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VENTURE EVALUATION AND REVIEW TECHNIQUE (VERT)

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This report is a User's/Analysts' Manual for the Venture Evaluation and Review Technique (VERT). The basic purpose of VERT is to support management in the assessment and quantification of the risk involved in new ventures and projects, to provide estimates of capital requirements, and to evaluate on-going projects, programs, and systems. VERT is totally computerized. It permits analyses of risk in three parameters -- time, cost, and performance. More importantly, it permits the user to scope his problem in any level of detail desired.

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ABSTRACT

This Users'/Analysts' Manual provides information in sufficient detail to permit installation and application of the VENTURE EVALUATION AND REVIEW TECHNIQUE (VERT). VERT is a computerized, mathematical oriented simulation network technique designed to model decision environments under risk. Historically, VERT has been used principally to assess the risks involved in the undertaking of a new venture, as well as in the estimation of future capital requirements, control monitoring, and overall evaluation of on-going projects, programs, and systems. Modeling is accomplished with a small set of easily comprehended operators which readily facilitates the structuring of a symbolic pictorial network layout of the system under study. VERT is an adaptive tool, thereby allowing the scope and level of abstraction to rest almost entirely in the hands of the analyst. Thus, modeling can be accomplished on a one-for-one basis, whereby one real world event and activity is correspondingly represented symbolically as one event and activity in the VERT network; or, modeling can also be accomplished on a compressive basis whereby a multitude of real world events and activities are compressed into the symbolic representation of a few events and activities in the VERT network.

FOREWORD

This report provides a description and instructions in sufficient detail to permit installation and use of the Venture Evaluation and Review Technique (VERT). The technique and this documentation were developed by the Joint Conventional Ammunition Program Coordinating Group Decision Models Directorate. This directorate is now the Decision Models Directorate of the US Army Armament Materiel Readiness Command.

Configuration management of VERT will be retained by the Decision Models Directorate. Proposals for modification and inquiries with respect to application should be addressed to the Commander, US Army Armament Materiel Readiness Command, ATTN: DRSAR-DM, Rock Island, IL 61299. Telephone inquiries should be addressed to Mr. Albert J. Patsche, AUTOVON 793-5292.

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CHAPTER 1 INTRODUCTION

1-1. Management Overview of VERT

One of the most pervasive and recurring situations encountered by management is the requirement to make decisions with incomplete or inadequate information about the alternatives. These DECISIONS UNDER RISK usually relate to the three general categories of cost, schedule and performance (production levels, returns on investments, etc.)

To assist the manager in making decisions under risk, many techniques have been developed and used over the past years. Linear programming, game theory and various modeling techniques are some examples. One of the most popular modeling approaches in recent years for modeling complex problems has been the technique called SIMULATION. The easy accessibility to large scale general purpose computers has made this technique a valuable tool for the manager.

VERT, an acronym for VENTURE EVALUATION AND REVIEW TECHNIQUE, is a computerized, mathematical oriented simulation networking technique designed to systematically assess the risks involved in the undertaking of a new venture and in the resource planning, control monitoring and overall evaluation of on-going projects, programs and systems. The features structured in VERT enable expeditious modeling of extremely complex decisions which heretofore had defied analysis. Modeling is accomplished with a small set of easily comprehensible operators which readily facilitates the structuring of a symbolic pictorial network layout of the system under study. VERT is an adaptive tool, thereby allowing the scope and level of abstraction to rest almost entirely in the hands of the analyst. Thus, modeling can be accomplished on a one-for-one basis, whereby one real world event and activity is correspondingly represented symbolically as one event and activity in the VERT network; or, modeling can also be accomplished on a compressive basis whereby a multitude of real world events and activities are compressed into the symbolic representation of a few events and activities in the VERT network. However, a compressive model frequently omits important considerations, causing it to be afflicted with TUNNEL VISION.

The real power afforded by VERT which is not found in other tools lies in its ability to handle with complete unrestricted generality the large scale management decision problems which are typically vested with imprecision and uncertainty in the data as well as uncertainty in the possible outcomes.

Two basic symbols, with minor variations in each, are used to symbolically structure the network model: (1) Nodes (squares) are used to represent milestones or decision points and, (2) arcs (lines) are used to represent activities. Fourteen different node logics are available for modeling events. Activities can be related to nodes and other activities via combinations of the thirty-seven embedded mathematical relationships. Activities can also be modeled as random variates via the fourteen embedded standard statistical distributions or via a user developed histogram. Network, in the VERT context, denotes a pictorial schematic flow type device in which the nodes (decision points) channel or gate the flow into arcs (activities) which carry the flow from an input node to an output node. These nodes and arcs are formed and coupled together in a working pictorial drawing to symbolically model the system under analysis. Flow in the network represents the actual completion of the portion of the system the flow has traversed. While a network is being graphically formed, numerical values for each activity's time, cost and performance should be assigned in terms of (1) one of the standard statistical distributions (including a constant) embedded in VERT or (2) a histogram or (3) a numerical relationship with the time and/or cost and/or performance of other nodes and/or arcs which will be processed prior to this arc. These values must be entered in a consistent manner throughout the network. Performance can be modeled in terms of any meaningful unit of measure, such as levels of quantities produced, return on investment or a dimensionless index that combines the many required diverse characteristics needed to fully define the resultant output of the capital expenditure. Decisions can be made and modeled within the network via time and/or cost and/or performance considerations. The logic structured in VERT enables local optimization at critical decision points or milestones as well as overall network optimization.

VERT also has the facility to determine the critical path as well as its opposite, the optimal path. Since time, cost and performance share the same status level, these critical and optimal paths can be found as a function of the time and/or cost and/or performance generated in the network. The automated data base feature of VERT greatly facilitates performing sensitivity analyses, so that WHAT IF strategy questions can readily be answered.

A final characteristic which makes VERT a desirable tool is the output options available. The program provides distributions depicting the frequency at which certain paths through the network were followed. It also provides distributions showing the times, costs and performances involved in traversing the different paths.

You don't have to be a computer programmer or systems analyst to effectively utilize VERT. An individual familiar with basic mathematics and statistics can productively use VERT after several hours of study. Complete mastery of all the model's capabilities probably would require a week of continuous effort. However, such proficiency would only be required in simulating very complex or unique situations. Actually, even in the most complex situations, the modeling can be simplified to a great degree by breaking down the network into subnetworks. The results of these subnetworks can then be used as inputs to a higher level, more general network which ties all the subnetworks together. This approach usually saves time and reduces the number of errors made.

1-2. VERT History

With the advent of the large cost overruns and schedule slippages experienced on many major development projects in the defense sector of the U.S. economy in the late sixties and early seventies, military managers realized a need for RISK ANALYSIS. In view of the lack of generalized tools and the heavy emphasis of Defense Secretary Packard on risk analysis, the logistics training activity of the Army Materiel Command, the U.S. Army Logistics Management and Training Center (ALMC) let a contract to Mathematica of Princeton, New Jersey to develop a course on RISK ANALYSIS. While developing this course, Mathematica pioneered what proved to be a significant change in network analysis by developing a computer program named MATHNET. It initially was intended to be used as a teaching aid. However, since it was the only viable tool available for RISK ANALYSIS, its use soon spread army wide. Because MATHNET was structured rather hurriedly, and thus not thoroughly debugged and tested on real problems, it proved to have some computational mistakes. Thus, a number of computer programs which were corrected and expanded versions of MATHNET evolved within the Army. RISCA (Risk Information System and Cost Analysis) was developed at ALMC. STATNET was developed at the U.S. Army Management Engineering Training Agency (AMETA) located on the Rock Island Arsenal at Rock Island, Illinois. Stephen Percy of the U.S. Army Armaments Command at Picatinny Arsenal, Dover, New Jersey developed the most sophisticated and novel expansion of the three called SOLVNET.

These three simulation networking tools presented a real significant addition of capability available to the development manager. These tools have AND and OR input logic teamed-up with ALL and PROBABILITY output logic. Also, they have some nodes with unit logic which tied a specific input arc to a specific output arc. These nodes selectively transfer flow from the input arcs to the output arcs via time or preference considerations. These logic combinations enable modeling much closer to the real world. Additionally, activity processing times could be entered as a normal, uniform or triangular distribution. Activity times can also be entered in histogram form in STATNET and SOLVNET. Also these two network tools have critical path capabilities. SOLVNET additionally has the capability to structure some time dependencies. The expanded logic capabilities coupled with the stochastic input capabilities and the simulation treatment given the network enabled the development of total risk profiles with a minimum amount of abstraction required when MATHNET and its three off-shoots came into being.

In early 1971, AMETA was tasked with the job of building a library of computer models that would be useful to the army project manager. One part of this effort determined that while MATHNET and its three off-shoots presented a significant advancement in network analysis, there were additional features they didn't have which were highly desirable. For instance, the MATHNET group is time centered like PERT. Cost is given a bookkeeping, second-class, tag-along, non-decision status. Additionally, performance is omitted from any direct numeric analysis. It is only considered in gross alternatives through the network, moreover, there weren't enough node logics available, especially one enabling invoking the time, cost and performance constraints imposed by management on all development ventures. These and other deficiencies culminated in the development of VERT.

VERT gave the analyst the capability to model decisions within the network in terms of time and/or cost and/or performance considerations rather than being constrained to time alone. At last, performance could be entered in the network in numeric terms rather than as gross alternatives. VERT thus gave the usual three dimensions used universally to discuss a project (i.e., time, cost and performance) the same status and treatment level. In a large part, the ability to represent the real world within a network lies in the flexibility of its nodes. VERT made a quantum jump in this area by the introduction of new types of node logics. But, perhaps, the most significant innovation was the introduction of its mathematical relationships. VERT has the capability of being able to establish a mathematical relationship between any given arc's time and/or cost and/or performance and any other arc and/or node's time and/or cost and/or performance. Thus, any two points within the network could be tied together by a mathematical relationship selected by the user out of the array of mathematical relationships available in VERT. Additionally, these same mathematical relationships can be used to establish relationships among the time, cost and performance variables of a given arc. VERT is designed to be very open-ended and comprehensive when establishing relationships among network parameters.

CHAPTER 2 THE VERT SYSTEM

2-1. Description of the VERT Process

VERT is a network tool used to develop deterministic and/or stochastic models of decision environments. It has a comprehensive array of logical, statistical and mathematical features which makes it possible to model and analyze a system in a more direct and less inductive manner than traditionally possible.

VERT has two parts. Part one consists of the construction of a symbolic network model of the system in question. Two basic symbols with minor variations in each are used to structure the model: (1) nodes (squares) are used to represent milestones or decision points and (2) arcs (lines) are used to represent activities. An activity generally consumes resources while producing an output.

Network in the VERT context denotes a pictorial schematic flow device in which the nodes channel or gate the flow into arc(s) which carry the flow from an input node to an output node. These nodes and arcs are structured and coupled together in a working drawing to symbolically model the development of a system. Flow through the network represents the completion or execution of the portion of the system that the flow has traversed. These flows are usually characterized by the three most universally accepted parameters used to discuss a project, namely time, cost and performance. However, these flows can also be carrying just one parameter like direct cost, indirect cost or performance factors like weight, speed or return on investment. As will become apparent upon mastering VERT, the mathematical relationships capability enables creating and isolating many separate flows which allows modeling well beyond the basic three dimensions. However, going beyond three dimensions generally proves to be difficult for the manager to cope with.

While graphically forming a network, numerical values for activity's time, cost and performance should be assigned. These values must be measured in consistent units throughout the network. For example, time cannot be entered in terms of weeks in one section of the network and in terms of years elsewhere. Likewise, cost must be measured in identical units of ten, hundred or thousand dollars, etc. throughout the network. Performance can be entered in terms of any meaningful unit of measure. For example, it can be expressed as a dimensionless index which combines the many required baseline characteristics such as horsepower, weight, speed, reliability, availability, range, maintainability, mobility, etc. A method of accomplishing this task consists of using the values derived in the design requirements document as a base for normalizing the current estimates of these base line performance characteristics. The requirement values (R1, R2, ---RN) are divided into the current estimates (E1, E2 --- EN). Further, to give more emphasis to specific performance characteristics, weights (W1, W2, --- WN where W1 + W2 + --- + WN = 1) may be assigned to each performance characteristic. These weights are then multiplied by the normalized estimates and entered into the network - ((W1)(E1)/R1, (W2)(E2)/R2, --- (WN)(EN)/RN). If these estimates were exactly equal to the requirements, the value generated for the overall networks performance would be unity.

The degree or extent to which a project needs to be segmented into activities and events is determined by the available data and the results desired. Some managers prefer to estimate parameters for entire modules or high level work packages, rather than estimating parameters for the smaller elemental items in those larger units. Problem size sometimes has a bearing on the way the network is structured. If a problem is large, it is advisable to construct lower level networks (subnetworks) of major modules. The histogram input capability structured in VERT expedites stochastic substitution of results from lower level subnetworks into a higher level network. However, the main task in constructing a VERT model is to structure as much realism in the model as possible with a minimum of abstraction. This realism should be achieved by structuring in the network all the activities (arcs) required to be processed (having a flow through them) before a given activity can be processed (having a network flow through this given arc). But, most important, the given activity should be a unit of work or task that can be estimated (in terms of the time required for completion, the cost incurred and the performance developed) with reasonable accuracy. The precision afforded by the VERT approach will be entirely lost if the unit activities are gross aggregations of units of work or tasks, or if the unit activities are such abstractions of the real world that the estimation of the time, cost and performance parameters for these unit activities becomes a guessing game.

Part two of VERT consists of analyzing the symbolic model with the aid of a computer program designed to simulate VERT networks. VERT simulation is the creation of a network flow which traverses the network from initial node(s) to terminal node(s) thus creating one trial solution of the problem being modeled. This simulation process is repeated as many times as the user requests in order to create a sufficiently large sample of possible outcomes. Node completion time, cost and performance values may be obtained as follows:

1. Relative frequency distribution.
2. Cumulative frequency distribution (Ogive).
3. Mean observation.
4. Standard error (standard deviation of the sample).
5. Coefficient of variation.
6. Mode.
7. Beta 2 measure of kurtosis.
8. Pearsonian measure of skewness.

This information is displayed for those requested internal nodes and intervals between internal nodes and for all terminal nodes. Additionally, all terminal node's time, cost and performance data are combined to give a composite terminal node time, cost and performance printout. Two sets of cost data are generated for each of the preceding node printouts. The first set labeled 'path cost', consists of the total cost accumulated in processing all the activities on the path(s) through which the network flow(s) had to come in order to process the node requesting the printout information. The second set, labeled 'overall cost', consists of the path cost plus the cost of all the other activities processed during and prior to the time this node was processed. Also, slack time on each arc and node per user-request is exhibited in the above form. Slack time is the excess time available for processing an arc or is the additional amount of time that a decision can be delayed before the node appears on the critical path. The overall network cost incurred and the overall network performance gained between selected time intervals (for example, yearly time intervals) as requested by the user is also exhibited in the above form. Information of this type is very useful for constructing budgets for future periods of expenditure or for comparing investment alternatives.

The relative frequency distribution provides a picture of the range and concentration of the time, cost and performance values observed at a given node. The probability of exceeding certain value levels can be obtained from the cumulative frequency distribution, which results in the ability to infer confidence levels. The mean is the average of all the observations. The sum of the squares of the differences between the observations and the mean value, divided by the number of observations, is known as the variance, or the mean square. The square root of the variance is the standard deviation, also known as the root mean square. The standard deviation, being in original units, is an absolute measure of dispersion and does not permit comparisons to be made between the dispersion of various distributions that are on different scales or in different units. The coefficient of variation has been designed for such comparative purposes. Since it is the ratio of the standard deviation to the mean, the coefficient of variation is an abstract measure of dispersion. The greater the dispersion of a distribution, the higher the value of the standard deviation relative to the mean. Hence, the relative dispersion of a number of distributions may be determined by simply comparing the values of their coefficients of variation. That value in a series of observations occurring with the greatest frequency is known as the mode. It is the most meaningful measure of central tendency in the case of strongly skewed or nonsymetric distributions, since it provides the best indication of the point of heaviest concentration. Though a distribution has only one mean and one median (mid point), it may have several modes, depending upon the number of peaks of concentration. The mode is not affected by extreme values while the mean is influenced by such values. In a symmetrical distribution, these two measures of central tendency are equal. But if the distribution is skewed, the value of the mean will be strongly influenced in the direction of the skew, while the mode will remain stationary. Hence, the difference between these two measures of central tendency is a measure of the skewness of a distribution. This measure of skew can be converted into relative terms by dividing it by the standard deviation. As a general rule, a distribution is not considered to be markedly skewed as long as the aforedescribed Pearsonian formula yields an absolute value less than one. Kurtosis is a Greek word referring to the relative height of a distribution, i.e., its peakedness. A distribution is said to be mesokurtic if it has so-called 'normal' kurtosis, platykurtic, if its peak is abnormally flat, and leptikurtic, if its peak is abnormally sharp. The beta 2 measure of kurtosis is defined as the fourth moment about the mean divided by the standard deviation raised to the fourth power. Beta 2 is a relative measure of kurtosis based on the principle that as the relative height of a distribution increases, the value of the standard deviation decreases relative to its fourth moment. In other words, the more peaked a distribution is, the greater the value of beta 2. For the standard normal distribution, beta 2 is equal to 3. Since the normal distribution plays such a large role in statistical theory, this value is taken as the norm. The more platykurtic a distribution is, the further will beta 2 decrease below 3, and the more leptokurtic a distribution is, the more beta 2 will exceed 3.

VERT prints out a bar graph of the optimum terminal node index. It is through using this printout that the project risk can be ascertained. A decision risk analysis network takes the usual form of having one or several terminal nodes collect successful project completions, and having one or several terminal nodes collect unsuccessful project completions. Realization of these various terminal nodes compared to the total number of iterations gives an indication of project success or failure. In the event more than one terminal node can be realized at the same time, the optimum terminal node is chosen as the one with the lowest completion time, lowest cost or highest performance, or the best weighted combination of these factors, per user developed weights. Entering negative terminal node selection weights will produce an opposite effect.

The program next prints out the critical-optimum path index for nodes and arcs. The critical path is chosen as the path through the network with the longest completion time, highest cost, lowest performance or the least desirable weighted combination of these factors as per user-developed weights. Entering negative critical-optimum path weights will cause the optimum path to be chosen. The optimal path is chosen as the path through the network with the shortest completion time, lowest cost, highest performance or the most desirable weighted combination of these factors as per user-developed weights (i.e., the optimum path is just the opposite of the critical path). VERT allows optional supression of critical-optimum paths terminating in user-selected terminal nodes. This feature facilitates the finding of trouble-producing activities. Since different stochastic paths can be realized in the process of simulating the network, the critical-optimum path tends to change from iteration to iteration. The program computes the portion of time each arc and node is on the critical-optimum path and lists this information in a bar chart display. Time, cost and performance correlations and plots are printed, upon request, for each terminal node, enabling determining if there is a possible relationship among these variables.

2-2. Operands

Arcs and nodes are the basic symbolic operators used to express the unique aspects of the system being modeled. Arcs perform a primary function of representing project activities by using four basic parameters which characterizes every activity modeled. These parameters are: (1) the probability of successfully completing this activity, (2) the time consumed, (3) the cost incurred, and (4) the performance generated in completing this activity. Arcs have a secondary function of carrying the network flow from its input node to its output node. When an arc is used in this latter capacity only, it is sometimes referred to as a transportation arc. For some network problems, it is desirable to enter some time and/or cost and/or performance data in the network without this data going directly into the network flow. This special data input task is accomplished by what is known as a FREE ARC. Free arcs are not wired into the network with input and output nodes like the conventional arc previously defined. Free arcs do not have input and output nodes, nor do they have a probability of being successfully completed. They are always assumed to be successfully completed. However, the rest of the input data capabilities associated with the conventional arcs is resident in the free arcs. Conventional arcs within the network flow and other free arcs external to the network flow can reference free arcs when structuring mathematical relationships. Free arcs are very useful for entering the many diverse characteristics used to describe performance. After entering these performance characteristics, mathematical relationships can be used to pull these many diverse characteristics together in one or several meaningful indexes or performance flows for data collection in the network.

Nodes gate or channel the network flow they receive from input arc(s) to specific output arc(s) based on the embedded node logic. Nodes generally represent decision points. However, they sometimes do not represent any particular decision point, but rather they aid in structuring the model logic by accumulating or dispersing network flows.

Nodes and arcs are similar in that both have time, cost and performance attributes. Arcs have a primary and cumulative set of time, cost and performance values associated with them while nodes have only the cumulative set. The primary set represents the time expended, the cost incurred and the performance generated to complete the specific activity this arc represents. The cumulative set represents the total time expended, cost incurred and performance generated to process all the arcs encountered along the path the network flow came through in order to complete the processing of a given arc or node.

An activity's primary time, cost and performance can be jointly or singularly modeled as a mathematical relationship (a deterministic equation) with other arcs or nodes in the network and as a random variable. This dual capability enables modeling the residual along with the mathematical relationship portion of a regression equation. VERT has thirty-seven transformations (see 3-2,B8) to aid in the task of structuring mathematical relationships. An arc's primary T+/C+/P (time and/or cost and/or performance) can be modeled as a function of any previously processed T+/C+/P of any node or arc, including the arc being processed. This means that an arc's cost can be made a function of the time expended on this activity. Fourteen statistical distributions have been embedded in VERT to facilitate the modeling of random variables. Other distributions may be entered as histograms.

VERT has two types of nodes which either start, stop, gate or channel the network flow. The most commonly used type is the one having split node logic. It has separate input and output logic which invokes specific types of input and output operations. The other node type has a single unit logic which covers both input and output operations simultaneously. There are four basic input logics available for the split logic nodes. They are defined below.

A. <u>Initial Input Logic</u>

```
.........
. I .   .----- INITIAL input logic serves as a starting point for the net-
. N .   .----- work flow. Multiple initial nodes may be used. All initial
. I .   .----- nodes are assigned the same time, cost and performance val-
. T .   .----- ues by the user.
.........
```

Before defining the three remaining input logics, it should be noted that when the input arcs have a probability of successful completion of less than 1.0, one or more of these input arcs may be failures. When these failure conditions prevail, it may be necessary, as specifically defined for each input logic below, to short circuit the node's output logic and to send the flow out on the escape arc. Utilization of the escape arc is regarded as a failure state for the node. The escape arc acts as a relief path for the flows into the node to escape on when a failure condition arises rather than letting these flows hang up on the node.

B. And Input Logic

```
     .........
-----. A .   .-----
-----. N .   .-----
-----. D .   .-----
-----.   .   .-----
     .........
```

AND input logic requires all the input arcs to be successfully completed before the combined input network flow is transferred over to the output logic for the appropriate distribution among the output arcs. If at least one of the input arcs is a failure, the network flow will be sent out the escape arc. The time computed for the nodes bearing AND input logic is computed as the maximum cumulative time of all the input arcs. Cost and performance are computed as the sum of all the cumulative cost and performance values of all input arcs. However, if the node is a failure (escape arc is used), performance for the node is set to 0.0 while the time and cost computation remain as previously defined.

C. Partial And Input Logic

```
     .........
-----. P .   .-----
-----. A .   .-----
-----. N .   .-----
-----. D .   .-----
     .........
```

PARTIAL AND input logic is nearly the same as AND input logic except that it requires a minimum of one input arc to be successfully completed before allowing flow to continue on through this node. However, this logic will wait for all the input arcs to come in or be eliminated from the network before processing. If all the active input arcs are failures, the network flow will be sent out the escape arc. The same computations are used for calculating the node time, cost and performance values for this input logic as are used for the AND logic even when the node is a failure (escape arc used).

D. Or Input Logic

```
     .........
-----.   .   .-----
-----. O .   .-----
-----. R .   .-----
-----.   .   .-----
     .........
```

OR input logic is quite similar to the PARTIAL AND logic. It also requires just a minimum of one input arc to be successfully completed before allowing the flow to continue on through this node. This logic, however, will not wait for all the input arcs to come in or be eliminated from the network before the flow is processed. As soon as an input arc is successfully completed, the flow will be sent on to the output logic for processing. If all the active input arcs are failures, the network flow will be sent out the escape arc. The time and performance assigned to this node are the cumulative time and performance value carried by this first successful input arc to processed. Cost is computed as the sum of all the cumulative costs of all the active input arcs. If the node is a failure (escape arc used), then the performance for the node is set equal to 0.0 while the time and cost computations remain as previously described. Arcs flowing directly and indirectly into a node having OR input logic may, at the user's discretion, be pruned from the network, providing that an arc's input node has a larger completion time than the node bearing the OR logic.

Arcs emanating from nodes having split node logic will be eliminated from further consideration as network flow carriers when the input logic can not be executed. This will occur for the PAND and OR input logics when all the input arcs are not carrying a flow (these input arcs have been logically eliminated). However, whenever any of the input arcs for the AND input logic are not carrying flows, all of this node's output arcs will be logically eliminated from further consideration as network flow carriers. It should be readily observed that AND input logic will impede a flow within the network whenever some of its input arcs are carrying flows and the rest are not carrying flows. All other node logics in VERT are passive in the sense that they will not impede the flow; they will always pass it on.

The following split node output logics' task is to distribute the network flow out to the appropriate output arc(s). However, if some of the input arcs have the potential of failing (a probability of successful completion of less than 1.0) then, the last output arc entered in the computer will be assumed to be the escape arc which is used as described above in the input logic definitions. The output logic will ignore the escape arc except for the filter output logics described below. The escape arc used for the filters is assumed to be the same one required of the input logic. The output logics are defined below.

A. Terminal Output Logic

```
      .........
-----.   . T .
-----.   . E .
-----.   . R .
-----.   . M .
      .........
```

TERMINAL output logic serves as an end point of the network. It is a sink for network flow(s). Terminal nodes can be given a class designation (chapter 3, D1) which allows for optimization within a class as a function of the time and/or cost and/or performance values carried by the active terminal nodes. However, nodes within a class are excluded from competing for being the optimal terminal node when a terminal node of a higher (more important) class is active.

B. All Output Logic

```
      .........
-----.   . A .-----
-----.   . L .-----
-----.   . L .-----
-----.   .   .-----
      .........
```

ALL output logic simultaneously initiates the processing of all the output arcs.

C. Monte Carlo Output Logic

```
      .........
-----.   .   .-----
-----.   . M .-----
-----.   . C .-----
-----.   .   .-----
      .........
```

MONTE CARLO output logic initiates the processing of one and only one output arc per simulation iteration by the use of the monte carlo method. This means that the output arcs are initiated randomly by user-developed probability weights that are placed on these output arcs. The sum of these weights must be equal to 1.0. As an added feature, multiple sets of probability weights may be entered for the purpose of conditionally randomly initiating the output arc. These sets must be separated by T/C/P (time or cost or performance) boundaries. N separate sets of probability weights are separated by N-1 non-decreasing T/C/P boundaries. These boundaries create T/C/P regions where each of these sets apply. Region selection is based on the T/C/P computed for this node. For example, if the T/C/P computed for this node is less than T/C/P boundary number one, then region number one is applicable and, therefore, probability set number one is used. Likewise, if this node's T/C/P lies between T/C/P boundaries 1 and 2, probability set number two will be used. This continues on until lastly, if this node's T/C/P lies beyond the (N - 1)st T/C/P boundary, the probability set residing in the Nth region will be used. If T/C/P conditioning is not required, T/C/P boundaries are not needed and only probability set number one needs to be entered.

D. Filter 1 Output Logic

```
      .........
-----.   . F .-----
-----.   . L .-----
-----.   . T .-----
-----.   . 1 .-----
      .........
```

FILTER 1 output logic initiates one or a multiple number of output arcs depending on the joint or singular satisfaction of the T+/C+/P (time and/or cost and/or performance) constraints placed on this node's output arcs. These constraints consist of upper and lower T+/C+/P boundaries. If this node's T+/C+/P lies within the T+/C+/P constraint boundaries placed on a given output arc, that arc will be processed. Otherwise, the arc will be eliminated from further consideration for this iteration. N-1 of the N output arcs must have constraints placed on them. The Nth output arc must be free of constraints. It will be processed only when none of the constrained arcs can be processed. FILTER 1 has an optional feature called the subtraction feature. This feature enables temporarily altering this node's T+/C+/P prior to reviewing the output arcs constraints. This alteration consists of temporarily subtracting, by absolute arithmetic, the T+/C+/P of a designated previously processed node from this node's T+/C+/P. After reviewing the constraints this node's original T+/C+/P values are restored.

Boundaries for the constrained output arcs can be overlapping, continuous, or non-continuous (i.e., having gaps). Also, the constraints need not be uniformly applied (i.e., a cost and performance constraint may be used on output arc number one with only a time constraint on output arc number two, and a time and performance constraint on output arc number three).

E. Filter 2 Output Logic

```
      .........
-----. P . F .-----
-----. A . L .-----
-----. N . T .-----
-----. D . 2 .-----
      .........
```

FILTER 2 output logic is the same as FILTER 1 except for the following three factors: (1) only one constraint rather than one to three constraints can be placed on the constraint bearing output arcs; this constraint consists of an upper and a lower bound on the number of input arcs successfully processed, (2) only PAND input logic may be used with FILTER 2 output logic, and (3) FILTER 2 does not have the subtraction feature.

F. Filter 3 Output Logic

```
      .........
-----.   . F .-----
-----.   . L .-----
-----.   . T .-----
-----.   . 3 .-----
      .........
```

FILTER 3 output logic has the same N-1 constrained and 1 unconstrained output arc configuration as the other FILTER logics. The constraints for FILTER 3 are not boundaries. Rather, they consist of the name(s) of other previously processed arcs. These constraining arcs are prefixed with a plus (+) or minus (-) sign. If a plus sign is attached to the constraining arc name, this arc must have been successfully processed before the output arc being constrained can be initiated.

If a minus sign is attached to the constraining arc's name, this arc must have failed to have been successfully processed or eliminated from the network before the output arc being constrained can be initiated for processing. Each output arc may have up to the total number of arcs in the network minus one (the given arc carrying the constraints) constraining arcs attached to it.

The cumulative time, cost and performance values assigned to initiated output arcs emanating from a split logic node consist of the sum of the time, cost and performance values derived for those activities plus the time, cost and performance values computed for the arc's input node.

Two nodes have unit logic rather than the separate input and output logic of the preceding nodes. These nodes have N input arcs each mating with one of N output arcs to enable direct transmission of the network flow from a given input arc to a given output arc. Additionally, there must be one uncoupled output arc. This arc will be initiated when input arc processing conditions are such that the node logic prevents initiating any of the mated output arcs. The number of output arcs requested to be processed is indicated in the symbolic network drawing where the asterisk appears in the small pictorials accompanying the node descriptions. This number is preceded by a plus (+) or minus (-) sign to indicate whether the processing state is a demand (+) or desired (-) condition. The demand condition requires that the output arc processing requests be completely filled. Otherwise, the escape arc will be processed. For instance, if a demand request for the processing of 3 output arcs has been made, at least 3 input arcs must be successfully processed to prevent the escape output arc from being the only output arc processed. The desired condition will allow processing from one to all of the output arcs requested for processing, or any subset thereof--down to one output arc, depending on the number of input arcs successfully processed. When processing by the desired condition, the escape output arc will be processed only when none of the input arcs have been successfully processed. The escape arc may be omitted when all the input arcs have a probability of successful completion of 1.0 and when the desired condition is used or when the demand condition is used with only one output arc requested for processing. Output arcs not selected for processing are eliminated from the network for the present iteration. In the event there are more successfully processed input arcs than there are output arc processing requests under either the demand or desired condition, the following logic embedded in each node will be used to select the optimal set of output arcs.

A. <u>Compare Node Logic</u>

```
    COMPARE *
     .........
-----.-------.-----
-----.-------.-----
-----.-------.-----
     .       .-----
     .........
```

COMPARE logic selects the optimal output arc set for processing by weights entered for time, cost and performance. If positive weights are entered, the optimal set consists of those output arcs whose corresponding input arcs have the best weighted combination of minimum cumulative time and cost and maximum cumulative performance. If negative weights are entered, the opposite effect will occur. Negative and positive weights cannot be used in the same application. The time value assigned to this node is the maximum cumulative time required by the most time-consuming arc in the optimum input arc set if time is used as the only decision criterion. If another criterion is used, the node time is computed as the maximum cumulative time of all the processed input arcs. The cost for this node is computed as the sum of the cumulative costs carried by all the processed input arcs. Performance is computed as the average of the cumulative performance carried by all the successfully processed input arcs.

B. Preferred Node Logic

```
    PREFERRED *
    .........
-----.-------.-----
-----.-------.-----
-----.-------.-----
    .       .-----
    .........
```

PREFERRED logic gives preference to the first input-output arc combination over the second and the second is given preference over the third, etc. Thus, the criterion for selection is preference. The only thing that will prevent output arc number one from being initialized when operating under the desired condition is that its corresponding input arc was not successfully completed. Cost and performance calculation are the same as the calculations used for COMPARE logic. Time is computed as the maximum cumulative time carried by the most time consuming arc in the preferred input arc set.

For the preceding two nodes, the cumulative cost and performance values assigned to the output arcs are computed as the sum of the primary cost and performance values derived for those arcs plus the cumulative cost and performance values generated for the linked input arcs. The cumulative time value assigned to the output arcs processed under the demand condition is calculated as the sum of the node time and the primary time generated on these arcs. When processing under the desired condition, the cumulative time value assigned to a linked output arc is generally computed as the sum of the cumulative time generated for the corresponding linked input arc and the primary time generated for this output arc. Exceptions to this rule occur when using cost and/or performance weights while using the COMPARE logic and when using PREFERRED processing output arcs further down the preferred list than the initial candidates. In these instances, some output arcs may have to wait on the processing of other input arcs. The escape arc's cumulative time and cost values are computed as the sum of the time and cost values derived for the input node while the value for cumulative performance is set equal to the primary performance generated for this arc.

Two other nodes also have unit logic. They are similar to the COMPARE and PREFERRED logics in structure, but are quite different in the way they operate on the network flow. Their names, which are indicative of the flow operations they perform, are QUEUE and SORT. They are defined below.

A. Queue Node Logic

```
     QUEUE *
    .........
-----.-------.-----
-----.-------.-----
-----.-------.-----
    .       .-----
    .........
```

QUEUE node has the same physical layout as the COMPARE and PREFERRED nodes having N input arcs coupled with N output arcs plus an additional uncoupled output arc. This arc will be initiated only in the event that all the active input arcs are unsuccessfully processed. The primary function of this node is to transfer network flows in a queueing manner from an input arc to its mating output arc. As the network flows in the live input arcs arrive, they are queued up and sequentially processed by the server(s). The number of servers is indicated on the symbolic network drawing where the asterisk appears. The program assumes that the output arcs carry the time required, the cost incurred and the performance rendered by the server in processing the flow carried by the mating input arc. The cumulative time computed for a given output arc is calculated as the sum of the following: (1) the cumulative time carried on this arc's mating input arc, (2) the time the flow had to wait in the queue before being served, and (3) the time required by the server to process this flow (the primary time generated on this arc). The cumulative cost and performance for this same output arc are computed in the same way as the cumulative time except that there is no factor no. 2 (i.e., there is no cost or performance generated for waiting in the queue). The time calculated for this node is computed as the maximum cumulative time observed over all the output arcs. The cost calculated for this node is computed as the sum of all the cumulative costs carried by the output arcs. This node's performance is computed in the same manner as the cost except that the total cumulative performance summed over the active output arcs is divided by the number of active output arcs, thus yielding an average performance value. Since the escape arc is used in a failure situation, the primary time, cost and performance generated on it does not relate to the server processing inbound network flows as it does on the other output arcs. Rather, this arc should be viewed as a point from which to proceed in a new program direction. Thus, the computations used to derive the cumulative time, cost and performance values reflect this point of view as follows: (1) cumulative time = maximum time observed over all the active input arcs + the primary time generated on this arc, (2) cumulative cost = the sum of the cumulative cost over all the active input arcs + the primary cost generated on this arc, (3) cumulative performance = the primary performance generated on this arc.

B. <u>Sort Node Logic</u>

```
      SORT
    .........
-----.       .-----
-----.       .-----
-----.       .-----
     .       .-----
    .........
```

SORT node has the same physical layout as the COMPARE, PREFERRED and QUEUE nodes having N input arcs paired with N output arcs plus an additional output arc. This arc will be initiated only in the event that all the active input arcs are unsuccessfully processed. The purpose of this node is to transfer flows from input arcs to output arcs by sorting using time and/or cost and/or performance sort weights. If time is given a weight of 1.0 while cost and performance are given weights of 0.0, the flow from the input arc arriving at this node first would be sent out on output arc number one, etc. If the cost weight was set equal to 1.0 while the time and performance weights were given the value of 0.0, then the flow coming in on the input arc having the smallest cost would be sent out on output arc number one, etc. If the performance weight was set equal to 1.0 while the time and cost weights were given the value of 0.0, then the flow coming in on the input arc having the largest performance value would be sent out on output arc number one, etc. If a mixture of positive weights occurs (for example, SORT time weight = 0.4, cost = 0.3 and performance = 0.3), the flow of the input arc with the best weighted combination of the minimum cumulative time and cost and maximum performance will be sent out on output arc number one. The flow of the input arc having the next best weighted combination will be sent out on output arc number two, etc. Entering negative weights will produce the opposite effect. Negative and positive weights can not be used in the same application.

CHAPTER 3 INPUT FOR THE COMPUTER PROGRAM

3-1. Overview

Entering a network problem into the VERT computer program requires the following data modules which must be sequenced in the order that they are listed below.

A. Control and Problem Options Cards. These initial cards define the options used to analyze the problem under study.

B. Master and Accompanying Satellite Arc Cards. All arc data for a given network problem are entered in this sequential position. Each arc requires a master arc card and may require additional satellite arc cards to input the arc data. These different types of satellite arc cards may be entered in the input data stream in any order, but they, as a group, must follow their parent master arc card. Therefore, all data items for a given arc must be entered as a group with the master arc card leading the group.

C. End of Arc Data Signaler. This one card marks the end of the input stream of arc data.

D. Master and Accompanying Satellite Node Cards. Same as B above except, replace the word ARC with the word NODE.

E. End of Node Data Signaler. This one card marks the end of the input stream of node data.

3-2. Layouts

The above data modules are defined as follows:

A. Control and Problem Options Cards.

A1. Control Card

Col. 1, Format I1. Problem identification card option. Entering a "1" in this column requires a problem identification card to be inserted after this control card. When a zero is entered or this field is left blank, the problem identification card must be omitted.

Col. 2, Format I1. Type of input option. This program has three input options. Option one requires entering a blank or zero in this field. Under this option, the program assumes that a complete, stand alone, problem is being read which will be placed on the master file as the new master problem. This new master problem will replace an old master problem if one was previously held on this file (IWF1 is the name for the master file in the FORTRAN program). Items A, B, C, D and E, above under overview, are required when using this option. Option two requires a "1" to be entered in this field. Under this option, the program assumes that a few temporary changes to the master problem are desired. These changes are temporarily merged into the master problem and simulated in that state. After simulation, these changes are abandoned and the problem on the master file remains as it was prior to simulating the problem with the changes. Items A, C, and E, above under overview, are required and items B and D are optional. Option three requires a "2" to be entered in this field. Under this option, the program assumes that a few permanent changes to the master problem are desired. These changes are permanently merged in the master problem and simulated in that state. Prior to the simulation, this changed problem is loaded on the master file as the new master problem, replacing the old master problem. Items A, C and E, above under overview, are required while items B and D are optional.

Note: When utilizing either options two or three, making a change in either an arc's or a node's input data requires resubmitting all the input cards needed to define that arc or node. Any arc or node not already on the master file may be submitted as a change. Arcs or nodes currently on the master file may be deleted by submitting a card with the arc or node name in columns 1-8 and "----" (four minus signs) in columns 9-12.

Col. 3, Format I1. Type of output option. The following optional lists are available from VERT in addition to a special listing of the control and identification cards and an 80/80 listing of all the remaining input cards. This special listing is automatically produced every time a problem is processed.

1. A listing of the two major storage arrays ASTORE and NSTORE.

2. A listing after each iteration of all the flow-carrying arcs and nodes.

3. A core storage utilization report which shows how well each of the internal storage arrays have been used.

4. A one line summary listing of the results obtained after each iteration.

5. A listing of the optimum terminal node index and an accompanying arcs and nodes critical-optimum path index.

The following output options apply to 1. Node and arc slack times, 2. Cost performance time intervals, (time, path cost, overall cost and performance for the following), 3. Internal nodes, 4. Intervals between nodes, 5. Terminal nodes and 6. The composite terminal node.

6. A one line listing of the minimum, mean and maximum values of the preceding.

7. A one page listing carrying A. The relative frequency distribution, B. The cumulative frequency distribution (ogive), C. The mean observation, D. The standard error (standard deviation of the sample), E. The coefficient of variation, F. The mode, G. The beta 2 measure of kurtosis, H. The pearsonian measure of skewness and I. The median-(for terminal and composite terminal nodes only).

8. Same as number 7 above except the relative frequency distribution is omitted.

9. Inclusion of the median in the preceding list for A. Internal nodes, B. Intervals between internal nodes, C. Node and arc slack times and D. Cost-performance time intervals. This inclusion requires a significant increase in computer processing time and is the reason for this setup.

These optional lists are grouped together in what is believed to be optimal output sets which are as follows:

Option No.	Field Entry	Preceding Lists Used
1.	0 or blank	5 and 6
2.	1	5 and 8
3.	2	4, 5 and 7
4.	3	1, 2 and 3
5.	4	5, 8 and 9
6.	5	4, 5, 7 and 9

Since option number four produces a large amount of output, it is limited to 100 iterations. This option is designed for debugging. The remaining options are designed to provide a diversified informational capability for analyzing the various types of problems solved by VERT.

Col. 4, Format I1. Cost-performance valuing and pruning options. This field is a multi-purpose field which carries the options available in VERT for assigning cost and performance values to arcs placed in one of the following situations: 1. Arcs flowing into a node having OR logic. 2. Arcs flowing into a node having COMPARE logic when the compare time selection weight is set equal to 100%. 3. Arcs not in the stream of the network flow going into the optimum terminal node when the time weight for selecting the optimum terminal node is set equal to 100%. VERT is structured to fully value or partially value the cost and performance generated on these arcs which are partially completed and to prune or include the cost and performance values of those activities which have not started processing. The various combinations of options available are as follows:

1. Full value the partially completed activities.

2. Partial value the partially completed activities.

3. Pruning the uninitiated activities.

4. Full value the uninitiated activities.

Option No.	Field Entry	Preceding Computations Used
1.	0 or blank	1 and 3
2.	1	2 and 3
3.	2	1 and 4

Col. 5, Format I1. Full print trip option. Entering a "1" in this column requires a card to be entered following the problem identification card which carries the names of arcs and/or nodes. When any of these arcs or nodes are active, the program will list all the arcs or nodes which were active for the given iteration.

Col. 6, Format I1. Correlation computation and plot option. Entering a "1" in this column requires a card to be entered following the full print trip option card, which carries the correlation and plot combinations wanted for terminal nodes.

Col. 7, Format I1. Cost-performance time interval option. Entering a "1", "2" or "3" in this column requires entering cards following the correlation computation and plot option card which carries the time intervals and possible upper and lower boundaries for the histograms used to plot the cost incurred and/or performance gained during these time intervals. Entering a "1" in this column indicates that cost only is desired, while entering a "2" indicates that performance only is desired. If both cost and performance are desired, a "3" should be entered in this column.

Col. 8, Format I1. Composite terminal node minimums and maximums option. Entering a "1" in this column requires a card to be entered following the time interval costing option cards which carries the minimums and maximums used to print the time, path cost, overall cost and performance for the composite terminal node.

Col. 9-19, Format I11. Enter the value initially assigned to the seed of the uniform (0.0 to 1.0) random number generator. The ending value of the seed is printed out at the end of each problem. If this field is left blank or has a "0" entered in it, the seed will be loaded with the value of 435459. Further, when running a series of problems via a single computer run, the program will carry the seed forward to subsequent problems providing this field is left blank in those subsequent problems. There is provision in VERT for embedding two generators, rather than just one uniform random number generator. If the seed is prefixed with a minus (-) sign, the sign will be stripped off the seed and generator number two will be used for the given problem. If the seed is prefixed with a plus (+) sign or no sign, the seed will be used as is and the generator number one will be employed for the given problem.

Cols. 20-24, Format I5. Enter the number of iterations desired for this problem.

Cols. 25-28, Format F4.2. Enter the yearly interest rate used for inflating cost and/or performance values for specific arcs as called out by the user. This number should be entered in percentage form. For example, 7.5 percent should be entered in columns 25-28 as 7.5. If none of the cost and/or performance values of the arcs in the network being processed require discounting, leave this field blank.

Cols. 29-32, Format F4.2. Enter the yearly interest rate used to discount cost and/or performance values for specific arcs as called out by the user. This number should be entered in percentage form similar to the preceding field. If none of the cost and/or performance values of the arcs in the network being processed require discounting, leave this field blank.

Note: The inflation and discounting calculations are made immediately after generating the time, cost and performance values for a given arc. These values are then stored in place of the original values and then used in all future mathematical relationships. However, when the time, cost and performance values for a given arc are interrelated, then the original unadjusted cost and/or performance values are used in the mathematical relationships to calculate values for the dependent variables.

Cols. 33-35, Format F3.2. Enter the time factor which converts the program time to a yearly basis. This program computes interest calculations on a yearly basis. This field carries the number of time units existing in the network time domain in one year. For example, if the network time is in months, a 12. should be entered in columns 33-35. Leave this field blank if the preceding two fields are blank.

Note: Values assigned to the following three fields must all lie within either the closed interval of -1.0 and 0.0 or the closed interval of 0.0 and +1.0. These fields must not jointly carry positive and negative values (i.e., field 1 cannot have a positive entry while fields 2 and/or 3 have negative entries). Entering positive values in these fields will give rise to choosing the terminal node with the least time and cost and the most performance combination as the optimum terminal node. Entering negative values in these fields will cause the terminal node with the largest time and cost and the least performance to be chosen as the optimum terminal node. For further information regarding winning terminal node selection, see the description of the terminal output logic (cols. 10-12 of section D1).

Cols. 36-38, Format F3.2. Enter the weight assigned to time when determining the optimum terminal node.

Cols. 39-41, Format F3.2. Enter the weight assigned to cost when determining the optimum terminal node.

Cols. 42-44, Format F3.2. Enter the weight assigned to performance when determining the optimum terminal node.

Note: Values assigned to the following three fields must all lie within either the closed interval of -1.0 and 0.0 or the closed interval of 0.0 and +1.0. These fields must not jointly carry positive and negative values (i.e., field 1 cannot have a positive entry while fields 2 and/or 3 have negative entries). Entering positive values in these fields will give rise to choosing the critical path as the path with the largest time and cost and the smallest performance. Entering negative values in these fields will cause the optimum path to be chosen as the path with the smallest time and cost and the largest performance.

Cols. 45-47, Format F3.2. Enter the weight assigned to time when determining the critical-optimum path.

Cols. 48-50, Format F3.2. Enter the weight assigned to cost when determining the critical-optimum path.

Cols. 51-53, Format F3.2. Enter the weight assigned to performance when determining the critical-optimum path.

Cols. 54-62, Format F9.0. Enter the time assigned to all the initial nodes (network start-up time).

Cols. 63-71, Format F9.0. Enter the cost assigned to all the initial nodes (project money spent prior to the start of the network).

Cols. 72-80, Format F9.0. Enter the performance assigned to all the initial nodes (performance generated prior to network start-up).

A2. Problem Identification Option Card.

Cols. 1-80, Format 20A4. Enter a card carrying any alphanumeric information deemed helpful in identifying this problem.

Note: The preceding card may be used only when a "1" has been entered in column 1 of the control card.

A3. Full Print Trip Option Card.

Cols. 1-8, Format 2A4. Enter the name of the first node or arc which, when active, will yield a full printout of all the arcs and nodes which were active during this iteration. Continue entering arc and node names in fields of 8 columns until all the arcs and/or nodes desired to cause this full print option to occur have been listed or a maximum of 10 has been reached, which will use up the whole card.

Note: The preceding card may be used only when a "1" has been entered in column 5 of the control card.

A4. Correlation Computation and Plot Option Card.

The following codes must be used to request plotting and computing the correlation coefficient between the following terminal node variables.

Code Number	Variable
1	Time
2	Path Cost
3	Overall Cost
4	Performance

Cols. 1-2, Format 2I1. Enter the code numbers for any 2 of the above variables for which a correlation coefficient is desired. A plot will be made of these variables in order to observe any possible mathematical relationship between these two variables. Continue on in fields of 2, requesting plot and correlation combination until all the desired combinations have been requested or until a maximum of 12 such combinations have been requested.

Note: The preceding card may be used only when a "1" has been entered in column 6 of the control card.

A5. Cost-performance time intervals option card(s). (The program considers only positive cost and/or performance observation within the designated time interval. Negative observations or observations having a value of zero are ignored.)

Cols. 1-10, Format F10.0. Enter the lower boundary of the time interval. The last card in this series of cards must have ENDCTPR in columns 1-7 of this field with the rest of the card being left blank.

Cols. 11-20, Format F10.0. Enter the upper boundary of the time interval.

Cols. 21-30, Format F10.0. Enter the lower value used to structure the cost histogram.

Cols. 31-40, Format F10.0. Enter the upper value used to structure the cost historgram. If this field and the preceding field are left blank or have zeros entered in them, the program will use the minimum and the maximum cost values observed during the simulation to construct this histogram.

Cols. 41-50. Same as cols. 21-30 except substitute the word PERFORMANCE for the word COST.

Cols. 51-60. Same as cols. 31-40 except substitute the word PERFORMANCE for the word COST.

Input in the following two fields will activate calculations which will aid management in the budgeting process. VERT assists in ascertaining the funds made available for critical budgeting periods of a development and for the entire life of the development have a very high chance of being adequate. For these calculations, VERT assumes the first N-1 cost-performance time interval request covers the entire planning horizon in N-1 ascending unique non-overlapping units of time. The last request of the series being entered, the Nth request, covers the entire planning horizon also; but in just one unit of time. An example of this situation would be that of entering eleven cost-performance time interval request, the first covering year one, the second covering year two, the third covering year three, etc. The eleventh request would cover the entire ten years.

To assist in this confidence level budgeting process, VERT requires the assignment of a desired confidence level to each cost-performance time interval request. The assignment of a unit step for each of the first N-1 cost-performance time interval requests is also required. The unit step will be used to incrementally adjust either upward or downward all of the confidence levels of the first N-1 periods to attain the assigned confidence level of the overall period (the Nth period). Entry of each of the unit steps enables holding the critical periods at a relatively fixed confidence level, while the confidence level of the remaining periods can vary more. The values assigned to the unit steps should be relatively small because VERT solves this problem by an iterative method. VERT will incrementally adjust each period's confidence level by its assigned unit step, compute the resultant sum of each period's cost and compare this sum to the cost associated with the overall period's confidence level. Once the cost associated with the overall period's confidence level has been crossed over, VERT will print the adjusted confidence levels of the previous iteration. Hence, the exactness of the solution depends upon the unit step size and the number of periods (cost-performance time intervals) requested.

Cols. 61-70, Format F10.0. Enter the confidence level described in the preceding two paragraphs. If this field and the following field are left blank or have zeros entered in them, VERT will not attempt any budget confidence computations.

Cols. 71-80, Format F10.0. Enter the unit step size described above.

Note: The preceding card(s) may be used only when a "1", "2" or "3" has been entered in column 7 of the control card.

A6. Composite terminal node minimums and maximums option card.

Cols. 1-10, Format F10.0. Enter the lower boundary value desired for the time histogram.

Cols. 11-20, Format F10.0. Enter the upper boundary value desired for the time histogram. If this field and the preceding field are left blank or have zeros entered in them, the program will use the minimum and maximum time value observed for this histogram during the simulation to construct this histogram.

Cols. 21-30. Same as cols. 1-10 except substitute the words PATH COST for the word TIME.

Cols. 31-40. Same as cols. 11-20 except substitute the words PATH COST for the word TIME.

Cols. 41-50. Same as cols. 1-10 except substitute the words OVERALL COST for the word TIME.

Cols. 51-60. Same as cols. 11-20 except substitute the words OVERALL COST for the word TIME.

Cols. 61-70. Same as cols. 1-10 except substitute the word PERFORMANCE for the word TIME.

Cols. 71-80. Same as cols. 11-20 except substitute the word PERFORMANCE for the word TIME.

Note: The preceding card may be used only when a "1" has been entered in column 8 of the control card.

B. Master and Accompanying Satellite Arc Cards

B1. Master Arc Card.

Cols. 1-8, Format 2A4. Enter the name of the arc being modeled.

Cols. 9-16, Format 2A4. Enter the arc's input node name. If this arc is a FREE ARC enter NOFLOW in columns 9-14.

Cols. 17-24, Format 2A4. Enter the arc's output node name. If this arc is a FREE ARC, enter DATAGEN in cols. 17-23.

Cols. 25-28, Format F4.2. Enter the probability of successfully completing this arc (activity). Acceptable entries are 1.0 and all the values between 0.0 and 1.0. If this arc is a FREE ARC, the program ignores any entry and puts a 1.0 in this field.

Col. 29, Format A1. Enter the letter S in this column to request a histogram of the slack time present on this arc, otherwise, leave this field blank. This histogram will be structured only when a time critical path (1.0 weight on the critical path time) is requested. Further, a satellite arc card (see B18) may be entered which will input a scale for this histogram. If this satellite card is omitted, the program will use the observed minimum and maximum slack time to structure its own scale. If this arc is a FREE ARC, the program ignores any entry and puts a blank in this field.

Cols. 30-80, Format A3, 12A4. Enter the description of the activity this arc represents.

Note: The following nine satellite arc cards (B2 - B10) are the basic vehicles used to input time, cost and performance data for each arc in the network. These cards carry the data needed to define an arc's time, cost and performance values.

B2. Time Statistical Distribution Satellite Arc Card.

This card carries the input parameters needed to define in part or in total the time value generated for this arc via the use of one of the following statistical distributions.

Distribution	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Constant	1	Constant				
Uniform	2	Min OBS	Max OBS			
Triangular	3	Min OBS	Max OBS	Most Likely OBS		
Normal	4	Min OBS	Max OBS	Mean	Std.Dev.	
Lognormal	5	Min OBS	Max OBS	Mean	Std.Dev.	
Gamma	6	Min OBS	Max OBS	Mean	Std.Dev.	
*Weibull	7	Min OBS	Max OBS	Scale Parameter	Shape Parameter	
Erlang	8	Min OBS	Max OBS	Mean	# of Exp.Dev.	
(Exponential)	8	Min OBS	Max OBS	Mean	1	
Chi Square	9	Min OBS	Max OBS	No. Degrees Freedom		
#Beta	10	Min OBS	Max OBS	A	B	
$Poisson	11	Min OBS	Max OBS	L		
%Pascal	12	Min OBS	Max OBS	P	K	
(Geometric)	12	Min OBS	Max OBS	P	1	
&Binomial	13	Min OBS	Max OBS	P	N	
+Hypergeometric	14	Min OBS	Max OBS	P		M

* The minimum observation is the location parameter.

$$\#F(X) = \frac{G(A+B)X^{A-1}(1-X)^{B-1}}{G(A)G(B)}$$

A Greater than zero
B Greater than zero
G = gamma function

$$\$F(X) = E^{-L}\frac{L^{X}}{X!} \qquad X=0,1,2...$$

L Greater than zero
E = natural log base
! = factorial

$$\%F(X) = \binom{K+X-1}{P}P^{K}Q^{X} \qquad X=0,1,2... \quad Q=1-P$$

$$\&F(X) = \binom{N}{X}P^{X}Q^{N-X} \qquad X=0,1,2...N \quad Q=1-P$$

$$+F(X) = \frac{\binom{NP}{X}\binom{NQ}{M-X}}{\binom{N}{M}} \qquad X=0,1,2...N \quad M-X=0,1,2...NQ \quad Q=1-P$$

Cols. 1-8, Format 2A4. Enter the name of the arc this satellite card is carrying information for.

Cols. 9-13, Format A4, A1. Enter the satellite type identifier - DTIME.

Cols. 14-15, Format I2. Enter the card sequence number. Only one card is needed to carry all the possible distribution data needed to define time in terms of one of the above statistical distributions. Therefore, enter a 1 in column 15.

Cols. 16-25, Format F10.0. Enter the data for field 1 as defined above.

Cols. 26-35, Format F10.0. Enter the data for field 2 as defined above.

Cols. 36-45, Format F10.0. Enter the data for field 3 as defined above.

Cols. 46-55, Format F10.0. Enter the data for field 4 as defined above.

Cols. 56-65, Format F10.0. Enter the data for field 5 as defined above.

Cols. 66-75, Format F10.0. Enter the data for field 6 as defined above.

B3. Cost Statistical Distribution Satellite Arc Card.

This card carries the input data needed to define in part or in total the cost value generated for this arc via the use of one of the previously defined statistical distributions. This card is the same as B2 except enter DCOST in columns 9-13 and enter the appropriate cost data. Further, if it is desired to inflate and/or discount the cost generated for this arc, in place of entering DCOST in columns 9-13, enter DCOSI to inflate the cost, enter DCOSD to discount the cost or enter DCOSB to both inflate and discount the cost by the appropriate interest rates entered in the control card.

B4. Performance Statistical Distribution Satellite Arc Card.

This card carries the input parameters needed to define in part or in total the performance value generated for this arc in columns 9-13 and enter the appropriate performance data. Further, if it is desired to inflate and/or discount the performance generated for this arc, in place of entering DPERF in columns 9-13, enter DPERI to inflate the performance, enter DPERD to discount the performance or enter DPERB to both inflate and discount the performance by the appropriate interest rates entered in the control card.

B5. Time Histogram Satellite Arc Card(s)

This card carries histogram data used to generate in part or in total the time value for this arc.

Cols. 1-8, Format 2A4. Enter the name of the arc this satellite card is carrying information for.

Cols. 9-13, Format A4, A1. Enter the satellite type identifier - HTIME.

Cols. 14-15, Format I2. Enter the card sequence number. The cards required to accomplish this task must be sequentially numbered. The maximum number of cards allowed equals the current maximum number of arcs allowed (value of the check variable MARC) divided by 6 or a total number of 99, whichever is the smaller.

Cols. 16-25, Format E10.0. Enter the left-hand time boundary of cell no. 1.

Cols. 26-35, Format E10.0. Enter the probability density of cell no. 1.

Cols. 36-45, Format E10.0. Enter the time boundary separating probability cells 1 and 2.

Cols. 46-55, Format E10.0. Enter the probability density of cell no. 2.

Cols. 56-65, Format F10.0. Enter the time boundary separating probability cells 2 and 3.

Cols. 66-75, Format F10.0. Enter the probability density of cell no. 3.

This completes the first card. Repeat the above sequence of steps for additional cards. The maximum number of cards allowed have been previously defined in columns 14-15.

B6. Cost Histogram Satellite Arc Card(s).

This card carries histogram data used to generate in part or in total the value for the cost carried by this arc. This card is the same as B5 except enter HCOST in columns 9-13 and enter the appropriate cost data. Further, if it is desired to inflate and/or discount the cost generated for this arc, in place of entering HCOST in columns 9-13, enter HCOSI to inflate the cost, enter HCOSD to discount the cost or enter HCOSB to both inflate and discount the cost by the appropriate interest rates entered in the control card.

B7. Performance Histogram Satellite Arc Card(s).

This card carries histogram data used to generate in part or in total the value for the performance carried by this arc. This card is the same as B5 except enter HPERF in columns 9-13 and enter the appropriate performance data. Further, if it is desired to inflate and/or discount the performance generated for this arc, in place of entering HPERF in columns 9-13, enter HPERI to inflate the performance, enter HPERD to discount the performance or enter HPERB to both inflate and discount the performance by the appropriate interest rates entered in the control card.

B8. Time Mathematically Related Satellite Arc Card(s).

This card carries the mathematical relationship(s) used to create in part or in total the time value for the arc under consideration. Entering mathematical relationship(s) requires using one or more of the following unit transformations.

Code Number$	Transformation		Restrictions	Notes
1 or 51	X*Y*Z	= R		(* Means Multiply)
2 or 52	(X*Y)/Z	= R	Z NE 0.0	(NE Means Not Equal To)
3 or 53	X/(Y*Z)	= R	Y*Z NE 0.0	
4 or 54	1/(X*Y*Z)	= R	X*Y*Z NE 0.0	
5 or 55	X+Y+Z	= R		

6 or 56	X+Y-Z = R			
7 or 57	X-Y-Z = R			
8 or 58	-X-Y-Z = R			
9 or 59	X*(Y+Z) = R			
10 or 60	X*(Y-Z) = R			
11 or 61	X/(Y+Z) = R	Y+Z NE 0.0		
12 or 62	X/(Y-Z) = R	Y-Z NE 0.0		
13 or 63	$X*(Y)^Z$ = R	Y GT 0.0	(GT Means Greater Than)	
14 or 64	$X*(LOG_E(Y*Z))$ = R	Y*Z GT 0.0	(E - Natural log base)	
15 or 65	$X*(LOG_{10}(Y*Z))$ = R	Y*Z GT 0.0		
16 or 66	X*(SIN(Y*Z)) = R			
17 or 67	X*(COS(Y*Z)) = R			
18 or 68	X*(ARCTAN(Y*Z)) = R			
19 or 69	X GE Y ------ Z = R		(GE Means Greater Than Or Equal To)	
	X LT Y ------ Y = R		(LT Means Less Than)	
20 or 70	X GE Y ------ Y = R X LT Y ------ Z = R			
21 or 71	X GE Y ------ Z = R X LT Y ------ X = R			
22 or 72	X GE Y ------ X = R X LT Y ------ Z = R			
23 or 73	(X*Y)+Z = R			
24 or 74	(X*Y)-Z = R			
25 or 75	(X/Y)+Z = R	Y NE 0.0		
26 or 76	(X/Y)-Z = R	Y NE 0.0		
27 or 77	(X+Y)*Z = R			
28 or 78	(X+Y)/Z = R	Z NE 0.0		
29 or 79	(X-Y)*Z = R			

30 or 80	(X-Y)/Z	= R	Z NE 0.0
31 or 81	X+(Y*Z)	= R	
32 or 82	X-(Y*Z)	= R	
33 or 83	X+(Y/Z)	= R	Z NE 0.0
34 or 84	X-(Y/Z)	= R	Z NE 0.0
35 or 85	-X-Y+Z	= R	
36 or 86	-X+Y+Z	= R	
37 or 87	X/Y/Z	= R	Y NE 0.0 Z NE 0.0

$Transformation numbers 1-37 and 51-87 use floating point computations to initially derive a value for R. However, transformations 51-87 truncate R to an integer value while transformations 1-37 retain R in its floating point form.

Structuring a mathematical relationship within a VERT network consists of essentially the following three phases:

1. Long or complicated mathematical relationships need to be broken down into a series of three-variable unit transformations shown above.

2. Values for each of the three variables (X, Y and Z) in each single unit transformation must be defined. These values can be retrieved from (A) previously processed arcs or nodes, (B) constants entered in these satellite arc cards, or (C) one of the previously processed transformations computed in the current series of transformations used to generate a time value for the current arc under consideration. Values calculated for each unit time transformation are consecutively, temporarily stored in a one dimensional array. This enables retrieving the value calculated for a prior transformation for use in the current unit transformation. Upon the completion of all the unit time transformations for a given arc, this temporary storage array is cleared. Thus, only the values calculated for previously derived unit time transformations developed for the current arc under consideration can be referenced. When retrieving numerical values from a previously processed arc or node, the time, or cost, or performance value calculated for the referenced node or the primary (not cumulative) time, or cost, or performance value generated for the referenced arc is retrieved.

3. Results of each of the unit transformations needed to develop a value for an arc's time can be either summed into the overall time value generated for the arc under consideration or it can be omitted. When the resulting value of a unit transformation is omitted, this transformation is generally being used as an intermediate step for calculating the value of a long or complicated mathematical relationship. An example mathematical relationship follows the complete description of all three types of mathematical relationships.

Cols.1-8, Format 2A4. Enter the name of the arc this satellite card is carrying information for.

Cols. 9-13, Format A4, A1. Enter the satellite type identifier - RTIME.

Cols. 14-15, Format I2. Enter the card sequence number. The cards required to accomplish this task must be sequentially numbered. The maximum number of cards allowed equals the current maximum number of arcs allowed (value of check variable MARC) or the current maximum number of nodes allowed (value of check variable MNODE) or a total number of 99, whichever is the smallest.

Cols. 16-17, Format I2. This field aids phase 1 of the transformation process. In this field, enter the code number of the transformation desired to be used.

Col. 18, Format A1. This field is concerned with phase 3 of the transformation process. Enter the letter 'S' to sum the resulting value of this transformation into the time value generated for this arc. Otherwise, enter the letter 'O' to omit it. In the event an arc or a node used in a given transformation is logically eliminated or is a failure, backup or alternate transformations may be entered. This task is accomplished by entering, directly after an initial transformation, additional backup transformation(s) carrying the letter 'B' in column 18 (or column 48.) An unlimited number of backup transformations may then follow a given initial transformation. The program will sequentially try processing each one of these backup transformations until it finds one that can be computed. It will then ignore the rest of the backup transformations. However, if the initial transformation plus all of its backups are infeasible, an error number will be listed and the simulation will then be terminated. The program assumes that the sum or omit disposition which applies to the initial transformation should apply to the backup transformations.

The following three groups of two fields per group are concerned with phase 2 of the transformation process, the retrieval phase. Groups 1, 2 and 3 structure the retrieval of numerical information for the transformation variables X, Y and Z respectively. The specific layout for the X group and similar layouts for the Y and Z groups are as follows.

Col. 19, Format A1. Acceptable entries in this field are the letters 'T', 'C', 'P', 'K' or a blank.

Cols. 20-27, Format 2A4 or F8.0. If a 'T' is entered in column 19, the time value carried by the node entered in this field or the primary time value carried by the arc entered in this field will be loaded into the transformation variable X when this transformation is executed. Also, entering a 'C' or 'P' in column 19 will promulgate the loading of the cost or performance values carried by the arc or node whose name is entered in this field, into the transformation variable X prior to executing this transformation. If a 'K' is entered in column 19, then a numerical constant must be entered in this field. This constant will be loaded into the transformation variable prior to executing this transformation. If column 19 is left blank, it is assumed that the value calculated for a previous transformation in the current series of time transformations be entered in variable X prior to executing this transformation. The series number of that previous transformation must be entered in this field. For example, if it is desired to load the resulting value of the 2nd unit time transformation into the variable X in the 3rd unit time transformation, a '2.0' should be entered in this data field when structuring the 3rd unit time transformation.

Col. 28. Same as column 19.

Cols. 29-36. Same as columns 20-27 except substitute Y for X.

Col. 37. Same as column 19.

Cols. 38-45. Same as columns 20-27 except substitute Z for X.

This card is structured to carry two unit time transformations. The fields in the second part of this card equate to the fields just defined in the first part of this card as follows:

Cols. 46-47. Are equivalent to columns 16-17.

Col. 48. Is equivalent to column 18.

Col. 49. Is equivalent to column 19.

Cols. 50-57. Are equivalent to columns 20-27.

Col. 58. Is equivalent to column 28.

Cols. 59-66. Are equivalent to columns 29-36.

Col. 67. Is equivalent to column 37.

Cols. 68-75. Are equivalent to columns 38-45.

Note: The second part of this card may optionally be left blank when loading a series of unit time transformations. However, the first part of this card must always be used.

B9. Cost mathematically related satellite arc card(s).

This card(s) carries the mathematical relationship(s) used to create in part or in total the cost value for the arc under consideration. The description of this card is the same as B8 except enter RCOST in columns 9-13 and substitute the word COST for the word TIME. Further, if it is desired to inflate and/or discount the cost generated for this arc, in place of entering

RCOST in columns 9-13, enter RCOSI to inflate the cost, enter RCOSD to discount the cost or enter RCOSB to both inflate and discount the cost by the appropriate interest rates entered in the control card.

B10. Performance mathematically related satellite arc card(s).

This card carries the mathematical relationship(s) used to create in part or in total the performance value for the arc under consideration. The description of this card is the same as B8 except, enter RPERF in columns 9-13 and substitute the word PERFORMANCE for the word TIME. Further, if it is desired to inflate and/or discount the performance generated for this arc, in place of entering RPERF in columns 9-13, enter RPERI to inflate the performance, enter RPERD to discount the performance or enter RPERB to both inflate and discount the performance by the appropriate interest rates entered in the control card.

Transformation Example. Suppose the value for the performance of a given arc is related to the time, cost and performance values generated on this arc and other previously processed arcs and nodes as follows:

$$PA10 = \frac{(PA1 + PA2 + PA3)}{(PA4 * PA5 * PA6)}*(TA1)*(\mathrm{LOG}_E\,(CA1 * CA2)) + (188.6*\frac{(TA10)}{(CA10)} + (15.8)*(TN1)$$

where:

TN1 = the time value for the node named N1.
TA1 = the time value for the arc named A1.
TA10 = the time value for the arc named A10.
CA1 = the cost value for the arc named A1.
CA2 = the cost value for the arc named A2.
CA10 = the cost value for the arc named A10.
PA1 = the performance value for the arc named A1.
PA2 = the performance value for the arc named A2.
PA3 = the performance value for the arc named A3.
PA4 = the performance value for the arc named A4.
PA5 = the performance value for the arc named A5.
PA6 = the performance value for the arc named A6.
PA7 = the performance value for the arc named A7.
PA8 = the performance value for the arc named A8.
PA9 = the performance value for the arc named A9.
PA10 = the performance value for the arc named A10.

The following dimensioned card layouts illustrates how the preceding equation is put into card form.

A10	RPERF 1 50PA1	PA2	PA3	trans. no. 1
A10	RPERF 2 40PA4	PA5	PA6	trans. no. 2

```
A10     RPERF 3140TA1      CA1       CA2              trans. no. 3
A10     RPERF 4 1$ 1.0      2.0       3.0             trans. no. 4
A10     RPERF 5 2SK188.6   TA10      CA10             trans. no. 5
A10     RPERF 6 1SK15.8    TN1       K1.0             trans. no. 6
********+++++**++*+********+********+********
********+++++**++*+********+********+********
Cols 1-8+++++**++*+ 20-27  + 29-36  + 38-45
        +++++**++*+        +        +
         9-13**++*19       28       37
             **++*
          14-15++18
               ++
               ++
             16-17
```

The preceding layout illustrates that the above equation can be modeled by using six sequential transformations. The first three transformations compute the values for (PA1 + PA2 + PA3), (1/(PA4 * PA5 * PA6)) and ((TA1)* (LOG_E(CA1 * CA2)) respectively. The letter '0' in column 18 of these transformations indicates that the resultant value of each of these transformations is not summed in the performance value for arc A10. However, transformation number four is summed into the resulting performance value of arc A10. It pulls these three previously derived values together to derive a composite value for the first major term of the equation. Transformations five and six compute the values for the second and third termsof the equation. These values are summed directly into the resulting performance value calculated for arc A10.

Note: The following seven satellite arc cards (B11 - B17) assist an arc's input node in its logic function. These satellites carry information used in conducting output logic functions.

B11. Filter number 1 satellite arc card (this arc's input node must have filter number 1 output logic).

Cols. 1-8, Format 2A4. Enter the name of the arc this satellite card is carrying information for.

Cols. 9-12, Format A4, A1. Enter the satellite type identifier - FILT1.

Cols.14-15, Format I2. Enter the card sequence number. Only one card per arc is required to carry all the information needed for this task. Therefore, enter a '1' in column 15.

Cols. 16-25, Format F10.0. Enter the lower boundary of the time constraint placed on this arc.

Cols. 26-35, Format F10.0. Enter the upper boundary of the time constraint placed on this arc.

Cols. 36-45, Format F10.0. Enter the lower boundary of the cost constraint placed on this arc.

Cols. 46-55, Format F10.0. Enter the upper boundary of the cost constraint placed on this arc.

Cols. 56-65, Format F10.0. Enter the lower boundary of the performance constraint placed on this arc.

Cols. 66-75, Format F10.0. Enter the upper boundary of the performance constraint placed on this arc.

B12. Filter number 2 satellite arc card (this arc's input node must have filter number 2 output logic.)

Cols. 1-8, Format 2A4. Enter the name of the arc this satellite card is carrying information for.

Cols. 9-13, Format A4, A1. Enter the satellite type identifier - FILT2.

Cols. 14-15, Format I2. Enter the card sequence number. Only one card per arc is required to carry all the information needed for this task. Therefore, enter a '1' in column 15.

Cols. 16-25, Format F10.0. Enter the lower boundary of the number of successfully completed input arcs constraint(s) placed on this arc.

Cols. 26-35, Format F10.0. Enter the upper boundary of the number of successfully completed input arcs constraint(s) placed on this arc.

B13. Filter Number 3 satellite arc card (this arc's input node must have filter number 3 output logic).

Cols. 1-8, Format 2A4. Enter the name of the arc this satellite card is carrying information for.

Cols. 9-13, Format A4, A1. Enter the satellite type identifier - FILT3.

Cols. 14-15, Format I2. Enter the card sequence number. The cards required to accomplish this task must be sequentially numbered. The maximum number of cards allowed equals the current maximum number of arcs allowed (value of the check variable MARC) divided by 6 or a total number of 99, whichever is the smaller.

Col. 16, Format 1X. Leave blank.

Col. 17, FORMAT A1. Enter a plus (+) sign if the following constraining arc must have been successfully completed before the output arc being constrained can be initiated. Otherwise, enter a minus (-) sign if the constraining arc must have been unsuccessfully processed or eliminated from the network before the output arc being constrained can be initiated.

Cols. 18-25, Format 2A4. Enter the name of the first constraining arc.

Col. 26. Same as column 16; leave blank.

Col. 27. Same as column 17 (if another constraining arc is needed).

Cols. 28-35, Format 2A4. Enter the name of the second constraining arc.

Continue this process until the constraint list has been exhausted or until the maximum number of these cards has been entered as previously defined in the card sequencer field.

B14. Monte Carlo satellite arc card (this arc's input node must have monte carlo output logic).

Cols. 1-8, Format 2A4. Enter the name of the arc this satellite card is carrying information for.

Cols. 9-13, Format A4, A1. Enter the satellite type identifier - M in column 9 and leave columns 10-13 blank.

Cols. 14-15, Format I2. Enter the card sequence number. Only one card is required to carry all the information needed for this task per arc. Therefore, enter a 1 in column 15.

Cols. 16-25, Format F10.0. Enter this arc's probability of being monte carlo initiated.

Note: The following 3 satellite arc cards are an addendum to B14. These cards will enable the construction of conditional probability situations where the probability of arc initiation is a function of either the time, cost or performance accumulated on this arc's input node. The layout of these card types consists of a probability element in the first data field, followed by either a time, cost or performance boundary in the second data field, followed by a probability element in the third data field, followed by another boundary in the fourth data field, etc. through the last element which must be a probability element. The boundaries must be identical in numerical value and field placement over all the output arcs of this arc's input node. The probability elements within a given field must have a value greater than zero or less than or equal to one. The sum of the probability elements in each of the probability element data fields must sum to one when summing these items over all the output arcs of this arc's input node. The probability field selected when processing the network will be the one whose left hand time, cost or performance boundary is less than or equal to the value generated for this arc's input node's time, cost or performance, and whose right hand time, cost or performance boundary is greater than the value generated for this arc's input node's time, cost or performance.

B15. Monte Carlo time conditioned satellite arc card (this arc's input node must have monte carlo output logic).

Cols. 1-8, Format 2A4. Enter the name of the arc this satellite card is carrying information for.

Cols. 9-13, Format A4, A1. Enter the satellite type identifier - MTIME.

Cols. 14-15, Format I2. Enter the card sequence number. The cards required to accomplish this task must be sequentially numbered. The maximum number of cards allowed equals the current maximum number of arcs allowed (value of the check variable MARC) divided by 6 or a total number of 99, whichever is the smaller.

Cols. 16-25, Format F10.0. Enter this arc's element to distribution number 1.

Cols. 26-35, Format F10.0. Enter time boundary number 1.

Cols. 36-45, Format F10.0. Enter this arc's element to distribution number 2.

Cols. 46-55, Format F10.0. Enter time boundary number 29.

Cols. 56-65, Format F10.0. Enter this arc's element to distribution number 3.

Cols. 66-75, Format F10.0. Enter time boundary number 3.

This completes the first card. Repeat the above sequence of steps for additional cards as necessary. The maximum number of cards allowed has been previously defined in the card sequence field, cols. 14-15.

B16. Monte Carlo cost conditioned satellite arc card (this arc's input node must have Monte Carlo output logic).

This description is the same as B15 except, enter MCOST in columns 9-13 and substitute the word COST for the word TIME in the narrative.

B17. Monte Carlo performance conditioned satellite arc card (this arc's input node must have monte carlo output logic).

This description is the same as B15 except enter MPERF in columns 9-13 and substitute the word PERFORMANCE for the word TIME in the narrative.

Note: The following satellite arc card is used to report arc slack information only.

B18. Slack histogram satellite arc card.

This card is used to input the minimum and maximum slack time value used to construct arc slack time histograms. This feature is optional. If this card is omitted, the program will use the minimum and maximum values observed during the simulation to construct the histogram cells. If the values generated during the simulation lie outside the minimum and maximum boundaries entered, the program accumulates these values in minimum and/or maximum overflow cells. Thus, outliers are accumulated in these peripheral cells while pictorializing the interior contents of the histogram.

Cols. 1-8, Format 2A4. Enter the name of the arc this satellite card is carrying information for.

Cols. 9-13, Format A4, A1. Enter the satellite type identifier - SLAK .

Cols. 14-15, Format I2. Enter the card sequence number. Only one card per arc is required to carry all the information needed for this task. Therefore, enter a '1' in column 15.

Cols. 16-25, Format F10.0. Enter the minimum slack time desired for constructing the slack time histogram.

Cols. 26-35, Format F10.0. Enter the maximum slack time desired for constructing the slack time histogram.

Cols. 36-80. Leave blank.

C. End of Arc Data Signaler.

Cols. 1-8, Format 2A4. Enter ENDARC in columns 1-6.

Cols. 9-80. Leave blank.

D. Master and Accompanying Satellite Node Cards.

D1. Master Node card.

Cols. 1-8, Format 2A4. Enter the name of the node being modeled.

Col. 9, Format I1. Enter the input logic code number (defined as follows).

Input Logic Code Number	Type of Input Logic
1	Initial
2	And
3	Partial and
4	Or

Note: The order in which the arc cards are entered in the computer is critical for proper functioning of the following logics. The first input arc read in will be linked or mated with the first output arc read in; likewise, the second input arc read in will be linked or mated with the second output arc read in, etc. It does not matter if the output arcs are read in first or vice versa or if the input and output arc cards are intermixed while being read in. The relative order in which the input arcs and output arcs by themselves are read in is the important factor.

5	Compare
6	Preferred
7	Queue
8	Sort

Cols. 10-12, Format I3. Enter the output logic code number (defined below) or enter the number of servers if QUEUE logic is used or enter the number of output arcs desired to be initiated if COMPARE or PREFERRED input logic was requested. Under this latter option, a minus sign (-) should prefix this number if utilization of the desired condition is wanted. Otherwise, this number will be picked up as a positive number and thus the demand condition will be invoked.

Output Logic Code Number	Type of Output Logic
1	Terminal*
2	All
3	Monte Carlo
4	Filter 1
5	Filter 2
6	Filter 3

*If the 1 in column 12 is prefixed with a 1, 2, 3 --- 99 to give a total field entry of 11, 21, 31 --- 991, the terminal node is given a 2nd, 3rd, 4th --- 100th class designation. The 1st class designation is given by leaving columns 10 and 11 blank. The higher the prefix number, the lower the class. When choosing the winning terminal node as described in section A1 (see the note before columns 33-35 description), the first class terminal nodes take precedence over the second class terminal nodes, the second class terminal nodes take precedence over the third class terminal nodes, etc. Competition is first conducted among the first class terminal nodes, providing there is at least one active 1st class terminal node for the given iteration. However, if there are not any active first class terminal nodes, then competition is conducted at the 2nd class level or the 3rd class level, or at the highest class level where active terminal nodes exist. There are no class size limitations; however, there cannot be more class levels than the number of nodes read in minus 1 or a grand total of 100 (including the zero - first class level) whichever is the smaller.

Cols. 13-14, Format I2. Enter the numeric code given below for the type of output desired from the next field.

Numeric Code	Time	Path Cost	Overall Cost	Performance
Blank or zero	Yes	Yes	Yes	Yes
1	Yes	No	No	No
2	No	Yes	No	No
3	No	No	Yes	No
4	No	No	No	Yes
5	Yes	Yes	No	No
6	Yes	No	Yes	No
7	Yes	No	No	Yes
8	No	Yes	Yes	No
9	No	Yes	No	Yes
10	No	No	Yes	Yes
11	Yes	Yes	Yes	No
12	Yes	Yes	No	Yes
13	Yes	No	Yes	Yes
14	No	Yes	Yes	Yes
15	No	No	No	No

Cols. 15-16, Format I2. This program has the facility for printing time, cost and performance histograms for a limited number of internal nodes. This limit is set by the programs embedded check variable MHIST. Internal nodes can be designated as candidates for statistical printouts by sequentially numbering these nodes in this field up to and including the value of MHIST. If it is desired to construct time, cost and performance histograms for an interval between 2 nodes, enter the same number in this field for the two nodes bridging the interval. Only two nodes at a time can be used to develop interval histograms.

Terminal node histograms will be listed automatically. Therefore, this field should be left blank when desiring the normal histogram listings for the terminal nodes. However, the previous field (cols. 13-14) should have an entry when this node is a terminal node. If a -1 is entered in this field when this node is a terminal node, all critical-optimum paths terminating in this node will be suppressed from the critical-optimum path analysis. Entering a -2 in this field will cause punching HTIME, HCOST and HPERF stochastic histogram satellite arc cards carrying the histograms. This will facilitate the substitution of the results obtained from a lower level network into a higher summary level network. Generally a terminal node in the lower level network becomes an arc in the higher level network.

Note: Values assigned to the following 3 fields must all lie within either the closed interval of -1 to 0 or the closed interval of 0 to +1. These fields must not jointly carry positive and negative values (field 1 cannot have a positive entry while fields 2 and/or 3 have negative entries, etc.). Entering positive values in these fields will cause the optimum input arc set to be chosen as the one with the least time and cost and the most performance. Entering negative values in these fields will cause the optimum input arc set to be chosen as the one with the largest time and cost and the least performance.

Cols. 17-20, Format F4.3. Enter the weight assigned to time when choosing the optimum input arc set via the COMPARE logic or when sorting input flows via the SORT logic.

Cols. 21-24, Format F4.3. Enter the weight assigned to cost when choosing the optimum input arc set via the COMPARE logic or when sorting input flows via the SORT logic.

Cols. 25-28, Format F4.3. Enter the weight assigned to performance when choosing the optimum input arc set via the COMPARE logic or when sorting input flows via the SORT logic.

Col. 29, Format A1. Enter the letter 'S' in this column to request a histogram of the slack time available at this node. Otherwise, leave this field blank. This histogram will be structured only when a time critical path (1.0 weight on the critical path time) is requested. Further, a satellite node card (see D4) may be entered which will input a scale for this histogram. If this satellite card is omitted, the program will use the observed minimum and maximum slack time to structure its own scale.

Cols. 30-80, Format A3, 12A4. Enter the description of the event this node represents.

D2. Histogram Satellite Node Card.

This card is used to input the minimum and maximum times, path cost, overall cost and performance values used to construct histograms generated for this node. Therefore, this node must be either a terminal node, or it must be an internal node used to gather statistics. This card is optional. If it is omitted, the program will use the minimum and maximum values observed during the simulation for constructing the histogram cells. However, if this card is used and values are generated which exceeds the minimum and/or maximum boundaries entered, the program accumulates these values in minimum and/or maximum overflow cells. Thus outliers can be accumulated in these peripheral cells while pictorializing the interior content of the data.

Cols. 1-8, Format 2A4. Enter the name of the node this satellite node card is carrying information for.

Cols. 9-12, Format A4. Satellite type identifier - enter HIST (abbreviation for histogram).

Cols. 13-20, Format F8.0. Enter the lower boundary value desired for the time histogram.

Cols. 21-28, Format F8.0. Enter the upper boundary value desired for the time histogram. If this field and the preceding field are left blank or have zeros entered in them, the program will use the minimum and maximum time values observed for this histogram during the simulation for its construction.

Cols. 29-36. Same as cols. 13-20 except substitute the words PATH COST for the word TIME.

Cols. 37-44. Same as cols. 21-28 except substitute the words PATH COST for the word TIME.

Cols. 45-52. Same as cols. 13-20 except substitute the words OVERALL COST for the word TIME.

Cols. 53-60. Same as cols. 21-28 except substitute the words OVERALL COST for the word TIME.

Cols. 61-68. Same as cols. 13-20 except substitute the word PERFORMANCE for the word TIME.

Cols. 69-76. Same as cols. 21-28 except substitute the word PERFORMANCE for the word TIME.

D3. Subtract Satellite Node Card.

This card is used to input the subtract node. This node must have FILTER NUMBER 1 output logic. If this card is omitted the subtraction feature (chapter 2-2) will not be utilized when using FILTER NUMBER 1 logic.

Cols. 1-8, Format 2A4. Enter the name of the node this satellite node card is carrying information for.

Cols. 9-12, Format A4. Satellite type identifier - enter SUBT (abbreviation for subtract).

Cols. 13-20, Format 2A4. Enter the subtract node name.

D4. Slack Histogram Satellite Node Card.

This card is used to input the minimum and maximum slack time values used to construct slack time histograms for this node. This card is optional in the same sense as the histogram satellite node card is (see D2).

Cols. 1-8, Format 2A4. Enter the name of the node this satellite node card is carrying information for.

Cols. 9-12, Format A4. Satellite type identifier - enter SLAK (abbreviation for slack).

Cols. 13-20, Format F8.0. Enter the minimum slack time desired for the slack time histogram.

Cols. 21-28, Format F8.0. Enter the maximum slack time desired for the slack time histogram. If this field and the preceding field are left blank or have zeros entered in them, the program will use the minimum and maximum time values observed for this histogram during the simulation for its construction.

<u>Cols. 29-80</u>. Leave blank.

E. <u>End of Node Data Signaler</u>.

<u>Cols. 1-7, Format 2A4</u>. Enter ENDNODE.

<u>Cols. 8-80</u>. Leave blank

CHAPTER 4 ERROR AND WARNING MESSAGES

Many of the major storage arrays in this program have a temporary task of storing input data. These tasks require a certain minimum size. The following check variables are required to have the following minimum sizes listed. If this minimum size is not achieved, the error number to the left of the check variable listed below will be printed. The user must expand these arrays along with the check variables listed below. This expansion can be accomplished by using the DIMEN program.

Error Number	Check Variable	Size
1300	MITER	Greater than or equal to 150.
1311	MARC	Greater than or equal to 120.
1322	LARC	Greater than or equal to 200.
1333	MNODE	Greater than or equal to 75.
1344	LNODE	Greater than or equal to 200.
1355	MTAG	Greater than or equal to 200.
1366	MHIST	Greater than or equal to 1.
1377	MTERM	Greater than or equal to 1.
1388	MSLACK	Greater than or equal to 1.
1399	MCPGAP	Greater than or equal to 1.
1400	MCPGAP	Less than or equal to MARC/2.

1444 The run identification card option (column one of the control card) must have a (Blank), (0) or (1) punched in it.

1500 The trip indicator (column five of the control card) must have a (Blank), (0) or (1) punched in it.

1511 The correlation indicator (column six of the control card) must have a (Blank), (0) or (1) punched in it.

1522 The cost-performance time intervals option (column seven of the control card) must have a (Blank), (0), (1), (2) or (3) punched in it.

1533 The entry of minimums and maximums for the composite terminal node indicator (column eight of the control card) must have a (0), (Blank) or (1) punched in it.

1622 There are too many cost-performance time interval cards being entered. Either the number of these cards must be reduced or the storage arrays in the common block/CPGAP/ must be expanded along with the check variable MCPGAP. This expansion can best be accomplished by using the DIMEN program.

1633 A key punching mistake (Alpha in a numeric field, two decimal points in one field, a gap within a number or between the number and its sign) has been sensed when examining the cost-performance time interval input data.

1677 The cost-performance time interval data has one or more of the following types of errors: (1) the lower time boundary is greater than or equal to the upper time boundary, (2) the upper time boundary is less than the time value given the initial node(s), (3) the lower value given to the cost histogram is greater than or equal to the upper value, (4) the lower value given to the performance histogram is greater than or equal to the upper value.

1733 A key punching mistake (Alpha in a numeric field, two decimal points in one field, a gap within a number or between the number and its sign) has been sensed when examining the minimums for the composite terminal node.

1777 The type of run parameter (column two of the control card) was incorrectly specified. Acceptable entries are (Blank) or (0) (Data will be automatically loaded and stored on the master file as a new problem), (1) (Changes mode run where the master file is retained as it was prior to this run) and (2) (changes mode run where the master file is augmented with the changes).

1844 The ENDARC card was omitted or incorrectly punched. ENDARC must reside in columns 1-6.

1877 One of the changes-run options is currently being used. The variables in common blocks /ARCS/ and /NODES/ are being used as temporary storage arrays for holding changes. These arrays are now being exceeded and must be expanded by increasing either or both check variables MARC and MNODE and all the arrays mnemonically dimensioned in terms of these variables. This expansion can be accomplished by using the DIMEN program. An alternative is that of incorporating the change cards in the master card deck and reloading as a new master problem.

2011 The variables in the common blocks /ARCS/ and /NODES/ are being used to hold the master arc card along with its satellites. These storage arrays are now being exceeded and must be expanded by increasing either or both check variables MARC and MNODE and all the arrays mnemonically dimensioned in terms of these variables. This expansion can be accomplished by using the DIMEN program. An alternative is that of breaking up the functions being performed by the arc or node causing the overflow.

2077 The arc listed has a satellite arc card which does not have an acceptable satellite arc card identifier.

2111 The arc name listed has already been used as an arc name. All arc and node names must be unique.

2144 There are too many arcs. Either the size of the network must be cut down by possibly making subnetworks or the arc storage arrays must be expanded by increasing the value of the check variable MARC and the arrays mnemonically dimensioned in terms of this variable. This expansion can be accomplished by using the DIMEN program.

2266 The node listed has a satellite card which does not have an acceptable identifier (must have <u>HIST</u>, <u>SUBT</u> or <u>SLAK</u> in columns 9-12).

2300 The node name listed has already been used as a node name. All arc and node names must be unique.

2333 There are too many nodes. Either the size of the network must be cut down by possibly making subnetworks or the node storage arrays must be expanded by increasing the value of the check variable MNODE and all the arrays mnemonically dimensioned in terms of this variable. This expansion can be accomplished by using the DIMEN program.

2511 The arc listed has more than one satellite M____, FILT1, FILT2, SLAK , DTIME, DCOST or DPERF arc card. One card is all that is necessary to carry all the information required by any of these satellites.

2599 The arc listed has alpha information in a numeric field, The number listed to the right of the error number is the number of times this violation has occurred after the master arc card and all its accompanying satellite arc cards were reviewed. This scan also assumes that any blank between digits of a number or between a number and its sign is a mistake.

2644 The node listed has more than one satellite HIST, SUBT or SLAK card. One card is all that is necessary to carry all the information required by any of these satellites.

2677 The node listed has Alpha information in a numeric field. The number listed to the right of the error number indicates the number of times this violation has occurred after the master node card and all its satellite node cards were reviewed. This scan also assumes that any blank between digits of a number or between a number and its sign is a mistake.

2766 The full-print, each-iteration, output option number four has been selected. This option will list all active arcs and nodes each iteration. Some designated arcs and nodes have been requested to invoke this option when they are active, which is unnecessary when the full-print option is selected.

2800 An arc or node was designated to invoke the full-print option for each iteration in which it is active; however, the arc or node listed in this error message does not match any of the arcs or nodes read in.

2866 The correlation combinations input card has an unacceptable combination punched in it.

2900 While reading the input card data, the computer prematurely encountered the end of the input card file.

3000 The arc listed does not have an acceptable input node.

3033 The arc listed does not have an acceptable output node.

3077 The arc listed appears to be tasked with the job of carrying more than one set of MONTE CARLO data and/or more than one set of FILTER data. This arc's input node can have only one type of output logic which requires at most one set of MONTE CARLO or FILTER data.

3099 While reading in arc data, it was observed that more slack histograms had been entered than there were spaces available. The number of requests must be reduced or the slack storage arrays must be expanded by increasing the value of the check variable MSLACK and the arrays mnemonically dimensioned in terms of this variable. This expansion can be accomplished by using the DIMEN program. However, this is only a warning message. Since output option number four was requested, the storage will not be needed. If another output option is requested, the space will be needed.

3100 Same as the preceding message except, output option number four was not selected, and, thus it is a fatal error this time.

3144 There is too much variable arc data. The variable arc storage array ASTORE is overflowing with data. Either the size of the network must be cut down by possibly making subnetworks, or ASTORE and the check variable LARC must be expanded. This expansion can be accomplished by using the DIMEN program.

3166 The arc listed has too many M____, MTIME, MCOST, MPERF, FILT1, or FILT2 satellite arc cards. The maximum number of M____, FILT1 or FILT2 satellite arc cards allowed per arc is one. The maximum number of MTIME, MCOST or MPERF satellite arc cards allowed per arc is the value of the check variable MARC divided by six. Either the number of these satellites must be reduced or the value of the check variable MARC and all the arrays mnemonically dimensioned in terms of this variable must be expanded. This expansion can be accomplished by using the DIMEN program.

3199 The arc listed has too many FILT3 satellite arc cards. The maximum number of FILT3 satellite arc cards allowed per arc is the value of the check variable MARC divided by six. Either the number of these satellites must be reduced or the value of the check variable MARC and all the arrays mnemonically dimensioned in terms of this variable must be expanded. This expansion can be accomplished by using the DIMEN program.

3233 The arc listed has FILT3 satellite arc card(s). The card sequence number in at least one of these cards is out of sequence.

3244 The arc listed has FILT3 satellite arc card(s). The plus (+) or minus (-) identifier is missing on one or more of the constraining arcs.

3277 The arc listed has FILT3 satellite arc card(s). A constraining arc does not match any of the arcs defined in this problem.

3322 The arc listed has a SLAK histogram satellite arc card entered, but a slack histogram was not requested for this arc (no 'S' was entered in column number 29 of the master arc card).

3333 The arc listed has more than one SLAK histogram satellite arc card entered for it. One of these cards is all that is necessary per arc.

3355 The arc listed has stochastic data being entered via one of the canned distributions (DTIME, DCOST or DPERF satellite arc cards) and also via histograms (HTIME, HCOST or HPERF satellite arc cards). Only one of the two options is allowed per random variable entry.

3366 The arc listed has too many DTIME, DCOST or DPERF satellite arc cards. The maximum number of DTIME, DCOST or DPERF satellite arc cards allowed per arc is one.

3377 The arc listed has too many HTIME, HCOST or HPERF satellite arc cards. The maximum number of HTIME, HCOST or HPERF satellite arc cards allowed per arc is the value of the check variable MARC divided by six. Either the number of these satellites must be reduced or the value of the check variable MARC and all the arrays mnemonically dimensioned in terms of this variable must be expanded. This expansion can best be accomplished by using the DIMEN program.

3388 The arc listed has too many RTIME, RCOST or RPERF satellite arc cards. The maximum number of RTIME, RCOST or RPERF satellite arc cards allowed per arc is equal to the value of the check variables MARC or MNODE whichever one is the smallest. The number of these satellites must be reduced or the value of the check variable MARC and/or MNODE and all of these arrays mnemonically dimensioned in terms of one or both of these variables must be expanded. This expansion can best be accomplished by using the DIMEN program.

3399 The arc listed has at least one satellite distribution arc card (DTIME, DCOST or DPERF satellite arc card). The distribution indicator in one of these cards lies outside the acceptable range of 1 to 14. The number listed in the error message is the distribution indicator.

3411 The arc listed has at least one satellite distribution arc card (DTIME, DCOST or DPERF satellite arc card). The content of information carried on this card is not consistent with the distribution requested. The number listed in the error message is the distribution indicator.

3499 The arc listed has a satellite distribution arc card (DTIME, DCOST, or DPERF satellite arc card) requesting the use of the lognormal distribution. Only positive non-zero parameters can be entered in this distribution.

3522 The arc listed has a satellite distribution arc card (DTIME, DCOST, or DPERF satellite arc card) requesting the use of the gamma distribution. Only positive non-zero parameters can be entered in this distribution.

3544 The arc listed has a satellite distribution arc card (DTIME, DCOST, or DPERF satellite arc card) requesting the use of the gamma distribution. The standard deviation is too large or the mean too small to yield at least one exponential deviate.

3566 The arc listed has a satellite distribution arc card (DTIME, DCOST, or DPERF satellite arc card) requesting the use of the Weibull distribution. Only positive non-zero parameters can be entered in this distribution.

3599 The arc listed has a satellite distribution arc card (DTIME, DCOST or DPERF satellite arc card) requesting the use of the Erlang distribution. Only positive non-zero parameters can be entered in this distribution and the number of exponential deviates must be an integer.

3622 The arc listed has a satellite distribution arc card (DTIME, DCOST, or DPERF satellite arc card) requesting the use of the Chi square distribution. Only positive non-zero parameters can be entered in this distribution and the number of degrees of freedom must be an integer.

3655 The arc listed has a satellite distribution arc card (DTIME, DCOST or DPERF satellite arc card) requesting the use of the Beta distribution. Only positive non-zero parameters can be entered in this distribution.

3677 The arc listed has a satellite distribution arc card (DTIME, DCOST or DPERF satellite arc card) requesting the use of the Poisson distribution. Only positive non-zero parameters can be entered in this distribution. Additionally, the numerical difference between the maximum and minimum observation allowed must be at least one.

3722 The arc listed has a satellite distribution arc card (DTIME, DCOST or DPERF satellite arc card) requesting the use of the Pascal distribution. The input data does not meet one of the following requirements:

1. The value assigned to P must lie between 0 and 1.
2. The value assigned to K must be a positive integer.
3. The minimum observation must not be negative.

Where, Pascal = $\binom{k+x-1}{x} P^{K} Q^{X}$ $X=0,1,2---N$ and $Q=1-P$

3766 The arc listed has a satellite distribution arc card (DTIME, DCOST or DPERF satellite arc card) requesting the use of the Binomial distribution. The input data does not meet one of the following requirements:

1. The value assigned to P must lie between 0 and 1.
2. The value assigned to N must be a positive integer.
3. The minimum observation must not be negative.

Where, Binomial = $\binom{N}{X} P^{X} Q^{N-X}$ $X=0,1,2---N$ and $Q=1-P$

3800 The arc listed has a satellite distribution arc card (DTIME, DCOST or DPERF satellite arc card) requesting the use of the Hypergeometric distribution. The input data does not meet one of the following requirements:

1. The value assigned to P must lie between 0 and 1.
2. The value assigned to N must be a positive integer.
3. The value assigned to M must be a positive integer less than N.
4. The minimum observation must not be negative.

Where, Hypergeometric = $\dfrac{\binom{NP}{X}\binom{NQ}{M-X}}{\binom{N}{M}}$ $X=0,1,---NP$ $M-X=0,1,---NQ$

3833 The arc listed has a satellite distribution arc card (DTIME, DCOST or DPERF satellite arc card) requiring a positive standard deviation which was not entered.

3855 The arc listed has a satellite distribution arc card (DTIME, DCOST or DPERF satellite arc card) having a mean outside the minimum and maximum values entered for this distribution.

3877 The arc listed has a satellite distribution arc card (DTIME, DCOST or DPERF satellite arc card) having a zero or a negative minimum - maximum value range.

3911 The arc listed has at least one satellite histogram arc card (HTIME, HCOST or HPERF satellite arc card). A check on the number of input entries indicates that there are not enough cell boundaries. For example, if ten cells are being used to carry the data, eleven cell boundaries must be entered.

3933 The arc listed has at least one satellite histogram arc card (HTIME, HCOST or HPERF satellite arc card). A check on the number of input entries indicates that there are less than two cells being used.

3955 The arc listed has at least one satellite histogram arc card (HTIME, HCOST or HPERF satellite arc card). A probability cell has a negative value entered in it.

3977 The arc listed has at least one satellite histogram arc card (HTIME, HCOST or HPERF satellite arc card). A check on the cell boundaries indicates that at least one cell does not have a smaller value for the left hand boundary than for the right hand boundary.

3988 The arc listed has at least one satellite histogram arc card (HTIME, HCOST or HPERF satellite arc card). The sum of all the probabilities entered for the cells does not equal 1.0.

4044 The arc listed has at least one satellite mathematical relationship arc card (RTIME, RCOST, or RPERF satellite arc card). The card sequence number in at least one of these cards is out of sequence.

4055 The arc listed has at least one satellite mathematical relationship arc card (RTIME, RCOST, or RPERF satellite arc card). The sum-omit-backup indicator started off specifying backup on the first transformation.

4099 The arc listed has at least one satellite mathematical relationship arc card (RTIME, RCOST, or RPERF satellite arc card). The sum-omit-backup indicator was not correctly specified.

4122 The arc listed has at least one satellite mathematical relationship arc card (RTIME, RCOST, or RPERF satellite arc card). The transformation indicator for one of the mathematical relationships was not greater than 0 and less than 37 or greater than 50 and less than 87.

4200 The arc listed has at least one satellite mathematical relationship arc card (RTIME, RCOST, or RPERF satellite arc card). The retrieval indicator was incorrectly specified in at least one of the mathematical relationships carried by these cards.

4233 The arc listed has at least one satellite mathematical relationship arc card (RTIME, RCOST, or RPERF satellite arc card). At least one of the mathematical relationships entered was dependent upon itself.

4288 The arc listed has at least one satellite mathematical relationship arc card (RTIME, RCOST, or RPERF satellite arc card). The independent variable entered for at least one of these relationships could not be identified as either an arc or a node when the retrieval indicator was loaded with a 'T', 'C' or 'P'.

4300 The arc listed has at least one satellite mathematical relationship arc card (RTIME, RCOST, or RPERF satellite arc card). The retrieval indicator for one of these transformations is requesting the use of the results of a transformation which will not be completed prior to the completion of this current transformation.

4322 The arc listed has at least one satellite mathematical relationship arc card (RTIME, RCOST, or RPERF satellite arc card). At least one of the constants entered in one of the relationships was given a value smaller than -900000.0.

4400 The arc listed has at least one satellite mathematical relationship arc card (RTIME, RCOST, or RPERF satellite arc card). At least one of the mathematical relationships entered was dependent upon another parameter (time, cost or performance value) of this arc. However, that other parameter was not given a value (i.e., there wasn't any input for this other parameter).

4422 The arc listed has at least one satellite mathematical relationship arc card (RTIME, RCOST, or RPERF satellite arc card). At least one of the mathematical relationships entered was dependent upon another parameter (time, cost or performance value) of this arc. However, that other parameter is dependent on one of the variables in the given mathematical relationship which thus forms an illogical dependency loop.

4500 The arc listed has one or more satellite arc cards which do not have their card sequence number in sequence.

4511 The arc listed has some satellite arc cards carrying input data having a value of less than -900000.0.

4588 While reading in node data, it was observed that more slack histograms have been entered than there are spaces available. Either the number of requests must be reduced or the slack storage arrays must be expanded by increasing the value of the check variable MSLACK and the arrays mnemonically dimensioned in terms of this variable. This expansion can be accomplished by using the DIMEN program. However, this is only a warning message since output option number four was requested, the storage will not be needed. If another option is requested, the space will be needed.

4599 Same as the preceding message except, output option number four was not selected and, thus, it is a fatal error this time.

4611 The node listed requested a slack histogram. This is a terminal node which does not require a slack analysis since it will either be on the critical path or have no effect on the slack analysis.

4633 The node listed has requested a position in the internal node statistics storage array which does not lie within the boundaries of this array. Either the request entered is nonpositive or it exceeds the value of the check variable MHIST. Nonpositive values are not allowed. If the check variable has been exceeded, the user must either cut down the number of internal node statistics requested or increase the value of the check variable MHIST along with all the arrays mnemonically dimensioned in terms of this check variable. This expansion can be accomplished by using the DIMEN program.

4699 The node listed should be a TERMINAL node. An attempt is being made to store the information carried on the HIST satellite card but this task can not be accomplished because there is insufficient space in the storage array TERM. A cut must be made in the number of HIST cards entered for terminal nodes or an increase must be made in the value of the check variable MTERM along with all the arrays mnemonically dimensioned in terms of this variable. This expansion can be accomplished by using the DIMEN program.

4733 The node listed has a SUBT satellite card, but it does not have FILTER 1 output logic.

4766 The node listed has FILTER 1 output logic and is utilizing the subtraction feature. The subtraction node is not defined or the subtraction node is an identity with this node.

4788 The node listed has a SLAK histogram satellite node card entered, but a slack histogram was not requested for this node (no 'S' was entered in column 29 of the master node card).

4799 The node listed has more than one SLAK histogram satellite node card entered for it. One of these cards is all that is necessary per node.

4855 There is too much variable node data. The front part of the variable node storage array NSTORE is overflowing with data. Either the size of the network must be cut down by possibly making subnetworks, or NSTORE and the check variable LNODE must be expanded. This expansion can be accomplished by using the DIMEN program.

4877 The node listed is defined as having QUEUE logic. The number of servers specified is less than or equal to zero.

4899 The node listed is defined as having either COMPARE or PREFERRED logic requiring an output arc initialization request. The request for this node is either less than one or greater than the number of input arcs.

4922 The node listed has COMPARE or SORT logic which requires selection weights to be assigned to each of the three principal parameters of time, cost and performance. These weights do not sum to 1.0.

5099 The output option specified in column three of the control card is not an acceptable entry.

5100 Trace option number 4 gives a complete listing of all the active arcs and nodes realized during each iteration. This usually results in large amounts of output if a large number of iterations have been concurrently requested. An upper limit of 100 iterations has been placed on this output option.

5111 The costing option specified in column four of the control card does not have an acceptable entry.

5122 Not enough (0 or less) or too many simulation iterations have been requested for this problem (columns 20-24 of the control card). If too many iterations have been requested either the number of iterations requested must be reduced or the check variable MITER must be expanded along with all the arrays mnemonically dimensioned in terms of this variable. This expansion can be accomplished by using the DIMEN program.

5133 The yearly interest rate used for inflating cost and/or performance does not have a positive entry (columns 20-24 of the control card) while a request for inflating cost and/or performance values has been made.

5155 The yearly interest rate used to discount cost and/or performance does not have a positive entry (columns 25-28 of the control card) while a request for discounting cost and/or performance values has been made.

5177 There has been a request for either or both inflating or discounting cost and/or performance values. However, the time conversion factor (columns 33-35 of the control card) does not have a positive entry.

5199 The time weight entered for choosing the optimum terminal node (columns 36-38 of the control card) is incorrect. Acceptable entries are blank and the closed interval between -1.0 and 1.0.

5200 The cost weight entered for choosing the optimum terminal node (columns 39-41 of the control card) is incorrect. Acceptable entries are blank and the closed interval between -1.0 and 1.0.

5211 The performance weight entered for choosing the optimum terminal node (columns 42-44 of the control card) is incorrect. Acceptable entries are blank and the closed interval between -1.0 and 1.0.

5222 The sum of the time, cost and performance weights entered for choosing the optimum terminal node (columns 36-44 of the control card) is not equal to -1.0 or 1.0.

5233 The time weight entered for determining the critical path (columns 45-47 of the control card) is incorrect. Acceptable entries are blank and the closed interval between -1.0 and 1.0.

5244 The cost weight entered for determining the critical path (columns 48-50 of the control card) is incorrect. Acceptable entries are blank and the closed interval between -1.0 and 1.0.

5255 The performance weight entered for determining the critical path (columns 51-53 of the control card) is incorrect. Acceptable entries are blank and the closed interval between -1.0 and 1.0.

5266 The sum of the time, cost and performance weights entered for determining the critical path (columns 45-53 of the control card) is not equal to -1.0 or 1.0.

5277 There is not enough space for storing internal node statistics. A cut must be made in the number of internal node statistics requested or an increase must be made in the value of the check variable MHIST along with all the arrays mnemonically dimensioned in terms of this variable. This expansion can be accomplished by using the DIMEN program.

5299 The number of the node listed is a node without a name. Node names must be something other than (blank).

5311 The node name listed was used to name an arc and a node. Node and arc names must be unique.

5333 The node listed has an input logic code number which is not within the acceptable limits of 1 and 8.

5366 The node listed has an output logic code number which is not within the acceptable limits of 1 and 6 or does not have an appropriate level prefixing of the terminal logic as described in Chapter 3-2, D1. The maximum number of levels allowed is equal to the number of nodes entered minus 1 or a total number of 100, whichever is the smaller.

5388 The node listed has an output logic requiring at least two output arcs.

5400 The node listed has terminal output logic. The matrix allocation field used for generating internal node histograms does not have an acceptable entry of 'Blank', '0', '-1' or '-2'.

5422 The node listed does not have any input arcs and it does not have INITIAL input logic.

5433 The node listed has output arcs and it has TERMINAL output logic.

5444 The node listed has TERMINAL output logic coupled with an unacceptable input logic. Acceptable input logics are AND, PARTIAL AND and OR.

5455 The output node of the arc listed has TERMINAL output logic. This arc must have a successful completion probability of one.

5499 The node listed is involved with at least two other nodes in attempting to generate internal node statistics. Internal node statistics can be collected on a node by itself, or it can be coupled with another node to collect interval statistics. A node cannot be used in both of these capacities at the same time for collecting internal node statistics.

5511 The node listed has input arcs and INITIAL input logic.

5522 The node listed does not have any output arcs, and it does not have TERMINAL output logic.

5533 The node listed has INITIAL input logic coupled with an unacceptable output logic. Acceptable output logics are ALL or MONTE CARLO.

5555 The node listed does not have any input arcs nor does it have INITIAL input logic.

5566 The node listed does not have any output arcs nor does it have TERMINAL output logic.

5599 The node listed is an internal node having at least one arc which has been entered as an input and an output arc.

5622 The node listed has either QUEUE or SORT logic having an input arc with the probability of successful completion less than 1.0 and no escape arc.

5655 The node listed has either COMPARE or PREFERRED logic without an escape arc.

5677 The node listed has AND, PAND or OR logic having at least one input arc with the probability of successful completion of less than 1.0 and only one output arc. This condition requires a minimum of at least two output arcs.

5700 The node listed has ALL output logic and has at least one output arc carrying MONTE CARLO or FILTER data.

5744 The arc listed has an input node with MONTE CARLO output logic. This arc is not carrying any MONTE CARLO information.

5766 The arc listed is the last output arc from a node having MONTE CARLO output logic and at least one input arc having a probability of successful completion of less than 1.0. This condition gives rise to the need of an escape arc which this last arc should be, but is not.

5788 The arc listed has an input node with MONTE CARLO output logic. This arc is not carrying an even number of bits of MONTE CARLO data.

5822 The arc listed has an input node with MONTE CARLO output logic. This arc is not carrying the same quantity of data that other output arcs of this node are carrying.

5855 The arc listed has an input node with MONTE CARLO output logic. The time, cost or performance boundaries of this arc are not the same as those of the other output arcs of this node.

5877 The arc listed has an input node with MONTE CARLO output logic. This arc has a satellite arc card which has a probability of either less than 0.0 or greater than 1.0.

5899 The arc listed has an input node with MONTE CARLO output logic. This arc has a satellite arc card which is not consistent with the satellite arc cards of the other output arcs of this node.

5922 The arc listed has an input node with MONTE CARLO output logic. The distributions carried on the output arcs of this node do not sum to 1.0.

5966 The arc listed has an input node with FILTER 1 or FILTER 2 output logic. This arc is not carrying an even number of bits of information.

5999 The arc listed is carrying FILTER 1 or FILTER 2 information for its input node. At least one lower constraint boundary is greater than an upper constraint boundary.

6000 The node listed has FILTER 2 output logic. It does not have the required PAND input logic.

6011 The arc listed is carrying FILTER 2 logic information for its input node. The quantity of information carried by this arc does not conform to the requirements of FILTER 2 logic.

6022 The arc listed is carrying FILTER 2 logic information for its input node. The lower constraint boundary is negative.

6033 The arc listed is carrying FILTER 2 logic information for its input node. The upper constraint boundary is greater than the number of input arcs to this node.

6055 The node listed has FILTER output logic. It has either more than one escape arc or none at all.

6077 This network does not have any nodes with INITIAL input logic.

6088 This network does not have any nodes with TERMINAL output logic.

6099 Some arc variables will be called upon to temporarily store TERMINAL node data. Either the number of TERMINAL nodes must be reduced or the arc storage arrays must be expanded by increasing the value of the check variable MARC and all the arrays mnemonically dimensioned in terms of this variable. This expansion can be accomplished by using the DIMEN program.

6100 The output node of the arc listed was entered before its input node. This is not conducive toward attaining minimum processing time. To attain maximum computational speed, nodes should be entered so that every arc's input node is entered before its output node.

6111 The number of the arc listed is an arc without a name. Arc names must be something other than blank.

6122 The arc listed has an unacceptable probability of successful completion. Acceptable entries are 1.0 and all values on the open interval between 0.0 and 1.0.

6135 This is a warning message to indicate the implications of requesting the median. This option requires a significant additional amount of computer time for all output options except for the time, path cost, overall cost and performance values on the terminal nodes. If computer time is not a factor, ignore this message. Otherwise, it may be advantageous to wait on using this option until the final runs are needed.

6140 This is a warning message to indicate the implications of requesting cost-performance time intervals. This option requires a significant additional amount of computer time. If computer time is not a factor, ignore this message. Otherwise, it may be advantageous to wait on using this option until the final runs are needed.

6144 This is a warning message to indicate the implications of requesting internal node statistics. This option requires a significant amount of additional computer time. If computer time is not a factor, ignore this message. Otherwise, it may be advantageous to wait on using this option until the final runs are needed.

6166 This is a warning message to indicate the implications of requesting the critical-optimum path. This option requires a significant amount of additional computer time. If computer time is not a factor, ignore this message. Otherwise, it may be advantageous to wait on using this option until the final runs are needed.

6177 This is a warning message to indicate the implications of requesting a slack analysis. This option requires a significant amount of additional computer time. If computer time is not a factor, ignore this message. Otherwise, it may be advantageous to wait on using this option until the final runs are needed.

6766 The node listed has FILTER 1 output logic. Its subtract node has not been processed prior to this node being processed. Networks must be structured so that all subtraction nodes are processed prior to the processing of the node utilizing the subtraction feature.

6888 The node listed has FILTER 3 output logic. At least one output arc has a constraining arc that has not been processed prior to processing this node. Networks must be structured so that all arcs functioning in a constraining capacity are processed prior to being utilized in that constraining capacity.

7444 The network being processed has passed all the previous error checks. It currently has a real time processing error causing the network flow to hang up somewhere within the network. This usually results from inadvertently constructing a loop within the network or not being able to satisfy the AND input logic of a key node. Failure to satisfy the AND logic may result from the incorrect use of the pruning logic. The unabridged listing of arcs and nodes following the error number indicator will enable tracing through the network to find the conditions creating the error. Only arcs and nodes in the immediate area of the network flow are made candidates for processing. Arc and node processing states are as follows (ignore the TERMINAL node name designated on the arc and node list following this error).

<u>Arcs</u>

-1 or 0 - Eliminated from the network (given this status prior to being processed)
1 - Non-processed
2 - Unsuccessfully completed
3 - Successfully completed
4 - Critical path candidate

<u>Nodes</u>

0 - Eliminated from the network (given this status prior to being processed)
1 - Non-processed
2 - Candidate for processing
3 - Successfully completed
4 - On the critical path
5 - On the critical path after calculation of the slacks

7822 The slack calculations have become erroneous. Call the program author immediately. The program did continue on from this point, but without attempting anymore slack calculations.

8555 The rear portion of NSTORE is used for storing arc addresses used in calculating node cost and performance. This area has been exceeded. MTAG and all arrays mnemonically dimensioned in terms of this check variable must be expanded. This expansion can be accomplished by using the DIMEN program.

8677 The program tried 1000 times to generate a distribution whose code number is listed in this error message for the arc listed. The value generated for this distribution always exceeded the maximum or minimum observation allowed.

9033 The arc listed is dependent upon other arc(s) or node(s) being processed prior to computing the time, cost or performance for this arc. The network was not constructed in such a manner to accomplish this objective (i.e., insufficient backups).

9111 The arc listed has requested a transformation (the number following the arc name on the error indicator) whose restriction has been violated.

CHAPTER 5 EXAMPLE PROBLEM
FUTURE ELECTRIC POWER GENERATING METHODS

This simple hypothetical problem is not intended to represent any actual problem. Rather, it consists of a fabricated scenario which is intended to serve only as a vehicle for illustrating how typical realistic situations might be modeled by using VERT.

The Federal Power Commission has retained a consulting firm to study the development of methods of generating our nation's future electric power needs. There are three new methods under consideration: nuclear fusion, nuclear fission and coal gasification. The consulting firm's main task is that of estimating what the probability is of successfully developing at least one of these three methods. Estimates of the following are also desired: (1) the overall time required and the cost incurred for completing the entire project. (2) The amount of money needed for each five year period over the project's entire twenty year budgeting horizon. These sums of money should be chosen in such a manner that there will be a 75% chance of having sufficient funds available over the entire twenty years and a 90% chance of having enough money available for the first five year period. Additionally, the confidence level associated with having enough money available for the remaining budgeting periods should be chosen in such a way that they are uniformly proportionally less than the first period.

The Commission has imposed time and cost limitations on the research and development (R&D) phase of each of these methods of 7 years and 70 million dollars. Failure to complete the R&D phase or failure to stay within the time and cost constraints will result in failure of any one of these three development efforts. Upon completion of the R&D phase, Commission engineers require that pilot generating stations be built and run to prove out each of these new concepts. The stations required are one for coal gas, one (of two different designs) for fission, and four (all the same) for fusion. The Commission engineers deem that the number of pilot stations being requested for testing is commensurate with the development risks inherent in each of these efforts. For example, the fusion development requires the creation of special new alloys that will be able to withstand the high temperatures associated with the fusion process. The fission process has radio active leakage problems that should be able to be circumvented by at least one or both of the two different pilot plant concepts being considered. In the event that the coal gas or fission pilot stations fail, that development effort will be abandoned and, thus, considered a failure. The fusion development effort will be considered a failure if more than one of the four stations fail.

Environmentalists have set a design goal for the temperature of the discharging cooling water at 10 degrees Fahrenheit above the ambient temperature of the receiving lake or stream. Temperatures greater than 20 degrees are considered unacceptable while temperatures under the 10 degree tolerance mark should merit a bonus. Additionally, power stations must have a high reliability so they can operate without major breakdowns which cause blackouts. Commission engineers have set a reliability design goal of 90 percent up time. Only two of the three concepts can be carried into the final phase of development, the shock test phase, because of limited funds. The method exhibiting the lowest performance will be eliminated at this point in the program, since it would be the least likely to pass the shock test. There is a 0.72, 0.88 and 0.93 chance that the fusion, fission and coal gas processes, respectively, will pass the shock test.

Upon completion of the shock tests, the Commission will pick the winning candidate of the two possible remaining candidates. The Commission members favor the fusion process over the others, followed by the fission process, and finally, the coal gas process since this ranking represents the order of abundance of the United States supplies of the raw materials used by each of these processes. Additional data items supplied by either the commission engineers or the consulting firm are given in Tables 5-1 to 5-4.

To observe how the information just presented can be transformed into a VERT network and then computer analyzed, Figures 5-1 and 5-2 should be reviewed. The following narrative is designed to help guide the reader through the pictorial network layout (figure 5-1) and computer solution (figure 5-2) of this problem.

Node START initiates three parallel independent network flows which represent the R&D effort being expended on the three electrical power generating methods under study. The flow through arc RDFU causes that arc to generate a success or fail status via the usual MONTE CARLO procedure using the 0.65 probability of successful completion given in Table 5-1. This arc also generates the time consumed and the cost incurred as given in Table 5-1. Likewise, the flows through arcs RDFI and RDCO create the generation of the success or fail status and the time and cost values for the fission and coal gas methods, respectively (see figure 5-1). The input card listing in Figure 5-2 should be consulted to observe how the time distribution data, especially the mathematical cost relationships given in Table 5-1, are entered in the input stream for arcs RDFU, RDFI and RDCO. In a real development project, these three arcs would represent so many activities and decisions that they would have to be expanded into individual subnetworks to attain an adequate level of analytical resolution. These arcs would then be used to input in this higher level network the results attained in the lower level subnetworks.

Node RDSFFU acts as a success-fail determinator of the basic fundamental research and development effort being modeled in arc RDFU. If this effort is successfully completed (arc RDFU has a success status) within 7 years and 70 million dollars (these two constraints are being carried by arc RDFUOK), node RDSFFU will route the network flow to arc RDFUOK, the success path which leads on toward the pilot plant testing of the resulting concepts derived in this successful R&D effort. Otherwise, the effort is considered a failure and node RDSFFU will route the fusion network flow to arc RDFUFAIL, the failure path which terminates further fusion work. Nodes RDSFFI and RDSFCO perform similar functions for the fission and coal gas network flows.

Node PIFU acts as a network flow expansion device. The four arcs going out of node PIFU represent the four pilot generating stations required to prove out the fusion process. Node PIFI acts as a selector for determining which of the equally likely pilot generating station designs will be used to prove out the fission process.

Arcs PIFU1, PIFU2, PIFU3 and PIFU4 each carry the data listed in row one of Table 5-3. Arcs PIFI1 and PIFI2 each carry the data listed in row two while PICO1 carries the data listed in row three of Table 5-3. These arcs represent the activities of constructing and running four fusion, two fission and one coal gas pilot generating stations. They generate the time consumed, cost incurred and probability of successfully constructing and running each of these pilot stations.

Nodes PISFFU1, PISFFU2, PISFFU3, PISFFU4, PISFFI1, PISFFI2 and PISFCO1 individually route their input flows to either a success path or a fail path, depending on whether their lone input arc was a success or a failure. Every time an input arc has a probability of successful completion, which is less than 1.0, there exists the chance that it will fail. In the event arc PIFU1 fails, for example, node PISFFU1 will then direct the network flow to arc PIFU1FAL. If PIFU1 is successfully completed, the network flow will be directed to arc PIFU1OK.

Arcs PIFU1OK, PIFU2OK, PIFU3OK and PIFU4OK, which carry the successful fusion pilot station flows converge upon node ENDPIFU. Thus, the four parallel flows which went through the four pilot stations developments now converge back into one flow through node ENDPIFU, providing none of these four fusion pilot flows got siphoned off to the failure sink by one of the failure arcs used in the pilot station structures. Arcs PIFU1OK, PIFU2OK, PIFU3OK and PIFU4OK are examples of the transportation arc previously defined in chapter 2-2. They carry the network flow from their input node to their output node and contribute nothing else to the network structure. Arcs PIFI1OK, PIFI2OK and PICO1OK perform analogous functions for the fission and coal gas structures. Node ENDPIFU directs the network flow either to arcs RELFU and COOLFU or to arc PIFUFAIL, depending on the number of successfully completed arcs coming into this node. If three or more fusion pilot stations were running successfully (three or more successfully completed input arcs), the output flow will then be passed on to arcs RELFU and COOLFU or to arc PIFUFAIL. The OR input logic of node ENDPIFI requires that one fission pilot station must run successfully before the fission flow will be allowed to flow to arcs RELFI and COOLFI. Node ENDPICO will not be realized unless the coal gas pilot station has been run successfully. If the coal gas flow enters node ENDPICO, this node will pass the flow to arcs RELCO and COOLCO.

Arcs RELFU, RELFI and RELCO generate station reliability data for the fusion, fission and coal gas processes, respectively. The data for RELFU and RELFI comes from the right half of Table 5-3 in the problem narrative, while the data for RELCO comes from Table 5-4. See the RELCO arc cards in Figure 5-2 for an example usage of the histogram input feature. Arcs COOLFU, COOLFI and COOLCO generate the cooling water temperature differential above the ambient temperature for the fusion, fission and coal gas processes, respectively. The data for these arcs comes from the left half of Table 5-3. Node COREFU accumulates the fusion network flow performance values generated by arcs RELFU and COOLFU in addition to carrying the current time and cost values accumulated throughout the network. Nodes COREFI and CORECO accomplish similar tasks for the fission and coal gas flows as COREFU does for fusion.

Arc PERFFU converts the performance data generated on arcs RELFU and COOLFU into a single number. This task is accomplished by using VERT's transformations. Refer to the card listing in Figure 5-2 and the transformations in chapter 3. Note that the first transformation in the first RPERF satellite arc card for arc PERFFU consists of negating the current performance flowing via the fusion network flow. This task could also be accomplished by using two transformations, whereby each transformation negates the raw values generated on arcs COOLFU and RELFU rather than the current negation of the combined performance values as carried by node COREFU. The second transformation listed on the first RPERF satellite arc card of arc PERFFU consists of normalizing and weighting the performance value generated by arc COOLFU. The first transformation listed on the second RPERF satellite arc card for arc PERFFU normalizes and weights the performance value generated by arc RELFU. These normalization bases came from the problem narrative while the preference weights are listed after Table 5-3. Note the difference between these two normalizations. The cooling water transformation will yield larger performance values for smaller temperature differentials, while the reliability transformation will yield larger performance values for larger measure of reliability. Arcs PERFFI and PERFCO accomplish similar tasks for the fission and coal gas flows as PERFFU does for the fusion network flow. Another possible way of generating these performance values without having the raw unnormalized values stream into the network is to generate these raw values on FREE ARCS and then reference these FREE ARCS when performing the normalization. The preceding treatment of the performance factors was illustrated to show how flows may be manipulated via use of the transformations.

Arcs SHOCKFU, SHOCKFI and SHOCKCO model the pilot station shock testing for each of the respective generating processes under study. These arcs simply add a constant time and cost to each of the network flows and have a probability of success of something less than one.

Node SELECT1 selects the winning generating method of the two possible methods left. SELECT1's preferred logic will give preference to arc WINFU over arc WINFI and arc WINFI over arc WINCO. This preference is in accord with the commission's observance of the abundance of supplies of raw materials for each of these various electric power generating methods. Arcs WINFU, WINFI and WINCO are transportation arcs constituting the last leg of a successful project completion to terminal nodes FUWINNER, FIWINNER and COWINNER, respectively. In the event the shock tests fail, SELECT1 will send the network flow out arc FAILSHCK on to terminal node FAILSHOC, the last of three possible failure sinks into which the network flow can terminate.

Terminal node FAILSHOC is a final repository for the network flow, unlike the other two failure terminal nodes FAILRD and FAILPILT. Since nodes FAILRD and FAILPILT have lower priority class designation numbers (see Figure 5-2), they will be selected as the winning terminal nodes only if there aren't any flows into terminal nodes FUWINNER, FIWINNER, COWINNER, or FAILSHOC. In fact, the node FAILRD class designation number is lower than all the other terminal nodes and, thus, will be designated as the winning terminal node only in the event all the other terminal nodes do not have flows coming into them. It can be observed in this example problem that the class designation ability of VERT enables failure flows which of themselves are not critical enough to terminate the problem as a failure to be siphoned off. However, if too many individual failures occur, the problem will be terminated at the last possible failure that can occur. The PAND input logic of FAILRD and FAILPILT also aids in causing the problem to be terminated at the last possible failure point that can occur. The PARTIAL AND input logic of FAILRD and FAILPILT also aids in enabling the network to be run-out as far as possible before declaring it a failure.

Terminal node FAILSHOC is a final repository for failure network flows. Unlike the other two failure terminal nodes, FAILRD and FAILPILT, FAILSHOC has a higher priority class designation number (see Figure 5-2). FAILRD and FAILPILT will be selected as the winning terminal nodes only if there aren't flows going into terminal nodes FUWINNER, FIWINNER, COWINNER or FAILSHOC. FAILRD'S class designation number is lower than all the other terminal nodes and will be chosen as the winning terminal node only when all the other terminal nodes do not have flows coming into them. This example problem illustrates that the class designation ability of VERT enables ignoring the failure flows which are not critical enough to terminate a problem. However, if too many individual failures do occur, the problem will be terminated at the last possible project failure point that can occur. The PAND input logic of FAILPILT also aids in enabling the network to be run-out as far as possible before failing.

The optimum terminal node index bar chart, the last chart in the computer run exhibited in Figure 5-2, indicates that the probability of successfully developing at least one of the three generating methods under study is equal to 54.1% (cowinner - coal gas + 33.6% (fiwinner - fission) + 7.1% (fuwinner - fusion) = 94.8%. It can further be observed that there exists about a 1% chance of failing in the pilot plant test phase (FAILPILT), a 4% chance of failing in the shock test phase (FAILSHOC) and virtually no chance of failing in the R&D phase (FAILRD).

The cumulative frequency distribution (CFD) of the network time for the composite terminal node (see Figure 5-2) indicates that the project will terminate somewhere within the time span of 11.08 and 17.53 years. There is a clustering of times between 14.95 and 17 years which accounts for approximately 96% of the observations.

The CFD of the overall cost for the composite terminal node indicates that the project will cost between 223.2 and 509.2 million dollars. Further, it can be observed that there exist two definite areas of concentration in this distribution. Approximately 85% of the observations lie within the first area of concentration between 223.2 and 327.2 million dollars. The remaining 15% of the observations fall between 418.2 and 509.2 million dollars. The path cost CFDs for the terminal nodes FUWINNER, FIWINNER and COWINNER indicates that the fusion development cost considerably more than fission or coal gas and it has a much wider variance. These facts account for the shape of the total project cost CFD.

VERT was given the initial confidence and unit step values of 0.90 and 0.0005, 0.80 and 0.002, 0.70 and 0.004, 0.60 and 0.006 for budgeting periods one thru four and a 0.75 fixed confidence value for the entire period (see the data listed under cost-performance time interval data in Figure 5-2). After simulating the network and then generating a CFD for the four budgeting periods and the entire development period, VERT found a workable solution to the budget query raised in paragraph two of this problem. This solution consists of budgeting $201.7M, $61.7M, $22.9M and $13.8M for period one thru four to yield a total of $300.1M for the entire development period (see the data listed under the cost confidence match among selected time periods print out in Figures 5-2).

Table 5-1 Research and Development Data

Power Generating Method	Time (years) Dist.	Min.	Max.	Mean	Std. Dev.	Cost (millions) T=Time, C=Cost	Prob. of Succ.
fusion	normal	4.0	7.5	5.75	1.25	$C=100*LOG_{10}(T)$	0.65
fission	normal	3.0	7.0	5.0	0.55	$C=T^2-T+50$	0.85
coal gas	normal	3.0	6.5	4.75	0.25	C=100+20*SIN(T)	0.95

Table 5-2 Pilot Station Data

Power Generating Method	Time(years) Cost(millions) Distribution Type	Minimum	Maximum	Mean or Most Likely	Std. Dev.	Prob. of Succ.
Fusion	Uniform	8	12			0.84
	gamma	40	60	52	5	
fission design A	triangular	5	10	8		0.92
	lognormal	40	50	44	3	
coal gas	triangular	10	12	11.4		0.97
	normal	20	40	27	4	

Table 5- 3 Station Performance Data

Power Generating Method	Cooling Water Temperature Above Ambient / Station Reliability				
	Distribution Type	Minimum	Maximum	Mean	No. Exponential Deviates or Std. Deviation
fusion	erlang	5	15	11	8
	normal	0.70	0.99	0.84	0.001
fission	erlang	3	14	9	
	normal	0.80	0.99	0.88	0.02
coal gas	erlang	2	12	7	7
	histogram data per Table 5-7 below				

Engineers assess the relative importance of the above factors as (1) cooling water = 0.2 and (2) station reliability = 0.8.

Table 5- 4 Coal Gas Reliability Histogram

```
0.15 -*                                         *-0.15
      *                                         *
      *                                         *        Relative
      *                                         *        Frequency
      *                                         *
0.10 -*                                         *-0.10
      *                      X                  *
      *                     XXX                 *
      *                    XXXXX                *
      *                   XXXXXXX               *
0.05 -*                 XXXXXXXXXX              *-0.05
      *             XXXXXXXXXXXXXXX             *
      *           XXXXXXXXXXXXXXXXXX            *
      *          XXXXXXXXXXXXXXXXXXXX           *
      *    X      X     XXXXXXXXXXXXXXXXXXXXXX  *
0.00 -******************************************-0.00
      I         I         I         I         I
     0.60      0.70      0.80      0.90      1.0

                 Station Reliability
```

Figure 5-1 Future Electric Power Generating Methods Network

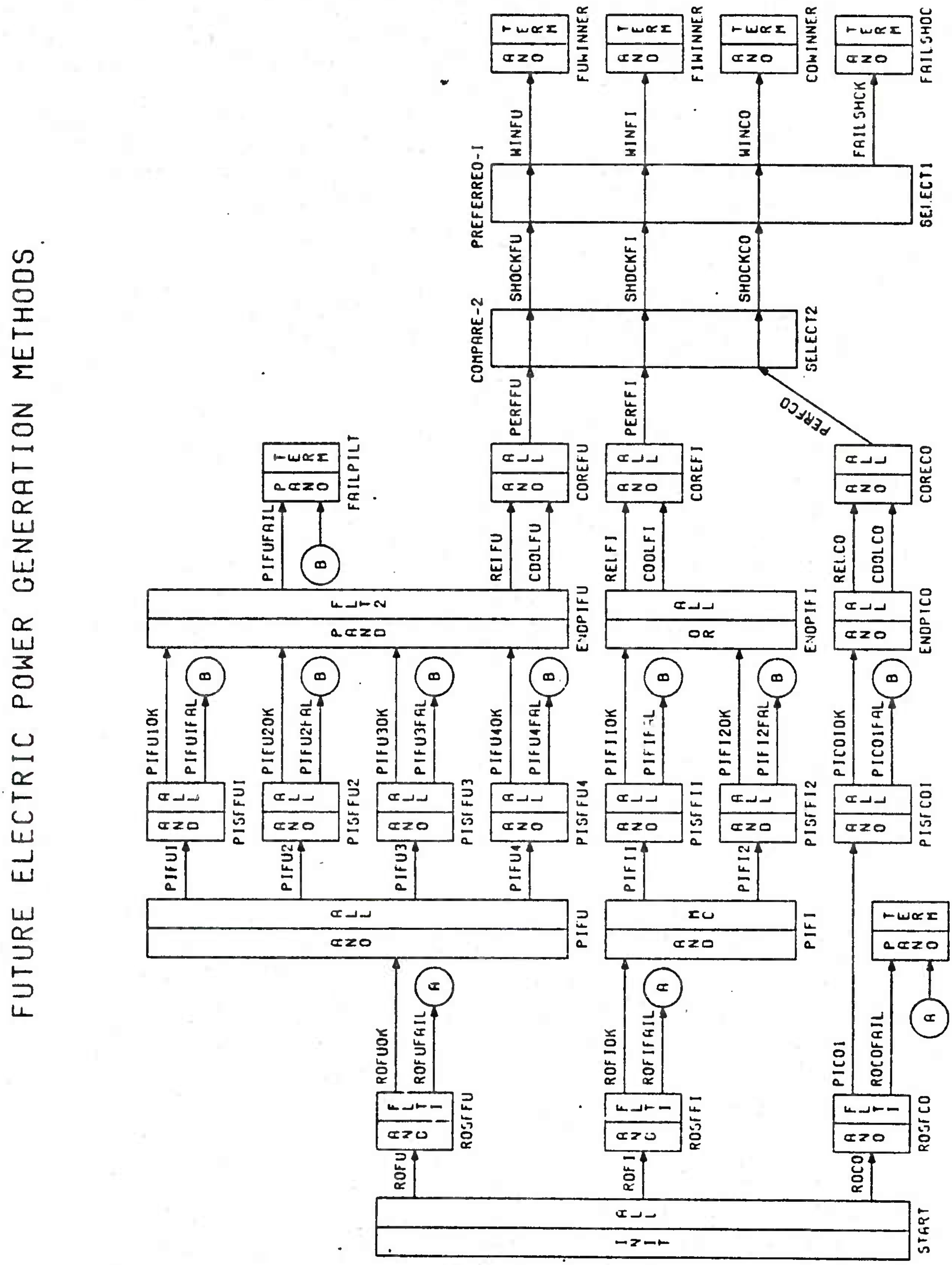

Figure 5-2 Computer Run of Future Electric Power Generating Methods Network

```
PROBLEM IDENTIFICATION CARD OPTION-------------------------          1
TYPE OF INPUT OPTION---------------------------------------          0
TYPE OF OUTPUT OPTION--------------------------------------          4
COSTING AND PRUNING OPTION---------------------------------          1
FULL PRINT TRIP OPTION-------------------------------------          0
CORRELATION COMPUTATION AND PLOT OPTION--------------------          0
COST-PERFORMANCE TIME INTERVAL OPTION----------------------          1
COMPOSITE TERMINAL NODE MINIMUMS AND MAXIMUMS OPTION-------          1
INITIAL SEED-----------------------------------------------     435459
NUMBER OF ITERATIONS---------------------------------------       1000
YEARLY INTEREST RATE USED FOR INFLATION ADJUSTMENTS--------        0.0
YEARLY INTEREST RATE USED FOR PRESENT VALUE DISCOUNTING----        0.0
TIME FACTOR WHICH CONVERTS PROGRAM TIME TO A YEARLY BASE---        0.0

                                    TIME      COST      PERF
TERMINAL NODE SELECTION WEIGHTS     1.00      0.0       0.0
CRITICAL - OPTIMUM PATH WEIGHTS     0.0       0.0       0.0
INITIAL VALUES                      0.0       0.0       0.0

COST-PERFORMANCE TIME INTERVAL DATA

    0.0       5.0      185.0     211.0                        0.90      0.0005
    5.0      10.0                                             0.80      0.002
   10.0      15.0                                             0.70      0.004
   15.0      20.0                                             0.60      0.006
    0.0      20.0                                             0.75
ENDCTPR


MINIMUMS AND MAXIMUMS FOR THE COMPOSITE TERMINAL NODE

    12.0       17.0

RDFU    START   RDSFFU  0.65 FUSION RESEARCH AND DEVELOPMENT
RDFU    DTIME 1    4.0       4.0        7.5        5.75       1.25
RDFU    RCOST 115SK  100.0 TRDFU    K   1.0

RDFI    START   RDSFFI  0.85 FISSION RESEARCH AND DEVELOPMENT
RDFI    DTIME I    4.0       3.0        7.0        5.0        0.55
RDFI    RCOST I IDTRDFI    TRDFI    K   1.0    6S    1.0  K  50.0   TROFI

RDCO    START   RDSFCO  0.97 COAL GAS RESEARCH AND DEVELOPMENT
RDCO    DTIME I    4.0       3.0        6.5        4.75       .0.25
```

```
RDCO     RCOST 1 1SK    80.0 K   1.0    K    1.0  16SK  20.0  TRDCO     K  1.0

RDFUOK   RDSFFU   PIFU     1.0  FUSION R&D OKAY, TRANSPORT TO PILOT TESTS
RDFUOK   FILT1 1     0.0        7.0         0.0        70.0

RDFIOK   RDSFFI   PIFI     1.0  FISSION R&D OKAY, TRANSPORT TO PILOT TEST
RDFIOK   FILT1 1     0.0        7.0         0.0        70.0

RDFUFAILRDSFFU   FAILRD   1.0  FUSION R&D FAILED, GO TO R&D FAILURE SINK

RDFIFAILRDSFFI   FAILRD   1.0  FISSION R&D FAILED, GO TO R&D FAILURE SINK

RDCOFAILRDSFCO   FAILRD   1.0  COAL GAS R&D FAILED, GO TO R&D FAILURE SINK

PIFU1    PIFU     PISFFU1 0.84 DEVELOPMENT OF FUSION PILOT STATION #1
PIFU1    DTIME 1     2.0        8.0        12.0
PIFU1    DCOST 1     6.0       40.0        60.0         52.0         5.0

PIFU2    PIFU     PISFFU2 0.84 DEVELOPMENT OF FUSION PILOT STATION #2
PIFU2    DTIME 1     2.0        8.0        12.0
PIFU2    DCOST 1     6.0       40.0        60.0         52.0         5.0

PIFU3    PIFU     PISFFU3 0.84 DEVELOPMENT OF FUSION PILOT STATION #3
PIFU3    DTIME 1     2.0        8.0        12.0
PIFU3    DCOST 1     6.0       40.0        60.0         52.0         5.0

PIFU4    PIFU     PISFFU4 0.84 DEVELOPMENT OF FUSION PILOT STATION #4
PIFU4    DTIME 1     2.0        8.0        12.0
PIFU4    DCOST 1     6.0       40.0        60.0         52.0         5.0

PIFI1    PIFI     PISFFI1 0.92 DEVELOPMENT OF FISSION PILOT STATION #1
PIFI1    DTIME 1     3.0        5.0        10.0          8.0
PIFI1    DCOST 1     5.0       40.0        50.0         44.0         3.0
PIFI1    M     1   0.5

PIFI2    PIFI     PISFFI2 0.92 DEVELOPMENT OF FISSION PILOT STATION #2
PIFI2    DTIME 1     3.0        5.0        10.0          8.0
PIFI2    DCOST 1     5.0       40.0        50.0         44.0         3.0
PIFI2    M     1   0.5

PICO1    RDSFCO   PISFCO1 0.97 DEVELOPMENT OF COAL GAS PILOT STATION #1
PICO1    FILT1 1     0.0        7.0         0.0         70.0
PICO1    DTIME 1     3.0       10.0        12.0         11.4
PICO1    DCOST 1     4.0       20.0        40.0         27.0         4.0

PIFU1OK PISFFU1 ENDPIFU 1.0   FUSION PILOT STATION #1 SUCCESSFUL

PIFU2OK PISFFU2 ENDPIFU 1.0   FUSION PILOT STATION #2 SUCCESSFUL

PIFU3OK PISFFU3 ENDPIFU 1.0   FUSION PILOT STATION #3 SUCCESSFUL

PIFU4OK PISFFU4 ENDPIFU 1.0   FUSION PILOT STATION #4 SUCCESSFUL

PIFI1OK PISFFI1 ENDPIFI 1.0   FISSION PILOT STATION #1 SUCCESSFUL

PIFI2OK PISFFI2 ENDPIFI 1.0   FISSION PILOT STATION #2 SUCCESSFUL

PICO1OK PISFCO1 ENDPICO 1.0   COAL GAS PILOT STATION #1 SUCCESSFUL

PIFU1FALPISFFU1 FAILPILT1.0   FUSION PILOT STATION #1 FAILED

PIFU2FALPISFFU2 FAILPILT1.0   FUSION PILOT STATION #2 FAILED
```

```
PIFU3FALPISFFU3 FAILPILT1.0  FUSION PILOT STATION #3 FAILED

PIFU4FALPISFFU4 FAILPILT1.0  FUSION PILOT STATION #4 FAILED

PIFI1FALPISFFI1 FAILPILT1.0  FISSION PILOT STATION #1 FAILED

PIFI2FALPISFFI2 FAILPILT1.0  FISSION PILOT STATION #2 FAILED

PICO1FALPISFCO1 FAILPILT1.0  COAL GAS PILOT STATION #1 FAILED

PIFUFAILENOPIFU FAILPILT1.0  TOO MANY FUSION PILOT STATIONS FAILED

RELFU   ENOPIFU COREFU   1.0  STATION RELIABILITY-FUSION
RELFU   FILT2 1    3.0        4.0
RELFU   OPERF 1    4.0        0.70        0.99        0.85        0.01

COOLFU  ENOPIFU COREFU   1.0  COOLING WATER TEMPERATURE-FUSION
COOLFU  FILT2 1    3.0        4.0
COOLFU  OPERF 1    8.0        5.0         15.0        11.0        8.0

RELFI   ENOPIFI COREFI   1.0  STATION RELIABILITY-FISSION
RELFI   OPERF 1    4.0        0.80        0.99        0.88        0.02

COOLFI  ENOPIFI COREFI   1.0  COOLING WATER TEMPERATURE-FISSION
COOLFI  OPERF 1    8.0        3.0         14.0        9.0         6.0

RELCO   ENOPICO CORECO   1.0  STATION RELIABILITY-COAL GAS
RELCO   HPERF 1  0.629     0.01        0.631       0.0         0.679       0.01
RELCO   HPERF 2  0.681     0.0         0.745       0.01        0.755       0.01
RELCO   HPERF 3  0.765     0.01        0.775       0.01        0.765       0.01
RELCO   HPERF 4  0.795     0.02        0.805       0.02        0.815       0.03
RELCO   HPERF 5  0.825     0.03        0.835       0.04        0.845       0.04
RELCO   HPERF 6  0.855     0.05        0.865       0.06        0.875       0.07
RELCO   HPERF 7  0.885     0.08        0.895       0.09        0.905       0.08
RELCO   HPERF 8  0.915     0.07        0.925       0.06        0.935       0.05
RELCO   HPERF 9  0.945     0.04        0.955       0.04        0.965       0.03
RELCO   HPERF10  0.975     0.02        0.985       0.01        0.995

COOLCO  ENOPICO CORECO   1.0  COOLING WATER TEMPERATURE-COAL GAS
COOLCO  OPERF 1    8.0        2.0         12.0        7.0         7.0

PERFFU  COREFU  SELECT2 1.0  AGGREGATE THE PERFORMANCE FOR FUSION
PERFFU  RPERF 1 1SPCOREFU  K -1.0    K    1.0   2SK  10.0  K  0.2   PCOOLFU
PERFFU  RPERF 2 2SPRELFU   K  0.8    K    0.90

PERFFI  COREFI  SELECT2 1.0  AGGREGATE THE PERFORMANCE FOR FISSION
PERFFI  RPERF 1 1SPCOREFI  K -1.0    K    1.0   2SK  10.0  K  0.2   PCOOLFI
PERFFI  RPERF 2 2SPRELFI   K  0.8    K    0.90

PERFCO  CORECO  SELECT2 1.0  AGGREGATE THE PERFORMANCE FOR COAL GAS
PERFCO  RPERF 1 1SPCORECO  K -1.0    K    1.0   2SK  10.0  K  0.2   PCOOLCO
PERFCO  RPERF 2 2SPRELCO   K  0.8    K    0.90

SHOCKFU SELECT2 SELECT1 0.72 SHOCK TEST-FUSION
SHOCKFU RTIME 1 1SK  0.2   K  1.0    K    1.0
SHOCKFU OCOST 1    1.0      10.0

SHOCKFI SELECT2 SELECT1 0.88 SHOCK TEST-FISSION
SHOCKFI OTIME 1    1.0      0.2
SHOCKFI OCOST 1    1.0      10.0
```

```
SHOCKCO SELECT2 SELECT1 0.93 SHOCK TEST-COAL GAS
SHOCKCO DTIME 1    1.0        0.2
SHOCKCO DCOST 1    1.0       10.0

WINFU    SELECT1 FUWINNER1.0  FUSION IS THE WINNER.

WINFI    SELECT1 FIWINNER1.0  FISSION IS THE WINNER

WINCO    SELECT1 COWINNER1.0  COAL GAS IS THE WINNER

FAILSHCKSELECT1 FAILSHOC1.0  TOTAL FAILURE OF THE SHOCK TEST

ENDARC

START    1  2                 STARTING POINT FOR THE NETWORK

RDSFFU   2  4                 R&D SUCCESS-FAIL DETERMINATOR-FUSION

RDSFFI   2  4                 R&D SUCCESS-FAIL DETERMINATOR-FISSION

RDSFCO   2  4                 R&D SUCCESS-FAIL DETERMINATOR-COAL GAS

PIFU     2  2                 INITIATION PILOT STATION-CONSTRUCTION-FUSION

PIFI     2  3                 INITIATION PILOT STATION-CONSTRUCTION-FISSION

FAILRD   3 3115               FAILURE OF R&D EFFORT

PISFFU1 2  2                  PILOT SUCCESS-FAIL DETERMINATOR STATION 1-FUSION

PISFFU2 2  2                  PILOT SUCCESS-FAIL DETERMINATOR STATION 2-FUSION

PISFFU3 2  2                  PILOT SUCCESS-FAIL DETERMINATOR STATION 3-FUSION

PISFFU4 2  2                  PILOT SUCCESS-FAIL DETERMINATOR STATION 4-FUSION

PISFFI1 2  2                  PILOT SUCCESS-FAIL DETERMINATOR STATION 1-FISSION

PISFFI2 2  2                  PILOT SUCCESS-FAIL DETERMINATOR STATION 2-FISSION

PISFCO1 2  2                  PILOT SUCCESS-FAIL DETERMINATOR STATION 1-COAL GAS

ENDPIFU 3  5                  END OF PILOT STATION EXERCISE-FUSION

ENDPIFI 4  2                  END OF PILOT STATION EXERCISE-FISSION

ENDPICO 2  2                  END OF PILOT STATION EXERCISE-COAL GAS

FAILPILT3 2115                FAILURE OF PILOT STATIONS TESTS

COREFU   2  2                 COOL + RELIABILITY-RAW GENERATES-FUSION

COREFI   2  2                 COOL + RELIABILITY-RAW GENERATES-FISSION

CORECO   2  2                 COOL + RELIABILITY-RAW GENERATES-COAL GAS

SELECT2 5 -2              1.0 SELECT 2 METHODS FOR SHOCK TESTING

SELECT1 6 -1                  SELECT THE MOST DESIRED METHOD

FAILSHOC2 1115                FAILURE OF THE SHOCK TEST

FUWINNER2  1 2                SUCCESSFULL PROJECT COMPLETION VIA FUSION
```

```
FIWINNER2  1 2                    SUCCESSFULL PROJECT COMPLETION VIA FISSION
FIWINNERHIST  15.00   17.00                   275.00  500.00   0.90    1.35

COWINNER2  1 2                    SUCCESSFULL PROJECT COMPLETION VIA COAL GAS

ENDNODE

W A R N I N G  NO.  6135  PARAMETER =

W A R N I N G  NO.  6140  PARAMETER =
```

```
POSITIVE COST INCURRED BETWEEN THE TIME PERIODS OF       0.0  -          5.00

                CFD  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
       180.0771 I----I----I----I----I----I----I----I----I----I----I MIN
                I                                                    0.005
       185.0000 I
                I                                                    0.009
       186.1818 I
                I*                                                   0.021
       187.3636 I
                I***                                                 0.052
       188.5454 I
                I*****                                               0.106
       189.7272 I
                I*********                                           0.175
       190.9090 I
                I************                                        0.250
       192.0909 I
                I******************                                  0.354
       193.2727 I
                I**********************                              0.450
       194.4545 I
                I****************************                        0.557
       195.6363 I
                I*********************************                   0.654
       196.8181 I
                I*************************************               0.742
       197.9999 I
                I*****************************************           0.818
       199.1817 I
                I*******************************************         0.858
       200.3635 I
                I********************************************        0.885
       201.5453 I
                I*********************************************       0.905
       202.7271 I
                I**********************************************      0.921
       203.9089 I
                I***********************************************     0.936
       205.0907 I
                I***********************************************     0.949
       206.2726 I
                I************************************************    0.967
       207.4544 I
                I*************************************************   0.976
       208.6362 I
                I*************************************************   0.985
       209.8180 I
                I**************************************************0.994
       211.0000 I
                I**************************************************1.000
       212.7589 I----I----I----I----I----I----I----I----I----I----I MAX

                NO OBS------------       1000   STD ERROR-           5.1157
                COEF OF VARIATION-       0.03   MEAN------         195.5337
                KURTOSIS (BETA 2)-       3.72   MEDIAN----         195.0414
                PEARSONIAN SKEW---       0.09   MODE------         195.0735
```

```
POSITIVE COST INCURRED BETWEEN THE TIME PERIODS OF        5.00 -        10.00

                CFD  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
        9.6800  I----I----I----I----I----I----I----I----I----I----I MIN
                I                                                    0.0
        9.6800  I
                I***                                                 0.057
       17.2586  I
                I********                                            0.153
       24.8373  I
                I***************                                     0.296
       32.4160  I
                I*********************                               0.426
       39.9946  I
                I****************************                        0.554
       47.5733  I
                I*********************************                   0.663
       55.1519  I
                I**************************************              0.763
       62.7306  I
                I*****************************************           0.830
       70.3092  I
                I******************************************          0.848
       77.8879  I
                I******************************************          0.849
       85.4666  I
                I******************************************          0.849
       93.0452  I
                I******************************************          0.850
      100.6239  I
                I*******************************************         0.859
      108.2025  I
                I********************************************        0.874
      115.7812  I
                I*********************************************       0.905
      123.3599  I
                I***********************************************     0.936
      130.9385  I
                I***********************************************     0.949
      138.5172  I
                I************************************************    0.964
      146.0958  I
                I*************************************************   0.989
      153.6745  I
                I**************************************************0.998
      161.2532  I
                I**************************************************0.999
      168.8318  I
                I**************************************************1.000
      176.4106  I
                I**************************************************1.000
      176.4106  I----I----I----I----I----I----I----I----I----I----I MAX

                NO OBS------------       1000   STD ERROR-         35.9099
                COEF OF VARIATION-       0.66   MEAN------         54.2576
                KURTOSIS (BETA 2)-       4.15   MEDIAN----         44.3195
                PEARSONIAN SKEW---       0.65   MODE------         30.7739
```

POSITIVE COST INCURRED BETWEEN THE TIME PERIODS OF 10.00 - 15.00

```
               CFD  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
      8.5026 I----I----I----I----I----I----I----I----I----I----I MIN
             I                                                     0.0
      8.5026 I
             I*********************                                0.422
     14.0671 I
             I**************************                           0.528
     19.6315 I
             I*********************************                    0.652
     25.1960 I
             I****************************************             0.794
     30.7605 I
             I******************************************           0.843
     36.3250 I
             I******************************************           0.847
     41.8895 I
             I******************************************           0.849
     47.4540 I
             I******************************************           0.849
     53.0184 I
             I******************************************           0.849
     58.5829 I
             I******************************************           0.849
     64.1474 I
             I******************************************           0.849
     69.7119 I
             I******************************************           0.849
     75.2764 I
             I******************************************           0.849
     80.8409 I
             I*******************************************          0.853
     86.4053 I
             I*******************************************          0.861
     91.9698 I
             I********************************************         0.883
     97.5343 I
             I**********************************************       0.919
    103.0988 I
             I************************************************     0.953
    108.6533 I
             I*************************************************    0.980
    114.2278 I
             I*************************************************    0.990
    119.7923 I
             I**************************************************0.995
    125.3567 I
             I**************************************************1.000
    130.9214 I
             I**************************************************1.000
    130.9214 I----I----I----I----I----I----I----I----I----I----I MAX

             NO OBS------------        1000   STD ERROR-         31.9100
             COEF OF VARIATION-        1.03   MEAN------         31.0489
             KURTOSIS (BETA 2)-        4.69   MEDIAN----         17.3702
             PEARSONIAN SKEW---        0.61   MODE------         11.6844
```

POSITIVE COST INCURRED BETWEEN THE TIME PERIODS OF 15.00 - 20.00

```
           CFD  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
   0.5393 I----I----I----I----I----I----I----I----I----I----I MIN
          I                                                    0.0
   0.5393 I
          I*                                                   0.013
   2.6387 I
          I*                                                   0.022
   4.7380 I
          I**                                                  0.031
   6.8374 I
          I**                                                  0.034
   8.9368 I
          I*****                                               0.094
  11.0361 I
          I********************                                0.408
  13.1355 I
          I***************************                         0.537
  15.2349 I
          I***************************                         0.543
  17.3342 I
          I***************************                         0.548
  19.4336 I
          I********************************                    0.631
  21.5330 I
          I*******************************************         0.854
  23.6323 I
          I**********************************************      0.919
  25.7317 I
          I***********************************************     0.943
  27.8311 I
          I************************************************    0.964
  29.9304 I
          I*************************************************   0.977
  32.0298 I
          I*************************************************   0.984
  34.1292 I
          I**************************************************0.992
  36.2285 I
          I**************************************************0.997
  38.3279 I
          I**************************************************0.999
  40.4272 I
          I**************************************************0.999
  42.5266 I
          I**************************************************0.999
  44.6260 I
          I**************************************************1.000
  46.7253 I
          I**************************************************1.000
  46.7253 I----I----I----I----I----I----I----I----I----I----I MAX

          NO OBS------------        987  STD ERROR-          6.7712
          COEF OF VARIATION-       0.39  MEAN------         17.3407
          KURTOSIS (BETA 2)-       3.10  MEDIAN----         13.8371
          PEARSONIAN SKEW---       0.75  MODE------         12.2503
```

```
POSITIVE COST INCURRED BETWEEN THE TIME PERIODS OF      0.0   -      20.00

               CFD  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
     223.1879 I----I----I----I----I----I----I----I----I----I----I MIN
              I                                                     0.0
     223.1879 I
              I**                                                   0.044
     236.1876 I
              I**************                                       0.271
     249.1873 I
              I***********************                              0.464
     262.1870 I
              I************************                             0.486
     275.1865 I
              I***************************                          0.548
     288.1860 I
              I**************************************               0.762
     301.1855 I
              I******************************************           0.845
     314.1851 I
              I******************************************           0.849
     327.1846 I
              I******************************************           0.849
     340.1841 I
              I******************************************           0.849
     353.1836 I
              I******************************************           0.849
     366.1831 I
              I******************************************           0.849
     379.1826 I
              I******************************************           0.849
     392.1821 I
              I******************************************           0.849
     405.1816 I
              I******************************************           0.849
     418.1812 I
              I*******************************************          0.856
     431.1807 I
              I********************************************         0.878
     444.1802 I
              I**********************************************       0.915
     457.1797 I
              I***********************************************      0.941
     470.1792 I
              I************************************************     0.956
     483.1787 I
              I*************************************************    0.985
     496.1782 I
              I**************************************************1.000
     509.1824 I
              I**************************************************1.000
     509.1824 I----I----I----I----I----I----I----I----I----I----I MAX

              NO OBS------------    1000  STD ERROR-         74.6949
              COEF OF VARIATION-    0.25  MEAN------        297.9580
              KURTOSIS (BETA 2)-    4.33  MEDIAN----        280.0195
              PEARSONIAN SKEW---    0.68  MODE------        247.1503
```

COST CONFIDENCE BALANCE AMONG SELECTED TIME PERIODS

CFD NO	TIME INTERVAL COVERED START		STOP	CONFIDENCES COMPUTED	COST INTERPOLATED FOR THE CONFIDENCES COMPUTED
1.	0.0	-	5.00	0.89	201.693024
2.	5.00	-	10.00	0.75	61.7453156
3.	10.00	-	15.00	0.60	22.8625183
4.	15.00	-	20.00	0.45	13.8157101
			SUM OF ABOVE COSTS		300.116211
5.	0.0	-	20.00	0.75	300.456543

PATH COST FOR NODE FJWINNER

```
           CFO  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
 209.4123 I----I----I----I----I----I----I----I----I----I----I MIN
          I                                                    0.0
 209.4123 I
          I*                                                   0.014
 213.5051 I
          I*                                                   0.014
 217.5980 I
          I*                                                   0.028
 221.6908 I
          I****                                                0.070
 225.7837 I
          I********                                            0.169
 229.8765 I
          I**************                                      0.282
 233.9694 I
          I******************                                  0.352
 238.0622 I
          I********************                                0.408
 242.1551 I
          I*********************                               0.423
 246.2479 I
          I*********************                               0.423
 250.3408 I
          I*********************                               0.423
 254.4336 I
          I*********************                               0.423
 258.5264 I
          I***********************                             0.451
 262.6191 I
          I*************************                           0.493
 266.7119 I
          I**************************                          0.521
 270.8047 I
          I******************************                      0.592
 274.8975 I
          I********************************                    0.634
 278.9902 I
          I**************************************              0.761
 283.0830 I
          I******************************************          0.845
 287.1758 I
          I**********************************************      0.930
 291.2686 I
          I***********************************************     0.944
 295.3613 I
          I**************************************************1.000
 299.4551 I
          I**************************************************1.000
 299.4551 I----I----I----I----I----I----I----I----I----I----I MAX

          NO OBS-----------        71  STD ERROR-         26.3123
          COEF OF VARIATION-     0.10  MEAN------        259.6079
          KURTOSIS (BETA 2)-     1.45  MEDIAN----        267.6016
          PEARSONIAN SKEW---     0.84  MODE------        281.7187
```

NETWORK TIME FOR THE COMPOSITE TERMINAL NODE

```
          CFD  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
11.0765 I----I----I----I----I----I----I----I----I----I----I MIN
        I                                                  0.005
12.0000 I
        I                                                  0.005
12.2273 I
        I                                                  0.006
12.4545 I
        I                                                  0.007
12.6818 I
        I                                                  0.007
12.9091 I
        I                                                  0.007
13.1364 I
        I                                                  0.007
13.3636 I
        I                                                  0.007
13.5909 I
        I                                                  0.007
13.8182 I
        I                                                  0.007
14.0454 I
        I                                                  0.008
14.2727 I
        I                                                  0.008
14.5000 I
        I                                                  0.009
14.7273 I
        I*                                                 0.020
14.9545 I
        I**                                                0.044
15.1818 I
        I*****                                             0.096
15.4091 I
        I********                                          0.165
15.6364 I
        I**************                                    0.271
15.8636 I
        I**********************                            0.432
16.0909 I
        I*******************************                   0.627
16.3182 I
        I***************************************           0.787
16.5454 I
        I*********************************************     0.910
16.7727 I
        I************************************************* 0.981
17.0000 I
        I**************************************************1.000
17.5292 I----I----I----I----I----I----I----I----I----I----I MAX

        NO OBS-----------       1000  STD ERROR-         0.6070
        COEF OF VARIATION-      0.04  MEAN------        16.1045
        KURTOSIS (BETA 2)-     19.66  MEDIAN----        16.1632
        PEARSONIAN SKEW---      0.16  MODE------        16.2029
```

PATH COST FOR THE COMPOSITE TERMINAL NODE

```
          CFD  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
  82.4049 I----I----I----I----I----I----I----I----I----I----I MIN
          I                                                   0.0
  82.4049 I
          I*******                                            0.131
  94.8342 I
          I*****************************                      0.580
 107.2635 I
          I************************************               0.720
 119.6927 I
          I**********************************************     0.923
 132.1220 I
          I**********************************************     0.923
 144.5513 I
          I**********************************************     0.923
 156.9806 I
          I**********************************************     0.923
 169.4098 I
          I**********************************************     0.923
 181.8391 I
          I**********************************************     0.923
 194.2684 I
          I**********************************************     0.923
 206.6977 I
          I**********************************************     0.928
 219.1269 I
          I***********************************************    0.944
 231.5562 I
          I************************************************   0.957
 243.9855 I
          I************************************************   0.958
 256.4146 I
          I************************************************   0.965
 268.8437 I
          I*************************************************  0.980
 281.2729 I
          I**************************************************0.994
 293.7021 I
          I**************************************************0.999
 306.1313 I
          I**************************************************0.999
 318.5605 I
          I**************************************************0.999
 330.9897 I
          I**************************************************0.999
 343.4189 I
          I**************************************************1.000
 355.8491 I
          I**************************************************1.000
 355.8491 I----I----I----I----I----I----I----I----I----I----I MAX

          NO OBS------------      1000  STD ERROR-          42.8560
          COEF OF VARIATION-      0.36  MEAN------         117.8486
          KURTOSIS (BETA 2)-     11.38  MEDIAN----         101.7044
          PEARSONIAN SKEW---      0.39  MODE------         101.1380
```

OVERALL COST FOR THE COMPOSITE TERMINAL NODE

```
          CFD  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
223.1879 I----I----I----I----I----I----I----I----I----I----I MIN
         I                                                  0.0
223.1879 I
         I**                                                0.044
236.1876 I
         I**************                                    0.271
249.1873 I
         I***********************                           0.464
262.1870 I
         I************************                          0.488
275.1865 I
         I****************************                      0.552
288.1860 I
         I**************************************            0.762
301.1855 I
         I******************************************        0.845
314.1851 I
         I******************************************        0.849
327.1846 I
         I******************************************        0.849
340.1841 I
         I******************************************        0.849
353.1836 I
         I******************************************        0.849
366.1831 I
         I******************************************        0.849
379.1826 I
         I******************************************        0.849
392.1821 I
         I******************************************        0.849
405.1816 I
         I******************************************        0.849
418.1812 I
         I*******************************************       0.856
431.1807 I
         I********************************************      0.879
444.1802 I
         I**********************************************    0.916
457.1797 I
         I***********************************************   0.941
470.1792 I
         I************************************************  0.957
483.1787 I
         I************************************************* 0.985
496.1782 I
         I**************************************************1.000
509.1824 I
         I**************************************************1.000
509.1824 I----I----I----I----I----I----I----I----I----I----I MAX

         NO OBS-----------     1000  STD ERROR-        74.5915
         COEF OF VARIATION-    0.25  MEAN------       297.8311
         KURTOSIS (BETA 2)-    4.34  MEDIAN----       279.0715
         PEARSONIAN SKEW---    0.68  MODE------       247.1503
```

PATH PERFORMANCE FOR THE COMPOSITE TERMINAL NODE

```
         CFO  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
0.0      I----I----I----I----I----I----I----I----I----I----I MIN
         I                                                  0.0
0.0      I
         I***                                               0.052
0.0845   I
         I***                                               0.052
0.1689   I
         I***                                               0.052
0.2534   I
         I***                                               0.052
0.3379   I
         I***                                               0.052
0.4223   I
         I***                                               0.052
0.5068   I
         I***                                               0.052
0.5913   I
         I***                                               0.052
0.6757   I
         I***                                               0.053
0.7602   I
         I***                                               0.056
0.8447   I
         I*****                                             0.108
0.9291   I
         I******************                                0.361
1.0136   I
         I********************************                  0.648
1.0980   I
         I*****************************************         0.819
1.1825   I
         I*********************************************     0.908
1.2670   I
         I************************************************  0.951
1.3514   I
         I************************************************* 0.976
1.4359   I
         I************************************************* 0.984
1.5204   I
         I************************************************* 0.990
1.6048   I
         I**************************************************0.994
1.6893   I
         I**************************************************0.998
1.7738   I
         I**************************************************1.000
1.8582   I
         I**************************************************1.000
1.8582   I----I----I----I----I----I----I----I----I----I----I MAX

         NO OBS------------       1000  STD ERROR-          0.2779
         COEF OF VARIATION-       0.27  MEAN------          1.0321
         KURTOSIS (BETA 2)-      10.56  MEDIAN----          1.0548
         PEARSONIAN SKEW---       0.00  MODE------          1.0327
```

```
OPTIMUM TERMINAL NODE INDEX - NO. ITERATIONS = 1000
                     0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0
                I----+----+----+----+----+----+----+----+----+----+I
FAILPILT 0.0130 I*                                                 I
                I    +    +    +    +    +    +    +    +    +    +I
FAILSHOC 0.0390 I**                                                I
                I    +    +    +    +    +    +    +    +    +    +I
FJWINNER 0.0710 I****                                              I
                I    +    +    +    +    +    +    +    +    +    +I
FIWINNER 0.3360 I*****************                                 I
                I    +    +    +    +    +    +    +    +    +    +I
CJWINNER 0.5410 I***************************                       I
                I----+----+----+----+----+----+----+----+----+----+I
                     0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9  1.0

    LAST RANDOM NUMBER SEED =   2073463875
```

CHAPTER 6 AUXILIARY PROGRAM TO AID VERT

There is a peripheral program used to assist the VERT effort. This program is known as DIMEN, which stands for dimensioning.

6-1. DIMEN - VERT's Core Storage Dimensioning Program

DIMEN dimensions VERT's storage arrays while simultaneously assigning compatible values to the check variables. These check variables are used to run a check on the quantity of information being put in these storage arrays. If they have the same value as the magnitude of the storage arrays, these check variables will insure that the boundaries of these storage arrays are not exceeded when VERT loads these arrays. DIMEN was specifically structured to accomplish this logical task.

A. Definition of Inputs.

DIMEN requires only one input card which has the following layout.

Columns	Format	Check Variable	Boundaries on the Check Variables#
1- 8	I8	MITER	MITER.GT.0.and.MITER.LT.100000
9-16	I8	MARC	MARC.GT.0.and.MARC.LT.10000
17-24	I8	LARC	LARC.GT.0.and.LARC.LT.100000
25-32	I8	MNODE	MNODE.GT.0.and.MNODE.LT.10000
33-40	I8	LNODE	(LNODE + MTAG).GT.0 ---and---
41-48	I8	MTAG	(LNODE + MTAG).LT.100000
49-56	I8	MHIST	MHIST.GT.0. and.MHIST.LT.100
57-64	I8	MTERM	MTERM.GT.0.and.MTERM.LT.1000
65-72	I8	MSLACK	MSLACK.GT.0.and.MSLACK.LT.1000
73-80	I8	MCPGAP	MCPGAP.GT.0.and.MCPGAP.LT.1000

\# GT = Greater than and LT = Less than

B. Example Output.

```
0COMMON/ARCS/ASTORE( 2000),UTIMEA( 125),TIMEA( 125),UCOSTA( 125),   GLM  710
1COSTA( 125),JPERFA( 125),PERFA( 125),WORK( 125),ISTATE( 125),      GLM  720
2NODEI( 125),NODEO( 125),ICRITA( 125),KEEPC( 125),KEEPP( 125),      GLM  730
3IARC1( 125),IARC2( 125),IPOINT( 125),JPOINT( 125),ISLAK( 125),     GLM  740
4KARC,LARC,MARC,NARC,ITALC,ITALP,ISTAR                              GLM  750
0COMMON/TRIALS/STORET(  500,4),TERM( 2,8),KPOINT( 2),NODET(  500),  GLM  960
1MTERM,NTERM,MITER,ITER                                             GLM  970
0COMMON/ARCS/ASTORE( 2000),UTIMEA( 125),TIMEA( 125),UCOSTA( 125),   GLM  980
1COSTA( 125),JPERFA( 125),PERFA( 125),WORK( 125),ISTATE( 125),      GLM  990
```

```
2NODEI( 125),NODEJ( 125),ICRITA( 125),KEEPC( 125),KEEPP( 125),     GLM 1000
3IARC1( 125),IARC2( 125),IPOINT( 125),JPOINT( 125),ISLAK( 125),     GLM 1010
4KARC,LARC,MARC,NARC,ITALC,ITALP,ISTAR                              GLM 1020
0COMMON/NODES/TIMEN(  75),COSTN(  75),PERFN(  75),NSTORE( 1200),    GLM 1030
1NODE1(  75),NODE2(  75),LOGI(  75),LOGJ(  75),NSTATE(  75),        GLM 1040
2NARCI(  75),NARCJ(  75),ISTAT(  75),INSTAT(  75),ICRITN(  75),     GLM 1050
3NPOINT(  75),NSLAK(  75),JUMP(  75),KNODE,LNODE,MNODE,NNODE,MTAG,  GLM 1060
4NTAG                                                               GLM 1065
0COMMON/HIST/XMIN( 4,4),XMAX( 4,4),HMIN( 4,4),HMAX( 4,4),           GLM 1070
1HAVE( 4,4),IOBS( 4),MHIST,NHIST                                    GLM 1080
0COMMON/SLACK/RMIN( 8),RMAX( 8),SMIN( 8),SMAX( 8),SAVE( 8),         GLM 1090
1JOBS( 8),MSLACK,NSLACK                                             GLM 1100
0COMMON/CPGAP/T1(10),T2(10),CSMIN(10),CSMAX(10),CHMIN(10),          GLM 1110
1CHMAX(10),CAVE(10),PSMIN(10),PSMAX(10),PHMIN(10),PHMAX(10),        GLM 1120
2PAVE(10),KCOBS(10),KPOBS(10),MCPGAP,NCPGAP,ICPGAP                  GLM 1130
 MITER  =  500                                                      GLM 2090
 MARC   =  125                                                      GLM 2100
 LARC   = 2000                                                      GLM 2110
 MNODE  =   75                                                      GLM 2120
 LNODE  =  500                                                      GLM 2130
 MTAG   =  600                                                      GLM 2140
 MHIST  =    4                                                      GLM 2150
 MTERM  =    2                                                      GLM 2160
 MSLACK=     8                                                      GLM 2170
 MCPGAP=    10                                                      GLM 2180
0COMMON/TRIALS/STORET(  500,4),TERM( 2,8),KPOINT( 2),NODET(  500),  GLM 8920
1MTERM,NTERM,MITER,ITER                                             GLM 8930
0COMMON/TRIALS/STORET(  500,4),TERM( 2,8),KPOINT( 2),NODET(  500),  GLM 9260
1MTERM,NTERM,MITER,ITER                                             GLM 9270
0COMMON/ARCS/ASTORE( 2000),UTIMEA( 125),TIMEA( 125),UCOSTA( 125),   GLM 9280
1COSTA( 125),JPERFA( 125),PERFA( 125),WORK( 125),ISTATE( 125),      GLM 9290
2NODEI( 125),NODEJ( 125),ICRITA( 125),KEEPC( 125),KEEPP( 125),     GLM 9300
3IARC1( 125),IARC2( 125),IPOINT( 125),JPOINT( 125),ISLAK( 125),     GLM 9310
4KARC,LARC,MARC,NARC,ITALC,ITALP,ISTAR                              GLM 9320
0COMMON/NODES/TIMEN(  75),COSTN(  75),PERFN(  75),NSTORE( 1200),    GLM 9330
1NODE1(  75),NODE2(  75),LOGI(  75),LOGJ(  75),NSTATE(  75),        GLM 9340
2NARCI(  75),NARCJ(  75),ISTAT(  75),INSTAT(  75),ICRITN(  75),     GLM 9350
3NPOINT(  75),NSLAK(  75),JUMP(  75),KNODE,LNODE,MNODE,NNODE,MTAG,  GLM 9360
4NTAG                                                               GLM 9365
0COMMON/HIST/XMIN( 4,4),XMAX( 4,4),HMIN( 4,4),HMAX( 4,4),           GLM 9370
1HAVE( 4,4),IOBS( 4),MHIST,NHIST                                    GLM 9380
0COMMON/SLACK/RMIN( 8),RMAX( 8),SMIN( 8),SMAX( 8),SAVE( 8),         GLM 9390
1JOBS( 8),MSLACK,NSLACK                                             GLM 9400
0COMMON/ARCS/ASTORE( 2000),UTIMEA( 125),TIMEA( 125),UCOSTA( 125),   GLM15410
1COSTA( 125),UPERFA( 125),PERFA( 125),WORK( 125),ISTATE( 125),      GLM15420
2NODEI( 125),NODEO( 125),ICRITA( 125),KEEPC( 125),KEEPP( 125),     GLM15430
3IARC1( 125),IARC2( 125),IPOINT( 125),JPOINT( 125),ISLAK( 125),     GLM15440
4KARC,LARC,MARC,NARC,ITALC,ITALP,ISTAR                              GLM15450
0COMMON/TRIALS/STORET(  500,4),TERM( 2,8),KPOINT( 2),NODET(  500),  GLM15790
1MTERM,NTERM,MITER,ITER                                             GLM15800
0COMMON/ARCS/ASTORE( 2000),UTIMEA( 125),TIMEA( 125),UCOSTA( 125),   GLM15810
1COSTA( 125),UPERFA( 125),PERFA( 125),WORK( 125),ISTATE( 125),      GLM15820
2NODEI( 125),NODEJ( 125),ICRITA( 125),KEEPC( 125),KEEPP( 125),     GLM15830
3IARC1( 125),IARC2( 125),IPOINT( 125),JPOINT( 125),ISLAK( 125),     GLM15840
4KARC,LARC,MARC,NARC,ITALC,ITALP,ISTAR                              GLM15850
0COMMON/NODES/TIMEN(  75),COSTN(  75),PERFN(  75),NSTORE( 1200),    GLM15860
1NODE1(  75),NODE2(  75),LOGI(  75),LOGJ(  75),NSTATE(  75),        GLM15870
2NARCI(  75),NARCJ(  75),ISTAT(  75),INSTAT(  75),ICRITN(  75),     GLM15880
3NPOINT(  75),NSLAK(  75),JUMP(  75),KNODE,LNODE,MNODE,NNODE,MTAG,  GLM15890
4NTAG                                                               GLM15895
0COMMON/HIST/XMIN( 4,4),XMAX( 4,4),HMIN( 4,4),HMAX( 4,4),           GLM15900
1HAVE( 4,4),IOBS( 4),MHIST,NHIST                                    GLM15910
```

```
0COMMON/SLACK/RMIN( 8),RMAX( 8),SMIN( 8),SMAX( 8),SAVE( 8),          GLM15920
1JOBS( 8),MSLACK,NSLACK                                               GLM15930
0COMMON/CPGAP/T1(10),T2(10),CSMIN(10),CSMAX(10),CHMIN(10),            GLM15932
1CHMAX(10),CAVE(10),PSMIN(10),PSMAX(10),PHMIN(10),PHMAX(10),          GLM15934
2PAVE(10),KCOBS(10),KPOBS(10),MCPGAP,NCPGAP,ICPGAP                    GLM15936
0COMMON/TRIALS/STORET(  500,4),TERM( 2,8),KPOINT( 2),NODET(  500),    GLM20940
1MTERM,NTERM,MITER,ITER                                               GLM20950
0COMMON/ARCS/ASTORE( 2000),UTIMEA( 125),TIMEA( 125),UCOSTA( 125),     GLM20960
1COSTA( 125),JPERFA( 125),PERFA( 125),WORK( 125),ISTATE( 125),        GLM20970
2NODEI( 125),NODEO( 125),ICRITA( 125),KEEPC( 125),KEEPP( 125),        GLM20980
3IARC1( 125),IARC2( 125),IPOINT( 125),JPOINT( 125),ISLAK( 125),       GLM20990
4KARC,LARC,MARC,NARC,ITALC,ITALP,ISTAR                                GLM21000
0COMMON/NODES/TIMEN(  75),COSTN(  75),PERFN(  75),NSTORE( 1200),      GLM21010
1NODE1(  75),NODE2(  75),LOGI(  75),LOGO(  75),NSTATE(  75),          GLM21020
2NARCI(  75),NARCO(  75),ISTAT(  75),INSTAT(  75),ICRITN(  75),       GLM21030
3NPOINT(  75),NSLAK(  75),JUMP(  75),KNODE,LNODE,MNODE,NNODE,MTAG,    GLM21040
4NTAG                                                                 GLM21045
0COMMON/HIST/XMIN( 4,4),XMAX( 4,4),HMIN( 4,4),HMAX( 4,4),            GLM21050
1HAVE( 4,4),IOBS( 4),MHIST,NHIST                                      GLM21060
0COMMON/SLACK/RMIN( 8),RMAX( 8),SMIN( 8),SMAX( 8),SAVE( 8),          GLM21070
1JOBS( 8),MSLACK,NSLACK                                               GLM21080
0COMMON/CPGAP/T1(10),T2(10),CSMIN(10),CSMAX(10),CHMIN(10),            GLM21090
1CHMAX(10),CAVE(10),PSMIN(10),PSMAX(10),PHMIN(10),PHMAX(10),          GLM21100
2PAVE(10),KCOBS(10),KPOBS(10),MCPGAP,NCPGAP,ICPGAP                    GLM21110
 DIMENSION SLACKA( 125), SLACKN(  75), IPATHA( 125), IPATHN(  75)     GLM21120
0COMMON/ARCS/ASTORE( 2000),UTIMEA( 125),TIMEA( 125),UCOSTA( 125),     GLM33250
1COSTA( 125),JPERFA( 125),PERFA( 125),WORK( 125),ISTATE( 125),        GLM33260
2NODEI( 125),NODEO( 125),ICRITA( 125),KEEPC( 125),KEEPP( 125),        GLM33270
3IARC1( 125),IARC2( 125),IPOINT( 125),JPOINT( 125),ISLAK( 125),       GLM33280
4KARC,LARC,MARC,NARC,ITALC,ITALP,ISTAR                                GLM33290
0COMMON/NODES/TIMEN(  75),COSTN(  75),PERFN(  75),NSTORE( 1200),      GLM33300
1NODE1(  75),NODE2(  75),LOGI(  75),LOGO(  75),NSTATE(  75),          GLM33310
2NARCI(  75),NARCO(  75),ISTAT(  75),INSTAT(  75),ICRITN(  75),       GLM33320
3NPOINT(  75),NSLAK(  75),JUMP(  75),KNODE,LNODE,MNODE,NNODE,MTAG,    GLM33330
4NTAG                                                                 GLM33335
0COMMON/ARCS/ASTORE( 2000),UTIMEA( 125),TIMEA( 125),UCOSTA( 125),     GLM33550
1COSTA( 125),JPERFA( 125),PERFA( 125),WORK( 125),ISTATE( 125),        GLM33560
2NODEI( 125),NODEO( 125),ICRITA( 125),KEEPC( 125),KEEPP( 125),        GLM33570
3IARC1( 125),IARC2( 125),IPOINT( 125),JPOINT( 125),ISLAK( 125),       GLM33580
4KARC,LARC,MARC,NARC,ITALC,ITALP,ISTAR                                GLM33590
0COMMON/NODES/TIMEN(  75),COSTN(  75),PERFN(  75),NSTORE( 1200),      GLM33600
1NODE1(  75),NODE2(  75),LOGI(  75),LOGO(  75),NSTATE(  75),          GLM33610
2NARCI(  75),NARCO(  75),ISTAT(  75),INSTAT(  75),ICRITN(  75),       GLM33620
3NPOINT(  75),NSLAK(  75),JUMP(  75),KNODE,LNODE,MNODE,NNODE,MTAG,    GLM33630
4NTAG                                                                 GLM33635
0COMMON/ARCS/ASTORE( 2000),UTIMEA( 125),TIMEA( 125),UCOSTA( 125),     GLM34260
1COSTA( 125),JPERFA( 125),PERFA( 125),WORK( 125),ISTATE( 125),        GLM34270
2NODEI( 125),NODEO( 125),ICRITA( 125),KEEPC( 125),KEEPP( 125),        GLM34280
3IARC1( 125),IARC2( 125),IPOINT( 125),JPOINT( 125),ISLAK( 125),       GLM34290
4KARC,LARC,MARC,NARC,ITALC,ITALP,ISTAR                                GLM34300
0COMMON/NODES/TIMEN(  75),COSTN(  75),PERFN(  75),NSTORE( 1200),      GLM34310
1NODE1(  75),NODE2(  75),LOGI(  75),LOGO(  75),NSTATE(  75),          GLM34320
2NARCI(  75),NARCO(  75),ISTAT(  75),INSTAT(  75),ICRITN(  75),       GLM34330
3NPOINT(  75),NSLAK(  75),JUMP(  75),KNODE,LNODE,MNODE,NNODE,MTAG,    GLM34340
4NTAG                                                                 GLM34345
0COMMON/ARCS/ASTORE( 2000),UTIMEA( 125),TIMEA( 125),UCOSTA( 125),     GLM34650
1COSTA( 125),JPERFA( 125),PERFA( 125),WORK( 125),ISTATE( 125),        GLM34660
2NODEI( 125),NODEO( 125),ICRITA( 125),KEEPC( 125),KEEPP( 125),        GLM34670
3IARC1( 125),IARC2( 125),IPOINT( 125),JPOINT( 125),ISLAK( 125),       GLM34680
4KARC,LARC,MARC,NARC,ITALC,ITALP,ISTAR                                GLM34690
0COMMON/NODES/TIMEN(  75),COSTN(  75),PERFN(  75),NSTORE( 1200),      GLM34700
1NODE1(  75),NODE2(  75),LOGI(  75),LOGO(  75),NSTATE(  75),          GLM34710
```

```
2NARCI(  75),NARCO(  75),ISTAT(  75),INSTAT(  75),ICRITN(  75),    GLM34720
3NPOINT(  75),NSLAK(  75),JUMP(  75),KNODE,LNODE,MNODE,NNODE,MTAG,  GLM34730
4NTAG                                                               GLM34735
OCOMMON/ARCS/ASTORE( 2000),UTIMEA( 125),TIMEA( 125),UCOSTA( 125),   GLM35310
1COSTA( 125),UPERFA( 125),PERFA( 125),WORK( 125),ISTATE( 125),      GLM35320
2NODEI( 125),NODEO( 125),ICRITA( 125),KEEPC( 125),KEEPP( 125),      GLM35330
3IARC1( 125),IARC2( 125),IPOINT( 125),JPOINT( 125),ISLAK( 125),     GLM35340
4KARC,LARC,MARC,NARC,ITALC,ITALP,ISTAR                              GLM35350
OCOMMON/NODES/TIMEN(  75),COSTN(  75),PERFN(  75),NSTORE( 1200),    GLM35360
1NODE1(  75),NODE2(  75),LOGI(  75),LOGO(  75),NSTATE(  75),        GLM35370
2NARCI(  75),NARCO(  75),ISTAT(  75),INSTAT(  75),ICRITN(  75),     GLM35380
3NPOINT(  75),NSLAK(  75),JUMP(  75),KNODE,LNODE,MNODE,NNODE,MTAG,  GLM35390
4NTAG                                                               GLM35395
OCOMMON/ARCS/ASTORE( 2000),UTIMEA( 125),TIMEA( 125),UCOSTA( 125),   GLM35740
1COSTA( 125),UPERFA( 125),PERFA( 125),WORK( 125),ISTATE( 125),      GLM35750
2NODEI( 125),NODEO( 125),ICRITA( 125),KEEPC( 125),KEEPP( 125),      GLM35760
3IARC1( 125),IARC2( 125),IPOINT( 125),JPOINT( 125),ISLAK( 125),     GLM35770
4KARC,LARC,MARC,NARC,ITALC,ITALP,ISTAR                              GLM35780
OCOMMON/NODES/TIMEN(  75),COSTN(  75),PERFN(  75),NSTORE( 1200),    GLM35790
1NODE1(  75),NODE2(  75),LOGI(  75),LOGO(  75),NSTATE(  75),        GLM35800
2NARCI(  75),NARCO(  75),ISTAT(  75),INSTAT(  75),ICRITN(  75),     GLM35810
3NPOINT(  75),NSLAK(  75),JUMP(  75),KNODE,LNODE,MNODE,NNODE,MTAG,  GLM35820
4NTAG                                                               GLM35825
OCOMMON/TRIALS/STORET(  500,4),TERM( 2,8),KPOINT( 2),NODET(  500),  GLM40050
1MTERM,NTERM,MITER,ITER                                             GLM40060
OCOMMON/ARCS/ASTORE( 2000),UTIMEA( 125),TIMEA( 125),UCOSTA( 125),   GLM40070
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