THE USE OF GERT IN PLANNING STRATEGIES FOR DEVELOPMENT TYPE PROJECTS*

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1. Introduction and Summary

The authors' philosophy regarding the applications of GERT is quite similar to that held by most people about PERT/CPM, which is a restricted subset of the logic embodied in GERT. That is, a great deal of benefit can be derived from drawing the network which represents a project plan, or a management policy regarding the operation of some system. However, using GERT nomenclature, the range of project types is enlarged considerably.

The hypothesis posed here is that the GERT network is an excellent means for documenting a project plan or a policy, and then examining it qualitatively for omissions, redundancies, inefficiencies, and inconsistencies. This concept will be illustrated below by reference to the network for a management policy governing the handling of university inventions.

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The addition of estimates of time, cost, resource requirements, branching probabilities, and other parameters associated with the network activities then leads to outputs that permit a quantitative assessment of the plan or policy to be made. The latter ideas will be developed in detail using as a vehicle, a developmental type project typical of those found in fields such as automotive, electronic, and weapons systems development where the periodic development of "new models" frequently follows established patterns. GERT is ideally suited to model such projects which frequently embody milestone events of a special nature. For example, branching events occur where knowledge gained in preceding activities lead the project along only one of several possible branches, and in cases where the preceding activities are of a testing nature, one or more of these branches may recycle back to some prior project event.

In development projects one frequently resorts to parallel development strategies, and other risky procedures to "buy time."[1*] In very simple networks the effects of alternative strategies can be estimated by inspection with an acceptable degree of accuracy. However, the presence of a number of branching events with feedback loops can quickly render this problem unmanageable from a "hand-computation" point of view. The use of the GERT-II simulation program will be illustrated for such a case.

Several ancillary topics will be presented along with the development of the above ideas. In particular, variance

*Numbered references are given at the end of this report.

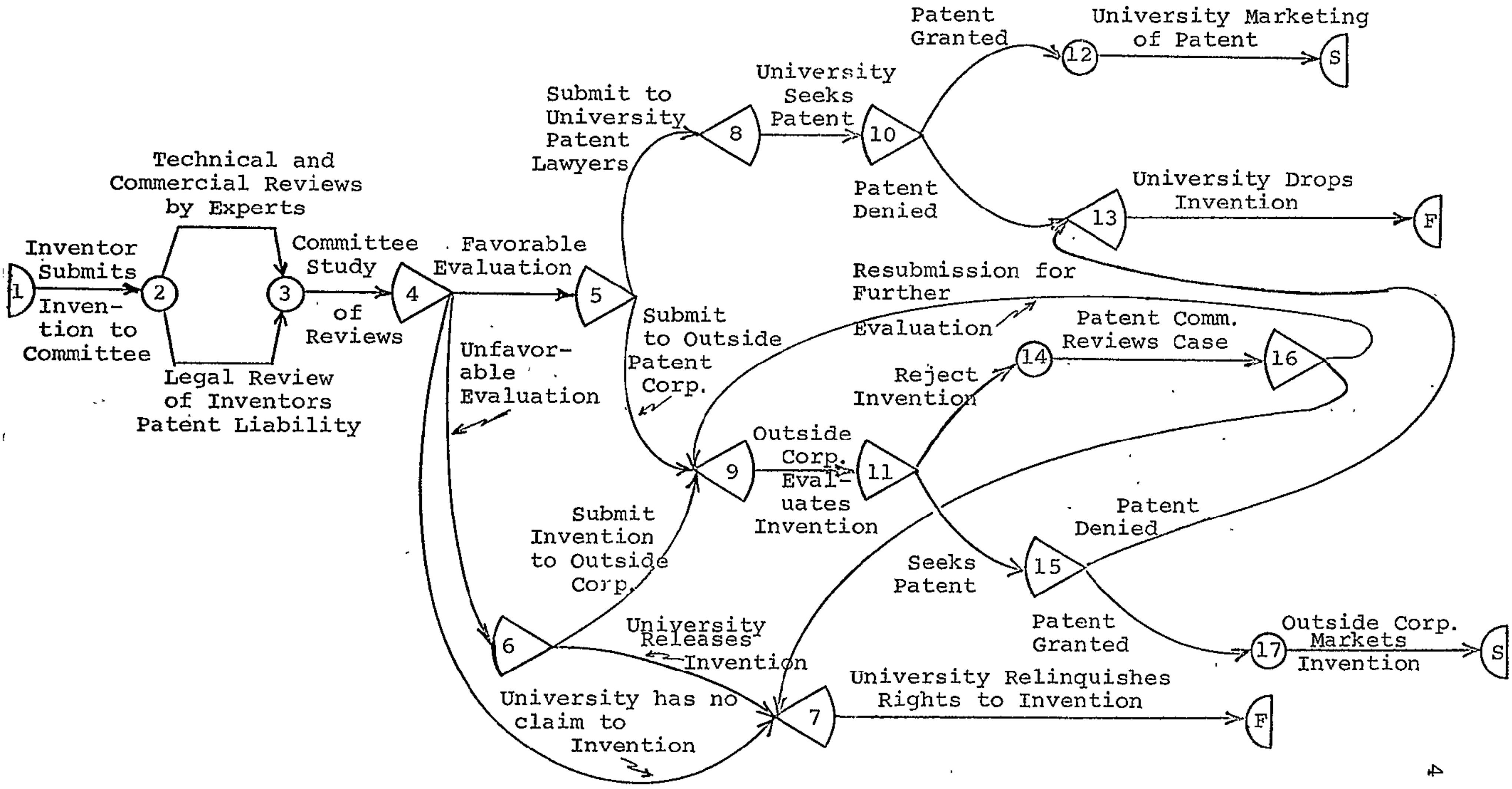
reduction techniques will be considered to reduce computer time requirements, and several modifications to the standard GERT-II simulator that were required to handle a development project network problem will be presented.

2. The Role of GERT in Management System Design and Documentation.

To illustrate the use of the GERT nomenclature in the documentation and qualitative study of a management policy, consider the network shown in Figure 1 which gives the operating policy and procedure for a typical University Patent Committee. This network has one initial event which occurs with the submission of an invention by the inventor to the Patent Committee. It has three terminal events which cover the possible modes of disposition of an invention. In developing this network, several aspects of the existing policy were found to need clarification and refinement. However, the resulting policy as stated in Figure 1 still contains certain omissions, inconsistencies, and inefficiencies.

The simultaneity of the two activities from node 2 to node 3 is inefficient since a negative legal review precludes the need for a technical review. Also, activity 4-7 represents a policy omission; it should be modified to give the inventor the option to have the university process his invention through their patenting and marketing channels. Finally, experience has shown that activity 6-7 represents an inconsistency in the policy. A person whose invention happens to get a poor evaluation from a patentability or marketability

Figure 1. POLICY FOR A UNIVERSITY PATENT COMMITTEE.



point of view is then given all rights to the invention, whereas a good evaluation of the same invention would give the inventor only partial royalty rights. This represents an important inconsistency because the risks of a good invention getting a poor review are not trivial.

The policy shown in Figure 1 does not appear to have redundant type errors. However, it has been the authors' experience that this type of error is quite prevalent in networks depicting information flow, notably in inventory and procurement type systems. Redundancy in record keeping has always been a problem in system design.

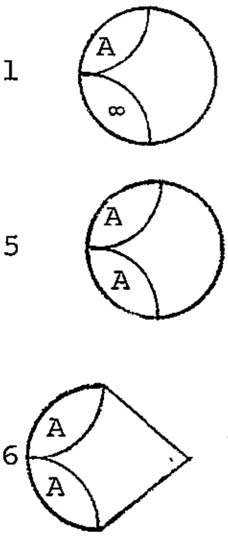
It is the authors' contention that while the problems described above could have been detected and possibly corrected without the GERT network, the precise expression of a complete policy or a plan in the form of a network cannot be duplicated by a written description. For this reason, GERT type nomenclature should be a standard tool of the systems analyst which has potential value in analysis and design, as well as communication.

3. The GERT-II Simulator

In this report, it will be assumed that the reader is familiar with the GERT-II Simulator as described in reference (2). A number of modifications and additions to this program were made to accomodate the type of problems being considered in this study. These modifications will be described in detail in this report. The modified program, called GERT-IIA, is given in Appendix I.

3.1 GERT-II Nomenclature

For the networks presented in this study, three node types from the original GERT-II are sufficient. They are shown in Figure 2. Node Type 1 is used for the start (source)



Node Type 1 — Can be realized only once per realization of the network.

Node Type 5 — Once realized it will reset itself to the original number of releases.

Node Type 6 — Same as node type 5, with the exception that it has probabalistic branching instead of deterministic output.

A = number of activity completions necessary to realize the node.

Figure 2. Three node types from GERT-II to Be Used in This Study.

and end (sink) nodes of the network, while the other two node types are used throughout the remainder of the network.

In GERT-II it is possible to change one node into another. This is done to permit changes in the output activities from a node, and it is brought about by the completion of a numbered activity. An example is given in Figure 3, along with illustrations of the three node types described above. In Figure 3 when branch 8 to 4 (activity number 2) occurs, node 5 is changed into node 10 to accomodate an altered sequence of subsequent activities on the recycle path. Similarly, when branch 12 to 3 (activity number 3)

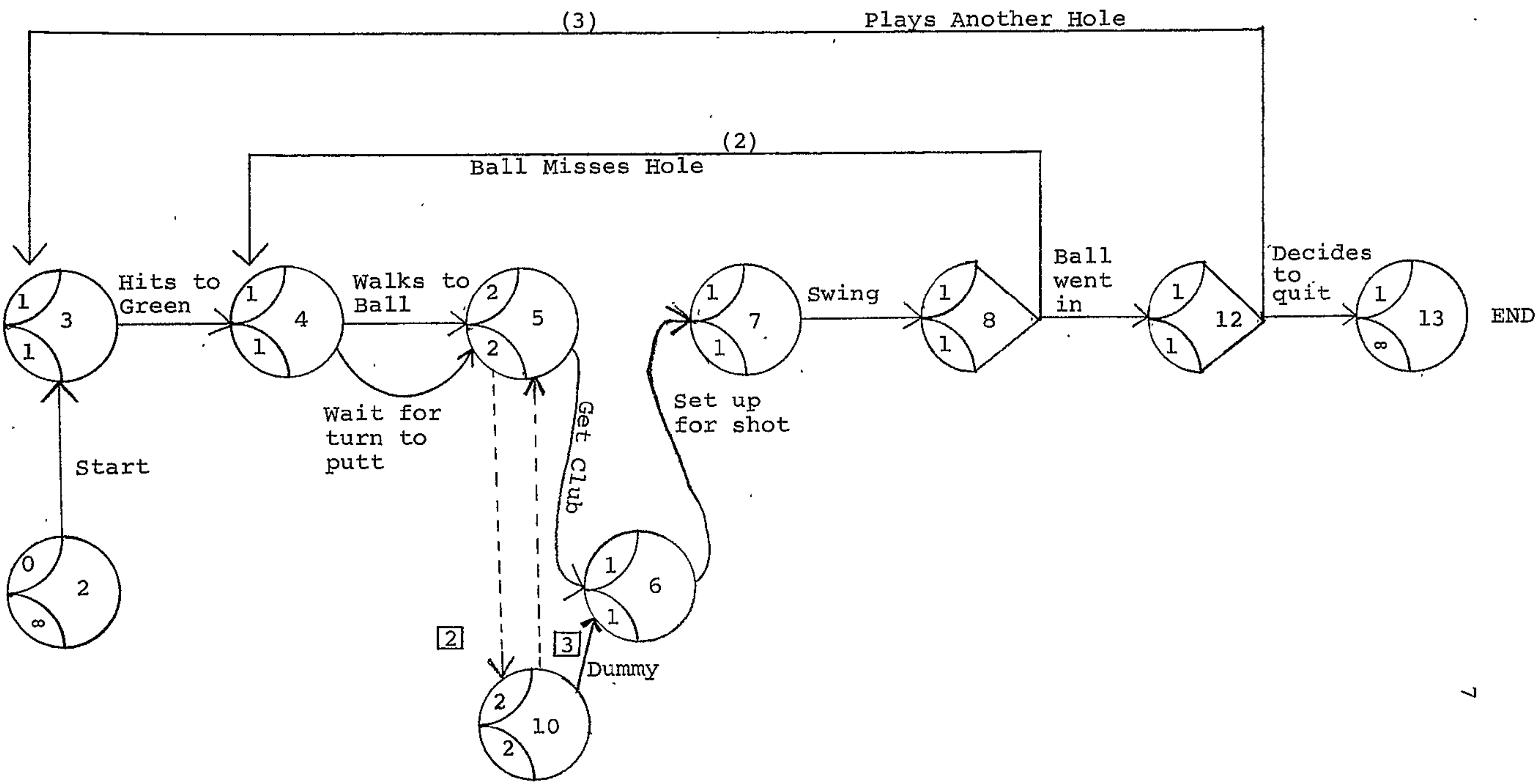


Figure 3. Illustration of Node Types and Node Changing - A Golfer on the Putting Greens.

occurs, node 10 is returned to the normal state, node 5, to accomodate the play of the next hole.

3.2 Modifications to GERT-II.

To accomplish the simulation of development-type projects, three techniques were developed and added to the GERT-II Simulator, i.e.

1) activity clear,
2) modification of node number of releases, and
3) logic node reset.

A cost collection routine was also added to test the overall effectiveness of alternate project management policies. The ability to consider resource constraints would be useful, but is not considered in this study.

Activity Clear and Modification of Node Number of Releases

In modeling development type projects, it is frequently necessary to abandon the work on some activity(s) because the results of some other activity is not successful. Thus it is necessary to destroy an activity(s) that may be in progress, or may already be completed and thus has partially realized a node by reducing its counter of releases to node realization.

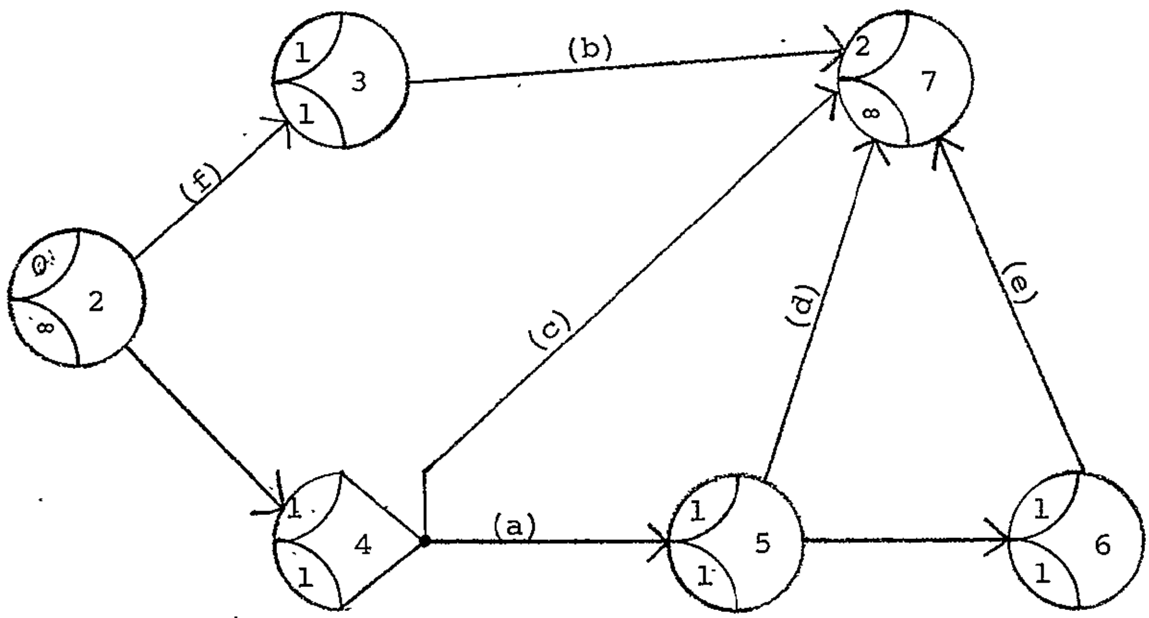


Figure 4. Example of Activity and Node Clear Procedures.

In the network shown in Figure 4, suppose we want node 7 to be realized by either the completion of activities (b) and (c), or activities (d) and (e). There is no problem if node 4 branches to activity (c); node 7 will eventually be realized by the completion of activities (b) and (c). However if node 4 branches to activity (a), then the activity clear routine is required. In this case, activity (b) may be in one of three states when activity (a) is completed.

1) Activity (b) can be completed, in which case the node 7 counter will have been changed to 1 activity to go before the node is realized. In this case the counter will be reset to 2 by the modification of node number of releases routine.
2) Activity (b) can be in progress, in which case it will be halted by the activity clear routine.

3) Activity (b) may not have been started, but it is free to be started as soon as activity (f) is completed. In this case, activity (f) will be halted by the activity clear routine.

Logic Node Reset

The reason for using the logic node reset is best explained by an example such as shown in Figure 5. If activity (6) is completed, node 9 must be reset to 2 or to 3, depending on whether node 5 branches to path III-A or III-B. The logic node, which is node number 1, is originally set to 3. If path III-B is taken, the logic node is set to 2 by the completion of activity (8). Then, on the completion of activity (6), node 9 is reset to the number of releases of the logic node. Node 9 will then be realized when paths I and II are completed. However, if path III-A is taken, the logic node setting remains at 3. Now, if activity (6) is realized, node 9 is reset to 3 since this case requires that paths I, II and III-A be reworked to realize node 9.*

Addition of Cost Parameters

To evaluate alternative policies for carrying out a project, GERT II-A includes an enumerative cost feature.

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*The above result could have been accomplished by changing node 9 into another node requiring two activity completions for realization. However, it is faster in large networks to use the logic node, which eliminates a search of each node in the network. So that the data of GERT-II programs would remain compatible with GERT-II-A, node 1 was the only node used as a logic node, however, any number of nodes could be so designated in the program.

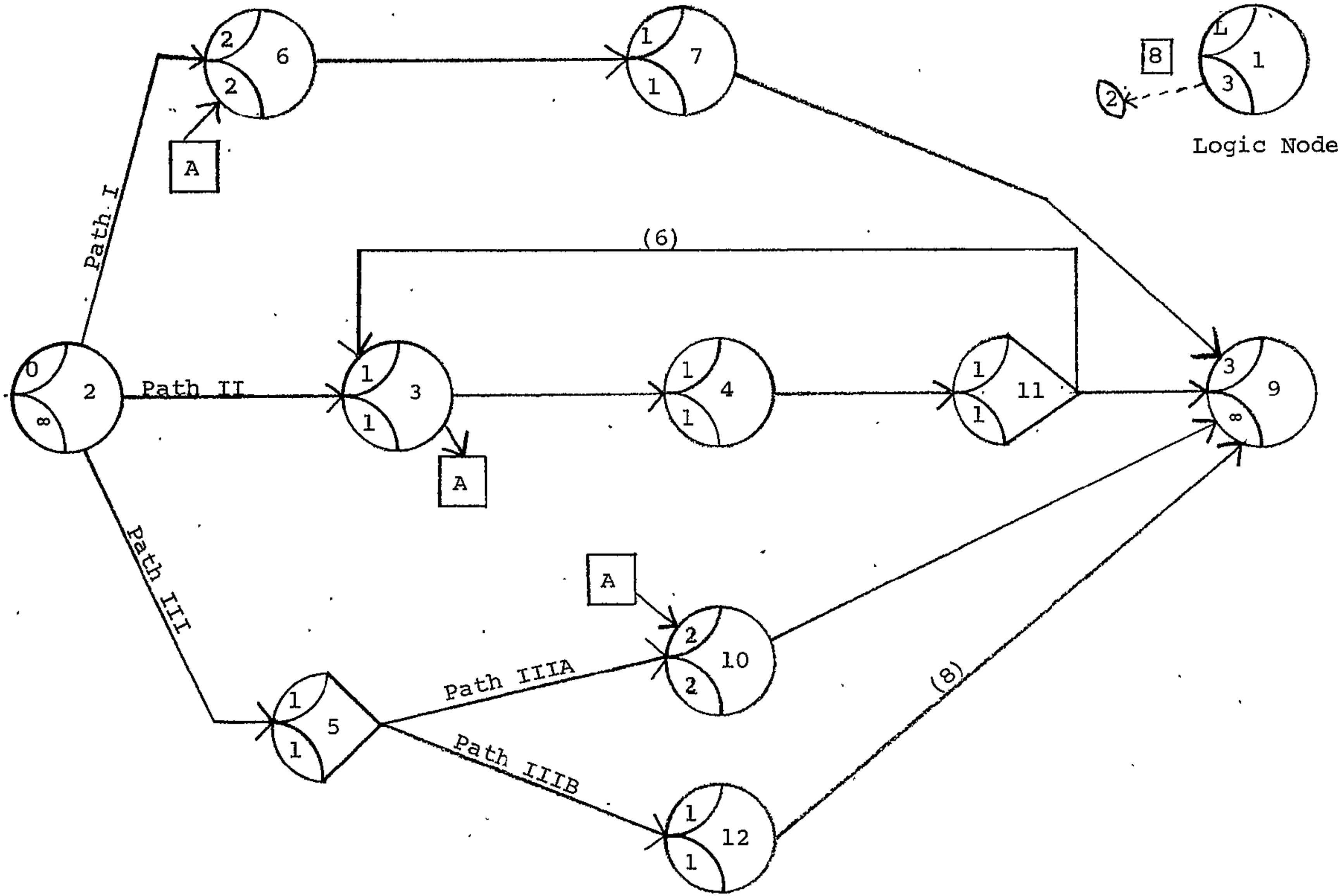

Figure 5. Example of the Use of the Logic Node Reset.

The cost of each activity is assumed to be a linear function of time,

$$\text{Cost} = a + b\ (t_1 - t_0),$$

where $(t_1 - t_0)$ is the elapsed activity time, b is a parameter which accounts for costs which vary linearly with elapsed time, and a is a constant or set-up cost.

Costs are accumulated for each activity performed up to the time of realization of a project end node. In cases where activities in progress are terminated, costs up to the time of termination are included in the total project cost.

3.3 Variance Reduction Techniques

Even with third generation computers, the cost of obtaining parameter estimates using the GERT-II Simulator is not insignificant. For this reason, it is natural to consider the use of Monte Carlo variance reduction techniques. One of the most promising approaches in this case is the use of an antithetic variable. A description and evaluation of this approach is given in Appendix II. The results of this study indicate that this approach is effective on PERT type networks, consisting entirely of and node input and deterministic output. In this case, the estimate of the mean duration of the project is improved but only at the expense of a less efficient estimate of the variance of project duration times. The results obtained on GERT networks with exclusive or node inputs and probabilistic outputs were not encouraging, and the use of the antithetic variable is not recommended in these cases.

4. Application of GERT to Development-Type Projects

The effect of adding project activity data such as time, cost, and branching probabilities, will be treated in this paper by considering a development-type project, characteristic of industries that regularly turn out new models of a product. Although our example is taken from the weapons industry, the concepts and techniques used in its analysis can be directly applied to the management of other development projects such as those found in the automotive and electronic industries.

Our illustrative example consists of three subassemblies to be developed concurrently. These subassemblies are of a general nature. For example, the chassis, the power train, and the body might be the subassembly breakdown used in the automotive industry. In our example, they are the submunition, the dispenser, and the fuse.

At several stages of product development, management must assure that the subassemblies are compatible. Precedence relationships are thus built in the network model to signify that development of a particular subassembly must be preceded at various stages by the design or partial design of other subassemblies. Finally, testing of prototypes may result in partial or total redesign of a subassembly which in turn may result in returning to an earlier development stage on other subassemblies.

Weapons System Development Project. To illustrate the above concepts, the development of Air Force munitions systems is modelled using GERT-IIA nomenclature. The complete network, which contains about 150 nodes and 200 activities, is sufficiently complex to require simulation for proper evaluation. A simplified version of the network is shown in Figure 6, with details of the three subassemblies being given in Figures 6A, 6B and 6C. Each of the three subassemblies provide for the choice of one of three paths depending on the decision to, (1) develop a completely new design, (2) modify an existing unit, or (3) use an existing unit. Progress in each of the three subassemblies is interrelated by "approval" signals. For example, if node 59 in Figure 6B is realized, approval signal D_2S is initiated. (The nomenclature adopted in this network is as follows. The symbol D_2S denotes that the second signal from the Dispenser subassembly goes to the Submunition subassembly.) The approval signal D_2S then enters one of the nodes 101, 87, 85 or 78 in the submunition subassembly, Figure 6A. It is sent to the proper node by using the node switching routine previously illustrated in Figure 3. In this case, the choice of paths out of node 76 (and possibly 83 as well) controls the node changing routine so that the approval signal D_2S is sent to the proper node. Special nodes to control the flow of these signals are not shown in Figure 6.

The standard management policy used in the development of new munition systems is depicted by the flow of approval signals shown in Figures 6, 6A, 6B and 6C. This will be denoted as Policy 1 below. A partial listing of the computer output for this policy is shown in Figure 7.

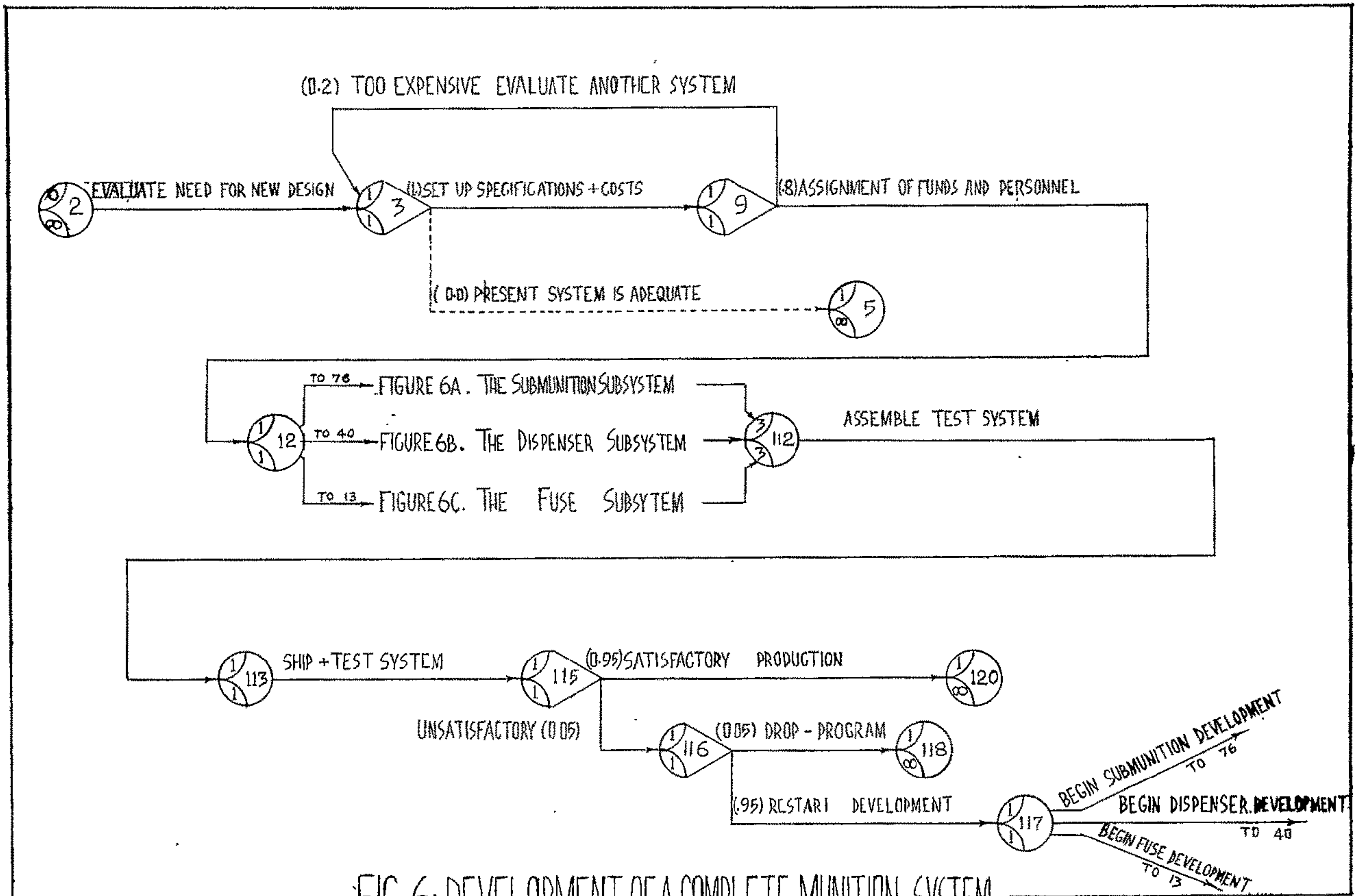

FIG. 6: DEVELOPMENT OF A COMPLETE MUNITION SYSTEM

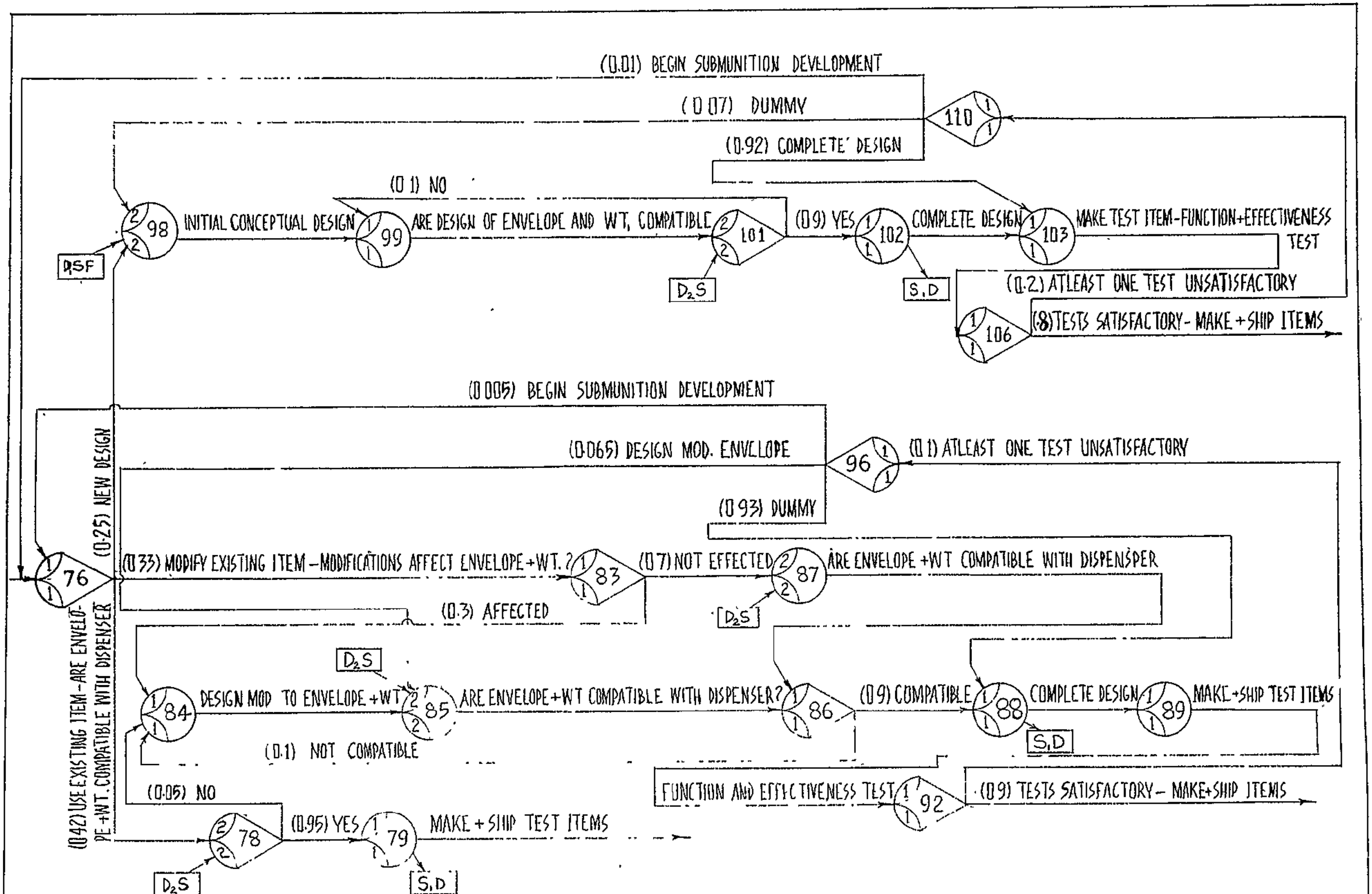

FIG.6A: THE SUBMUNITION SUBSYSTEM

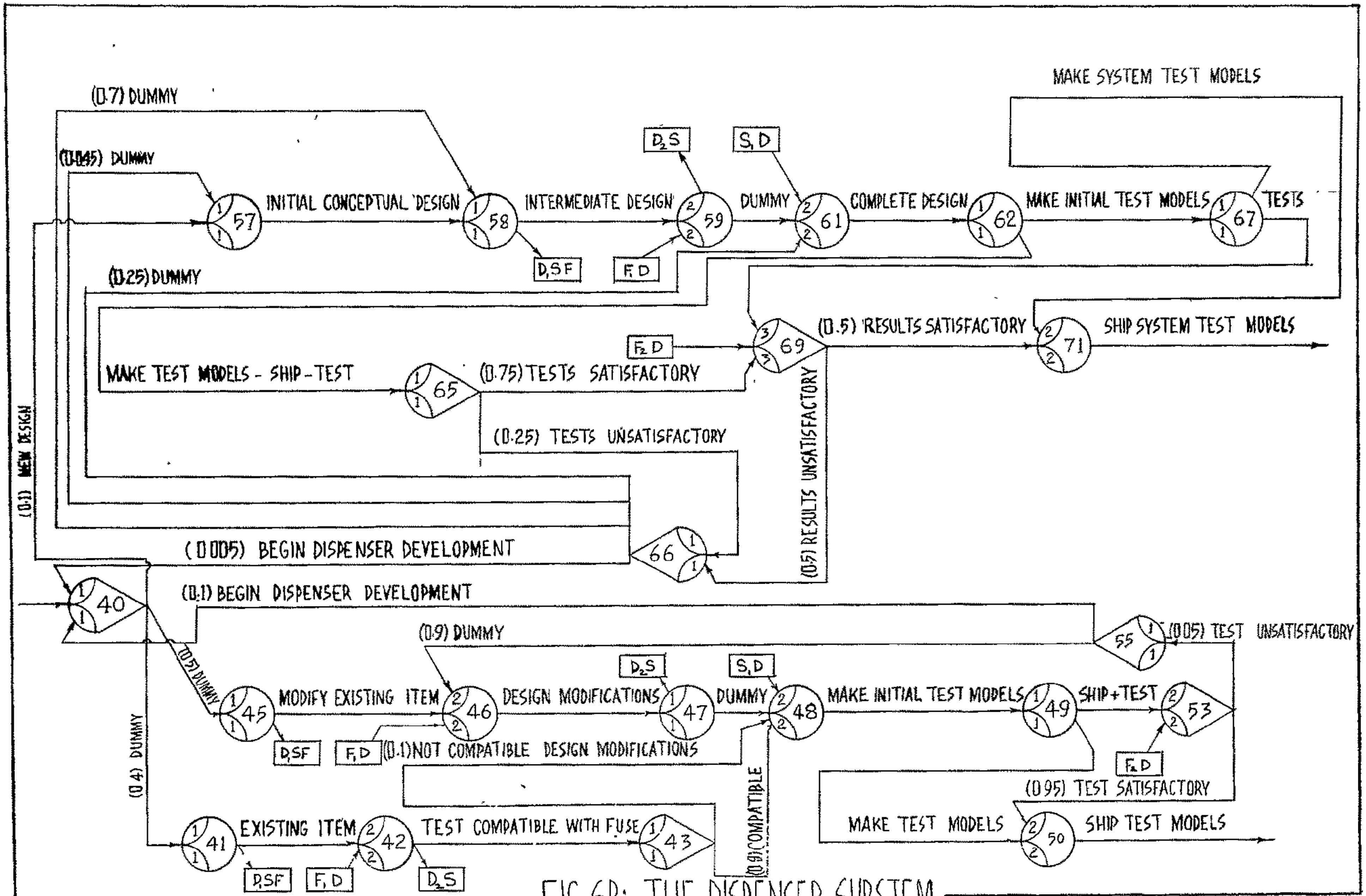

FIG.6B: THE DISPENSER SUBSTEM

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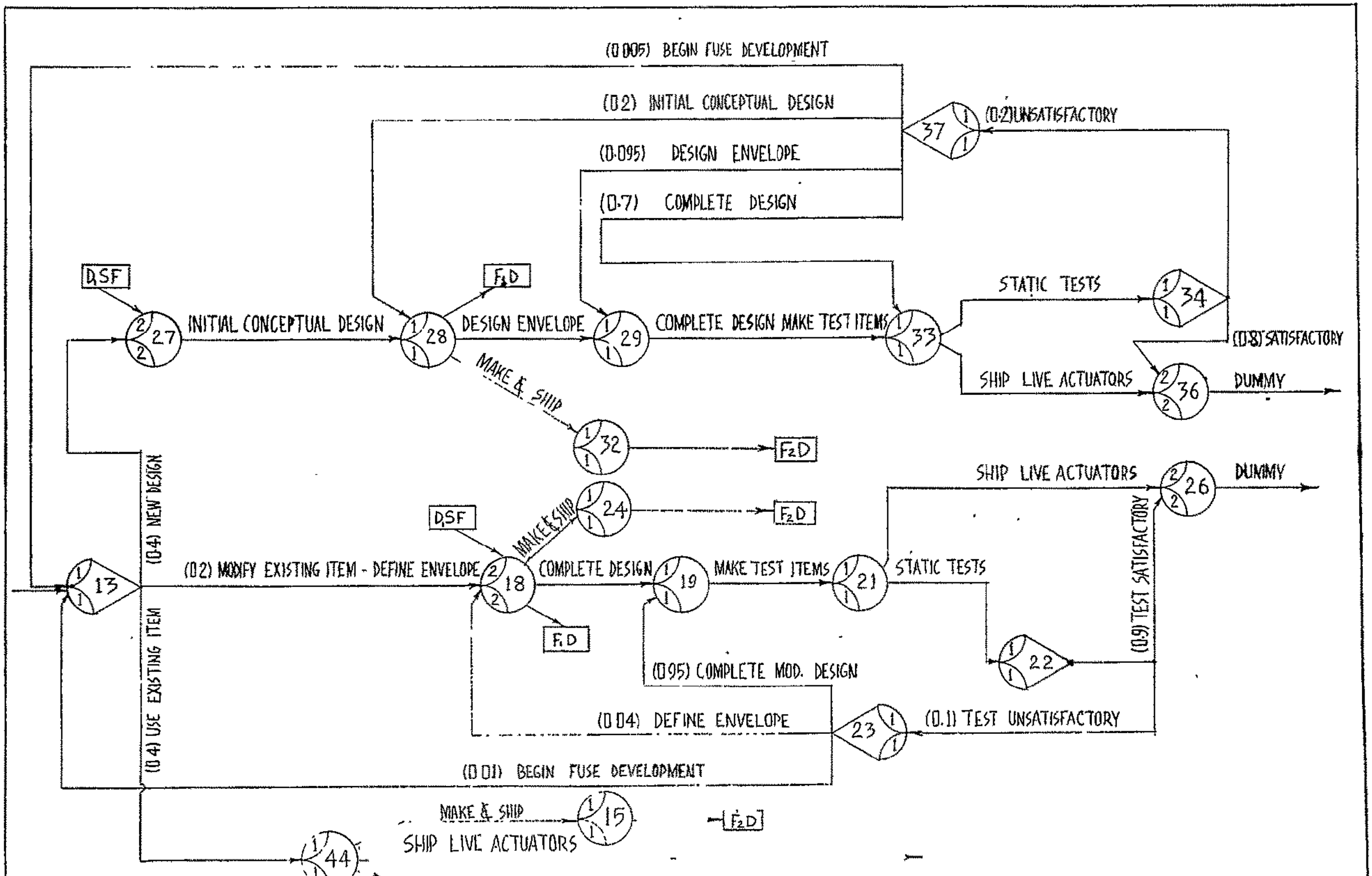

FIG.6C: THE FUSE SUBSYSTEM

GERT SIMULATION PROJECT 116 BY CLARK
DATE 4/ 23/ 1970

FINAL RESULTS FOR 200 SIMULATIONS

NODE	PROB./COUNT	MEAN	STD.DEV.	MIN.	MAX.	STD. ER OF MEAN
5	0	NO VALUES RECORDED				
120	1.0000	103.2355	49.7300	54.3450	363.2366	3.5164
118	0	NO VALUES RECORDED				

HISTOGRAMS

NODE	LOWER LIMIT	CELL WIDTH	FREQUENCIES										
5	0.0	0.30	0	0	0	0	0	0	0	0	0	0	0
			0	0	0	0	0	0	0	0	0	0	0
			0	0	0	0	0	0	0	0	0	0	
120	20.00	10.00	0	0	0	0	7	23	31	34	28	30	14
			6	7	4	2	1	1	0	2	2	0	1
			0	0	1	0	0	0	0	3	1	2	
118	20.00	4.00	0	0	0	0	0	0	0	0	0	0	0
			0	0	0	0	0	0	0	0	0	0	0
			0	0	0	0	0	0	0	0	0	0	

HISTOGRAMS

NODE	LOWER LIMIT	CELL WIDTH	FREQUENCIES										
COST	0.0	50.00	0	0	0	0	0	16	23	21	30	27	19
			16	18	8	5	3	0	0	3	0	0	0
			2	1	1	0	0	0	1	0	0	6	

AVE. COST PER REALIZATION 496.02
STANDARD DEVIATION 336.23
MIN. COST FOR REALIZATION 204.99
MAX. COST FOR REALIZATION 2326.48

NODE START	END	WITH ATTRIBUTES						TIME/END NODE	TIME/ACTIVITY	PERCENT
2	3	3	4	0	1	10	1	3.46	3.46	1.00
3	6	2	4	0	2	12	8	5.51	2.05	1.00
3	4	33	1	0	3	0	0	0.0	0.0	1.00
4	5	33	1	0	4	0	0	0.0	0.0	0.0
6	7	20	4	0	5	1	1	6.45	0.94	1.00
7	8	18	4	0	6	3	8	12.23	5.78	1.00
8	9	2	4	0	7	0	1	14.47	2.24	1.00
9	11	21	4	0	10	0	1	21.20	6.73	1.00
9	10	2	4	0	8	0	1	16.10	1.63	0.21
10	3	3	4	0	9	10	1	3.46	-12.64	1.00
11	12	24	4	0	11	1	1	26.34	5.13	1.00
12	13	1	4	0	12	2	3	27.41	1.08	1.00
12	40	1	4	0	193	3	6	27.37	1.03	1.00
12	76	1	4	0	99	3	3	27.43	1.09	1.00
13	14	33	1	0	29	0	4	29.97	2.55	0.44
13	27	5	4	0	35	3	8	32.86	5.45	0.35
13	17	2	4	0	13	2	4	33.64	6.23	0.25
14	15	2	4	0	32	0	1	32.12	2.16	0.44
14	16	2	4	0	33	0	1	32.17	2.20	0.44
14	121	33	1	0	0	0	0	29.18	-0.78	0.18
15	125	33	1	0	0	0	0	36.86	4.74	0.02
16	112	33	1	0	103	0	0	82.05	49.88	1.00
17	18	1	4	0	14	3	4	35.98	2.34	0.25
18	19	3	4	0	15	3	3	39.37	3.38	0.25
18	20	4	4	0	16	1	1	36.64	0.66	0.25
19	121	33	1	0	0	0	0	29.18	-6.80	0.18
19	21	3	4	0	17	2	3	42.38	3.02	0.25
20	24	2	4	0	21	0	1	38.71	2.06	0.25
21	22	5	4	0	18	2	2	45.45	3.06	0.25
21	26	2	4	0	19	0	1	46.36	3.98	0.25
22	26	33	1	0	22	0	0	46.36	0.91	0.25
22	23	33	1	0	23	0	0	44.38	-1.07	0.02
23	19	3	4	0	27	1	0	39.37	-5.01	0.25
23	18	1	4	0	28	3	0	35.98	-8.39	0.25
23	13	1	4	0	34	2	2	27.41	-16.97	1.00
24	125	33	1	0	0	0	0	36.86	-1.85	0.02
26	112	33	1	0	102	0	0	82.05	35.69	1.00
27	28	7	4	0	36	2	6	48.15	15.28	0.35
28	29	8	4	0	37	2	5	51.62	3.48	0.35
29	30	24	4	0	38	1	3	56.91	5.29	0.35
29	31	6	4	0	39	0	1	52.42	0.80	0.35
29	121	33	1	0	0	0	0	29.18	-22.44	0.18
30	33	3	4	0	41	1	1	60.58	3.68	0.35
31	32	2	4	0	40	0	1	54.63	2.21	0.35
32	125	33	1	0	0	0	0	36.86	-17.76	0.02
33	36	2	4	0	43	0	1	67.86	7.28	0.35
33	34	5	4	0	42	2	2	63.83	3.25	0.35
34	36	33	1	0	45	0	0	67.86	4.03	0.35
34	37	33	1	0	49	0	0	67.71	3.88	0.06
36	112	33	1	0	102	0	0	82.05	14.19	1.00
37	30	9	4	0	53	1	2	56.91	-10.81	0.35
37	28	7	4	0	51	2	4	48.15	-19.57	0.35
37	29	8	4	0	52	2	3	51.62	-16.09	0.35
37	13	1	4	0	50	2	2	27.41	-40.30	1.00
40	45	33	1	0	59	0	0	28.82	1.45	0.51

Figure 7 Output Data

Of particular interest in making a preliminary evaluation of alternative management policies is the listing of the mean time to the first realization of each node. For example, it might be proposed that the approval signals emanating from nodes 28 (F_1D) and 32 (F_2D) in the fuse subassembly be combined and issued from node 36 (Policy 2 below) as signal F_1D. The purpose of this change would be to hold up the dispenser development until the fuse passes final inspection, since the latter has a relatively high probability of failure. This change would then avoid having to repeat the dispenser work when an unsatisfactory test occurs in the fuse subassembly.

From the output of the type given at the bottom of Figure 7, the following average first node realization times could be determined.

Node No.	Ave. Realization Time	Node No.	Ave. Realization Time
28	48.2	42	37.3
32	54.6	46	38.3
36	67.9	59	56.3

From these times, it can be concluded that this policy change will cause a significant increase in the total project duration, since the time for node 36 is considerably later than node 28 which was already later than nodes 42 and 46. The node branching probabilities should, of course, also be considered in making evaluations of this type.

Two potentially useful modifications of the standard management policy are described below. Policies 2 and 3 are more conservative than Policy 1; they should result in less duplication of work, and thus less cost. This cost reduction, of course, is at the expense of increased project duration time which results from "holding up" the issuance of approval signals, or requiring special approvals not used in the standard policy, both of which potentially avoid duplication of work.

<u>Policy 1:</u> Standard development program policy as shown in Figures 6, 6A, 6B and 6C.

<u>Policy 2</u>: Modification of Policy 1 in which the approval signals to develop the dispenser assembly (F_1D and F_2D) are delayed and combined, and now emanate from node 36 instead of nodes 28 and 32, as signal F_1D.

<u>Policy 3:</u> Modification of Policy 1 in two parts. First, it delays development of the submunition assembly by moving D_2S from node 101 to 99 and from nodes 85 and 87 to 83. This also eliminates the need for the corresponding feedback loops. Also, it holds up the fabrication of the submunition assembly and the testing and shipping of the actuator until the dispenser development is completed. The latter is accomplished by holding up the realization of actuator nodes 33, 19 and submunition nodes 89, 103 until dispenser nodes 50 or 71 are realized.

Table 1. Results of Simulation of Three Policies for the Development of a Munitions System, As Shown in Figure 6.

Mean Values of the Runs

	Times			Costs		
Policies	(1)	(2)	(3)	(1)	(2)	(3)
Run 1	99.2	108.7	109.7	496.0	478.6	487.2
Run 2	106.6	110.2	109.9	468.7	503.3	479.6
Run 3	99.5	114.3	107.5	515.5	516.4	486.0
Run 4	104.8	102.9	106.9	466.1	453.1	467.6
Run 5	103.2	103.4	107.4	514.4	454.2	461.7
Run 6	103.2	109.5	104.7	496.0	470.1	456.0
Run 7	99.8	110.9	108.1	474.6	492.8	472.3
Run 8	102.9	114.8	115.5	498.1	508.9	519.3
Run 9	99.1	107.2	108.9	467.5	484.3	474.9
Run 10	104.2	112.0	98.8	498.4	497.4	429.5
Average*	102.3	109.4	107.7	489.5	485.9	473.4
Variance*	7.1	16.3	17.8	357.8	480.9	544.3
L.S.D.** (α=.05)		3.40			19.7	
(α=.10)		2.82			16.4	

Statistics on Single Network Realizations

Standard Deviations Among the 200 Simulations Within a Run

	Times			Costs		
Policies	(1)	(2)	(3)	(1)	(2)	(3)
Run 1	37.2	46.6	38.2	336.2	253.7	238.0
Run 2	46.1	52.5	43.5	239.2	295.0	242.3
Run 3	36.9	62.3	41.9	303.6	369.2	270.2
Run 4	48.9	36.2	41.0	209.9	182.7	244.7
Run 5	49.7	45.8	35.1	330.3	235.5	203.2
Run 6	49.7	44.1	39.7	336.2	215.0	203.3
Run 7	47.3	66.6	51.4	303.0	351.3	326.5
Run 8	48.7	56.1	46.7	311.1	329.7	301.7
Run 9	33.9	48.4	49.0	203.4	265.1	290.9
Run 10	42.9	55.8	29.4	279.7	312.8	168.4
Average*	44.1	51.4	41.6	285.3	281.0	248.9
Variance*	36.2	82.3	43.0	2563.3	3709.7	2428.4
L.S.D.* (α=.05)		6.20			49.4	
(α=.10)		5.15			40.9	
(Run Averages) Min.	51	50	51	198	196	196
(Run Averages) Max.	354	470	377	2230	2490	2230
(All Runs)	46	44	47	186	184	184
(All Runs)	456	814	572	2830	4300	3830

*The averages and the variances were computed from the corresponding 10 run values.

**L.S.D.=Least Significant Difference=$t_{\alpha/2}\sqrt{2(\text{Error Var.})/\text{No.Obs. in Ave.}}$
For the Mean Time, Error Var.=(7.1+16.3+17.8)/3=13.7, and for α=.05
L.S.D.=$2.052\sqrt{2\times 13.7/10}$=3.40.

Each of the above policies was evaluated using the GERT-IIA Simulator program. The data shown in Table 1 give the results of 30 computer runs, 10 for each of the 3 policies. Each run in turn consisted of 200 random realizations of the project network. The durations of the project activities were assumed to be constants or to have a Gamma distribution. The form of the input data, along with an example, is given in Appendix III.

The top half of Table 1 summarizes the mean values for time and cost for each of the 30 runs. The grand averages of the 10 runs for each policy indicate, as expected, that policies 2 and 3 require more time on the average than policy 1, but at reduced cost. Statistical tests using both the Duncan Multiple Range test and the Least Significant Difference method were performed. (See Reference 4) In both cases, no differences were found between the mean times for policies 2 and 3, but they both differ from policy 1, at the 5 percent level. With regards to mean costs, policy 3 is significantly lower than 1 at about the 10 percent level.

The lower half of Table 1 summarizes the standard deviations of time and cost, among the 200 network simulations which constitute each run. Policy 3 has the lowest standard deviation for both time and cost. While the differences are not statistically significant in all cases there is reason to believe that Policy 3, which reduces duplication of work, would have less variability among total project duration times.

Table 1 also gives the range of project duration times. The first set of values are the averages of the ranges for the

10 runs, while the second set is the range of values over all 10 runs.

The following conclusions could be drawn from this computer simulation study.

(1) Since Policy 3 has a lower cost, a lower variability among project duration times, and probably a lower mean project duration than Policy 2, the latter is not a desirable modification of Policy 1.

(2) Compared with Policy 1, Policy 3 reduces the expected project cost by about 3 percent with a corresponding increase in project duration of 5 percent. This may or may not be a desirable change.

(3) The observed range of project duration times, as well as the standard deviations given in Table 1, indicate that a great deal of uncertainty exists in the total project duration time and cost. It undoubtedly would be desirable to find ways to reduce this uncertainty.

(4) The computer (CPU) time required for 10 runs as shown in Table 1 was approximately 6 minutes on an IBM 360/65 system, with a corresponding total cost of about $30. This is considered to be reasonable, and is considerably less than the cost of using other simulation languages such as GPSS.

(5) Summary

The use of GERT network nomenclature to describe a project plan or system operating policy was considered. The advantages of using this approach in system analysis, design, and ultimately in communication were described. The flexibility of the GERT nomenclature, compared with the quite restrictive logic of PERT/CPM, makes this a tool of considerable utility. Finally, if estimates of time, cost, branching probabilities, etc. can be obtained to describe the network activities, the GERT simulation program provides a feasible way to both propose and evaluate system changes.

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APPENDIX I

Listing of Subroutines and the Purpose of Each

1. Main — Initializes reader, printer, and other variables.

2. Aloop — Cancels activities in process from the nodes specified and adds the partial cost of any activities removed.

3. Antim — Stores antithetic times and antithetic branching probabilities.

4. Colct — Stores statistics on the time that a node has been realized for the sink nodes and any others specified as input.

5. Datan — Reads in all data from the data cards and outputs what was read in.

6. Drand — Random number generator. If seed read from the data card is zero, it will automatically start with 1267.

7. Error — Prints out error messages. If called from Datan stops because all data has not been read in, and there is no way, as yet, to tell where one data set ends and another begins. If all data has been read in, it will restart the program with the next data set.

8. Filem — Used to file all activities in the activity file and to set up the predecessor and successor pointers.

9. Gasp — The most important routine which calls all other routines directly or indirectly (except main). This routine is the "supervisor" of the entire program.

10. Histo — Stores histogram information for time and cost.

11. Nfind — Used to find an activity entry in the activity file and to return the location of the activity.

12. Rmove — Removes an activity from the file and resets the pointers.

13. Rnorm — Routine for generating normal times.

14. Sampl — Routine for generating the time distributions allowed in the program both for antithetic and non-antithetic times.

15. Schat — Schedules activities from a node which has just been realized or the source nodes, and puts the activities in the activity file. Coordinates antithetic and non-antithetic branching.

16. Sumry — Calculates and summarizes the results and outputs them.

SUBROUTINE CALLING CONVENTIONS

ROUTINE	CALLS	CALLED BY
MAIN	GASP	
ALOOP	NFIND,RMOVE	GASP
ANTIM		SAMPL,SCHAT
COLCT	ERROR	GASP
DATAN	DRAND,ERROR,FILEM	GASP
DRAND		DATAN,SAMPL,SCHAT
ERROR	GASP	COLCT,DATAN,FILEM,GASP HISTO,NFIND,RMOVE,SCHAT, SUMRY
FILEM	ERROR	DATAN,GASP,SCHAT
GASP	ALOOP,COLCT,DATAN, ERROR,FILEM,HISTO, NFIND,RMOVE,SCHAT, SUMRY	MAIN,ERROR
HISTO	ERROR	GASP
NFIND	ERROR	ALOOP,GASP
RMOVE	ERROR	ALOOP,GASP
RNORM		SAMPL
SAMPL	ANTIM,DRAND,RNORM	SCHAT
SCHAT	ANTIM,DRAND,ERROR, FILEM,SAMPL	GASP
SUMRY	ERROR	GASP

FORTRAN IV G LEVEL 1, MOD 4 MAIN DATE = 70180 13/46/04 PAGE 0001

```
              DIMENSION NSET(5000),QSET(500)
              COMMON IMM,PARAM(300,4),JTRIB(8),ISEED,MFE(500),NPRNT,MXX
              COMMON MXC,ATRIB    ,JCELS(20,32),SUMA(100,5),NHIST,NCRDR
              COMMON ID,IM,NCLCT,MFA,TNOW,MLE(500),NQ(500),NNR,IBRNCH,ITIME,LOOP
              COMMON KOL,KOF,KLE
              COMMON NRUN,XLOW(20),NCTS,NSINK(20),WIDTH(20),NSKS
              COMMON NTYPE(500),MX,NFTBU(500),CSTAR,CINC
              COMMON NNM,IMN,NPD,NOQ,NPRMS,NPUNS,NYR,MAXNS,MAXA,NPRTOP ,
             1NAME(6),NPROJ,MON,NDAY,NSKST,NSRC,NRELP(500),NREL(500),    NSKSR,
             2NSORC(20),TOTIM,KOUNT(4),JSINK(20),NPO(3,500),NABA(3,800)
      C
      C*****SET EQUIPMENT NUMBERS FOR CARD READER(NCRDR) AND PRINTER (NPRNT). GRTS  90
      C*****SET NUMBER OF ATTRIBUTES AND FILE INDICATORS FOR NSET
      C                                                                   GRTS 100
            NCRDR=5                                                       GRTS 110
            NPRNT=6
             IM=8                                                         RMVS 110
            KOL = 7777                                                    RMVS 120
            KOF = 8888                                                    RMVS 130
            KLE = 9999
            IMN=800
      C
      C*****ANTITHETIC STORAGE
      C
            IMM=4
      7     CALL GASP (NSET,QSET)                                         GRTS 140
            GO TO 7                                                       GRTS 150
            END
```


FORTRAN IV G LEVEL 1, MOD 4 ALOOP DATE = 70180 13/46/04 PAGE 0001

```
            SUBROUTINE ALOOP (NSET,QSET,NPOS,COST,ACTIME,JJJ)
            DIMENSION NSET(1),QSET(1),ACTIME(1)
            COMMON IMM,PARAM(300,4),JTRIB(8),ISEED,MFE(500),NPRNT,MXX
            COMMON MXC,ATRIB    ,JCELS(20,32),SUMA(100,5),NHIST,NCRDR
            COMMON ID,IM,NCLCT,MFA,TNOW,MLE(500),NQ(500),NNR,IBRNCH,ITIME,LOOP
            COMMON KOL,KOF,KLE
            COMMON NRUN,XLOW(20),NCTS,NSINK(20),WIDTH(20),NSKS
            COMMON NTYPE(500),MX,NFTBU(500),CSTAR,CINC
            COMMON NNM,IMN,NPD,NOQ,NPRMS,NRUNS,NYR,MAXNS,MAXA,NPRTOP ,
           1NAME(6),NPROJ,MON,NDAY,NSKST,NSRC,NRELP(500),NREL(500),    NSKSR,
           2NSORC(20),TOTIM,KOUNT(4),JSINK(20),NPO(3,500),NABA(3,800)
            KNODE=NPOS
      1     INODE=NABA(3,NPOS)
            IF(INODE.LE.0) GOTO 11
      2     KCOL=NFIND(INODE,1,1,NSET,QSET)
            IF(KCOL.LE.0) GOTO 5
            CALL RMOVE(KCOL,1,NSET,QSET,NAT,KOWT)
            JA=JTRIB(1)
            TIME=TNOW-ACTIME(JA)
            COST=COST+FLOAT(JTRIB(8))+FLOAT(JTRIB(7))*TIME
            GOTO 2
      5     NPOS=NPOS+1
            GOTO 1
      11    IF(NPROJ.GE.0) RETURN
            IF(NRUN.LT.NABA(1,IMN).OR.NRUN.GT.NABA(1,IMN-1)) RETURN
            NPOS=NPOS-1
            WRITE(NPRNT,10) (NABA(3,K),K=KNODE,NPOS)
      10    FORMAT(/5X,' ACTIVITIES EMANATING FROM THE FOLLOWING NODES HAVE SE
           1LF DESTRUCTED',/(24I5))
            RETURN
            END
```

FORTRAN IV G LEVEL 1, MOD 4 ANTIM DATE = 70180 13/46/04 PAGE 0001

```
            SUBROUTINE ANTIM(IND,NEXT,STORE,TIBR)
            COMMON IMM,PARAM(300,4),JTRIB(8),ISEED,MFE(500),NPRNT,MXX
            DIMENSION STORE(1)
      C
      C***** IND=1 GENERATE AND STORE
      C*****      2 USE AND ZERO OUT
      C
            INDX=(NEXT-1)*IMM+1
            GOTO (1,2),IND
      1     DO 5 I=1,IMM
            IF(STORE(INDX).EQ.0.0) GOTO 6
      5     INDX=INDX+1
            WRITE(NPRNT,15) NEXT,IMM
      15    FORMAT(2I10,'OVERFLOW ANTITHETIC')
            RETURN
      6     STORE(INDX)=TIBR
            RETURN
      2     DO 10 I=1,IMM
            IF(STORE(INDX).NE.0.0) GOTO 11
      10    INDX=INDX+1
            GOTO 12
      11    TIBR=STORE(INDX)
            STORE(INDX)=0.0
            RETURN
      12    TIBR=0.0
            RETURN
            END
```

```
FORTRAN IV G LEVEL 1, MOD 4            COLCT           DATE = 70180        13/46/04            PAGE 0001

              SUBROUTINE COLCT (X,N)
              COMMON IMM,PARAM(300,4),JTRIB(8),ISEED,MFE(500),NPRNT,MXX
              COMMON MXC,ATRIB   ,JCELS(20,32),SUMA(100,5),NHIST,NCRDR
              COMMON ID,IM,NCLCT,MFA,TNOW,MLF(500),NQ(500),NNR,IBRNCH,ITIME,LOOP
              IF(N.GT.0.AND.N.LE.NCLCT) GOTO 3
              CALL ERROR(4,NSET,QSET)
            3 SUMA(N,1) = SUMA(N,1)+X                                          CLTS 100
              SUMA(N,2) = SUMA(N,2)+X*X                                        CLTS 110
              SUMA(N,3) = SUMA(N,3)+1.0                                        CLTS 120
              SUMA(N,4) = AMIN1(SUMA(N,4),X)
              SUMA(N,5) = AMAX1(SUMA(N,5),X)
              RETURN                                                           CLTS 150
              END                                                              CLTS 160
```

```
FORTRAN IV G LEVEL 1, MOD 4            DATAN           DATE = 70180        13/46/04            PAGE 0001

              SUBROUTINE DATAN (NSET,QSET,ATIME,BRNCH,ACTIME,LUPDO)
              DIMENSION NSET(1),QSET(1),ATIME(1),BRNCH(1),ACTIME(1)
              COMMON IMM,PARAM(300,4),JTRIB(8),ISEED,MFE(500),NPRNT,MXX
              COMMON MXC,ATRIB   ,JCELS(20,32),SUMA(100,5),NHIST,NCRDR
              COMMON ID,IM,NCLCT,MFA,TNOW,MLE(500),NQ(500),NNR,IBRNCH,ITIME,LOOP
              COMMON KOL,KOF,KLE
              COMMON NRUN,XLOW(20),NCTS,NSINK(20),WIDTH(20),NSKS
              COMMON NTYPE(500),MX,NFTBU(500),CSTAR,CINC
              COMMON NNM,IMN,NPD,NOQ,NPRMS,NRUNS,NYR,MAXNS,MAXA,NPRTOP ,
             1NAME(6),NPROJ,MON,NDAY,NSKST,NSRC,NRELP(500),NREL(500),   NSKSR,
             2NSORC(20),TOTIM,KOUNT(4),JSINK(20),NPO(3,500),NABA(3,800)
              NRUN = 1                                                         DATS 100
              READ(NCRDR,101,END=9999)NAME,NPROJ,MON,NDAY,NYR,NRUNS,NPRMS,ID,
             1JSEED,CSTAR,CINC
          101 FORMAT(6A2,I4,2I2,4I4,I10,2F10.0)
              IF(NPRMS.GT.300) CALL ERROR(1,NSET,QSET)
              IF(NRUNS) 30,30,5                                                DATS 130
           30 WRITE(NPRNT,241)
          241 FORMAT(/' NRUNS = 0 ***ON INPUT')
              CALL ERROR (1,NSET,QSET)
           10 FORMAT(25I3)                                                     DATS 150
           14 FORMAT(8F10.2)                                                   DATS 160
        C
        C*****READ LARGEST NODE NUMBER, NO. OF SINK NODES, NO. OF SOURCE NODES, DATS 170
        C*****NO. OF NODES NECESSARY TO REALIZE THE NETWORK,NODES MOD.,PRT CDE  DATS 180
        C
        5     READ(NCRDR,10)NOQ,NSRC,NPD,NSKST,NSKS,NCTS,NNM,NNR,LOOP,ITIME,
             1IBRNCH,LUPDO,NPRTOP,LOGIC
              IF(NSRC.GT.20) CALL ERROR(1,NSET,QSET)
              IF(NSKS.GT.20) CALL ERROR(1,NSET,QSET)
              NSKSR=NSKST                                                      DATS 200
        C
        C*****READ SOURCE AND SINK NODE NOS.                                    DATS 210
        C
              READ(NCRDR,10) (NSORC(J),J=1,NSRC), (NSINK(K),K=1,NSKS)          DATS 220
              IF(LOGIC.EQ.0) GOTO 13
              READ(NCRDR,10) NRELP(1),NTYPE(1)
              GOTO 16
        13     NRELP(1)=0
              NTYPE(1)=0
        C
        C*****READ NO. OF RELEASES FOR EACH NODE. NODE NOS. MUST BE .GE. TO 2.  DATS 230
        C
        16    READ(NCRDR,10) (NRELP(I),I=2,NOQ)
              DO 11 I=2,NOQ
           11 NREL(I)=NRELP(I)                                                 DATS 260
        C
        C*****READ NODE TYPE.  1 AND 3 ARE DETERMINISTIC.  2 AND 4 ARE PROBABILIDATS 270
```

```
FORTRAN IV G LEVEL 1, MOD 4            DATAN            DATE = 70180          13/46/04            PAGE 0002

             C*****3 AND 4 CAN BE REALIZED MORE THAN ONCE.                          DATS 280
             C
 0033              READ(NCRDR,10)(NTYPE(I),I=2,NOQ)
             C
             C*****READ LOWER LIMIT AND CELL WIDTH FOR HISTOGRAMS.                  DATS 300
             C
 0034              READ(NCRDR,14)(XLOW(K),K=1,NSKS)                                 DATS 310
 0035              READ (NCRDR,14)(WIDTH(K),K=1,NSKS)                               DATS 320
 0036              IF(NCTS) 135,135,125                                             DATS 330
 0037          125 DO 130 J=1,NCTS                                                  DATS 340
 0038          130 KOUNT(J)=0                                                       DATS 350
 0039          135 DO 140 K=1,NSKS                                                  DATS 360
 0040          140 JSINK(K)=1                                                       DATS 370
 0041              NHIST=NSKS                                                       DATS 380
 0042              NCLCT=NSKS*(NCTS+1)                                              DATS 390
 0043              MXC=32                                                           DATS 420
 0044              DO 9 I = 1,NPRMS                                                 DATS 450
 0045            9 READ (NCRDR,106) (PARAM(I,J),J=1,4)                              DATS 460
 0046          106 FORMAT(4F10.4)                                                   DATS 470
 0047              ISEED=JSEED                                                      DATS 490
 0048              RNUM=DRAND(ISEED)                                                DATS 500
 0049              TNOW=0.0                                                         DATS 510
             C
             C*****INITIALIZE NSET                                                  DATS 520
             C
 0050              MX  = IM +1                                                      DATS 560
 0051              MXX=IM+2                                                         DATS 570
 0052              MAXNS = ID * MXX                                                 DATS 590
 0053              MAXA=ID*IMM
 0054              DO 35 J=1,ID
 0055              ACTIME(J)=0.0
 0056           35 QSET(J)=0.0                                                      DATS 610
 0057              DO 40 J=1,MAXNS                                                  DATS 620
 0058           40 NSET(J)=0                                                        DATS 630
 0059              INDX=0
 0060              DO 45 I=1,ID                                                     DATS 640
 0061              INDX=INDX+MXX
 0062              NSET(INDX - 1) = I + 1                                           DATS 660
 0063           45 NSET(INDX)=I-1                                                   DATS 670
 0064              NSET(MAXNS - 1) = KOF                                            DATS 680
 0065              DO 3 K = 1,NOQ                                                   DATS 690
 0066              NQ(K)=0                                                          DATS 700
 0067              MFE(K)=0                                                         DATS 710
 0068            3 MLF(K)=0                                                         DATS 720
 0069              MFA=1
 0070              ATRIB=0.0
 0071              DO 301 K=1,IM
 0072          301 JTRIB(K)=0

FORTRAN IV G LEVEL 1, MOD 4            DATAN            DATE = 70180          13/46/04            PAGE 0003

 0073              CALL FILEM(1,NSET,QSET)                                          DATS 790
 0074              DO 320 JS = 1,ID
             C
             C*****DATA CARD TYPES NINE                                             DATS 810
             C
 0075              READ(NCRDR,1110) ATRIB    ,(JTRIB(JK),JK=1,IM)
 0076               JQ=JTRIB(1)
 0077        1110  FORMAT(F8.3,9I3)
 0078              IF(JQ)23,15,320                                                  DATS 840
 0079          320 CALL FILEM(JQ,NSET,QSET)                                         DATS 860
 0080        15    IF(NCLCT.LT.0.OR.NHIST.LT.0) GOTO 23
 0081           20 WRITE(NPRNT,21)                                                  DATS 980
 0082              WRITE(NPRNT,22) NPROJ,NAME,MON,NDAY,NYR                          DATS 990
 0083              WRITE(NPRNT,24)                                                  DATS1000
 0084              DO 80 JQ=2,NOQ                                                   DATS1010
 0085              PROB = 0.0                                                       DATS1020
 0086              LINE = MFE(JQ)                                                   DATS1030
 0087              NT = NTYPE(JQ)                                                   DATS1040
 0088              IF(LINE)80,80,82                                                 DATS1050
 0089           82 IB = (LINE-1) * MXX + 1                                          DATS1060
 0090              IE = IB + IM-1                                                   DATS1070
 0091              DPROB=QSET(LINE)
 0092              GO TO (72,73,72,73,72,73,72,73),NT                               DATS1100
 0093        73    QSET(LINE)=QSET(LINE)+PROB
 0094              PROB = PROB + DPROB                                              DATS1120
 0095        72    WRITE(NPRNT,12) (NSET(I),I=IB,IE),DPROB
 0096              LINE = NSET(IE+1)                                                DATS1140
 0097              IF(LINE - 7777) 82,80,84                                         DATS1150
 0098        84    CALL ERROR(2,NSET,QSET)
 0099           80 CONTINUE                                                         DATS1170
 0100              WRITE(NPRNT,26)                                                  DATS1180
 0101              DO 50 I = 1,NPRMS                                                DATS1190
 0102           50 WRITE(NPRNT,28) I,(PARAM(I,J),J=1,4)                             DATS1200
 0103           21 FORMAT(1H1)                                                      DATS1210
 0104           22 FORMAT(32X,23HGERT SIMULATION PROJECT,I4,4H BY ,6A2/45X,4HDATE,  DATS1220
                  1I3,1H/,I3,1H/,I5//)                                              DATS1230
 0105           24 FORMAT(42X,23H**NETWORK DESCRIPTION**//16X5HSTART,6X3HEND,6X,    DATS1240
                  19HPARAMETER,6X,12HDISTRIBUTION,6X,5HCOUNT,6X,8HACTIVITY,6X,      DATS1250
                  A'VAR. COST',4X,'FIX. COST',3X,
                  2 11HPROBABILITY/                                                 DATS1260
                  317X4HNODE,6X,4HNODE,7X,6HNUMBER,11X4HTYPE,11X4HTYPE,7X,6HNUMBER/) DATS1270
 0106           12 FORMAT(I19,I11,I12,I16,4I14,F17.4)
 0107          199 FORMAT(///36X26HERROR EXIT, TYPE 70 ERROR.)                      DATS1290
 0108           26 FORMAT(//39X23H**ACTIVITY PARAMETERS**//16X9HPARAMETER32X,10HPARAMDATS1300
                  1ETERS/17X6HNUMBER,16X1H1,13X1H2,13X,1H3,13X1H4/)                 DATS1310
 0109           28 FORMAT(I21,7X,4F14.4)                                            DATS1320
 0110              DO 1024 I=1,3
 0111              DO 1024 J=1,ID
```

```
      1024 NPO(I,J)=0
           NP=1
           IF(NNM.LE.0) GOTO 1020
      1025 WRITE(NPRNT,1004)
      1004 FORMAT(//39X25H**NETWORK MODIFICATIONS**// 2X,8HACTIVITY,12(1X,9HNDATS1390
          1ODE FILE)/)                                                    DATS1400
C
C*****NETWORK MODIFICATIONS STORED IN NABA(1,ACTIVITY NUMBER)
C*****NODE RESETTING STORED IN NABA(2,ACTIVITY NUMBER)
C*****LOOPING STORED IN NABA(3,ACTIVITY NUMBER)
C
           NPOS=1
      1026 IE=NPOS+23
           IF(IE.GT.IMN) CALL ERROR(1,NSET,QSET)
           READ(NCRDR,10) NACTN,(NABA(NP,J),J=NPOS,IE)
           IF(NACTN.LE.0) GOTO 1020
           IF(NPO(NP,NACTN).GT.0) GOTO 1039
           NPO(NP,NACTN)=NPOS
           GOTO 1040
      1039 DO 1037 K=NPOS,IF
           NABA(NP,K-1)=NABA(NP,K)
           IF(NABA(NP,K).EQ.0) GOTO 1005
      1037 CONTINUE
           GOTO 1800
      1005 IE=K-1
      1800 NPOS=NPOS-1
           GOTO 1035
      1040 DO 1038 I=NPOS,IE
           IF(NABA(NP,I).EQ.0) GOTO 1036
      1038 CONTINUE
           IE=IE+1
           GOTO 1035
      1036 IE=I
      1035 NABA(NP,IE)=0
           WRITE(NPRNT,1006) NACTN,(NABA(NP,J),J=NPOS,IE)
           NPOS=IE+1
           GOTO 1026
      1006 FORMAT(I7,2X,12(I5,I5),I3)
      1020 NP=NP+1
           IF(NNR.GT.0.AND.NP.EQ.2) GOTO 1025
           IF(LOOP.GT.0.AND.NP.EQ.3) GOTO 1025
           DO 1041 KK=1,NOQ
      1041 NFTBU(KK)=KK                                                   DATS1590
           NABA(1,IMN)=0
           NABA(1,IMN-1)=0
           IF(NPROJ) 1591,1592,1592                                       DATS1591
      1591 READ(NCRDR,10) NABA(1,IMN),NABA(1,IMN-1)
      1592 WRITE(NPRNT,221) NOQ,NSRC,NPD,NSKST,NSKS,NPPMS,JSEED,ITIME,IBRNCH
```



```
           WRITE(NPRNT,223) (NSORC(J),J=1,NSRC)                           DATS1610
           WRITE(NPRNT,225) (NSINK(K),K=1,NPD)                            DATS1620
           KPP=NPD+1
           IF(KPP.GT.NSKS) GOTO 541
           WRITE(NPRNT,227) (NSINK(K),K=KPP,NSKS)                         DATS1630
       541 WRITE(NPRNT,229)                                               DATS1640
           DO  231 J=1,NOO
       231 WRITE(NPRNT,233) J,NRELP(J),NTYPE(J)                           DATS1660
       221 FORMAT(1H1,14X22HHIGHEST NODE NUMBER IS,I5,/15X,25HNUMBER OF SOURCDATS1670
          1E NODES IS,I5/15X,23HNUMBER OF SINK NODES IS,I5/15X41HNUMBER OF NODATS1680
          2DES TO REALIZE THE NETWORK IS,I5/15X,23HSTATISTICS COLLECTED ON,I5DATS1690
          3,6H NODES/15X,27HNUMBER OF PARAMETER SETS IS,I5/15X24HINITIAL RANDDATS1700
          4OM NUMBER IS, I5/15X,'ANTITHETIC TIME INDICATOR IS', I5/15X,
          5'ANTITHETIC BRANCH INDICATOR IS',I5/)
       223 FORMAT(15X,19HSOURCE NODE NUMBERS/17X,10(10I5))                DATS1720
       225 FORMAT(/15X,17HSINK NODE NUMBERS/17X,10(10I5))                 DATS1730
       227 FORMAT(/15X,34HSTATISTICS COLLECTED ALSO ON NODES/17X,10(10I5))  DATS1740
       229 FORMAT(/25X,5HNODE 5X, 6HNUMBER,5X,4HNODE/34X,8HRELEASES,4X,4HTYPEDATS1750
          1/)                                                             DATS1760
       233 FORMAT(I28,I10,I10)                                            DATS1770
           RETURN                                                         DATS1780
        23 CALL ERROR(3,NSET,QSET)
      9999 WRITE(NPRNT,551)
       551 FORMAT('0 ***END OF DATA***')
           CALLEXIT
           END                                                            DATS1790
```



```
           FUNCTION DRAND(ISEED)
           IF(ISEED.EQ.0) ISEED=1267
           ISEED=ISEED*65539
           IF(ISEED.GT.0) GOTO 6
         5 ISEED=ISEED+2147483647+1
         6 DRAND=ISEED
           DRAND=DRAND*.4656613E-9
           RETURN
           END
```

```
              SUBROUTINE ERROR(J,NSET,QSET)
              DIMENSION NSET(1),QSET(1)
              COMMON IMM,PARAM(300,4),JTRIB(8),ISEED,MFE(500),NPRNT,MXX
              COMMON MXC,ATRIB    ,JCELS(20,32),SUMA(100,5),NHIST,NCRDR
              COMMON ID,IM,NCLCT,MFA,TNOW,MLE(500),NQ(500),NNR,IBRNCH,ITIME,LOOP
              COMMON KOL,KOF,KLE
              COMMON NRUN,XLOW(20),NCTS,NSINK(20),WIDTH(20),NSKS
              COMMON NTYPE(500),MX,NFTBU(500),CSTAR,CINC
              COMMON NNM,IMN,NPD,NOQ,NPRMS,NRUNS,NYR,MAXNS,MAXA,NPRTOP ,
             1NAME(6),NPROJ,MON,NDAY,NSKST,NSRC,NRFLP(500),NRFL(500),  NSKSR,
             2NSORC(20),TOTIM,KOUNT(4),JSINK(20),NPO(3,500),NABA(3,800)
              GOTO (1,2,3,4,5,6,7,8,9),J
    1         WRITE(NPRNT,20)
   20         FORMAT(//' ERROR EXIT TYPE 1**EXCEEDING DIMENSIONS FOR THE NUMBER OF
             1OF SOURCE NODES, THE NUMBER OF NODES ON WHICH STATISTICS ARE TO BE
             2 COLLECTED,',/,' THE NUMBER OF ALLOWABLEPARAMETERS, OR THE NUMBER OF
             3OF ALLOWABLE NODE MODIFICATIONS')
              CALL EXIT
    3         WRITE(NPRNT,40)
   40         FORMAT(//' ERROR TYPE 3***THE START NODE WAS NEGATIVE, THE NUMBER
             1OF NODES STATISTICS ARE TO BE COLLECTED ON IS NEGATIVE,'/
             2' OR NUMBER OF COUNTS IS NEGATIVE')
              GOTO 9
    4         WRITE(NPRNT,250)
  250          FORMAT(//' ERROR IN COLCT OR HISTOGRAM**THE NUMBER OF NODES STATI
             1STICS ARE TO BE COLLECTED ON IS NOT WITHIN THE ALLOWABLE RANGE')
              GOTO 9
    6         WRITE(NPRNT,60)
   60         FORMAT(//' THE NUMBER OF SINK NODES NEEDED TO REALIZE THE NETWORK
             1IS NEGATIVE,OR THE NUMBER OF ACTIVITIES FOR A NODE IS NEGATIVE')
              GOTO 9
    8          WRITE(NPRNT,80)
   80          FORMAT(//' AN ELEMENT IN THE ARRAY FOR FIRST ENTRY IN THE FILE IS
             1 NEGATIVE**OCCURED IN NFIND')
              GOTO 9
    2         WRITE(NPRNT,30)
   30          FORMAT(//' THE INDICATOR IN THE ACTIVITY FILE IS GREATER THAN 777
             17***ERROR NUMBER 2***OCCURRED IN FILEM OR SCHAT')
              GOTO 10
    5         WRITE(NPRNT,50)
   50         FORMAT(//' THE ACTIVITY FILE IS FULL**THE OVERLAP SET FOLLOWS')
    7         WRITE(NPRNT,70)
   70         FORMAT(//' THE ARRAY FOR COLLECTING STATISTICS HAS A NEGATIVE NUMBER FOR T
             1ER FOR THE COUNTER')
   10         WRITE(NPRNT,99)
              WRITE(NPRNT,100) J,TNOW,NRUN,MFE(1),NQ(1), IBRNCH,ITIME
  100 FORMAT(//36X16HERROR EXIT, TYPE,I3,7H ERROR.//21H FILE STATUS AT
             1TIME,F10.4,5X,'ON RUN NUMBER',I5,5X,'MFE(1) =',I5,'  NQ(1) =',I5,
```



```
             2'  IBRNCH =',I5,'  ITIME =',I5/)
              WRITE (NPRNT,200)
  200         FORMAT(27X,'QSET',15X,'NSET'/)
              IL=1
              IV=MXX
              DO 210 I=1,ID
              WRITE(NPRNT,90) I,QSET(I),(NSET(IJ),IJ=IL,IV)
              IL=IL+MXX
  210 IV=IV+MXX
   90         FORMAT(13X,I5,5X,E12.6,5X,11I8)
              WRITE (NPRNT,99)
   99 FORMAT(1H1)
              IF(NCLCT) 19,19,18
   18         WRITE(NPRNT,98)
   98 FORMAT(/11H ARRAY SUMA,/)
              DO 110 I=1,NCLCT
  110          WRITE(NPRNT,81) I,(SUMA(I,K),K=1,5)
   81         FORMAT(I10,5F10.4)
              WRITE (NPRNT,99)
   19         IF(NHIST) 9,9,12
   12 WRITE (NPRNT,96)
   96 FORMAT (/12H ARRAY JCELS/)
              DO 112 I=1,NHIST
  112 WRITE (NPRNT,26) I,(JCELS(I,K),K=1,MXC)
   26 FORMAT(17X,I3,5X,11I4/(25X,11I4))
    9         CALL GASP (NSET,QSET)
              GOTO 9
              END
```

```
            SUBROUTINE FILEM (JQ,NSET,QSET)                                 FILS  10
            DIMENSION NSET(1),QSET(1)
            COMMON IMM,PARAM(300,4),JTRIB(8),ISEED,MFE(500),NPRNT,MXX
            COMMON MXC,ATRIB    ,JCELS(20,32),SUMA(100,5),NHIST,NCRDR
            COMMON ID,IM,NCLCT,MFA,TNOW,MLE(500),NQ(500),NNR,IBRNCH,ITIME,LOOP
            COMMON KOL,KOF,KLE
            IND1=MFA*MXX-1
            IND2= IND1+1
      C
      C*****TEST TO SEE IF THERE IS AN AVAILABLE COLUMN FOR STORAGE          FILS  70
      C
            IF (MFA - ID ) 2,2,3                                            FILS  80
      3     CALL ERROR(5,NSET,QSET)
      C
      C*****PUT ATTRIBUTE VALUES IN FILE                                    FILS 120
      C
      2     QSET(MFA)=ATRIB
            INDX = (MFA - 1) * MXX                                          FILS 200
            DO 10 I = 1,IM                                                  FILS 210
            INDX = INDX + 1                                                 FILS 220
         10 NSET(INDX) = JTRIB(I)                                           FILS 230
            MFEX=MFE(JQ)                                                    FILS 240
            KNT = 2                                                         FILS 250
            NXFA = NSET(IND1)                                               FILS 280
            MLEX=MLE(JQ)                                                    FILS 290
            IF(MLEX)100,27,11                                               FILS 300
        100 CALL ERROR (88,NSET,QSET)                                       FILS 310
         27 NSET(IND2) = KLE                                                FILS 330
            MFE(JQ) = MFA                                                   FILS 340
         17 NSET(IND1) = KOL                                                FILS 360
            MLE(JQ) = MFA                                                   FILS 370
         14 MFA =NXFA                                                       FILS 380
            IF(MFA-KOF) 237,238,238                                         FILS 390
        237 NSET(NXFA*MXX)=KLE
        238 NQ(JQ)=NQ(JQ)+1                                                 FILS 420
            RETURN                                                          RMVS 510
      11    IF(JQ-1) 241,241,242                                            FILS 455
      241   IF (QSET(MFA)-QSET(MLEX)) 12,13,13
      242   IF (QSET(MFA)-QSET(MLEX)) 13,13,12
         13 IND3= MLEX*MXX-1
            MSU = NSET(IND3)
            NSET(IND3) = MFA                                                FILS 490
            NSET(IND2) = MLEX                                               FILS 510
            GO TO (18,17),KNT                                               FILS 520
         18 NSET(IND1) = MSU                                                FILS 540
            NSET(MSU*MXX)=MFA
            GO TO 14                                                        FILS 570
         12 KNT = 1                                                         FILS 580
```



```
            MLEX=NSET(MLEX*MXX)
            IF(MLEX-KLE)  11,16,11                                          FILS 610
         16 NSET(IND2)=KLE
            MFE(JQ) = MFA                                                   FILS 640
            NSET(IND1)=MFEX
            NSET(MFEX*MXX)=MFA
            GO TO 14                                                        FILS 690
            END                                                             FILS 700
```

```
FORTRAN IV G LEVEL 1, MOD 4          GASP           DATE = 70180        13/46/04           PAGE 0001

            SUBROUTINE GASP (NSET,QSET)
            DIMENSION NSET(1),QSET(1),ATIME(2000),BRNCH(2000),ACTIME(500),
           1TSAVE(500),CSAVE(500)
            COMMON IMM,PARAM(300,4),JTRIB(8),ISEED,MFE(500),NPRNT,MXX
            COMMON MXC,ATRIB    ,JCELS(20,32),SUMA(100,5),NHIST,NCRDR
            COMMON ID,IM,NCLCT,MFA,TNOW,MLE(500),NQ(500),NNR,IBRNCH,ITIME,LOOP
            COMMON KOL,KOF,KLE
            COMMON NRUN,XLOW(20),NCTS,NSINK(20),WIDTH(20),NSKS
            COMMON NTYPE(500),MX,NFTBU(500),CSTAR,CINC
            COMMON NNM,IMN,NPD,NOQ,NPRMS,NRUNS,NYR,MAXNS,MAXA,NPRTOP ,
           1NAME(6),NPROJ,MON,NDAY,NSKST,NSRC,NRELP(500),NREL(500),    NSKSR,
           2NSORC(20),TOTIM,KOUNT(4),JSINK(20),NPO(3,500),NABA(3,800)
            CALL DATAN (NSET,QSET,ATIME,BRNCH,ACTIME,LUPDO)
            IF(LUPDO.EQ.0) LUPDO=1
            DO 2125 MMM=1,LUPDO
            KOWT=1
            COSSQR=0.0
            CMIN=.1E20
            CMAX=0.0
             COST=0.0
            TOTCOS=0.0
            IF(NPRTOP.EQ.0) GOTO 2
            DO 3 I=1,NOQ
            TSAVE(I)=0.0
     3      CSAVE(I)=0.0
     2      NAT=1
            IF(ITIME.EQ.0) GOTO 2168
            DO 6740 J=1,MAXA
            ATIME(J)=0.0
  6740      BRNCH(J)=0.0
  2168      IF(NCLCT.EQ.0)    GOTO 2160
  2127      DO 2121 I=1,NCLCT
            DO 2122 J=1,3
  2122       SUMA(I,J)=0.0
            SUMA(I,4)=1.0E20
  2121      SUMA(I,5)=-1.0E20
  2160      IF(NHIST.EQ.0) GOTO 42
            DO 2123 K=1,NHIST
            DO 2123 L=1,MXC
  2123      JCELS(K,L)=0
            DO 2124 L=1,MXC
  2124      JCELS(20,L)=0
      C
      C*****OBTAIN NEXT EVENT WHICH IS FIRST ENTRY IN FILE 1.  ATRIB(1) IS     GSPS 110
      C*****EVENT TIME, JTRIB(1) IS EVENT CODE                                 GSPS 120
      C
    42      KCOL=MFE(1)
            CALL RMOVE(KCOL,1,NSET,QSET,NAT,KOWT)
```

```
FORTRAN IV G LEVEL 1, MOD 4          GASP           DATE = 70180        13/46/04           PAGE 0002

            IF(NAT.EQ.2) GOTO 120
            IF(NAT.EQ.0) GOTO 120
            TNOW=ATRIB
            NEND=JTRIB(2)
      C
      C*****IF END NODE IS ZERO START NETWORK BY SCHEDULING ACTIVITIES         GSPS 160
      C*****FROM EACH SOURCE NODE                                              GSPS 170
      C
            IF(NEND)4,4,5                                                     GSPS 180
          4 DO 10 N=1,NSRC                                                    GSPS 190
            M=NSORC(N)                                                        GSPS 200
    10      CALL SCHAT (M,NSET,QSET,BRNCH,ATIME)
            GO TO 42                                                          GSPS 230
      C
      C*****REDUCE NO. OF RELEASES FOR END NODE BY 1.                          GSPS 240
      C*****TEST TO SEE IF NODE IS RELEASED.                                   GSPS 250
      C
          5 NEND=NFTBU(NEND)                                                  GSPS 260
            NREL(NEND)=NREL(NEND)-1                                           GSPS 261
            JA=JTRIB(1)
            TIME=TNOW-ACTIME(JA)
            COST=COST+FLOAT(JTRIB(8))+FLOAT(JTRIB(7))*TIME
            IF(NPROJ) 511,512,512                                             GSPS 262
   511      IF( NRUN.LT.NABA(1,IMN) .OR.NRUN.GT. NABA(1,IMN-1)) GOTO 512
   515      WRITE(NPRNT,598) TNOW,(JTRIB(I),I=2,IM),COST
   598 FORMAT(/5X,7HAT TIME,F8.2,17H ACTIVITY ON NODE,I5,16H WITH ATTRIBUGSPS 267
           1TES,6I5,13H WAS REALIZED,2X,'ACCUMULATED COST =',F8.2)
      C
      C*****DO NODE MODIFICATIONS OR RESET OR LOOP
      C
   512      IF(JTRIB(5)) 665,665,60
    60      L=JTRIB(5)
            KOUNT(L)=KOUNT(L)+1                                               GSPS 290
   665      NP=4
            IF(JTRIB(6).LE.0) GOTO 65
            JJJ=JTRIB(6)
    68      NP=NP-1
            IF(NPO(NP,JJJ).LE.0) GOTO 65
            NPOS=NPO(NP,JJJ)
            IF(NP.EQ.3) GOTO 2155
    69      NON=NABA(NP,NPOS)
            NTBI=NABA(NP,NPOS+1)
            IF(NP.EQ.1) GOTO 66
            IF(NON.NE.1) GOTO 2111
            NRELP(NON)=NRELP(NTBI)
            GOTO 2010
  2111      NREL(NON)=NRELP(NTBI)
  2010      IF(NRUN.LT.NABA(1,IMN).OR.NRUN.GT.NABA(1,IMN-1)) GOTO 1902
```

```
                WRITE(NPRNT,1806) NDN,NRELP(NTBI)
          1806  FORMAT(/5X,'NODE',I5,' WAS RESET TO',I5)
          1902  GOTO 67
          2155  CALL ALOOP(NSET,QSET,NPOS,COST,ACTIME,JJJ)
                GOTO 68
          66    DO 1901 N=1,NOQ
                IF(NFTBU(N).NE.NDN) GOTO 1901
            672 NFTBU(N)=NTBI
          669   IF(NRUN.LT.NABA(1,IMN).OR.NRUN.GT.NABA(1,IMN-1)) GOTO 1901
                WRITE(NPRNT,1807) NDN,NTBI,NREL(NTBI)
          1807  FORMAT(/5X,'NODE',I5,' WAS CHANGED TO NODE',I5,' AND SET TO',I5)
          1901  CONTINUE
          67    IF(NABA(NP,NPOS+2).LE.0) GOTO 65
                NPOS=NPOS+2
                 GOTO 69
          65    IF(NP.EQ.2.OR.NP.EQ.3) GOTO 68
                IF(NREL(NEND).GT.0) GOTO 42
                IF(NPRTOP.EQ.0) GOTO 6
                IF(ACTIME(NEND).NE.0.0) GOTO 6
                TSAVE(NEND)=TSAVE(NEND)+TNOW
                CSAVE(NEND)=CSAVE(NEND)+1.0
          6     ACTIME(NEND)=TNOW
                IF(NRFL(NEND).EQ.0) GOTO 7
          C
          C*****TEST TO SEE IF NODE CAN BE RELEASED MORE THAN ONCE.             GSPS 400
          C
              9 IF(NTYPE(NEND)-2)42,42,50                                      GSPS 410
          C
          C*****TEST TO SEE IF STATISTICS ARE TO BE COLLECTED ON THE NODE.      GSPS 420
          C*****STORE TIME NODE REALIZED, SAVE TIME FIRST REALIZED
          C
          7     DO 8 K=1,NSKS
                IF(NEND-NSINK(K))8,39,8                                        GSPS 440
             39 IF(JSINK(K))50,50,40                                           GSPS 450
              8 CONTINUE                                                       GSPS 460
             50 NT=NTYPE(NEND)                                                 GSPS 470
                GO TO (52,52,52,52,52,52,54,54),NT                             GSPS 471
             54 KCOL=NFIND(NEND,1,2,NSET,QSET)
                IF(KCOL) 52,52,56                                              GSPS 473
          56    CALL RMOVE(KCOL,1,NSET,QSET,NAT,KOWT)
                GO TO 54                                                       GSPS 475
          52    CALL SCHAT (NEND,NSET,QSET,BRNCH,ATIME)
                GO TO (42,42,42,42,51,51,51,51),NT                             GSPS 480
             51 NREL(NEND)=NRELP(NEND)                                         GSPS 490
                GO TO 42                                                       GSPS 500
          C
          C*****REDUCE NO. OF SINK NODES REALIZED BY ONE.  COLLECT STATISTICS.  GSPS 510
          C
```



```
             40 IF(K-NPD) 440,440,441                                          GSPS 515
            440 NSKSR=NSKSR-1                                                  GSPS 520
            441 JSINK(K)=0                                                     GSPS 530
                CALL HISTO(TNOW,XLOW(K),WIDTH(K),K)                            GSPS 540
                NL=K+(K-1)*NCTS                                                GSPS 550
                CALL COLCT (TNOW,NL)
                IF(NCTS) 45,45,46                                              GSPS 570
             46 DO 70 I=1,NCTS                                                 GSPS 580
                NL=NL+1                                                        GSPS 590
                XC=KOUNT(I)                                                    GSPS 600
          70    CALL COLCT (XC,NL)
          C
          C*****TEST TO SEE IF NETWORK SIMULATION IS COMPLETE.                  GSPS 620
          C
             45 IF(NSKSR) 22,100,999                                           GSPS 630
            999 IF(NQ(NEND))22,42,50                                           GSPS 640
          22    CALL ERROR(6,NSET,QSET)
          C
          C*****NETWORK HAS BEEN SIMULATED ONE MORE TIME.  ADD TNOW TO TOTAL TIMF.GSPS 660
          C*****ANTITHETIC TIME AND BRANCH INDICATORS
          C
            100 TOTIM=TOTIM+TNOW                                               GSPS 670
                IF(ITIME) 2000,2001,2002
          2000  ITIME=1
                DO 7210 I=1,MAXA
          7210  ATIME(I)=0.0
                GOTO 2001
          2002  ITIME=-1
          2001   IF(IBRNCH)2005,2006,2007
          2005  IBRNCH=1
                DO 7211 I=1,MAXA
          7211  BRNCH(I)=0.0
                GOTO 2006
          2007  IBRNCH=-1
          2006  CONTINUE
          C
          C*****REINITIALE FOR ANOTHER RUN BY REMOVING ALL EVENTS FROM EVENT    GSPS 700
          C*****FILE AND RESETTING NETWORK VALUES.                              GSPS 710
          C
            115 IF(NQ(1))22,120,116                                            GSPS 720
          116   KCOL=MFE(1)
                CALL RMOVE(KCOL,1,NSET,QSET,NAT,KOWT)
                IF(NAT.EQ.2) GOTO 120
                IF(NAT.EQ.0) GOTO 120
                GO TO 115                                                      GSPS 740
          120   JTRIB(2)=0
                ATRIB=0.0
                CALL FILEM(1,NSET,QSET)                                        GSPS 780
```

```
      C*****STORE COST INFORMATION
      C
            CALL HISTO (COST,CSTAR,CINC,2
            COSSQR=COSSQR+COST*COST
            CMIN=AMIN1(CMIN,COST)
            CMAX=AMAX1(CMAX,COST)
            TOTCOS=TOTCOS+COST
            COST=0.0
            TNOW=0.
            NSKSR=NSKST
            DO 80 K=1,NSKS
         80 JSINK(K)=1
            DO 85 J=1,NCTS
         85 KOUNT(J)=0
            DO 37 IJ=1,NOQ
            ACTIME(IJ)=0.0
            NFTBU(IJ)=IJ
         37 NRFL(IJ)=NRELP(IJ)
      C
      C*****TEST TO SEE IF ALL RUNS HAVE BEEN MADE.
      C
            IF(NAT.EQ.0) GOTO 2126
            IF(NRUNS-NRUN) 110,110,6718
       6718 NRUN=NRUN+1
            NAT=1
            IRSAVE=ISEED
            GOTO 42
        110  CALL SUMRY (NSET,TSAVE,CSAVE,TOTCOS,COSSQR,CMIN,CMAX)
            NRUN=1
            GOTO 2125
       2126 ISEED=IRSAVE
            WRITE(NPRNT,2130) NRUN
       2130 FORMAT(10X,' RUN NUMBER IS',
            NAT=-1
            KOWT=KOWT+1
            NABA(1,IMN)=NRUN
            NABA(1,IMN-1)=NRUN
            IF(ITIME.LE.0) GOTO 2163
            DO 2164 I=1,MAXA
       2164  ATIME(I)=0.0
       2163 IF(IBRNCH.LE.0) GOTO 2166
            DO 2167 I=1,MAXA
       2167 BRNCH(I)=0.0
       2166 IF(NPROJ.LE.0) GOTO 42
            NPROJ=-NPROJ
             GOTO 42
       2125 CONTINUE
            RETURN
```



```
            END
```



```
            SUBROUTINE HISTO (X1,A,W,N)
            COMMON IMM,PARAM(300,4),JTRIB(8),ISEED,MFE(500),NPRNT,MXX
            COMMON MXC,ATRIB    ,JCELS(20,32),SUMA(100,5),NHIST,NCRDR
            IF(W.EQ.0.0) RETURN
            IF(N.EQ.20) GOTO 3
            IF(N.LE.NHIST.AND.N.GT.0) GOTO 3
            CALL ERROR(4,NSET,QSET)
      C
      C*****TRANSLATE X1 BY SUBTRACTING A IF X.LE.A THEN ADD 1 TO FIRST CELL
      C
          3 X = X1 - A
            IF (X)6,7,7
          6 IC = 1
            GO TO 8
      C
      C*****DETERMINE CELL NUMBER IC. ADD 1 FOR LOWER LIMIT CELL AND 1 FOR
      C*****TRUNCATION
      C
          7 IC = X/W + 2.   +.0001
            IF(IC.GT.MXC) IC=MXC
          8 JCELS(N,IC) = JCELS(N,IC) + 1
            RETURN
            END
```

```
FORTRAN IV G LEVEL 1, MOD 4          NFIND          DATE = 70180          13/46/04          PAGE 0001

              FUNCTION NFIND(NVAL,JQ,JATT,NSET,QSET)                              FIND  10
              DIMENSION NSET(1),QSET(1)
              COMMON IMM,PARAM(300,4),JTRIB(8),ISEED,MFE(500),NPRNT,MXX
              NEXTK=MFE(JQ)                                                       FIND  70
              IF(NEXTK) 16,1,20                                                   FIND  80
     16       CALL ERROR(8,NSET,QSET)
            1 NFIND=0                                                             FIND 100
              RETURN                                                              FIND 110
           20 INDX=(NEXTK-1)*MXX +JATT                                            FIND 120
              IF(NSET(INDX)-NVAL) 4,21,4                                          FIND 130
            4 NEXTK=NSET(NEXTK*MXX-1)
              IF(NEXTK-7777) 20,1,1                                               FIND 160
           21 NFIND=NEXTK                                                         FIND 170
              RETURN                                                              FIND 180
              END                                                                 FIND 190
```

```
FORTRAN IV G LEVEL 1, MOD 4          RMOVE          DATE = 70180          13/46/04          PAGE 0001

              SUBROUTINE RMOVE (KCOL,JQ,NSET,QSET,NAT,KOWT)
              DIMENSION NSET(1),QSET(1)
              COMMON IMM,PARAM(300,4),JTRIB(8),ISEED,MFE(500),NPRNT,MXX
              COMMON MXC,ATRIB    ,JCFLS(20,32),SUMA(100,5),NHIST,NCROR
              COMMON ID,IM,NCLCT,MFA,TNOW,MLE(500),NQ(500),NNR,IBRNCH,ITIME,LOOP
              COMMON KOL,KOF,KLE
              IF (KCOL) 16,16,2                                                   RMVS 150
     16       IF(KOWT.GE.5) GOTO 1000
              IF(NAT.EQ.1) GOTO 50
              NAT=2
              RETURN
     50        NAT=0
              RETURN
     1000     CALL ERROR(9,NSET,QSET)
     C
     C*****PUT VALUES OF KCOL IN ATTRIB,JTRIB                                     RMVS 170
     C
     2        ATRIB=QSET(KCOL)
              QSET(KCOL)=0.0
              INDX = (KCOL - 1) * MXX                                             RMVS 220
              DO 10 I =1,IM                                                       RMVS 230
              INDX = INDX + 1                                                     RMVS 240
              JTRIB(I) = NSET(INDX)                                               RMVS 250
           10 NSET(INDX) = 0                                                      RMVS 330
              INDX=KCOL*MXX                                                       RMVS 340
              JL = NSET(INDX - 1)                                                 RMVS 350
              JK = NSET(INDX)                                                     RMVS 360
              IND1=JK*MXX-1
              IND2=JL*MXX
              IF (JL- KOL) 33,34,33                                               RMVS 370
           33 IF (JK- KLE) 35,36,35                                               RMVS 380
           35 NSET(IND1)=JL
              NSET(IND2)=JK
           37 INDX=KCOL*MXX-1                                                     RMVS 430
              NSET(INDX) = MFA                                                    RMVS 440
              NSET(INDX+1) = KLE                                                  RMVS 450
              IF(MFA-KOF) 234,235,235                                             RMVS 460
          234 NSET(MFA*MXX)=KCOL
          235 MFA=KCOL                                                            RMVS 490
              NQ(JQ) = NQ(JQ)-1                                                   RMVS 500
              RETURN
           36 NSET(IND2)=KLE
              MFE(JQ) = JL                                                        RMVS 540
              GO TO 37                                                            RMVS 550
           34 IF (JK-KLE)  38,39,38                                               RMVS 560
           38 NSET(IND1)=KOL
              MLE(JQ) = JK                                                        RMVS 590
              GO TO 37                                                            RMVS 600
```



```
FORTRAN IV G LEVEL 1, MOD 4          RMOVE          DATE = 70180          13/46/04          PAGE 0002

           39 MFE(JQ) = 0                                                         RMVS 610
              MLE(JQ) = 0                                                         RMVS 620
              GO TO 37                                                            RMVS 630
              END                                                                 RMVS 640
```

```
FORTRAN IV G LEVEL 1, MOD 4          RNORM          DATE = 70180          13/46/04          PAGE 0001

              FUNCTION RNORM (J,RA,RB)
              COMMON IMM,PARAM(300,4),JTRIB(8),ISEED,MFE(500),NPRNT,MXX
              V=(-2.0*ALOG(RA))**0.5*COS (6.283*RB)                               NRLS  80
              RNORM  = V*PARAM (J,4) + PARAM (J,1)                                NRLS  90
              IF (RNORM -PARAM (J,2)) 6,7,8                                       NRLS 100
            6 RNORM  = PARAM (J,2)                                                NRLS 110
            7 RETURN                                                              NRLS 120
            8 IF (RNORM -PARAM (J,3)) 7,7,9                                       NRLS 130
            9 RNORM  = PARAM (J,3)                                                NRLS 140
              RETURN                                                              NRLS 150
              END                                                                 NRLS 160
```

FORTRAN IV G LEVEL 1, MOD 4   SAMPL   DATE = 70180   13/46/04   PAGE 0001

```
          SUBROUTINE SAMPL(DEV,ATIME,NEXT)
           DIMENSION ATIME(1)
          COMMON IMM,PARAM(300,4),JTRIB(8),ISEED,MFE(500),NPRNT,MXX
          COMMON MXC,ATRIB   ,JCELS(20,32),SUMA(100,5),NHIST,NCRDR
          COMMON ID,IM,NCLCT,MFA,TNOW,MLE(500),NQ(500),NNR,IBRNCH,ITIME,LOOP
          J=JTRIB(3)
          JD=JTRIB(4)
          IF(JD.EQ.1) GOTO 1
C
C*****JD=JTRIB(4)=1 CONSTANT
C*****             2 NORMAL
C*****             3 UNIFORM
C*****             4 ERLANG
C*****             5 LOGNORMAL
C*****             6 POISSON
C**** IF ITIME IS NEGATIVE USE PREVIOUSLY GENERATED TIME
C***** IF ITIME IS ZERO RUN THE PROGRAM NORMALLY
C***** IF ITIME IS POSITIVE GENERATE TIMES
C
          IF(ITIME) 50,60,70
   60     JD=JD+5
   70     GO TO (1,2,3,4,2,6,52,53,4,52, 6) ,JD
    1     DEV=PARAM(J,1)
          RETURN
    2     RA=DRAND(ISEED)
          RB=DRAND(ISEED)
          DEV=RNORM(J,RA,RB)
   79      IF(JD.EQ.5) GOTO81
          TIBR=2.*PARAM(J,1)-DEV
          CALL ANTIM (1,NEXT,ATIME,TIBR)
          GOTO 77
   52      RA=DRAND(ISEED)
          RB=DRAND(ISEED)
          DEV=RNORM(J,RA,RB)
          IF(JD.EQ.10) GOTO 82
   77     RETURN
   81     TIBR=EXP(2.*PARAM(J,1)-DEV)
          CALL ANTIM (1,NEXT,ATIME,TIBR)
   82     DEV=EXP(DEV)
          RETURN
    3     RNUM=DRAND(ISEED)
          TIBR=PARAM(J,2)+(PARAM(J,3)-PARAM(J,2))*(1.0-RNUM)
          CALL ANTIM (1,NEXT,ATIME,TIBR)
          GOTO 78
   53     RNUM=DRAND(ISEED)
   78     DEV=PARAM(J,2)+(PARAM(J,3)-PARAM(J,2))*RNUM
          RETURN
    4     K=PARAM(J,4)
```


FORTRAN IV G LEVEL 1, MOD 4   SAMPL   DATE = 70180   13/46/04   PAGE 0002

```
          IF(K-1) 118,10,10
  118      WRITE(NPRNT,20)J
   20     FORMAT(/' K=0 FOR ERLANG',I7)
          CALLEXIT
   10     DEV=0.0
          ADEV=0.0
          DO112 I=1,K
          RNUM=DRAND(ISEED)
          IF(ITIME.EQ.0) GOTO112
          ADEV=ADEV-PARAM(J,1)*ALOG(1.0-RNUM)
  112      DEV=DEV-PARAM(J,1)*ALOG(RNUM)
           IF(ITIME.LE.0) GOTO 7757
          IF(ADEV-PARAM(J,2)) 217,215,216
  217     TIBR=PARAM(J,2)
          GOTO 54
  215     TIBR=ADEV
          GOTO 54
  216      IF(ADEV.LE.PARAM(J,3)) GOTO 215
          TIBR=PARAM(J,3)
   54     CALL ANTIM (1,NEXT,ATIME,TIBR)
 7757     IF(DEV-PARAM(J,2)) 117,115,116
  117      DEV=PARAM(J,2)
  115     RETURN
  116     IF(DEV.LE.PARAM(J,3)) GOTO 115
          DEV=PARAM(J,3)
          RETURN
    6     NP=0
          NPSSN=0
          P=PARAM(J,1)
          IF(P.GT.6.) GOTO 14
          Y=EXP(-P)
          X=DRAND(ISEED)
          Z=1.0-X
   13     RNUM=DRAND(ISEED)
          IF(ITIME.LE.0) GOTO 91
          IF(X.GE.Y.AND.Z.GE.Y) GOTO 8001
          IF(Z.GE.Y) GOTO 8003
   91     IF(X.GE.Y) GOTO 8002
          GOTO 16
 8001     X=X*RNUM
          NPSSN=NPSSN+1
 8003     Z=Z*(1.0-RNUM)
          NP=NP+1
          GOTO 13
 8002     NPSSN=NPSSN+1
          X=X*RNUM
          GOTO 13
   14     TEMP=PARAM(J,4)
```

FORTRAN IV G LEVEL 1, MOD 4 SAMPL DATE = 70180 13/46/04 PAGE 0003

```
          PARAM(J,4)=(PARAM(J,1))**0.5
          RA= DRAND(ISEED)
          RB=DRAND(ISEED)
          DE=RNORM(J,RA,RB)
          IF(ITIME.LE.0) GOTO 24
          NP=2.*P-DE +0.5
   24     NPSSN=DE +0.5
   16     IF(ITIME.LE.0) GOTO 23
          NP=PARAM(J,2)+NP
          IF(NP-PARAM(J,3)) 21,21,22
   22     NP=PARAM(J,3)
   21     TIBR=NP
          CALL ANTIM (1,NEXT,ATIME,TIBR)
   23     NPSSN=PARAM(J,2)+NPSSN
          IF(NPSSN-PARAM(J,3)) 17,17,19
   19     NPSSN=PARAM(J,3)
   17     DEV=NPSSN
          RETURN
   50     CALL ANTIM (2,NEXT,ATIME,TIBR)
          IF(TIBR.EQ.0.0) GOTO 60
          DEV=TIBR
          RETURN
          END
```

FORTRAN IV G LEVEL 1, MOD 4 SCHAT DATE = 70180 13/46/04 PAGE 0001

```
          SUBROUTINE SCHAT (NODE,NSET,QSET,BRNCH,ATIME)
          DIMENSION NSET(1),QSET(1),ATIME(1),BRNCH(1)
          COMMON IMM,PARAM(300,4),JTRIB(8),ISEED,MFE(500),NPRNT,MXX
          COMMON MXC,ATRIB    ,JCELS(20,32),SUMA(100,5),NHIST,NCRDR
          COMMON ID,IM,NCLCT,MFA,TNOW,MLE(500),NQ(500),NNR,IBRNCH,ITIME,LOOP
          COMMON KOL,KOF,KLE
          COMMON NRUN,XLOW(20),NCTS,NSINK(20),WIDTH(20),NSKS
          COMMON NTYPE(500),MX,NFTBU(500),CSTAR,CINC
C
C*****NEXT IS LOCATION OF FIRST ENTRY IN FILE OF ACTIVITIES WITH START
C*****NODE- NODE. NT IS THE NODE TYPE.
C
          NODE=NFTBU(NODE)
          NT=NTYPE(NODE)
          NEXT=MFE(NODE)
          IF(NEXT) 4,4,5
C
C*****GENERATE A RANDOM NUMBER RNUM.
C
        5 RNUM=DRAND(ISEED)
          HOLD=RNUM
C
C*****OBTAIN STARTING LOCATION IN NSET OF ENTRY.
C
        1 INDXN=(NEXT-1)*MXX
C
C*****TEST IF DETERMINISTIC OR PROBABILISTIC NODE.
C
          GO TO (100,200,100,200,100,200,100,200),NT
      100 DO 10 I=1,IM
          INDX=INDXN+I
       10 JTRIB(I)=NSET(INDX)
C
C*****OBTAIN SAMPLE FOR ACTIVITY.
C
          CALL SAMPL (DEV,ATIME,NEXT)
          ATRIB=TNOW+DEV
C
C*****FILE END OF ACTIVITY EVENT IN EVENT FILE.
C
          CALL FILEM(1,NSET,QSET)
          GO TO (110,4,110,4,110,4,110,4),NT
C
C*****DETERMINE IF OTHER ACTIVITIES ARE IN FILE.
C
      110 INDX=INDXN+MX
          NEXT=NSET(INDX)
          IF(NEXT-7777)1,4,23
```

FORTRAN IV G LEVEL 1, MOD 4 SCHAT DATE = 70180 13/46/04 PAGE 0002

```
   23     CALL ERROR(2,NSET,QSET)
        4 RETURN
C
C*****TEST RNUM AGAINST PROBABILITY (CUM.) OF REALIZING THE ACTIVITY.
C*****ANTITHETIC BRANCHING
C
  200     IF(IBRNCH) 201,202,203
  201     CALL ANTIM (2,NEXT,BRNCH,TIBR)
          RNUM=1.0-TIBR
          IF(TIBR.EQ.0.0) RNUM=HOLD
          GOTO 202
  203     CALL ANTIM (1,NEXT,BRNCH,RNUM)
  202     IF(QSET(NEXT)-RNUM) 110,110,100
          END
```

```
      SUBROUTINE SUMRY (NSET,TSAVE,CSAVE,TOTCOS,COSSQR,CMIN,CMAX)
      DIMENSION NSET(1),TSAVE(1),CSAVE(1)
      COMMON IMM,PARAM(300,4),JTRIB(8),ISEED,MFE(500),NPRNT,MXX
      COMMON MXC,ATRIB    ,JCELS(20,32),SUMA(100,5),NHIST,NCRDR
      COMMON ID,IM,NCLCT,MFA,TNOW,MLE(500),NQ(500),NNR,IBRACH,ITIME,LOOP
      COMMON KOL,KOF,KLE
      COMMON NRUN,XLOW(20),NCTS,NSINK(20),WIDTH(20),NSKS
      COMMON NTYPE(500),MX,NFTBU(500),CSTAR,CINC
      COMMON NNN,IMN,NPD,NOQ,NPRMS,NRUNS,NYR,MAXNS,MAXA,NPRTOP ,
     1NAME(6),NPROJ,MON,NDAY,NSKST,NSRC,NRELP(500),NREL(500),    NSKSR,
     2NSORC(20),TOTIM,KOUNT(4),JSINK(20),NPO(3,500),NABA(3,800)
   21 FORMAT(1H1)
   10 FORMAT(32X,23HGERT SIMULATION PROJECT,I4,4H BY ,6A2/45X,4HDATE,I3,
     11H/,I3,1H/,I5//)
   15 FORMAT(//31X19H**FINAL RESULTS FOR,I5,14H SIMULATIONS**/)
   16 FORMAT(16X4HNODE3X11HPROB./COUNT,5X4HMEAN,4X8HSTD.DEV.,4X,
     14HMIN.,6X,'MAX.',4X,'STD.ER  OF MEAN')
   18 FORMAT(//43X,14H**HISTOGRAMS**//20X          ,5HLOWER,3X,4HCELL/13X
     1,4HNODE,3X,5HLIMIT,3X,5HWIDTH,31X,11HFREQUENCIES )
   19 FORMAT(/I16,F9.2,F8.2,5X,11I6/(38X,11I6))
      WRITE(NPRNT,21)
      WRITE (NPRNT,10) NPROJ,NAME,MON,NDAY,NYR
      WRITE (NPRNT,15) NRUN
      WRITE(NPRNT,16)
      NCTS1=NCTS+1
      DO 6 K=1,NSKS
      DO 6 J=1,NCTS1
      I=(K-1)*NCTS1+J
      JJ=J-1
      IF(SUMA(I,3))5,62,61
    5 CALL ERROR(7,NSET,QSET)
   62 WRITE(NPRNT,63) NSINK(K),JJ
   63 FORMAT(I19,I13,9X,18HNO VALUES RECORDED)
      GO TO 6
   61 AVG=SUMA(I,1)/SUMA(I,3)
      IF(SUMA(I,3).LE.1.0) GOTO 44
      STD=(((SUMA(I,3)*SUMA(I,2))-(SUMA(I,1)*SUMA(I,1)))/
     A(SUMA(I,3)*(SUMA(I,3)-1.0)))**0.5
      GOTO 43
   44 STD=0.0
   43 IF(JJ) 41,41,42
   41 PROB=SUMA(I,3) / FLOAT(NRUN)
      STMER=STD/SQRT(PROB*FLOAT(NRUN))
      WRITE(NPRNT,17) NSINK(K),PROB,AVG,STD,SUMA(I,4),SUMA(I,5),STMER
   17 FORMAT(/I18,F9.4,7X,4F10.4,F15.4)
      GO TO 6
   42 WRITE(NPRNT,20) NSINK(K),JJ,AVG,STD,SUMA(I,4),SUMA(I,5)
   20 FORMAT(I18,I13,3X,4F10.4)
    6 CONTINUE
      WRITE(NPRNT,18)
      DO 82 I=1,NHIST
   82 WRITE(NPRNT, 19) NSINK(I),XLOW(I),WIDTH(I),(JCELS(I,J),J=1,MXC)
      WRITE(NPRNT,21)
      WRITE(NPRNT,18)
      WRITE(NPRNT,6735) CSTAR,CINC,(JCELS(20,J),J=1,MXC)
 6735 FORMAT(/12X,'COST',F9.2,F8.2,5X,11I6/(38X,11I6))
 6719 FORMAT(' AVE. COST PER REALIZATION',F8.2,/' STANDARD DEVIATION',
     A6X,F8.2/' MIN. COST FOR REALIZATION',F8.2/' MAX. COST FOR REALIZAT
     BION',F8.2//)
      IF(NRUN.EQ.1) GOTO 22
      CSTD=((FLOAT(NRUN)*COSSQR-TOTCOS*TOTCOS)/(FLOAT(NRUN*(NRUN-1))
     A))**0.5
      GOTO 23
   22 CSTD=0.0
   23 TOTCOS=TOTCOS/FLOAT(NRUN)
      WRITE(NPRNT,6719)  TOTCOS ,CSTD,CMIN,CMAX
      IF(NPRTOP.EQ.0) GOTO 100
      DO 6720 I=1,NOQ
      IF(CSAVE(I).EQ.0.0) GOTO 6720
      TSAVE(I)=TSAVE(I)/CSAVE(I)
 6720 CONTINUE
      WRITE(NPRNT,6717)
 6717 FORMAT(4X,'NODE START',5X,'END',12X,'WITH ATTRIBUTES',
     AT85,'TIME/END NODE',2X,'TIME/ACTIVITY',7X,'PERCENT'/)
      DO 6715 JC=2,NOQ
      LINE=MFE(JC)
      IF(LINE.EQ.0) GOTO 6715
 6713 IB=(LINE-1)*MXX+1
      TAVG=0.0
      CAVG=0.0
      IN=NSET(IB+1)
      IE=IB+IM-1
      IF(JC.EQ.IN) GOTO 6740
      IF(TSAVE(JC).NE.0.0) GOTO 6730
      DO 6731 I=1,NSRC
      IF(JC.EQ.NSORC(I)) GOTO 6730
 6731 CONTINUE
      GOTO 6736
 6730 IF(TSAVE(IN).EQ.0.0) GOTO 6721
      TAVG=TSAVE(IN)-TSAVE(JC)
 6736 CAVG=TSAVE(IN)
      PERC=CSAVE(IN)/FLOAT(NRUN)
 6721 WRITE(NPRNT,6714)     (NSET(I),I=IB,IE),CAVG,TAVG,PERC
 6714  FORMAT(2X,8I10,F10.2,6X,F10.2,8X,F10.2)
      GOTO 6750
 6740 WRITE (NPRNT,6745) (NSET(I),I=IB,IE)
 6745 FORMAT(2X,8I10,4X,'NO INFORMATION')
 6750 LINE=NSET(IE+1)
      IF(LINE.LT.7777) GOTO 6713
 6715 CONTINUE
  100  RETURN
      END
```

A

Variance Reduction in the GERT II Simulator

One of the most promising approaches to variance reduction in connection with the GERT-II Simulator is through the introduction of an antithetic variable. The theory of this technique is based on the linear estimate of a parameter, say t, given in Equation (1).

(1) $\hat{t} = a_1\hat{t}_1 + a_2\hat{t}_2$

Here, a_1 and a_2 are arbitrary constants, and $\hat{t}_1$ is a "regular" estimator of t while $\hat{t}_2$ is the antithetic variable estimator. Now, $\hat{t}$ is an unbiased estimate of t if $a_1 + a_2 = 1$, and $E(\hat{t}_i) = E(\hat{t}_2) = t$. Also, the variance of this estimate is given by Equation (2).

(2) $V(\hat{t}) = a_1^2\sigma_1^2 + 2\rho a_1 a_2 \sigma_1 \sigma_2 + a_2^2\sigma_2^2$

Here, σ_1^2 and σ_2^2 are the variances of $\hat{t}_1$ and $\hat{t}_2$ respectively, and ρ is the correlation coefficient between $\hat{t}_1$ and $\hat{t}_2$. If we let $a_1 = a_2 = 1/2$, and if $\sigma_1 = \sigma_2 = \sigma$, which is the case in the procedure being described here, then equation (2) reduces to (3).

(3) $V(\hat{t}) = \sigma^2(1 + \rho)/2.$

Thus, the objective of the use of the antithetic variable is to achieve as strong a negative correlation as possible between the estimators t_1 and t_2, which makes $V(\hat{t})$ approach zero as ρ approaches minus one. To achieve this, two approaches are possible in the GERT-II Simulator;

1) Through the choice of random values for the activity duration times, and

2) Through the choice of random numbers used to determine branching from the stochastic nodes.

In each of these cases, the desired result can be obtained by preserving the order of the random numbers used in the simulation so that wherever the random number r_i is used in the estimator $\hat{t}_1$, the number $(1 - r_i)$ will be used in the estimator $\hat{t}_2$. In this way, pairs of random samples from any symmetrical distribution will have a correlation of -1. The effect in branching, however, is not quite so clear.

The modification of GERT II for the above purpose was accomplished by storing in an array (parallel in form to Qset and Nset) up to a maximum of four each, the values of antithetic random times and branching numbers for each activity and node completed during odd numbered realizations of the network being studied.* If feedback was present and a certain activity was completed more than once, a second value was placed in storage for both time and branching. Fifth and subsequent realizations of the same activity were not stored. Next, during even numbered realizations the stored antithetic activity duration and/or branching numbers were used in the same order in which they were placed in storage. If no stored variables were available at any time, new ones were generated as needed.

---

*Special procedures are sometimes required, e.g. the usual procedure for generating normally distributed random variates requires a pair of random numbers, and it will not produce a negative correlation if the above procedure is followed.

To illustrate this procedure, the PERT network shown in Figure II-1 was studied with and without the use of the antithetic variable. In this study a total of 20 simulation runs were made, where each run consisted of 250 realizations of the network. Statistics on the times required to realize nodes 5, 6, 7, 8 and 9 are given in Table II-1.

First, in the top half of the table the grand averages of the two sets of 10 runs each, and the variance among the 10 run means are given for the simulation with and without the antithetic variable. For all nodes the two grand means are almost identical and equal to the theoretical values, thus indicating both simulation procedures are unbiased. However, there is a considerable difference in the variance among the run means. The ratio of these variances indicates the effective increase in sample size due to the use of the antithetic variable. The ratio is infinite for nodes 5, 6, and 7 since the occurrence time of these nodes is merely the direct sum of one or two normally distributed random variates, and perfect negative correlation is achieved for the antithetic variable.

Examination of the lower portion of Table II-1 indicates that the use of the antithetic variable actually represents a trade-off, because estimates of the standard deviation of the actual times to the realization of a particular node are poorer when the antithetic variable is used. This results because the number of independent random samples is reduced by one-half when the antithetic variable is used. The

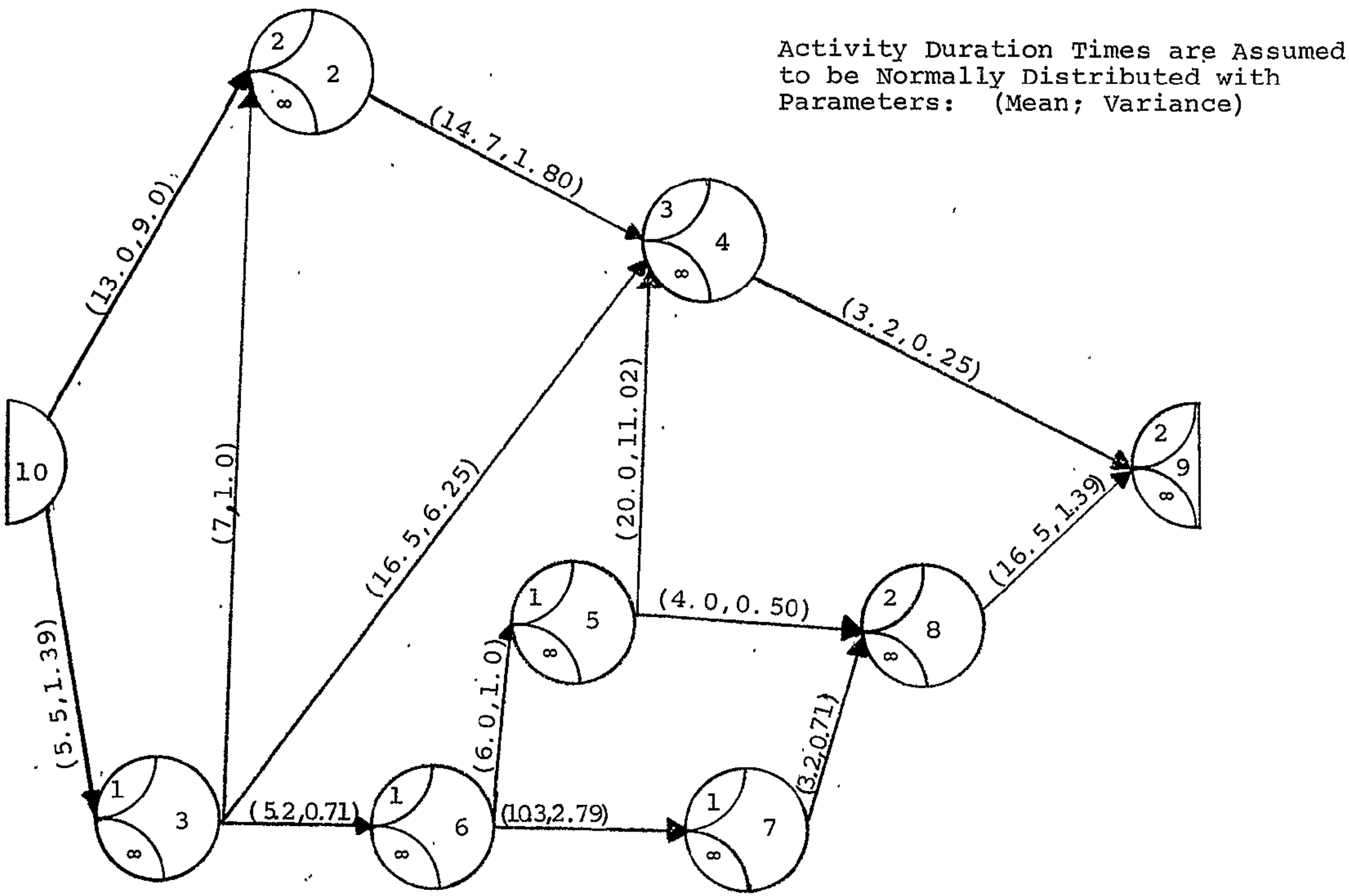

Figure II-1. Illustrative PERT Network (Project 13 in Reference 1).

variance ratios given in the last column vary randomly about the expected value of two, and the average ratio of 2.09 is quite close to this value.

To illustrate the effect of antithetic branching as well as activity duration times, the network shown in Figure II-2 was used. A procedure similar to that used for Figure II-1 was employed. A total of 80 simulation runs were made, 20 for each of the four conditions listed below, where each run consisted of 250 realizations of the network.

1) NONE: no antithetic variables
2) Branching: antithetic branching only
3) Time: antithetic activity duration times only
4) B and T: antithetic branching and activity duration times.

The above experiment was carried out using exponentially distributed activity duration times, and then the entire experiment was repeated using normally distributed times. The results of these two experiments, given in Table II-2, are discouraging. While the four procedures studied appear to be unbiased, there is no statistically significant evidence of a reduction in the variance among the run estimates.

The results for the B and T procedure were slightly superior to the average results in most cases in Table II-2. Further testing of this procedure was carried out on the large network shown in Figure 6. The results were again negative.

Table II-1. Results of the Simulation of the Network Given in Figure II-1.

Node No.	Statistic	Grand Ave. of Run Estimates			Variance Among Run Estimates		
		With	Without	True Est.	With	Without	Ratio*
6	Means	10.700	10.711	10.700	Zero	.00578	∞
5	"	16.700	16.696	16.700	Zero	.01150	∞
7	"	21.000	21.022	21.000	Zero	.00864	∞
8	"	24.256	24.270	-	.00017	.01900	112.0
9	"	42.021	42.027	-	.0185	.0236	1.28
6	Std. Dev.	1.419	1.437	1.448	.00720	.00406	1.77
5	" "	1.790	1.733	1.760	.01470	.00756	1.94
7	" "	2.202	2.187	2.211	.03080	.00884	3.48
8	" "	2.270	2.267	-	.02560	.01070	2.39
9	" "	2.705	2.708	-	.01730	.01960	0.88
						Average	2.09

*Without/with for Means and with/without for Std. Dev.

Conclusion

The results of these tests suggest that the antithetic variable is useful on PERT type networks if it is desirable to improve the estimate of the mean at the expense of the variance estimate. In general GERT type networks, however, it is not advisable to use the antithetic variable as employed in this study. More involved procedures on the use of the antithetic variable may, however, improve its effectiveness.

Each Activity Duration is Assumed to be a Random Variable with Parameters (Probability, Mean, Variance).

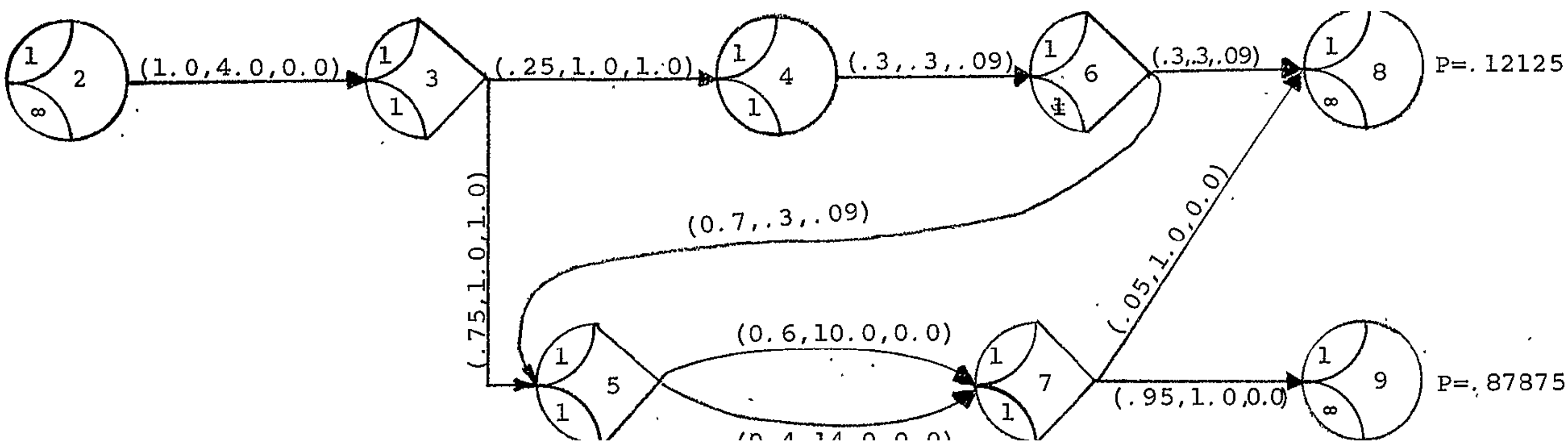

Figure II-2. GERT Network of a Manufacturing Process (Project 3 in Reference 1).

Table II-2. Results of the Simulation of the Network Given in Figure II-2.

Variance Reduction Technique	Statistic	EXPONENTIAL ACTIVITY DURATIONS				NORMAL ACTIVITY DURATIONS			
		Grand Average of Run Estimates		Variance Among Run Estimates		Grand Average of Run Estimates		Variance Among Run Estimates	
		Node 8	Node 9	Node 8	Node 9	Node 8	Node 9	Node 8	Node 9
None	Mean Value	12.16	18.26	.660	.0228	16.19	21.54	.641	.0349
Branching	" "	12.14	18.22	.564	.0312	16.15	21.55	1.063	.0375
Time	" "	12.50	18.24	.498	.0232	16.19	21.58	.711	.0317
B and T	" "	12.10	18.21	.784	.0175	16.14	21.57	.528	.0173
Grand Ave	" "	12.22	18.23	.626	.0237	16.17	21.56	.736	.0304
True Value	" "	12.22	18.26	.819	.0309	–	–	–	–
None	Std. Dev.	5.18	2.56	.0681	.0207	4.43	3.00	.236	.0144
Branching	" "	5.16	2.51	.1665	.0140	4.48	3.01	.399	.0278
Time	" "	5.38	2.55	.1501	.0107	4.53	2.98	.183	.0249
B and T	" "	5.09	2.56	.3845	.0126	4.45	3.05	.202	.0114
Grand Ave.	" "	5.20	2.54	.1923	.0145	4.47	3.01	.255	.0196
True Value	" "	5.08	2.60			–	–	–	–
None	Prob. of Realizing	.128	–	.000368	–	.123	–	.000278	–
Branching	" " "	.131	–	.000389	–	.132	–	.000331	–
Time	" " "	.121	–	.000426	–	.120	–	.000384	–
B and T	" " "	.123	–	.000368	–	.124	–	.000215	–
Grand Ave.	" " "	.126	–	.000388	–	.125	–	.000302	–
True Value	" " "	.121	–	.000426	–	.121	–	.000426	–

APPENDIX III

The following text will explain in general some of the important features of the GERT program.

The program functions around the arrays or files NSET (the activity file) and QSET (the probability or time file). NSET is set up so that each node has associated (by means of pointers) with it, a file of activities emanating from the node. Every node can be considered a separate file in the range 2 to NOQ, except those nodes which do not appear in the network. File 1 which would be associated with node 1, if node 1 was allowed, is used to store all activities as they occur in the network and therefore will be called the working file. QSET contains, for the original data read in, the probability of an activity occurring. The values of QSET associated with the activities contained in the working file are the times at which the activity occurs.

The files are initially set up by Datan reading the activity information from cards and calling Filem to put the activities in the activity file. The portion of NSET and QSET read in will be called the static file. Once the file is set up all activities are scheduled by Schat and put into the working file.

After an activity is taken from the working file (by Rmove according to lowest time first) and is realized, the following sequence (in the order given) of events happen: (1) the cost is accumulated, (2) the node counter is decremented, (3) activity cancellation(if specified), (4) node resets (if specified), (5) node modifications (if specified), and lastly (6) check to see if the node decremented has been realized. If the node has not been realized the program will remove another activity from the working file.

Once a node has been realized, the program (by Schat) immediately schedules all activities emanating from that node and puts them into the working file, along with the associated time.

The program will schedule and realize activities until either the network is realized or it has found no more activities in the working file, in which case, an error occurs.

Figure III-1 gives an example of the network of Figure 3 during execution. The static file is contained in locations 15 through 26. The top half of Figure III-1 shows two activities in process in the working file. The bottom half shows the file at a later time.

FILE STATUS AT TIME 8.5732 ON RUN NUMBER 1 MFE(1) = 1 NQ(1) = 2 IBRNCH = 0 ITIME = 0

	QSET	NSET									
1	0.928485E 01	5	7	6	3	0	11	0	1	15	9999
2	0.100000E 01	2	3	7	1	0	0	0	0	7777	9999
3	0.100000E 01	3	4	2	2	0	1	4	2	7777	9999
4	0.100000E 01	4	5	3	2	0	4	2	1	5	9999
5	0.100000E 01	4	5	4	2	0	5	1	0	7777	4
6	0.100000E 01	5	7	5	2	0	0	5	1	7	9999
7	0.100000E 01	5	7	6	3	0	11	0	1	7777	6
8	0.100000E 01	10	11	5	2	0	9	5	1	7777	9999
9	0.100000E 01	7	8	3	2	0	0	2	2	7777	9999
10	0.100000E 01	11	8	3	2	0	10	2	2	7777	9999
11	0.500000E 00	8	4	1	1	0	2	0	0	13	9999
12	0.950000E 00	12	3	1	1	0	3	0	0	14	9999
13	0.100000E 01	8	12	1	1	0	0	0	0	7777	11
14	0.100000E 01	12	13	1	1	0	0	0	0	7777	12
15	0.109116E 02	5	7	5	2	0	0	5	1	7777	1
16	0.0	0	0	0	0	0	0	0	0	17	9999
17	0.0	0	0	0	0	0	0	0	0	18	16
18	0.0	0	0	0	0	0	0	0	0	19	17
19	0.0	0	0	0	0	0	0	0	0	20	18
20	0.0	0	0	0	0	0	0	0	0	21	19
21	0.0	0	0	0	0	0	0	0	0	22	20
22	0.0	0	0	0	0	0	0	0	0	23	21
23	0.0	0	0	0	0	0	0	0	0	24	22
24	0.0	0	0	0	0	0	0	0	0	25	23
25	0.0	0	0	0	0	0	0	0	0	26	24
26	0.0	0	0	0	0	0	0	0	0	8888	25

FILE STATUS AT TIME 10.9116 ON RUN NUMBER 1 MFE(1) = 15 NQ(1) = 1 IBRNCH = 0 ITIME = 0

	QSET	NSET									
1	0.0	0	0	0	0	0	0	0	0	16	9999
2	0.100000E 01	2	3	7	1	0	0	0	0	7777	9999
3	0.100000E 01	3	4	2	2	0	1	4	2	7777	9999
4	0.100000E 01	4	5	3	2	0	4	2	1	5	9999
5	0.100000E 01	4	5	4	2	0	5	1	0	7777	4
6	0.100000E 01	5	7	5	2	0	0	5	1	7	9999
7	0.100000E 01	5	7	6	3	0	11	0	1	7777	6
8	0.100000E 01	10	11	5	2	0	9	5	1	7777	9999
9	0.100000E 01	7	8	3	2	0	0	2	2	7777	9999
10	0.100000E 01	11	8	3	2	0	10	2	2	7777	9999
11	0.500000E 00	8	4	1	1	0	2	0	0	13	9999
12	0.950000E 00	12	3	1	1	0	3	0	0	14	9999
13	0.100000E 01	8	12	1	1	0	0	0	0	7777	11
14	0.100000E 01	12	13	1	1	0	0	0	0	7777	12
15	0.132436E 02	7	8	3	2	0	0	2	2	7777	9999
16	0.0	0	0	0	0	0	0	0	0	17	1
17	0.0	0	0	0	0	0	0	0	0	18	16
18	0.0	0	0	0	0	0	0	0	0	19	17
19	0.0	0	0	0	0	0	0	0	0	20	18
20	0.0	0	0	0	0	0	0	0	0	21	19
21	0.0	0	0	0	0	0	0	0	0	22	20
22	0.0	0	0	0	0	0	0	0	0	23	21
23	0.0	0	0	0	0	0	0	0	0	24	22
24	0.0	0	0	0	0	0	0	0	0	25	23
25	0.0	0	0	0	0	0	0	0	0	26	24
26	0.0	0	0	0	0	0	0	0	0	8888	25

Figure III-1

How To Input Data

Data Card 1		Card Columns**
Field 1	Analyst's name (6A2) (Name(6))	1-12
Field 2	Project number, if negative data card 11 is required (I4) (Nproj)	13-16
Field 3	Month (I2) (Mon)	17-18
Field 4	Day (I2) (Nday)	19-20
Field 5	Year (I4) (Nyr)	21-24
Field 6	Number of times network is to be simulated (I4) (Nruns)	25-28
Field 7	Number of parameter sets (I4) (Nprms)	29-32
Field 8	The largest number of activities which can be accomodated in the activity file. For most networks twice the number of nodes is sufficient. The maximum size of this is 500, although it can be expanded depending on the memory of the machine used. (I4) (Id)	33-36
Field 9	Integer random number seed (I10) (Jseed) any large odd number	37-46
Field 10	Starting value of cost histogram (F10.0) (Cstar)	N 47-56
Field 11	Cell width of cost histogram (F10.0) (Cinc)	N 57-66

Data Card 2		
Field 1	Largest node number used (I3) (Noq)	1-3
Field 2	Number of source nodes (I3) (Nsrc)	4-6
Field 3	Number of sink nodes (I3) (Npd)	7-9

**All numbers are right justified unless they can be placed anywhere in the field when punched with a decimal point in which case an 'N' appears before the column numbers.

		Card Columns**
Field 4	Number of sink nodes that must be realized before the network is realized (I3) (Nskst)	10-12
Field 5	Number of nodes on which statistics are to be collected, including all sink nodes (I3) (Nsks)	13-15
Field 6	Number of types of counts (Max of 4) (I3) (Ncts)	16-18
Field 7	A '1' if network modifications exists otherwise a blank or zero (I3) (Nnm)	19-21
Field 8	A '1' if node resets exist; '0' or blank otherwise (I3) (Nnr)	22-24
Field 9	A '1' if activity cancellation exists; '0' or blank otherwise (I3) (Loop)	25-27
Field 10	A '1' if antithetic time; '0' or blank otherwise (I3) (Itime)	28-30
Field 11	A '1' if antithetic branching; '0' or blank otherwise (I3) (Ibrnch)	31-33
Field 12	The number of times the program is to be restarted from run 1 using a different random number; if '0', '1', or blank, '1' is assumed (I3) (Lupdo)	34-36
Field 13	Option to print average time that node is first realized for every node in the network, the average time for the activity (difference of the averages of the two nodes the activity is between), percentage of time node is realized (number of times realized/number of runs); a '1' if print option wanted; '0' or blank if not (I3) (Nprtop)	37-39
Field 14	If logic node reset is used a '1' otherwise '0' or blank; if '1' then data card 3A is required (I3) (Logic) otherwise leave out	40-42

		Card Columns**
△ Data Card 3		
Fields 1-25	The source node numbers followed by the sink node numbers followed by any other nodes on which statistics are to be collected. (25I3) (Nsorc(Nsrc), Nsink (Nsks))	1-3 4-6 . . . 72-75
Data Card 3A		

Needed only if a '1' is punched in Field 14 of Data Card 2.

Field 1	The number of realizations of the logic reset node (I3) (Nrelp(1))	1-3
△ Data Card 4		
Fields 1-25	The number of realizations necessary to realize each node starting with node 2 and giving a value for each and every node sequentially until the maximum node number. If the realizations are zero it may be put in or left blank (25I3) (Nrelp (Noq))	1-3 4-6 72-75
△ Data Card 5		
Fields 1-25	The node type of each node from 2 to the end node with a value given for each. If the node is not used, zero or blank may be used. (25I3) (Ntype(Noq))	1-3 4-6 72-75
	Node Type 1 can be realized only once per realization of the network.	
	Node Type 5 deterministic output - is reset to original number of releases.	
	Node Type 6 probabalistic output - is reset to original number of releases.	

△With at most 25 values per card for as many cards as needed.

		Card Columns**
ΔΔ Data Card 6		
Field 1-8	The lower limit of the histograms for the sink nodes and for the nodes statistics are to be collected on, in the order in which they appear on Data Card 3. (8F10.0) (Xlow(Nsks))	N 1-10 N 11-20 . . . N 71-80
ΔΔ Data Card 7		
Fields 1-8	The cell width of the histograms for the sink nodes and for the nodes statistics are to be collected in the order which they appear on Data Card 3, (8F10.0) (Width(Nsks))	N 1-10 N 11-20 . . . N 71-80

Data Card 8

The next (Nprms) cards with one parameter definition per card. (Param (Nprms,4))

Fields 1-4	(Depends on distribution) (4F10.0)	N 1-10 N 11-20 N 21-30 N 31-40

Distribution Type 1 - Constant

Field 1 The constant time

Fields 2-4 Not used

Distribution Type 2 - Normal

Field 1 Mean Value

Field 2 Minimum Value

Field 3 Maximum Value

Field 4 Standard Deviation

Distribution Type 3 - Uniform

Field 1 Not Used

Field 2 Minimum Value

ΔΔ With at most 8 values per card for as many cards as needed.

Field 3 Maximum Value

Field 4 Not Used

Distribution Type 4 - Erlang

Field 1 Mean time for the erlang variable divided by the value given in Field 4.

Field 2 Minimum Value

Field 3 Maximum Value

Field 4 Number of exponential deviates to be included in the sample obtained from the erlang distribution.

Distribution Type 5 - Lognormal

Given μ = mean of lognormal

σ^2 = Variance of lognormal

Min Q = Smallest allowable value

Max Q = Largest allowable value

Field 1 $\text{Ln}\ \mu - 1/2\ (\text{value of Field 4})^2$

Field 2 Ln (min Q)

Field 3 Ln (max Q)

Field 4 $\sqrt{\text{Ln}\ (\sigma^2/\mu^2 + 1)}$

Distribution Type 6 - Poisson

Field 1 Mean minus minimum value

Field 2 Minimum Value

Field 3 Maximum Value

Field 4 Not Used

The interpretation of the mean for the poisson distribution should be the mean number of time units per time period.

If the random time generated is greater than the maximum allowable or less than the minimum allowable, the time will be set to whichever limit was exceeded.

Data Card 9		Card Columns**

This card inputs the activity and probability files.

Field 1	Probability of activity occurring (F8.0) (Atrib)	N 1-8
Field 2	Start node (I3) (Jtrib(1))	9-11
Field 3	End node (I3) (Jtrib(2))	12-14
Field 4	Parameter number (I3) (Jtrib(3))	15-17
Field 5	Distribution type (I3) (Jtrib(4))	18-20
Field 6	Count type (I3) (Jtrib(5))	21-23
Field 7	Activity number (I3) (Jrib(6))	24-26
Field 8	Variable cost for activity (I3) if zero can be left blank (Jtrib(7))	27-29
Field 9	Fixed cost for activity (I3) if zero can be left blank (Jtrib(8))	30-32

The last card of this type has a zero or blank for Field 2.

*Data Card 10

Only required if network modifications exist; a '1' in Field 7 of Data Card 2.

Field 1	Activity number (I3)	1-3
Field 2	Number of node to be modified (I3)	4-6
Field 3	Number of node inserted (I3)	7-9
Fields 4-25	Repetition of Fields 2 and 3 (Naba(1,K))	72-75

The last data card of this type must have a blank or zero in Field 1.

---

*For Data Cards 10, 10A and 10B continuation may exist. The continuation card must have the same activity number and must follow immediately the card being continued. The number of continuation cards allowed only depends on the memory allowance.

*Data Card 10A		Data Columns**

Only required if using node resets. A '1' punched in Field 8 of Data Card 2.

Field 1	Activity number (I3)	1-3
Field 2	Node number to be changed (I3)	4-6
Field 3	Number of node which has the original number of releases that is required for the node in Field 2 (I3)	7-9
Field 4-25	Repeat Field 2 and Field 3 (Naba(2,K))	10-12
		.
		.
		73-75

The last card of this type must have a zero or blank in Field 1.

*Data Card 10B

Only required if activity cancellation is required. A 'I' punched in Field 9 of Data Card 2.

Field 1	Activity number (I3)	1-3
Field 2	The node number from which activities in process emanate are destroyed (I3)	4-6
Field 3-25	Repetition of Field 2 (Naba(3,K))	7-9
		.
		.
		73-75

The last card of this type must have a zero or blank in Field 1.

Data Card 11

Only used if project number (Data Card 1, Field 2) is negative.

Field 1	The run number for which tracing should begin (I3) Naba(1, Imn)	1-3

		Card olumns**
Field 2	The run number for which tracing should end (I3) (Naba(1, Imn-1))	4-6

Multiple networks may be simulated by stacking the data cards for each network one after the other with no intervening cards.

(Example of Input and Output)

To illustrate the preparation of data the following example will be used. It should be noted that the network is that given in Figure 3. The costs used can represent mental and physical exertion. The input data is given in Figure III-3. The output is given in Figure III-4 and Figure III-4A.

Figure III-4 shows what was originally read in and gives a small portion of tracing. Figure III-4A shows the answers for time and cost. The bottom of this figure illustrates what is printed, if the print option is specified (Data Card 2, Field 13). The 'Time/End Node' column gives the average time at which the end node shown is first realized. The 'Time/Activity' takes the difference of the 'Time/End Node' for the start and end nodes of the activity. The 'Percent' column is calculated as the number of times the end node shown is first realized divided by the total number of realizations of the network.

```
R. A. CLARK -33 6 11970   50   .7  36      5271 0.0        20.0           GF010
 13  1   1   1   1   0   1   0   0   0   0  0   1   0                     GF020
  2 13                                                                    GF030
  0  1   1   2   0   2   1   0   2   1   1  1                             GF040
  1  5   5   5   0   5   6   0   5   5   6  1                             GF050
0.0
50.0
0.0                                                                       GF080
1.0          0.0         2.0         0.3                                  GF090
3.0          0.0         6.0         1.0                                  GF100
5.0          0.0         10.0        2.0                                  GF110
2.0          0.0         3.5         0.5                                  GF120
             0.0         1.0                                              GF130
1.0
1.0          2   3   7   1   0   0   0   0
1.0          3   4   2   2   0   1   4   2                                GF150
1.0          4   5   3   2   0   4   2   1                                GF160
1.0          4   5   4   2   0   5   1   0                                GF170
1.0          5   7   5   2   0   0   5   1                                GF180
1.0          5   7   6   3   0  11   0   1                                GF190
1.0         10  11   5   2   0   9   5   1                                GF200
1.0          7   8   3   2   0   0   2   2                                GF210
1.0         11   8   3   2   0  10   2   2                                GF220
0.5          3   4   1   1   0   2   0   0                                GF230
0.95        12   3   1   1   0   3   0   0                                GF240
0.5          8  12   1   1   0   0   0   0                                GF250
0.05        12  13   1   1   0   0   0   0                                GF260
             0                                                            GF270
  2  5  10                                                                GF280
  3 10   5                                                                GF290
  0                                                                       GF300
  1  1                                                                    GF310
```

NOT REPRODUCIBLE

Figure III-3. Input Data

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GERT SIMULATION PROJECT -33 BY R. A. CLARK
DATE 6/ 1/ 1970

NETWORK DESCRIPTION

START NODE	END NODE	PARAMETER NUMBER	DISTRIBUTION TYPE	COUNT TYPE	ACTIVITY NUMBER	VAR. COST	FIX. COST	PROBABILITY
2	3	7	1	0	0	0	0	1.0000
3	4	2	2	0	1	4	2	1.0000
4	5	3	2	0	4	2	1	1.0000
4	5	4	2	0	5	1	0	1.0000
5	7	5	2	0	0	5	1	1.0000
5	7	6	3	0	11	0	1	1.0000
7	8	3	2	0	0	2	2	1.0000
8	4	1	1	0	2	0	0	0.5000
8	12	1	1	0	0	0	0	0.5000
10	11	5	2	0	9	5	1	1.0000
11	8	3	2	0	10	2	2	1.0000
12	3	1	1	0	3	0	0	0.9500
12	13	1	1	0	0	0	0	0.0500

ACTIVITY PARAMETERS

PARAMETER NUMBER	PARAMETERS 1	2	3	4
1	0.0	0.0	0.0	0.0
2	1.0000	0.0	2.0000	0.3000
3	3.0000	0.0	6.0000	1.0000
4	5.0000	0.0	10.0000	2.0000
5	2.0000	0.0	3.5000	0.5000
6	0.0	0.0	1.0000	0.0
7	1.0000	0.0	0.0	0.0

NETWORK MODIFICATIONS

IVITY NODE FILE NODE FILE NODE FILE NODE FILE NODE FILE NODE FILE NODE FILE NODE FILE NODE FILE NODE FILE NODE FILE NODE FILE NODE FILE

2	5	10	0
3	10	5	0

HIGHEST NODE NUMBER IS 13
NUMBER OF SOURCE NODES IS 1
NUMBER OF SINK NODES IS 1
NUMBER OF NODES TO REALIZE THE NETWORK IS 1
STATISTICS COLLECTED ON 1 NODES
NUMBER OF PARAMETER SETS IS 7
INITIAL RANDOM NUMBER IS 5271
ANTITHETIC TIME INDICATOR IS 0
ANTITHETIC BRANCH INDICATOR IS 0

SOURCE NODE NUMBERS
2

SINK NODE NUMBERS
13

NODE	NUMBER RELEASES	NODE TYPE
1	0	0
2	0	1
3	1	5
4	1	5
5	2	5
6	0	0
7	2	5
8	1	6
9	0	0
10	2	5
11	1	5
12	1	6
13	1	1

AT TIME 1.00 ACTIVITY ON NODE 3 WITH ATTRIBUTES 7 1 0 0 0 0 WAS REALIZED ACCUMULATED COST = 0.0

AT TIME 2.25 ACTIVITY ON NODE 4 WITH ATTRIBUTES 2 2 0 1 4 2 WAS REALIZED ACCUMULATED COST = 7.01

AT TIME 4.84 ACTIVITY ON NODE 5 WITH ATTRIBUTES 3 2 0 4 2 1 WAS REALIZED ACCUMULATED COST = 13.17

AT TIME 8.57 ACTIVITY ON NODE 5 WITH ATTRIBUTES 4 2 0 5 1 0 WAS REALIZED ACCUMULATED COST = 19.50

AT TIME 9.28 ACTIVITY ON NODE 7 WITH ATTRIBUTES 6 3 0 11 0 1 WAS REALIZED ACCUMULATED COST = 20.50

AT TIME 10.91 ACTIVITY ON NODE 7 WITH ATTRIBUTES 5 2 0 0 5 1 WAS REALIZED ACCUMULATED COST = 33.19

AT TIME 13.24 ACTIVITY ON NODE 8 WITH ATTRIBUTES 3 2 0 0 2 2 WAS REALIZED ACCUMULATED COST = 39.85

AT TIME 13.24 ACTIVITY ON NODE 12 WITH ATTRIBUTES 1 1 0 0 0 0 WAS REALIZED ACCUMULATED COST = 39.85

AT TIME 13.24 ACTIVITY ON NODE 3 WITH ATTRIBUTES 1 1 0 3 0 0 WAS REALIZED ACCUMULATED COST = 39.85

NODE 10 WAS CHANGED TO NODE 5 AND SET TO 2

AT TIME 13.98 ACTIVITY ON NODE 4 WITH ATTRIBUTES 2 2 0 1 4 2 WAS REALIZED ACCUMULATED COST = 44.78

AT TIME 17.51 ACTIVITY ON NODE 5 WITH ATTRIBUTES 3 2 0 4 2 1 WAS REALIZED ACCUMULATED COST = 52.85

AT TIME 22.10 ACTIVITY ON NODE 5 WITH ATTRIBUTES 4 2 0 5 1 0 WAS REALIZED ACCUMULATED COST = 60.98

AT TIME 22.88 ACTIVITY ON NODE 7 WITH ATTRIBUTES 6 3 0 11 0 1 WAS REALIZED ACCUMULATED COST = 61.98

Figure III-4

GERT SIMULATION PROJECT -33 BY R. A. CLARK
DATE 6/ 1/ 1970

FINAL RESULTS FOR 50 SIMULATIONS

NODE	PROB./COUNT	MEAN	STD.DEV.	MIN.	MAX.
13	1.0000	400.4487	299.7185	10.3260	1023.9724

HISTOGRAMS

NODE	LOWER LIMIT	CELL WIDTH	FREQUENCIES										
13	0.0	50.00	0	3	5	5	2	5	3	3	4	2	3
			1	0	1	2	2	1	3	1	1	0	3
			0	0	0	0	0	0	0	0	0	0	

HISTOGRAMS

NODE	LOWER LIMIT	CELL WIDTH	FREQUENCIES										
COST	0.0	20.00	0	0	1	0	1	0	0	1	0	1	1
			1	0	1	0	0	0	1	1	3	0	0
			0	1	0	0	1	0	0	0	0	36	

AVE. COST PER REALIZATION 1280.54
STANDARD DEVIATION 959.73
MIN. COST FOR REALIZATION 35.74
MAX. COST FOR REALIZATION 3334.73

NODE START	END	WITH ATTRIBUTES						TIME/END NODE	TIME/ACTIVITY	PERCENT
2	3	7	1	0	0	0	0	1.00	1.00	1.00
3	4	2	2	0	1	4	2	2.03	1.03	1.00
4	5	3	2	0	4	2	1	7.41	5.38	1.00
4	5	4	2	0	5	1	0	7.41	5.38	1.00
5	7	5	2	0	0	5	1	9.44	2.03	1.00
5	7	6	3	0	11	0	1	9.44	2.03	1.00
7	9	3	2	0	0	2	2	12.46	3.02	1.00
8	4	1	1	0	2	0	0	2.03	-10.43	1.00
8	12	1	1	0	0	0	0	26.85	14.39	1.00
10	11	5	2	0	9	5	1	29.04	1.99	0.96
11	8	3	2	0	10	2	2	12.46	-16.58	1.00
12	3	1	1	0	3	0	0	1.00	-25.85	1.00
12	13	1	1	0	0	0	0	400.45	373.60	1.00

Figure III-4A

A list of variables not explained in the input data description.

ACTIME (NOQ)	Stores the time a node has been realized.
ATIME (MAXA)	Array used to store the values of antithetic times.
ATRIB	Used to transfer values to and from Qset.
BRNCH (MAXA)	Used to store antithetic branching probabilities.
CMAX	Stores maximum cost.
CMIN	Stores minimum cost.
COSSQR	Stores the $\Sigma_i\ (cost_i)^2$.
COST	The cost for realization.
CSAVE(NOQ)	Counts the number of times the node has first been realized.
IM	Number of entries for an activity, excluding the two pointers, in NSET.
IMM	Specifies number of antithetic variables stored.
IMN	Specifies size of array NABA
ISEED	Random number generator seed.
JCELS (NHIST,MXC)	Array used to store histogram information.
KLE	Last entry in file indicator (9999)
KOF	Last entry of array NSET indicator (8888)
KOL	Beginning of node file indicator (7777)
KOUNT(NCTS)	Used to store count statistics.
KOWT	Used as error counter.
MAXA	Maximum number of locations for antithetic storage.
MAXNS	Maximum number of locations of NSET used = ID*MXX
MFA	First available location in NSET for next activity
MFE(NOQ)	First entry in a file.

MLE(NOQ)	Last entry in a file.
MX	= IM+1
MXC	Number of cells in histogram.
MXX	= IM+2
NCLCT	Number of sets of statistics that can be collected in COLCT.
NCRDR	Number used for card reader.
NFTBU(NOQ)	Used to store the next node to be used.
NHIST	The number of nodes that have histograms = NSKS
NPO (3, activity number)	Stores the location of modifications in NABA by activity number.
NPRNT	Number of the printer
NQ(NOQ)	Current number of entries in any file.
NREL(NOQ)	Number of releases to go for each node.
NRUN	Counter incremented after each realization until it = NRUNS
NSET(MAXNS)	Stores all activities and the activity working file.
NSKSR	= NSKST
NTYPE(NOQ)	Stores the node type for each node.
QSET(ID)	Stores the probability or time for each activity.
SUMA(NSKS,5)	Stores the statistics collected
TIBR	Used for antithetic time and branching.
TNOW	The time now of a realization.
TOTIM	Total Time.
TSAVE(NOQ)	Saves the sum of the times the node is first realized.