessing the range of variability of V^* too narrow. Even though such an assessment may reflect the high confidence of the decision maker in his assessment of the provisional value, it is also possible that it results from too much concentration on a specific possibility which may lead to other values for the subgoal (potentially outside the assessed range). Such a situation will cause an erroneous expected value of analysis too small, or even in some cases equal to zero. This phenomena is portrayed in Figures 3-8 and 3-9.

Similar inaccuracies may result from different causes. Since the impacts of subgoals are quantified by numbers smaller than one (weight factors) at each

if $EVA = wp(v+\Delta-m) = 0$

since $w \neq 0$

then,

either $R = 0$
or $v+\Delta-m = 0$

Neither case will
occur unless:

$$|\Delta| > v - v_{\min}$$

Therefore, the graphic
representation for
 $EVA = 0$ will be:

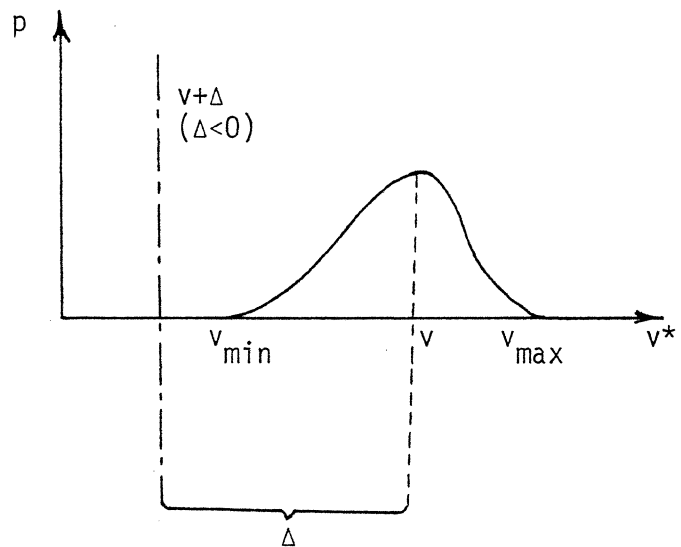
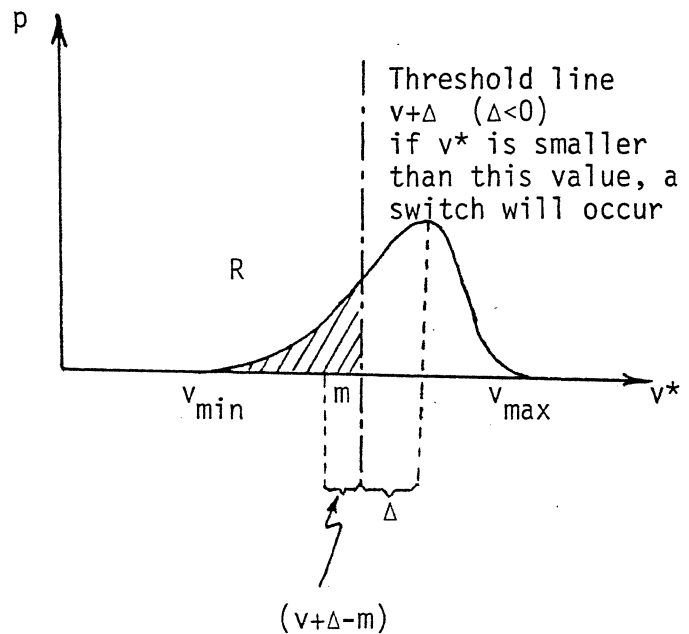


Figure 3-8. Cause for $EVA = 0$

(Case 1: The Subgoal Emerging From the Most Effective Local Action)

if $EVA = wq(v+\Delta-n) = 0$

since $w \neq 0$

then,

either $q = 0$
or $v+\Delta-n = 0$

Neither of the two cases
will occur unless:

$$|\Delta| > v_{\max} - v$$

Therefore, the graphic
representation for
 $EVA = 0$ will be:

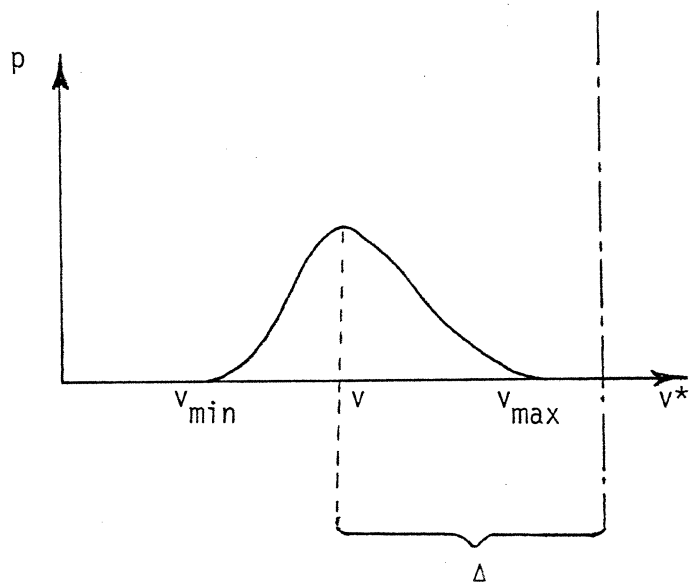
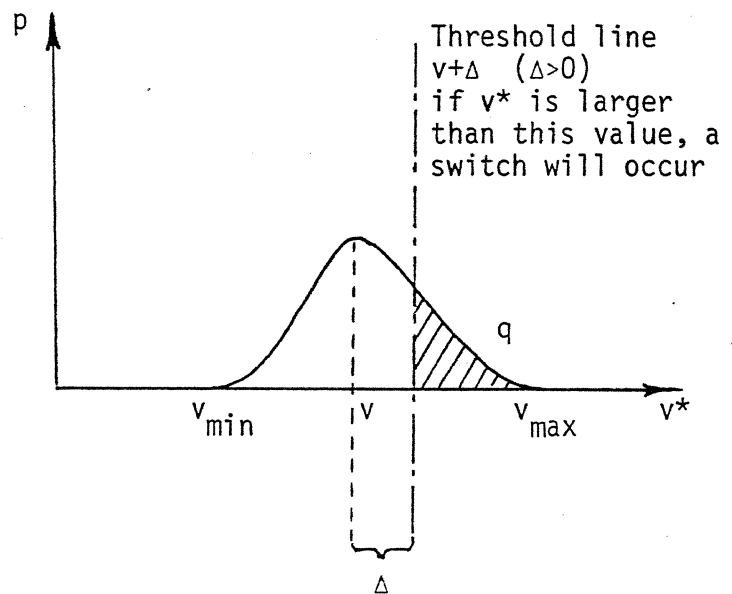


Figure 3-9. Cause For $EVA = 0$

(Case 2: The Subgoal Not Emerging From the Most Effective Local Action)

junction, the value of G becomes less sensitive to variations in the levels of subgoals remote from the root. Consequently, as the subgoal appears in deeper levels of the graph, its calculated w decreases. This situation will result in a fading effect in the magnitude of the expected value of analysis that ultimately in deeper levels will cause it equal to zero for all terminal nodes.

Although the first problem can be solved by a careful design of dialogue phrasing (e.g., suggesting considerations of all factors), the second represents a basic difficiency in the rationale for using the EVA criterion and calls for consideration of drastically different alternatives.

Although in some rare cases the utility of analysis for all terminal subgoals would indeed be zero, and should be interpreted as a signal to stop further analysis, in the more common case, the value of analysis (as defined above) will become zero even when further analysis is still desirable. This reflects a basic difficiency in the expected value of analysis as a criterion for dialogue management.

The expected value of analysis measure has been derived under the assumption that the level of attainment of all subgoals except the one in question remains fixed at its most likely value. However, since the value of other subgoals are also subject to uncertainty within their range of variability, this assumption gives rise to the discrepancy above. In reality, the level of attainment of every subgoal is a random variable. Consequently, Δ (the change V required to result in a decision switch) must also be considered as a random variable rather than a constant. Whenever the distribution of V^* overlaps that of $V + \Delta$, there would be a finite probability for a decision switch which, in turn, would result in a finite value for the utility of analysis.

The exact calculation of the expected value of analysis will then be resulted as:

$$EVA = E_{\Delta} E_{V^*} \Delta G$$

However, due to insufficient data to estimate distribution of Δ , we decided to drive the dialogue by an approximate criterion related to the likelihood of obtaining a decision switch rather than the exact value of ΔG . The criterion chosen is the ratio between the potential effective range of variation and the amount of change required for a decision switch.

At this point two possible cases may be considered separately: (1) the subgoal subject to analysis emerges from the presently most effective local action, and (2) the subgoal subject to analysis emerges from a local action other than the presently most effective one.

In the first case, a switch will occur if the value of the random variable V^* falls below the value of the random variable $V + \Delta$. The potential range of variation effective for a switch, in this case, is $V - V_{\min}$ which positively contributes to the occurrence of a switch. Here also the likelihood of a switch is inversely effected by Δ . Therefore, the likelihood of a switch (LS_1) will be:

$$LS_1 = \frac{\text{Potential Effective Range of Variation}}{\text{Mean of Change Required for a Switch}} = \frac{V - V_{\min}}{\Delta'}$$

where Δ' is calculated, as before, on the basis of the provisional values of all other subgoals.

In the second case, a switch will occur if the value of the random variable V^* exceeds the value of the random variable $V + \Delta$. However, the potential range of variation effective for a switch is $V_{\max} - V$ which is a positive factor for causing a switch. The likelihood of a switch is also inversely affected by the amount of change required for a switch. This amount is equal to Δ . The likelihood of a switch (LS_2) then becomes:

$$LS_2 = \frac{\text{Potential Effective Range of Variation}}{\text{Mean of Change Required for a Switch}} = \frac{V_{\max} - V}{\Delta'}$$

3.4. Dialogue Management Algorithm

The dialogue management algorithm described here is based on the ratio criterion described in the previous section. Here, we assume the user provides only V_{\min} and V_{\max} for every subgoal and that the provisional value is located at the midpoint $(V_{\max} - V_{\min})/2$. Therefore:

$$LS_1 = \frac{V - V_{\min}}{\Delta'} = \frac{\text{Range of } V}{2 \Delta'}$$

$$LS_2 = \frac{V_{\max} - V}{\Delta'} = \frac{\text{Range of } V}{2 \Delta'}$$

The algorithm is as follows:

- (1) Do the following for all subgoals (S) subject to expansion.
 - (a) Calculate Range of $V(S)$, $V_{\max}(S) - V_{\min}(S)$.
 - (b) Calculate $\Delta'(S_1)$ assuming all other subgoals attaining the value $(V_{\max} - V_{\min})/2$ as described in the algorithm of Section 3.2.2.
 - (c) Calculate $LS = \frac{\text{Range of } V}{2 \Delta'(S)}$.
- (2) Choose the subgoal with the largest LS for further analysis.

4.0. IMPLEMENTATION PROGRESS

4.1. Elicitation

The program is currently able to elicit from the decision maker all of the required information for the construction of a goal-directed decision graph. The five major node types elicited are (1) objectives, (2) action strategies, (3) action modes, (4) preconditions, and (5) states. Specific information requested for each type is the following:

(1) Objectives (subgoals)

- (a) Names - the name of each objective that describes the overall goal.
- (b) Weights - the relative importance of each objective.
- (c) Levels - a gross estimate of the expected level of achievement of each objective.

(2) Action Strategies

- (a) Names - the name of every action strategy (including "no action" if applicable) that could be taken to accomplish the corresponding objective. This list should be mutually exclusive and complete.
- (b) Levels - an estimate of the level of achievement of the corresponding objective if each action were to be implemented.
- (c) Side Effects - an estimate of the amount of decrease in the achievement level of non-related objectives. The program currently elicits adverse side-effects only.

(3) Action Modes

- (a) Names - a list of the different methods that could be used to implement the corresponding action strategy.
- (b) Levels - a revised estimate of the effectiveness of the corresponding action strategy due to the implementation of the particular action mode.

(4) Preconditions

- (a) Names - the preconditions that must be satisfied before the corresponding action mode can be taken.
- (b) Criticality Thresholds - the completion level of each precondition in which the corresponding action mode just begins to become effective. That is, the precondition completion level below which the action mode is completely ineffective.
- (c) Completion levels - an estimate of the completion level of each precondition.

(5) States

- (a) Names - the names of the states of nature that describe the corresponding precondition.
- (b) Probabilities - the probability of occurrence of each state.
- (c) Levels - the completion level that the corresponding precondition would receive if the particular state of nature were to occur.

During the elicitation process, the user is prompted by explanation of the type of information he is to provide. If he does not understand, or wishes more explanation, he may enter a question mark on the computer terminal and an alternate, more detailed explanation will be printed. The user is also kept aware of his current "location" in the decision structure by constant reference to nodes along the path to the goal.

At the completion of each node expansion, the user is asked if he wishes to continue elicitation procedure or suspend it. If he chooses not to continue, the program exits from the elicitation procedure and enters a "system mode" in which the user can exercise various program options that process the current structure. To resume elicitation, the user simply types "continue" and the elicitation procedure is re-entered at the proper point. This feature allows

the user to gain information about the current structure whenever he wishes, without resorting to a great number of questions.

4.2. Computations and Heuristic Optimization

The level of each node is calculated from the information available on all of its successors. The exact formulas for node level determination were explained in the previous section. The following is a summary of these formulas and a listing of the currently operational computations in the program:

- (1) Goal - the level of the goal is a weighted average of its successor objectives (sub-goals).
- (2) Objectives - the level of each objective is the maximum of the levels of its successor action strategies modified by any side effects.
- (3) Action Strategies - the level of each action strategy is the maximum of the levels of its successor action modes.
- (4) Action Modes - the level of each action mode is the product of its successor preconditions. The preconditions may be individually modified by a criticality threshold.
- (5) Preconditions - each precondition is characterized by a vector of values corresponding to its successor states. The overall effect of a precondition on its parent action is given by the expected value of the latter with respect to the successor states.
- (6) States - the level of each state is a weighted average of its successor objectives.

Currently, a single number is requested for each level estimate. Future implementation will provide an opportunity to input a minimum and a maximum value. Side effects are only allowed on action strategies and not on action modes. Further, the side effect is assumed to be adverse. Side effects that benefit related objectives is planned as a future task.

4.3. System Features

Once a user has entered "system mode", he may exercise a number of options that will provide information about the decision structure that he has built so far. All of the system options require only a single keyword to be typed into the computer terminal. These keywords operate only in system mode and are not effective during the elicitation procedure. The following is a listing of the currently available options and an explanation of their function. An example of the use of these features may be found in the scenario section.

4.3.1. HELP

By typing HELP; the user can get a listing of all of the available option keywords as well as an explanation of how to get back into elicitation mode.

4.3.2. START

The START option clears out the memory containing the decision structure and begins a new elicitation session.

4.3.3. CONTINUE

The CONTINUE keyword allows the user to re-enter elicitation mode and continue building the decision structure from the point it was previously terminated.

4.3.4. ROLLBACK

This feature allows the user to find the current value of the goal as well as the best actions to take in order to maximize the goal value. The value of each node is computed from the value of its successors for all possible combinations of action strategies. That combination which produces the highest goal value is chosen for recommendation along with the expected attainment level of each objective.

4.3.5. GOALCHECK

This option allows the user to calculate the goal value with any desired

action subset. He inputs the combination of actions he wishes (currently by node number) and the program will calculate the value of the goal with that particular set. It does not disturb the current values.

4.3.6. STRUCTURE

The STRUCTURE option prints out the complete decision graph along with levels and modifiers (i.e., weights, criticalities, probabilities). The structure is printed in outline form with successor relationships shown as indentations.

4.3.7. ACTIONS

This option prints only the action subsets and their predecessors. It is helpful for the GOALCHECK option which requires a subset of actions by node number.

4.3.8. GOAL

The current value of the goal can always be checked by using this option.

4.3.9. INFO

This option allows the user to obtain all of the information about a particular node. This information includes:

- (1) The name.
- (2) The value.
- (3) The modifier value.
- (4) The predecessor.
- (5) The successors.
- (6) The side effects.
- (7) Whether or not it has been expanded.
- (8) Whether or not it is on the best path.

The node is specified by number which can be obtained using the STRUCTURE option.

4.3.10. TRACE

This option allows the user to "watch" the rollback function as it calculates

the goal value for all possible combinations of action strategies looking for the one that maximizes the goal. Each and every action combination will be printed along with the corresponding goal value.

4.3.11. LOAD and SAVE

This command causes a copy of the program to be loaded from disc or to be saved on disc. Thus, a user can stop the session and continue at another time with all information saved.

4.3.12. PATH

By specifying any internal node, this option will print the path from that node to the goal.

4.3.13. CHANGE

This option allows the user to change the name or value of any node. (Future options will allow restructuring.)

4.3.14. EXPAND

If the user does not wish to expand the node recommended by the elicitation management algorithm, he may choose any terminal node he wishes and expand it.

4.4. Programmer Feature

The following features were implemented for the purpose of facilitating programmer changes to the elicitation messages and phrases.

4.4.1. MESSAGE

By using a specific message code, the programmer can print any of the 240 message lines.

4.4.2. MESSAGEMAP

Allows the programmer to peer inside the message file and determine which messages are stored for various elicitation procedures.

4.4.3. EDIT

Allows easy editing of specific message lines. This includes options to

break the line if a small CRT terminal is in use or the option of inserting node names directly into the text.

5.0. SAMPLE SCENARIO

5.1. Preface

In this chapter a sample scenario, resulting from an actual goal-directed system application, is demonstrated. The user is a man in his mid-thirties with a Ph.D. in an engineering field of high demand. He is currently employed in a high technology research and development company. The company's incentive and payroll system is organized such that the total pay and qualification for more overtime are directly related to the quality of work. The user owns a house in the city and a piece of undeveloped land in the suburban area. He has never owned or managed his own business before. However, he believes that with the proper assistance he will be capable of conducting a personally owned business. He is married with two children both of preschool age. At the present time, his expenses are covered by his present salary, but he is unable to save substantial amounts of money. He considers his problem to be that of planning the best strategy for improving his financial status without reducing the standard of living of his family.

5.2. Goal-Directed System Interview

"load onr
saved 13.11.47 09/06/79
start

Goal Directed Decision Support System

Do you wish to begin a new problem?

yes

What is your problem?

Improve my financial status

We will assume that your ultimate goal is to
reach a satisfactory solution of the problem:

"Improve my financial status "

List all major objectives which, if realized, would
contribute to the fulfillment of the goal.

1:

?

Let's analyze ways of achieving the main goal by
considering its major components. List the
major objectives which must be achieved before the goal can be attained.

1:

Have large assets

2:

Have high steady income

3:

Estimate the importance (0 to 10) of the objectives above.

objective 1: "Have large assets"

?

C-1

Assume that all objectives are partially satisfied
and that you have a choice of increasing the
level by which a particular objective will be attained.

Rate the importance of such an improvement
on each of the listed objectives. Use a scale of 0 to 10
for assessing the degree of importance:

the higher the assessment value, the more important the objective.

objective 1: "Have large assets"

6

objective 2: "Have high steady income"

4

C-2

What level (0 to 10) is the following objective
expected to reach in a well-planned strategy?

objective 1: "Have large assets"

?

Recall your previous experiences in this problem area.

Imagine similar situations in the past and
assume that you are given a sufficient amount of
time to plan your actions judiciously.

Estimate a reasonable level (0 to 10) of attainment
for each objective which reflects

both environmental constraints and your available resources.

objective 1: "Have large assets"

6

C-3

objective 2: "Have high steady income"

7

C-4

Let's consider the objective "Have large assets"
List all possible action strategies that you can take
toward the fulfillment of "Have large assets".
Make sure that the list contains all
physically feasible approaches (including possibly
"doing nothing") and that no two of them can be combined.

1:

Develop my land

2:

Invest in stock market

3:

Invest in real estate

4:

Speculate in precious metals

5:

Suppose that these actions are taken. What is your
assessment of the resulting level of attainment
of "Have large assets" under such conditions?

action strategy 1: "Develop my land"

9

C-5

action strategy 2: "Invest in stock market"

6

C-6

action strategy 3: "Invest in real estate"

7

C-7

action strategy 4: "Speculate in precious metals"

6

C-8

Consider the following objectives:

1 Have large assets

2 Have high steady income

Does the action strategy "Develop my land"

have any adverse effect on any of the above objectives?

yes

List the affected objectives by number (separated by spaces)

2

C-9

Suppose that the objective "Have high steady income"

would otherwise attain a level of (for example) 8.

What would its new level be assuming that

"Develop my land" was enacted?

5

Consider the following objectives:

1 Have large assets

2 Have high steady income

Does the action strategy "Invest in stock market"

have any adverse effect on any of the above objectives?

no

C-10

Consider the following objectives:

1 Have large assets

2 Have high steady income

Does the action strategy "Invest in real estate"

have any adverse effect on any of the above objectives?

no

C-11

Consider the following objectives:

- 1 Have large assets
- 2 Have high steady income

Does the action strategy "Speculate in precious metals" have any adverse effect on any of the above objectives?

yes

C-12

List the affected objectives by number (separated by spaces)

2

Suppose that the objective "Have high steady income" would otherwise attain a level of (for example) 8. What would its new level be assuming that "Speculate in precious metals" was enacted?

6

Continue elicitation?

yes

Let's consider the objective "Have high steady income"

List all possible action strategies that you can take toward the fulfillment of "Have high steady income".

Make sure that the list contains all physically feasible approaches (including possibly "doing nothing") and that no two of them can be combined.

1:

Open a business

2:

Find a second job

3:

Increase my over-time

4:

Suppose that these actions are taken. What is your assessment of the resulting level of attainment of "Have high steady income" under such conditions?

action strategy 1: "Open a business"

8

C-13

action strategy 2: "Find a second job"

4

C-14

action strategy 3: "Increase my over-time"

4

C-15

Consider the following objectives:

- 1 Have large assets
- 2 Have high steady income

Does the action strategy "Open a business" have any adverse effect on any of the above objectives?

yes

List the affected objectives by number (separated by spaces)

1

C-16

Suppose that the objective "Have large assets" would otherwise attain a level of (for example) 8. What would its new level be assuming that "Open a business" was enacted?

3

Consider the following objectives:

- 1 Have large assets
- 2 Have high steady income

Does the action strategy "Find a second job"

have any adverse effect on any of the above objectives?

yes

C-17

List the affected objectives by number (separated by spaces)

1

Suppose that the objective "Have large assets" would otherwise attain a level of (for example) 8.

What would its new level be assuming that

"Find a second job" was enacted?

3

Consider the following objectives:

- 1 Have large assets
- 2 Have high steady income

Does the action strategy "Increase my over-time"

have any adverse effect on any of the above objectives?

yes

C-18

List the affected objectives by number (separated by spaces)

1

Suppose that the objective "Have large assets" would otherwise attain a level of (for example) 8.

What would its new level be assuming that

"Increase my over-time" was enacted?

4

Continue elicitation?

no

Exit elicitation mode.

Enter system mode.

"save onr

13.21.56 09/06/79

continue

Exit system mode.

Enter elicitation mode.

Let's consider the action strategy "Develop my land"

List the names for various detailed methods by which

"Develop my land" can be executed.

1:

?

Normally, approaches such as "Develop my land" can be executed in a variety of different ways (methods) in varying degrees of detail. Think about the most promising execution plans available and list their names. (Make sure that the list consists of mutually exclusive modes of operation).

1:

Build a house

C-19

2:

For each mode, reestimate the level (0 to 10) that

"Have large assets" would attain as a result of enacting:
action mode 1: "Develop my land - Build a house"

?

You previously estimated that "Develop my land" would have a certain effectiveness on a scale from 0 to 10. Normally, this value depends on the selected mode of implementation. For each listed mode, enter the revised level that objective "Have large assets" would assume, given that the mode was actually implemented.

action mode 1: "Develop my land - Build a house"

9

Continue elicitation?

yes

Let's consider the action strategy "Invest in stock market"

List the names for various detailed methods by which

"Invest in stock market" can be executed.

1:

Utilities

C-20

2:

Energy

3:

Electronics

4:

For each mode, reestimate the level (0 to 10) that

"Have large assets" would attain as a result of enacting:

action mode 1: "Invest in stock market - Utilities"

5

C-21

action mode 2: "Invest in stock market - Energy"

7

C-22

action mode 3: "Invest in stock market - Electronics"

8

C-23

Continue elicitation?

yes

Let's consider the action strategy "Invest in real estate"

List the names for various detailed methods by which

"Invest in real estate" can be executed.

1:

Apartment building

2:

Undeveloped land

3:

For each mode, reestimate the level (0 to 10) that

"Have large assets" would attain as a result of enacting:

action mode 1: "Invest in real estate - Apartment building"

7

C-24

action mode 2: "Invest in real estate - Undeveloped land"

5

C-25

Continue elicitation?

yes

Let's consider the action strategy "Speculate in precious metals"

List the names for various detailed methods by which

"Speculate in precious metals" can be executed.

1:

Gold

2:

Silver

3:

For each mode, reestimate the level (0 to 10) that
"Have large assets" would attain as a result of enacting:
action mode 1: "Speculate in precious metals - Gold"

7

C-26

action mode 2: "Speculate in precious metals - Silver"

5

C-27

Continue elicitation?

yes

Let's consider the action strategy "Open a business"

List the names for various detailed methods by which

"Open a business" can be executed.

1:

Franchise

C-28

2:

Joint venture

3:

For each mode, reestimate the level (0 to 10) that

"Have high steady income" would attain as a result of enacting:

action mode 1: "Open a business - Franchise"

3

C-29

action mode 2: "Open a business - Joint venture"

8

Continue elicitation?

yes

Let's consider the action strategy "Find a second job"

List the names for various detailed methods by which

"Find a second job" can be executed.

1:

none

C-30

2:

Continue elicitation?

yes

Let's consider the action strategy "Increase my over-time"

List the names for various detailed methods by which

"Increase my over-time" can be executed.

1:

none

C-31

2:

Continue elicitation?

no

Exit elicitation mode.

Enter system mode.

"save onr

13.26.51 09/06/79

continue

Exit system mode.

Enter elicitation mode.

Let's consider the action mode "Develop my land - Build a house"

List any preconditions that must be established

before mode "Develop my land - Build a house" can be implemented.

1:

?

C-32

Normally, some preparation is usually required to secure an effective execution of "Develop my land - Build a house". List the conditions that must materialize (be satisfied) or must be maintained (require effort to guard against deterioration) so that the effectiveness of "Develop my land - Build a house" (in terms of accomplishing objective "Have large assets") is enhanced or secured.

1:

Have sufficient funds

2:

Let's explore the importance of the realization of these preconditions with respect to securing the effectiveness of "Develop my land - Build a house". Estimate (on a scale from 0 to 10) the level of completion of the preconditions below which "Develop my land - Build a house" is totally ineffective.

precondition 1: "Have sufficient funds"

?

C-33

It may be helpful to think about two extreme physical quantities reflecting the completion level of the preconditions to follow. Mentally assign 10 to the highest imagined quantity and 0 to the lowest. Keeping these quantities in mind, estimate (on a scale from 0 to 10) where the following precondition should be placed so that "Develop my land - Build a house" just begins to become effective.

precondition 1: "Have sufficient funds"

8

C-34

What level (0 to 10) would you expect the following precondition to reach in a well-planned strategy aimed at realizing the precondition in question and at the same time not having a severe adverse effect on your other objectives?

precondition 1: "Have sufficient funds"

?

Recall your previous experiences in this problem area.

Imagine similar situations in the past and assume that you are given a sufficient amount of time to plan your actions judiciously.

Estimate a reasonable level (0 to 10) of attainment for each precondition to follow which reflects both environmental constraints and your available resources.

precondition 1: "Have sufficient funds"

9

C-35

Continue elicitation?

yes

Let's consider the action mode "Invest in stock market - Utilities"

List any preconditions that must be established before mode "Invest in stock market - Utilities" can be implemented.

1:

none

C-36

2:

Continue elicitation?

yes

Let's consider the action mode "Invest in stock market - Energy"
List any preconditions that must be established
before mode "Invest in stock market - Energy" can be implemented.

1:

none

2:

C-37

Continue elicitation?

yes

Let's consider the action mode "Invest in stock market - Electronics"
List any preconditions that must be established
before mode "Invest in stock market - Electronics" can be implemented.

1:

none

2:

C-38

Continue elicitation?

yes

Let's consider the action mode "Invest in real estate - Apartment building"
List any preconditions that must be established
before mode "Invest in real estate - Apartment building" can be implemented.

1:

Secure mortgage loan

2:

Let's explore the importance of the realization
of these preconditions with respect to securing the
effectiveness of "Invest in real estate - Apartment building". Estimate
(on a scale from 0 to 10) the level of completion
of the preconditions below which "Invest in real estate - Apartment building"
is totally ineffective.

precondition 1: "Secure mortgage loan"

1

What level (0 to 10) would you expect the following
precondition to reach in a well-planned
strategy aimed at realizing the precondition in question
and at the same time not having a
severe adverse effect on your other objectives?

precondition 1: "Secure mortgage loan"

8

Continue elicitation?

yes

Let's consider the action mode "Invest in real estate - Undeveloped land"
List any preconditions that must be established
before mode "Invest in real estate - Undeveloped land" can be implemented.

1:

Secure mortgage loan

2:

C-39

C-40

C-41

Let's explore the importance of the realization of these preconditions with respect to securing the effectiveness of "Invest in real estate - Undeveloped land". Estimate (on a scale from 0 to 10) the level of completion of the preconditions below which "Invest in real estate - Undeveloped land" is totally ineffective.

precondition 1: "Secure mortgage loan"

1

C-42

What level (0 to 10) would you expect the following precondition to reach in a well-planned strategy aimed at realizing the precondition in question and at the same time not having a severe adverse effect on your other objectives?

precondition 1: "Secure mortgage loan"

8

Continue elicitation?

yes

Let's consider the action mode "Speculate in precious metals - Gold"

List any preconditions that must be established

before mode "Speculate in precious metals - Gold" can be implemented.

1:

none

C-43

2:

Continue elicitation?

yes

Let's consider the action mode "Speculate in precious metals - Silver"

List any preconditions that must be established

before mode "Speculate in precious metals - Silver" can be implemented.

1:

none

C-44

2:

Continue elicitation?

yes

Let's consider the action mode "Open a business - Franchise"

List any preconditions that must be established

before mode "Open a business - Franchise" can be implemented.

1:

none

C-45

2:

Continue elicitation?

yes

Let's consider the action mode "Open a business - Joint venture"

List any preconditions that must be established

before mode "Open a business - Joint venture" can be implemented.

1:

Having management assistance

C-46

2:

Let's explore the importance of the realization of these preconditions with respect to securing the effectiveness of "Open a business - Joint venture". Estimate (on a scale from 0 to 10) the level of completion of the preconditions below which "Open a business - Joint venture" is totally ineffective.

precondition 1: "Having management assistance"

2

C-47

What level (0 to 10) would you expect the following precondition to reach in a well-planned strategy aimed at realizing the precondition in question and at the same time not having a severe adverse effect on your other objectives?
precondition 1: "Having management assistance"

6

C-48

Continue elicitation?

no

Exit elicitation mode.

Enter system mode.

"save onr

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continue

Exit system mode.

Enter elicitation mode.

Let's consider the precondition "Have sufficient funds"

List conditions over which you have no direct control

but which may, if they hold true,

significantly impair or enhance the degree of

effectiveness of "Develop my land - Build a house".

1:

?

Consider the effect of "Develop my land - Build a house" on "Have large assets".

There may be uncertain factors (possible

events, unexpected developments, unknown conditions, etc.)

whose occurrence will significantly

influence the effectiveness of "Develop my land - Build a house".

Name such events.

1:

Funds available

2:

Funds not available

3:

What is the probability that the following event will hold true? (e.g. 0.6)

state 1: "Funds available"

.7

C-49

state 2: "Funds not available"

.3

Previously, you estimated that enacting "Develop my land - Build a house" would result in level 6 for objective "Have large assets".

Now, suppose that the following event occurs.

Re-estimate the new level objective

"Have large assets" would reach.

state 1: "Funds available"

8

state 2: "Funds not available"

2

C-50

Continue elicitation?

yes

Let's consider the precondition "Secure mortgage loan"

List conditions over which you have no direct control

but which may, if they hold true,

significantly impair or enhance the degree of

effectiveness of "Invest in real estate - Apartment building".

1:

Loan approved

2:

Loan denied

3:

What is the probability that the following event

will hold true? (e.g. 0.6)

state 1: "Loan approved"

.8

C-51

state 2: "Loan denied"

.2

Previously, you estimated that enacting "Invest in real estate - Apartment building" would result in level 6 for objective "Have large assets".

Now, suppose that the following event occurs.

Re-estimate the new level objective

"Have large assets" would reach.

state 1: "Loan approved"

10

C-52

state 2: "Loan denied"

0

Continue elicitation?

yes

Let's consider the precondition "Secure mortgage loan"

List conditions over which you have no direct control

but which may, if they hold true,

significantly impair or enhance the degree of

effectiveness of "Invest in real estate - Undeveloped land".

1:

Loan approved

2:

Loan denied

3:

What is the probability that the following event

will hold true? (e.g. 0.6)

state 1: "Loan approved"

.6

C-53

state 2: "Loan denied"

.4

Previously, you estimated that enacting "Invest in real estate - Undeveloped land" would result in level 6 for objective "Have large assets".

Now, suppose that the following event occurs.

Re-estimate the new level objective

"Have large assets" would reach.

state 1: "Loan approved"

10

C-54

state 2: "Loan denied"

0

Continue elicitation?

yes

Let's consider the precondition "Having management assistance"
List conditions over which you have no direct control
but which may, if they hold true,
significantly impair or enhance the degree of
effectiveness of "Open a business - Joint venture".

1:

Assistance not available

2:

Assistance available

3:

What is the probability that the following event
will hold true? (e.g. 0.6)

state 1: "Assistance not available"

.5

C-55

state 2: "Assistance available"

.5

Previously, you estimated that enacting "Open a business - Joint venture"
would result in level 7 for objective "Have high steady income".
Now, suppose that the following event occurs.

Re-estimate the new level objective

"Have high steady income" would reach.

state 1: "Assistance not available"

4

C-56

state 2: "Assistance available"

7

Continue elicitation?

no

Exit elicitation mode.

Enter system mode.

"save onr

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continue

Exit system mode.

Enter elicitation mode.

Let's consider the state "Funds available"

Consider this state as a new goal.

List all major objectives which, if realized, would
contribute to the fulfillment of the goal.

1:

Get funds

2:

What level (0 to 10) is the following objective
expected to reach in a well-planned strategy?

objective 1: "Get funds"

7

C-57

Continue elicitation?

yes

Let's consider the state "Funds not available"

Consider this state as a new goal.

List all major objectives which, if realized, would
contribute to the fulfillment of the goal.

1:

none

C-58

2:

Continue elicitation?

yes

Let's consider the state "Loan approved"

Consider this state as a new goal.

List all major objectives which, if realized, would contribute to the fulfillment of the goal.

1:

none

2:

C-59

Continue elicitation?

yes

Let's consider the state "Loan denied"

Consider this state as a new goal.

List all major objectives which, if realized, would contribute to the fulfillment of the goal.

1:

none

2:

C-60

Continue elicitation?

yes

Let's consider the state "Loan approved"

Consider this state as a new goal.

List all major objectives which, if realized, would contribute to the fulfillment of the goal.

1:

none

2:

C-61

Continue elicitation?

yes

Let's consider the state "Loan denied"

Consider this state as a new goal.

List all major objectives which, if realized, would contribute to the fulfillment of the goal.

1:

none

2:

C-62

Continue elicitation?

yes

Let's consider the state "Assistance not available"

Consider this state as a new goal.

List all major objectives which, if realized, would contribute to the fulfillment of the goal.

1:

Find management assistance

2:

C-63

What level (0 to 10) is the following objective expected to reach in a well-planned strategy?

objective 1: "Find management assistance"

7

C-64

Continue elicitation?

yes

Let's consider the state "Assistance available"

Consider this state as a new goal.

List all major objectives which, if realized, would contribute to the fulfillment of the goal.

1:

none

2:

C-65

Continue elicitation?

no

Exit elicitation mode.

Enter system mode.

"save onr

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continue

Exit system mode.

Enter elicitation mode.

Let's consider the objective "Get funds"

List all possible action strategies that you can take toward the fulfillment of "Get funds".

Make sure that the list contains all physically feasible approaches (including possibly "doing nothing") and that no two of them can be combined.

1:

Get building loan

2:

Refinance my house

3:

Join with another investor

4:

C-66

Suppose that these actions are taken. What is your assessment of the resulting level of attainment of "Get funds" under such conditions?

action strategy 1: "Get building loan"

8

action strategy 2: "Refinance my house"

7

action strategy 3: "Join with another investor"

8

Consider the following objectives:

1 Have large assets

2 Have high steady income

3 Get funds

4 Find management assistance

Does the action strategy "Get building loan"

have any adverse effect on any of the above objectives?

yes

List the affected objectives by number (separated by spaces)

2

Suppose that the objective "Have high steady income"

would otherwise attain a level of (for example) 8.

What would its new level be assuming that

"Get building loan" was enacted?

6

C-67

C-68

C-69

Consider the following objectives:

- 1 Have large assets
- 2 Have high steady income
- 3 Get funds
- 4 Find management assistance

Does the action strategy "Refinance my house" have any adverse effect on any of the above objectives?
yes

C-70

List the affected objectives by number (separated by spaces)

2

Suppose that the objective "Have high steady income" would otherwise attain a level of (for example) 8. What would its new level be assuming that "Refinance my house" was enacted?

6

Consider the following objectives:

- 1 Have large assets
- 2 Have high steady income
- 3 Get funds
- 4 Find management assistance

Does the action strategy "Join with another investor" have any adverse effect on any of the above objectives?
no

C-71

Continue elicitation?

yes

Let's consider the objective "Find management assistance" List all possible action strategies that you can take toward the fulfillment of "Find management assistance". Make sure that the list contains all physically feasible approaches (including possibly "doing nothing") and that no two of them can be combined.

1:

Get a partner

2:

Hire a manager

3:

Join an existing business

4:

C-72

Suppose that these actions are taken. What is your assessment of the resulting level of attainment of "Find management assistance" under such conditions?

action strategy 1: "Get a partner"

8

C-73

action strategy 2: "Hire a manager"

7

action strategy 3: "Join an existing business"

9

Consider the following objectives:

- 1 Have large assets
- 2 Have high steady income
- 3 Get funds
- 4 Find management assistance

Does the action strategy "Get a partner" have any adverse effect on any of the above objectives?
no

Consider the following objectives:

- 1 Have large assets
- 2 Have high steady income
- 3 Get funds
- 4 Find management assistance

Does the action strategy "Hire a manager"

have any adverse effect on any of the above objectives?

no

Consider the following objectives:

- 1 Have large assets
- 2 Have high steady income
- 3 Get funds
- 4 Find management assistance

Does the action strategy "Join an existing business"

have any adverse effect on any of the above objectives?

yes

List the affected objectives by number (separated by spaces)

1

Suppose that the objective "Have large assets"
would otherwise attain a level of (for example) 8.

What would its new level be assuming that

"Join an existing business" was enacted?

6

Continue elicitation?

no

Exit elicitation mode.

Enter system mode.

"save onr

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C-74

5.3. Interview Comments

- C-1: I did not understand what is meant by importance.
- C-2: Although both objectives, "Have large assets" and "Have high steady income", are instrumental for improving my financial status, I perceive having large assets to be more crucial to providing improvement in my financial status.
- C-3: Considering my present status and potential, it is possible to plan an investment program that would result in assets of about \$70k in three years.
- C-4: Considering my upcoming promotion and the possibility of increasing my overtime, there is a very high probability of increasing my steady income by about 25 percent in the near future. Besides, there is a possibility of finding a second job, therefore increasing my income by another factor of about 30 percent at the expense of reducing some of my overtime work at the present job.
- C-5: Current expected profit margin in land development is extremely high.
- C-6: Although I am familiar with some stocks with good expectation, the present economical situation makes investment in the stock market somewhat risky.
- C-7: Although the expected recession may decrease the market demand, real estate prices are tied to the inflation rate which is still rising. However, the option of investing in real estate will not be as profitable as developing my land.
- C-8: Since I consider buying only futures on a margin, although the price of precious metals rise with inflation, local fluctuations may get me out of the game, thus, losing even my original investment.
- C-9: My present work environment is organized such that compensation, bonuses, and promotions are directly related to my effort. Considering that developing my land will make demands on my time and effort, it may

actually decrease my potential for increasing my steady income.

C-10: Since my investment in the stock market would be through my broker, the required time and effort would be negligible, permitting me to pursue other activities.

C-11: The situation would be the same as investing in the stock market.

C-12: Although speculation in precious metals would also be done through a broker, it requires continuous monitoring and analysis of market behavior, and thus demanding a considerable portion of my time and effort (however, less than the amount required for developing my land).

C-13: Considering my potential level of investment in a business and my degree of capability in running it, I am pretty confident that I can develop a business with a net profit of at least \$25k per year.

C-14: I expect finding a second job will increase my steady income by about \$17k per year.

C-15: The amount of increase in my overtime at my present job is limited. I expect to be able to increase my income by about \$10k per year through extra overtime at my present job.

C-16: Opening a business will occupy so much of my time that I will hardly be able to pursue any active investment at all.

C-17: Having two jobs at the same time takes almost all my time.

C-18: Although not as much as opening a business or having a second job, increasing my overtime sufficiently also decreases my available time and energy for pursuing an active investment.

C-19: Considering the R1 zoning of my land, the only feasible development would be to build a single family residential unit.

C-20: Considering the economic situation and its effect on different stocks, I consider the only three stocks with a promising future to be utilities,

energy, and electronic stocks.

- C-21: Although the profit margins of utility companies are increasing, the rise in fuel cost is very likely to slow down the profit margin rate of increase, thus negatively affecting the rate of increase in stocks.
- C-22: Energy stocks, especially the alternative energy stocks, are very promising in this period of energy shortage.
- C-23: Due to the rapid growth of the industry, resulting from the innovative technology, electronic stocks are probably the most promising stock today.
- C-24: Due to the high inflation rate, the price of building materials and construction workers' salaries is rising so rapidly that the rate of increase in the price of the building itself seems to be higher than the rate of increase in the price of undeveloped land.
- C-25: Although high inflation is always an insurance for an increase in real estate prices, the potential forthcoming recession will slow down the building activities, thus decreasing the demand for undeveloped land, which in turn will lower the rate of increase in undeveloped land price.
- C-26: Due to the historical importance of gold, a high inflation rate will cause the price of gold to increase greatly.
- C-27: Although the price of silver also rises according to the inflation rate, since the major use of silver is its industrial application, the potential forthcoming recession will have a negative effect on rising silver prices.
- C-28: Since I do not have sufficient know-how in running a business independently. Opening an independent business is not feasible.
- C-29: Although major help is offered in areas such as management and advertising by the parent company, a considerable portion of the profit will be indirectly transferred to the parent company.
- C-30: There are no different ways of finding a second job.

- C-31: There is no other way of increasing my overtime.
- C-32: What is meant by precondition?
- C-33: I need more explanation.
- C-34: Having sufficient funds is very critical. I cannot complete building the house unless initially I have at least 80 percent of the sufficient funds required to build the house.
- C-35: Considering available resources, I am very confident that I can acquire the sufficient funds.
- C-36: Although there are different utility companies that I can invest in, the nature of the investment in all these prospects would be the same.
- C-37: The same as in utility stocks.
- C-38: The same as in utility stocks.
- C-39: I cannot invest in an apartment building unless I acquire a mortgage loan.
- C-40: Considering my credit record, I am pretty confident that I can acquire a mortgage loan.
- C-41: The same as in the case of investing in an apartment building.
- C-42: Again, acquiring a mortgage loan is absolutely critical.
- C-43: The only feasible way to speculate in gold is to buy different gold futures on margin, which are basically the same.
- C-44: The same as speculating in gold.
- C-45: The nature of all feasible franchises are sufficiently similar.
- C-46: Not having sufficient background in managing a business, I need to have some management assistance.
- C-47: If I have 50 percent assistance in management, I can still operate a joint venture effectively.
- C-48: I think I can find management assistance at least sufficient to effectively run the business.

- C-49: Since I have different sources, other than getting a construction loan, to provide funds (such as a second mortgage on my present house), the probability of having funds available is pretty high.
- C-50: Even if sufficient funds for completing the building project were not available, I can still increase the value of my land by grading it using some savings that I already have.
- C-51: Considering my credit history and the fact that the apartment will create some further income, I will have a good chance of getting my loan approved.
- C-52: I can purchase the apartment only if my loan is approved.
- C-53: Since the land does not provide any form of income, the chance of approval of a mortgage loan application for purchasing land is less than that for purchasing an apartment.
- C-54: Again, I cannot purchase the land unless my loan is approved.
- C-55: At this point, I believe that I have a 50-50 chance of finding assistance.
- C-56: Without assistance, I can still run the business, but considerably less effectively.
- C-57: There is a good chance of getting sufficient funds.
- C-58: I can't think of any particular objectives.
- C-59: There is none.
- C-60: There is no particular objective.
- C-61: There is none.
- C-62: There is none.
- C-63: If there was no assistance available, I can search for other sources (such as finding a partner or employing a manager) for management assistance.
- C-64: I have a good chance of finding management assistance for the kind of business I have in mind.
- C-65: No particular objective.

- C-66: Besides getting a construction loan or refinancing my present house, I realize that I can provide sufficient funds by joining another investor.
- C-67: I believe the capital gain on my house is sufficient. However, I am more confident in the other two alternative ways of acquiring funds.
- C-68: Since I have to repay the mortgage loan monthly, my net steady income will decrease.
- C-69: Considering the monthly payments and my present income.
- C-70: The same as in getting a construction loan.
- C-71: Since I offer the land and he provides the money for construction, there will not be any monthly payments from one to the other.
- C-72: Now I realize that besides getting a partner or hiring a manager, I can acquire management assistance also by joining an existing business rather than opening my own.
- C-73: A partner may also not be a good manager and hired assistance may be good in management but unfamiliar with this business. The partners in an existing business, however, have proven to be good managers and also familiar with the business.
- C-74: Although it has many advantages, joining an existing business does not provide me with as much capital investment as in the case of opening my own business. In other words, I am paying something for the convenience of having the management assistance and working business.

5.4. Resulting Goal-Directed Graph Structure

```

structure
(Node number, Node name, Value, Modifier.)
Improve my financial status 0
  objective (level 1)
-   1. Have large assets 6 6
      action strategy (level 2)
-   -   1. Develop my land 9 0
          action mode (level 3)
-   -   -   1. Develop my land - Build a house 9 0
              precondition (level 4)
-   -   -   -   1. Have sufficient funds 9 8
                  state (level 5)
-   -   -   -   -   1. Funds available 8 0.7
                      objective (level 1)
-   -   -   -   -   -   3. Get funds 7 10
                          action strategy (level 2)
-   -   -   -   -   -   -   8. Get building loan 8 0
-   -   -   -   -   -   -   9. Refinance my house 7 0
-   -   -   -   -   -   -   10. Join with another investor 8 0
-   -   -   -   -   2. Funds not available 2 0.3
-   -   2. Invest in stock market 6 0
          action mode (level 3)
-   -   -   2. Invest in stock market - Utilities 5 0
-   -   -   3. Invest in stock market - Energy 7 0
-   -   -   4. Invest in stock market - Electronics 8 0
-   -   3. Invest in real estate 7 0
          action mode (level 3)
-   -   -   5. Invest in real estate - Apartment building 7 0
              precondition (level 4)
-   -   -   -   2. Secure mortgage loan 8 1
                  state (level 5)
-   -   -   -   -   3. Loan approved 10 0.8
-   -   -   -   -   4. Loan denied 0 0.2
-   -   -   6. Invest in real estate - Undeveloped land 5 0
              precondition (level 4)
-   -   -   -   3. Secure mortgage loan 8 1
                  state (level 5)
-   -   -   -   -   5. Loan approved 10 0.6
-   -   -   -   -   6. Loan denied 0 0.4
-   -   4. Speculate in precious metals 6 0
          action mode (level 3)
-   -   -   7. Speculate in precious metals - Gold 7 0
-   -   -   8. Speculate in precious metals - Silver 5 0

```

- 2. Have high steady income 7 4
action strategy (level 2)
- - 5. Open a business 8 0
action mode (level 3)
- - - 9. Open a business - Franchise 3 0
- - - 10. Open a business - Joint venture 8 0
precondition (level 4)
- - - - 4. Having management assistance 6 2
state (level 5)
- - - - - 7. Assistance not available 4 0.5
objective (level 1)
- - - - - - 4. Find management assistance 7 10
action strategy (level 2)
- - - - - - - 11. Get a partner 8 0
- - - - - - - 12. Hire a manager 7 0
- - - - - - - 13. Join an existing business 9 0
- - - - 8. Assistance available 7 0.5
- - 6. Find a second job 4 0
- - 7. Increase my over-time 4 0

Side effects:

(Action number, Affected objective number, Adverse effect)

1 2 0.625
4 2 0.75
5 1 0.375
6 1 0.375
7 1 0.5
8 2 0.75
9 2 0.75
13 1 0.75

5.5. System Recommendation

The goal of "Improve my financial status" can be attained to a level of 4.55 if the following actions are taken:

Implement "Invest in stock market - Electronics" toward the objective "Have large assets".

Simultaneously, implement "Get a partner" toward "Find management assistance" which will eventually facilitate implementation of "Open a business - Joint venture" leading to attainment of "Have high steady income".

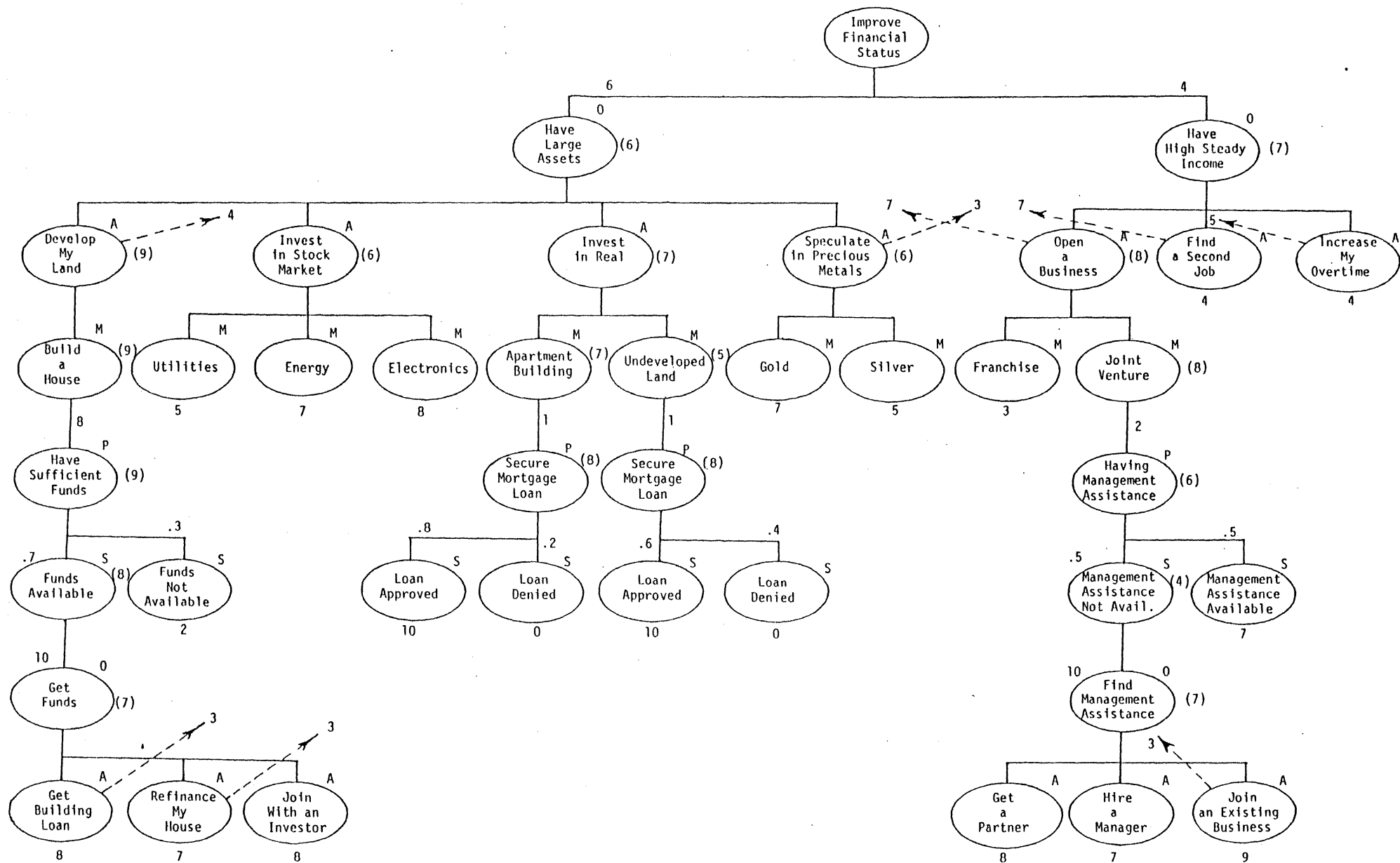


Figure 5-1. Structure of Goal-Directed Graph Elicited During the Scenario

References

- [1] Pearl, J., "A Goal-Directed Approach to Structuring Decision Problems," UCLA-ENG-7811, University of California, Los Angeles, February 1978.
- [2] Merkhofer, M.W., A.C. Miller, III, B.E. Robinson, and R.J. Korsan, "Decision Structuring Aid: Characterization and Preliminary Implementation," Stanford Research Institute, Menlo Park, September 1977.

