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DOCUMENTATION OF DECISION-AIDING SOFTWARE:

INFER FUNCTIONAL DESCRIPTION

DECISIONS AND DESIGNS INC.

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by

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INFER FUNCTIONAL DESCRIPTION

1.0 INTRODUCTION

1.1 Purpose of the Functional Description

This functional description provides a technical delineation of the specific functions that the INFER software system must perform. It serves as a formal basis for mutual understanding between the functional designer of the system and the software design and development personnel. Together with the INFER System Specification, the INFER Functional Description serves as the basic documentation for system development and implementation.

1.2 References

1.2.1 Barclay, Scott, et al. Handbook for Decision Analysis. Technical Report 77-6-30. McLean, Virginia: Decisions and Designs, Inc., September 1977.

1.2.2 Amey, Dorothy M.; Feuerwerger, Phillip H.; Gulick, Roy M. Documentation of Decision-Aiding Software: INFER Users Manual. McLean, Virginia: Decisions and Designs, Inc., June 1979.

1.2.3 Amey, Dorothy M.; Feuerwerger, Phillip H.; Gulick, Roy M. Documentation of Decision-Aiding Software: INFER Systems Specification. McLean, Virginia: Decisions and Designs, Inc., June 1979.

1.3 Terms and Abbreviations

1.3.1 INFER - INFER, the name of the system, is an abbreviation for inference, reflecting the logical process supported by the software.

1.3.2 Terms - Standard mathematical notations and terminology common to both probability theory and decision analysis are used throughout this functional description. Reference 1.2.1 provides more detail on decision analysis, should it be desired.

2.0 SYSTEM SUMMARY

2.1 System Description

INFER is a model-building software system that supports a particular logical process used in the discipline of decision analysis. The general purpose of the system is to aid decision makers by providing them a capability to construct, store, retrieve, exercise, and refine inference models that characterize and approximate key uncertain future events. Inference models serve as organizing frameworks for dealing logically and systematically with uncertainty.

The models assist the decision maker in processing the relevant objective and subjective information that determines the relative likelihoods of the various possible outcomes of a future event. INFER assists the decision maker by automating the model-building, model-manipulation, and model-storage and retrieval process. It must be emphasized that INFER does not replace experienced human judgment; rather, it serves as an accessory to the decision-making process: it aids human judgment.

The overall objective of INFER is to ensure that the decision maker's considered beliefs about the outcomes of a future uncertain event are realistic and wholly consistent with the available information pertaining to the unfolding of that event. For a more complete description of the purpose and use of INFER, see <u>Documentation of Decision-Aiding Software: INFER Users Manual</u>, Reference 1.2.2.

2.2 Design Objectives

The INFER software system is designed to be used interactively by end users who are relatively unsophisticated with respect to computer technology. Accordingly, the software design satisfies two human-factors objectives: INFER is a menu-driven system, and one that is generally forgiving of procedural errors by the user.

In addition, to facilitate the production of the program specifications and coding necessary to implement INFER at a physical site, the system is designed in a hierarchically structured, modular fashion. The complete logical structure of INFER is contained in the INFER System Specification, Reference 1.2.3.

3.0 DETAILED CHARACTERISTICS

The fundamental product of INFER is an inference model. The INFER software system enables the user to create, store, retrieve, exercise, and revise inference models interactively.

All of the specific functions that INFER performs are related to the inference model. Therefore, to establish a frame of reference for understanding the INFER functions described herein, it is necessary to begin with a description of the general concept and format of an inference model. Descriptions of the specific functions that INFER performs on inference models appear in Section 4.0.

3.1 Concept of an Inference Model

Consider a key future event, E, having several plausible, discrete outcomes. The nature of the problem addressed by INFER is to determine the relative likelihoods of all of the possible outcomes, E_i.

There is but one standard measure for expressing the likelihood, or degree of uncertainty, of the outcome of a future event: probability. A probability is a number between 0 and 1, inclusive, that represents the extent to which an individual believes that a future event will occur. Hence, the problem is to determine $P(E_i)$, the probability of the i^{th} outcome of event E, for all i. INFER assists the user in deriving event outcome probabilities that are coherent; that is, they are consistent with the user's state of knowledge concerning future events as well as consistent with the laws of probability theory.

A key assumption in the use of INFER is that the unaided, direct assessment of $P(E_i)$ is either impracticable or inadvisable because of intricate dependencies of $P(E_i)$ on the outcomes of other preceding events. For example, assume that $P(E_i)$ is influenced by the outcomes of three other events: A, B, and C. Figure 3-1 illustrates one possible influencing relationship among the key event, E, and the three preceding events. Each of the four events has, of course, several possible future outcomes: A_l, B_k, C_j, E_i.

3.1.1 Influence diagrams - The diagram in Figure 3-1 is called an influence diagram, since it pictorially represents the manner in which each event influences the other. An arrow indicates that one event directly influences another, the direction of the arrow indicating the direction of the influence. The absence of an arrow between any two events indicates the absence of a direct causal relationship. For example, Figure 3-1 illustrates that the outcome of Event E is not directly influenced by the outcome of Event A and that the outcome of Event E depends only on the joint outcomes of Events B and C.

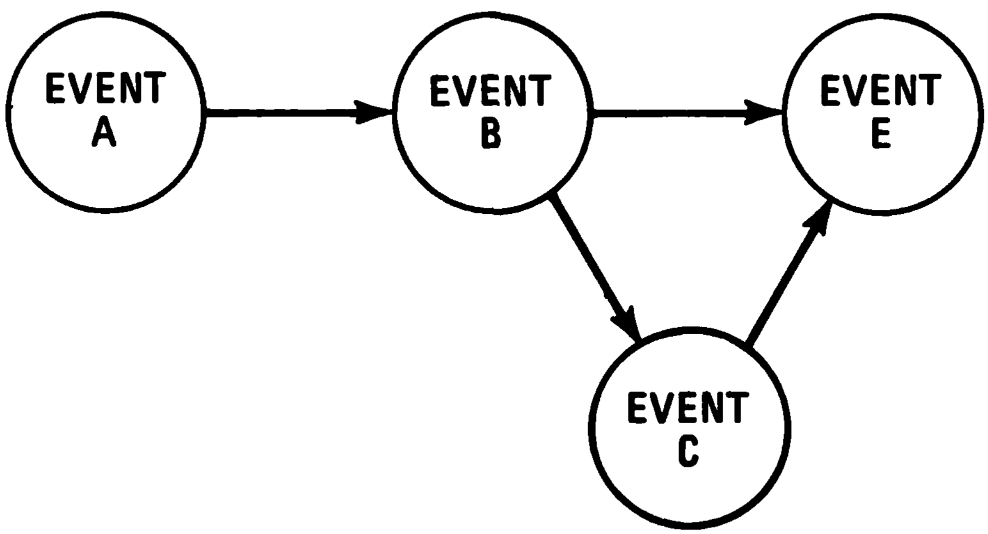


Figure 3-1
AN INFLUENCE DIAGRAM

The probabilities of the various event outcomes may also be influenced by certain evidence, or key indicators, that may be observed in the future. Over time, the indicators will be either observed or not observed. The influence diagram shown in Figure 3-2, which is a revision of the previous influence diagram, contains an indicator, X. The diagram now shows that if Indicator X is observed, then $P(C_j)$, the probabilities of the outcomes of Event C, must be changed.

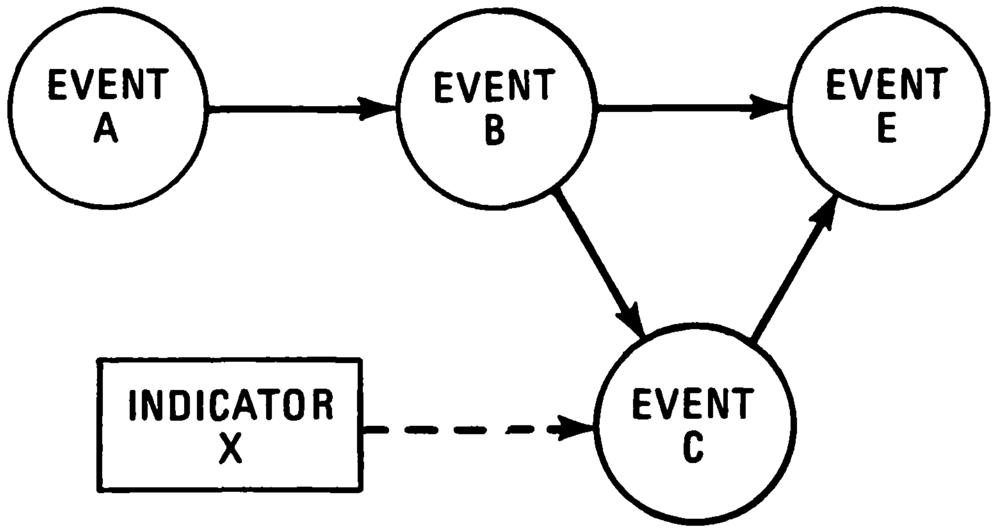


Figure 3-2
INFLUENCE DIAGRAM REVISED TO INCLUDE AN INDICATOR

3.1.2 Event nodes - An influence diagram, the basis for the inference model, consists of indicators and event nodes. Indicators are discussed in the following section.

There are two different types of event nodes: conditioned and unconditioned.

Unconditioned event nodes represent events that are not influenced by any other event, hence they have no arrows directed toward them. Event node A in Figure 3-2 is the only unconditioned event node shown. However, there may be more than one unconditioned event node in an influence diagram.

Conditioned event nodes represent events that are directly influenced by one or two other events; hence, they have arrows directed toward them. Nodes B, C, and E in Figure 3-2 are all conditioned event nodes. However, there are two types of conditioned event nodes: intermediate and terminal.

An influence diagram contains only one terminal event node: the key event of interest. Event E in Figure 3-2 is the terminal event node. Note that Event E does not influence any other event.

Event nodes B and C in the figure are intermediate event nodes. They both influence other events, as well as being influenced themselves.

In order to completely specify an inference model, one must specify the probabilities of the outcomes of the unconditioned events and the conditional probabilities of the outcomes of the conditioned events. For example, in Figure 3-2, one must specify $P(A_1)$ and the following conditional probabilities:

$$P(B_k | A_1)$$

$$P(C_j | B_k)$$

$$P(E_i | B_k, C_j)$$

3.1.3 Indicators - the effect of new information - For any event, INFER permits the user to incorporate into the model the impact that new information would have on the event outcome probabilities derived prior to observation of the new information. The underlying process is one of Bayesian updating, that is, calculating posterior probabilities based on the prior probabilities and the conditional probabilities that the information would be observed given that each particular event outcome did, in fact, occur.

The determination of the posterior probabilities is a straightforward application of Bayes' Theorem. For example, considering Indicator X in Figure 3-2:

$$P(C_j|X) = \frac{P(X|C_j)P(C_j)}{P(X)}$$

$$= \frac{P(X|C_j)P(C_j)}{\sum_k P(X|C_k)P(C_k)}$$

For all of the possible outcomes of Event C, the user must assess and specify $P(X|C_j)$, the probability that Indicator X would be observed, given that event outcome C_j had, in fact, occurred. However, for ease of elicitation, INFER permits the user to specify, for each event outcome, only the relative likelihoods that the evidence would be observed.

The required likelihoods are expressed as an ordered vector, L_j, in which the least likely outcome for observing the indicator is assigned a value of 1, and the other outcomes are each assigned a value corresponding to the number of times that outcome is more likely to occur than is the least likely outcome. For example, assuming that Event C has three possible outcomes, the likelihood vector 3 1 6 would indicate that Indicator X is three times more likely to be observed if C_1 has occurred than C_2, and two times more likely if C_3 has occurred than C_1.

Since $P(X|C_j)$ is equal to $\frac{L_j}{\sum_k L_k}$, the calculation of the posterior probabilities becomes:

$$P(C_j|X) = \frac{L_j P(C_j)}{\sum_k L_k P(C_k)}$$

Note that $P(C_j)$ is the prior probability of the event outcome; and $P(C_j|X)$ is the updated, or posterior, probability that replaces $P(C_j)$ if the indicator should be observed. Note also that the posterior probabilities are computed by multiplying each prior by its associated likelihood, and then normalizing the results to sum to 1.

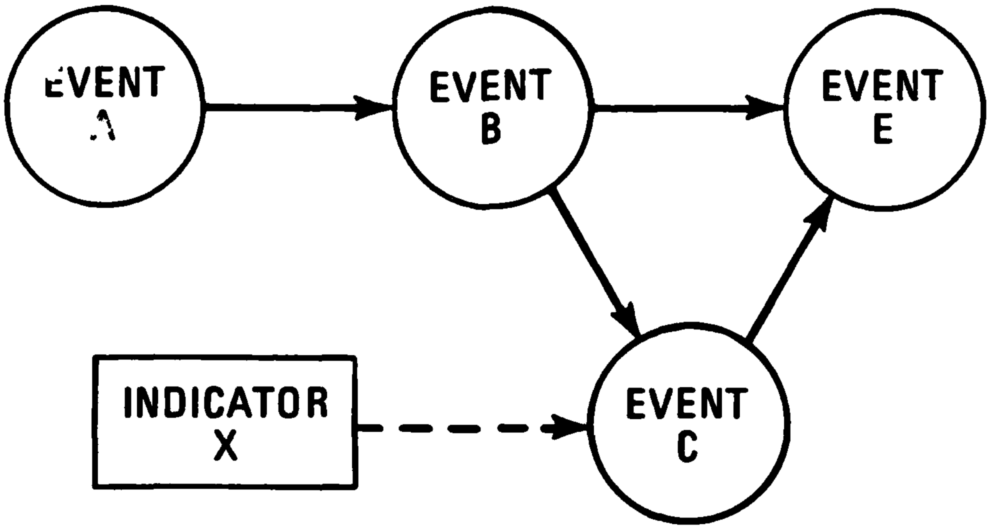
3.2 Model Description

Each inference model created by the user is constructed by using the same generic format. The format always consists of the following elements of information which, when they are completely specified, uniquely define an INFER inference model.

3.2.1 The terminal event - A label defining the key event of interest. The label also identifies the inference model for future storage and retrieval.

3.2.2 Conditioning events - A list of the one or two events whose outcomes condition the terminal event.

3.2.3 Remaining events - For all of the remaining conditioning (non-terminal) events, a list of the one or two events whose outcomes condition them. If no conditioning events are specified, the event is assumed to be an unconditioned event. Figure 3-3 illustrates a model whose structure has been specified to this point in the description.



Event	Conditioning Events		Event Type
E	B	C	TERMINAL
B	A	–	INTERMEDIATE
A	–	–	UNCONDITIONED
C	B	–	INTERMEDIATE

Figure 3-3
SPECIFICATION OF EVENTS

3.2.4 Event outcomes - For each event, a list of the discrete event outcomes, each appropriately labeled, that together define the universe of possibilities regarding the eventual unfolding of the event.

3.2.5 <u>Unconditioned event outcome probabilities</u> - For each unconditioned event, a vector of event outcome probabilities. For example, $P(A_i)$ in Figure 3-3.

3.2.6 <u>Conditioned event outcome probabilities</u> - For each conditioned event, a matrix of conditional probabilities for the event outcomes. For example, the diagram in Figure 3-3 requires the following matrices:

$$P(E_i | C_j, B_k)$$

$$P(C_j | B_k)$$

$$P(B_k | A_l)$$

3.2.7 <u>Indicators</u> - For each event affected by an indicator, the name of the indicator and the associated likelihood vector, as described in section 3.1.3. Furthermore, indicators must be specified as being either ON (observed) or OFF (not observed).

This completes the model format. The inference model is completely and uniquely specified when the elements described above are defined by the user.

It is important to note that INFER places a restriction on the number of events that are allowed to condition another event. Any event in an INFER model may be conditioned by zero, one, or two other events, and never by more than two. Although this constraint appears unduly restrictive, that is not the case since dummy events can always be created and inserted in the model to satisfy the constraint yet leave the logical relationships unaltered.

3.3 Results of the Model

The input specifications described above can be processed to produce the event outcome probabilities of the terminal event and any other event of interest. The resulting outcome probabilities are referred to as marginal probabilities. Except for the unconditioned events (whose outcome probabilities are directly specified), marginal probabilities are computed by straightforward matrix multiplication, proceeding from the unconditioned events through the intermediate events to the terminal event.

Using Figure 3-3 as an example, the results would be computed in the following steps:

1. $P(A_l)$ is specified.

2. $P(B_k) = \sum_{l} P(B_k|A_l)P(A_l)$

3. $P(C_j) = \sum_{k} P(C_j|B_k)P(B_k)$

4. $P(E_i) = \sum_{(j,k)} P(E_i|B_k,C_j)P(B_k,C_j)$

Note that joint probabilities $P(B_k, C_j)$ are used when an event is conditioned by two other events. Note also that if Indicator X is turned on, $P(C_j|X)$ replaces $P(C_j)$ in step 3 and the succeeding step.

4.0 INFER FUNCTIONS

INFER is designed to perform the basic functions described below. The detailed logical design of the INFER functions is contained in the INFER System Specification, Reference 1.2.3, which should be consulted in conjunction with this description.

4.1 Maintain a Library of Existing INFER Models

Store various INFER models that have been constructed by the user. Models are stored under the name of its terminal event.

4.2 Load an Existing INFER Model

Display the names of those INFER models stored in the model library and permit the user to select and retrieve any desired model. The loaded model is referred to hereafter as the current model.

4.3 Display the Results of the Current Model

For the terminal event only, display the name of the event, the names of the possible event outcomes, and the computed event outcome probabilities (expressed as percentages), as shown in Figure 4-1.

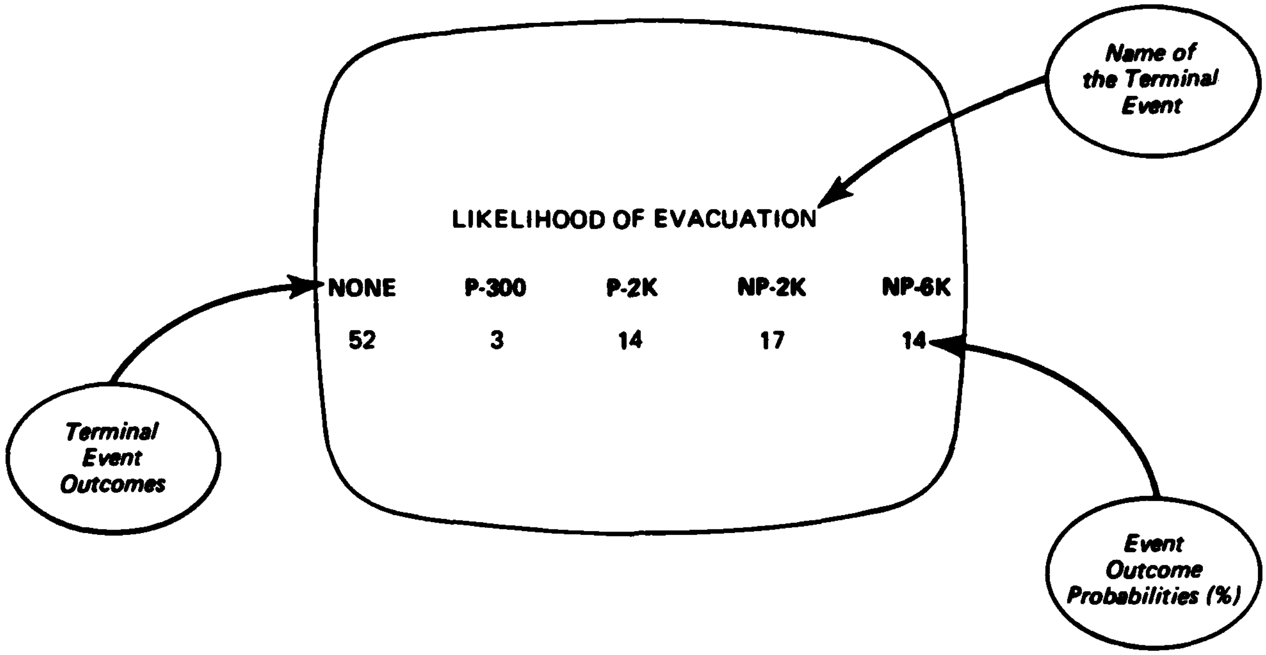


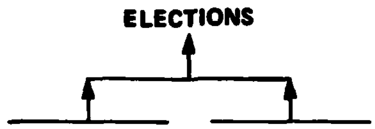
Figure 4-1
EXAMPLE OF THE "DISPLAY RESULTS" OUTPUT

4.4 Display the Inference Model

Display the names of all of the events contained in the model, and permit the user to select one. For the selected event, display the following items as shown in Figure 4-2:

a. an influence diagram indicating the name of the selected event and the names of those one or two events that condition it (if any); and

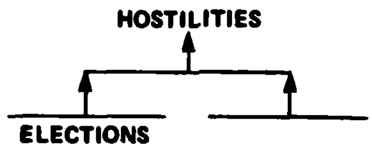
b. a matrix containing the conditional event outcome probabilities (if there are conditioning events), the calculated (or directly assessed) probabilities of the conditioning event outcomes, and the calculated marginal (or directly assessed) probabilities of the selected event outcomes.



LIKELIHOODS FOR EVENT ELECTIONS

	YES-S	YES-N	NO-S	NO-O
MARGINAL PROB.	40	10	20	30

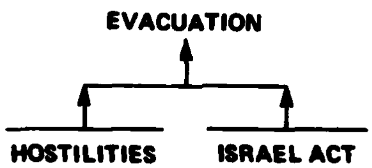
a. Unconditioned Event



LIKELIHOODS FOR EVENT HOSTILITIES GIVEN THE
FOLLOWING OUTCOMES OF EVENT ELECTIONS

		DECR.	SQ	BEIRT	CNTRY
YES-S	(40)	29	20	29	20
YES-N	(10)	20	29	29	20
NO-S	(20)	5	25	39	29
NO-O	(30)	5	20	34	39
MARGINAL PROB.		16	22	33	28

b. Event Conditioned by One Other Event



LIKELIHOODS FOR EVENT EVACUATION GIVEN THE FOLLOWING
OUTCOMES OF EVENTS HOSTILITIES AND ISRAEL ACT.

	NONE	P-300	P-2K	NP-2K	NP-6K
DECR. IINVAD(3)	10	5	24	29	29
DECR. INOINV(14)	99	0	0	0	0
SQ IINVAD(4)	10	5	24	29	29
SQ IINOINV(18)	79	5	5	10	0
BEIRTIINVAD(5)	5	0	10	39	44
BEIRTINOINV(28)	49	5	20	15	10
CNTRYIINVAD(5)	5	0	10	39	44
CNTRYINOINV(23)	39	0	20	20	20
MARGINAL PROB.	53	3	14	17	14

c. Event Conditioned by Two Other Events

Figure 4-2

EXAMPLE OF THE "DISPLAY INFLUENCE MODEL" OUTPUT

4.5 Edit the Current Model

Permit the user to make the following changes to the model:

a. Change the unconditional or conditional probabilities previously assigned to a selected event.

b. Change a previously specified indicator.

c. Add a new indicator.

The marginal probabilities are recalculated after this procedure is completed.

4.6 Reset Indicators

Display a list of all of the indicators and their current status (ON or OFF). Permit the user to change the status of one or more indicators. The marginal probabilities are recalculated after this procedure.

4.7 Save the Current Model

Permit the user to add the current model to the model library, either by substituting the current model for a previous version of the same model or by augmenting the library.

4.8 Create a New INFER Model

Permit the user to create an entirely new model, which is then referred to as the current model. The user creates a new model by specifying all of the elements comprising the model format, as described in Section 3.2.

The system creates the model in the following order:

a. It elicits the name of the key (terminal) event.

b. It elicits and develops a complete influence structure, proceeding from the terminal event to the unconditioned events.

c. It determines the order for eliciting the event outcomes and the unconditional and conditional probabilities (proceeding from the unconditional events to the terminal event).

d. Proceeding event by event, it elicits the name of the event outcomes and the associated unconditional and conditional probabilities.

e. It elicits a list of indicators, together with their associated likelihood vectors and the indicator status (ON or OFF).

f. It calculates all of the conditioned probabilities proceeding from the unconditioned events to the terminal event, including revisions due to any indicators being turned on.