PERT and Its Application to Highway Management

ROBERT N. GRUNOW, U. S. Bureau of Public Roads

Recognizing the value of several management tools such as Critical Path Method (CPM) and Program Evaluation Review Technique (PERT), the Committee on Highway Programing at its annual meeting in January 1962 assigned the writer to investigate the possible use of PERT and its application by highway management in prosecution of highway project programing. The writer at that time was a staff member of the Highways Division of the Automotive Safety Foundation, which was engaged in a programing study for the Joint Legislative Fact-Finding Committee on Highways, Streets and Bridges in the State of Washington. The Foundation in the pursuit of its duties with the Legislative Committee worked closely with the Washington State Highway Department. Thus a workshop was provided to the writer.

•HIGHWAY MANAGEMENT has become very complex. Ever present are obstacles which thwart the manager's responsibility to best utilize all resources so as to complete a task on time.

Highway management is not confined to the top level, such as the commission or the director. There are many levels, extending down to the project engineer and supervisory personnel such as a chief of party. The difference is in the degree of authority and the breadth of responsibility. However, three purposes are common at all levels.

Each has a specific objective. The commission or the director primarily is concerned with the total operation of the state highway system, the district engineer with operations within the district, and the project engineer with the completion of his project.

Each must organize all available resources by means of a logical and time-phased plan to reach his objective.

Each must be able to measure actual performance in terms of the plan in order to manipulate resources to meet changing conditions.

Highway engineers with long tenure of service at all levels of operation are familiar with their job and can plan and program activities from experience. However, they are plagued with delays from numerous sources (for example, lack of manpower, non-availability of right-of-way, lack of approvals by other units of government, and securing necessary agreements).

New appointive or elected officials heading highway departments are often unfamiliar with laws, rules and regulations that govern department operations and may impose unwarranted demands upon engineers, causing confusion and unnecessary delays in instituting needed improvements.

Both the career engineer and the political official need a management plan that will enable them to know the workings of their complex operation; to anticipate time,

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money and manpower required for each operation; to manipulate resources to hold the plan on schedule; to concentrate on the critical phases of the schedule; and to determine how, when and with what results the schedule can be increased, retarded or adjusted.

MANAGEMENT TOOLS

Several management tools have been developed and are in use today in business, industry and government. These management tools have been highly successful in planning and manipulating resources to attain a stated goal.

All of these tools aid the manager in performing his function more decisively. They do not manage by themselves nor are they intended to usurp the manager's duties.

All of these tools display the problem in perspective so that all factors relating to the problem can be judged. They are an effective method of reducing uncertainty so that timely decisions can be made and corrective actions taken pertinent to the actual problem which have a predictable possibility of success.

All tools employ two basic elements: (1) Events or happenings such as a completed field survey which can be described as a point in time, and (2) activities or the forces necessary to produce these events, expressed in time consumed.

All tools use a graphic representation of the plan which portrays the events and activities in their logical sequence of completion.

Management tools that have been most successful are always cited as examples of what can be done. Some of these are the development of the Polaris missile and individual construction projects. Each example, although composed of many interdependent operations, resulted in one end product.

Highway programs, like the Polaris missile program, have one end product if the objective is the total program in a given length of time. Highway programs differ in the respect that the total program is composed of individual projects varying greatly in the number of events and activities required to meet the objective.

Several simple resurfacing projects could be started and completed in the same time required for a single complex project involving multiple hearings, purchases of rights-of-way, utility agreements, and cooperation with other units of government. They are further complicated by the fact that in some states individual project development is delegated to several district offices.

How to combine all the projects of varying magnitude into one management system, with one end objective, requires considerable research.

It is the intent of this paper to suggest an idea as to how one of these management tools may be applied to control a group of isolated individual projects which, in one sense, comprises a single annual objective of a highway department. It is not the intent to delve deeply into the mechanics of the management tool's characteristics.

PERT

There are several of these management tools in use today. Among these are the Critical Path Method (CPM), Program Evaluation Review Technique (PERT) and, more recently, Resource Allocation and Multi-Project Scheduling (RAMPS).

The Critical Path Method employs one time and one cost estimate for each activity.

The Program Evaluation Review Technique utilizes three time estimates and no costs for each activity.

The Resource Allocation and Multi-Project Scheduling method goes beyond PERT in introducing competition among activities for a given resource and in jointly handling many projects, many resources, and many costs.

The first step in the implementation of any of these management tools is to thoroughly define events and their interdependency one with the other, estimate the time required to produce each event, and display them graphically in a total network. The difficulty encountered in most methods has been estimating the time required from the activity. This problem is lessened where an activity has been done over and over and the time element is fairly firm. Where this is not the case, estimated completion dates can be widely misjudged.

PERT employs a method of estimating time to narrow the limits of error. Three time estimates are used: the most optimistic, t_o, which is one chance in 100 that the activity can be completed in the shortest time; the most likely, t_m, which in the experience of the estimator is the time which would most often be required if the activity were performed 100 times; and the most pessimistic, t_p, or the maximum time required if everything went wrong. These three time estimates are then weighted and averaged to arrive at the expected time, t_e, or the one that has a statistical 50-50 probability. The formula used is

$$t_e = \frac{t_o + 4\,t_m + t_p}{6} \tag{1}$$

PERT at present does not directly use costs of operation as a factor in influencing judgment for action. Savings according to proponents of PERT are reflected in the following eight benefits:

1. It can be used for small non-technical tasks, as well as complex engineering projects.
2. It demands, and forces, complete and logical planning.
3. It is a major organizing mechanism.
4. It provides an excellent communication medium.
5. It reveals the relationships inherent to work effort within a project.
6. It calls attention to critical problems.
7. It provides for a reporting system to show status of project at all times.
8. It is a means of assigning responsibilities.

APPLICATION OF PERT TO A HIGHWAY PROGRAM

Initial investigation as to the feasibility of applying PERT to a highway program was made possible during the programing study for the Washington State Joint Legislative Fact-Finding Committee. Washington State Highway Department headquarters staff and district engineers cooperated with ASF staff to determine significant events and the sequence of actions from the inception of projects into their biennium budget until the

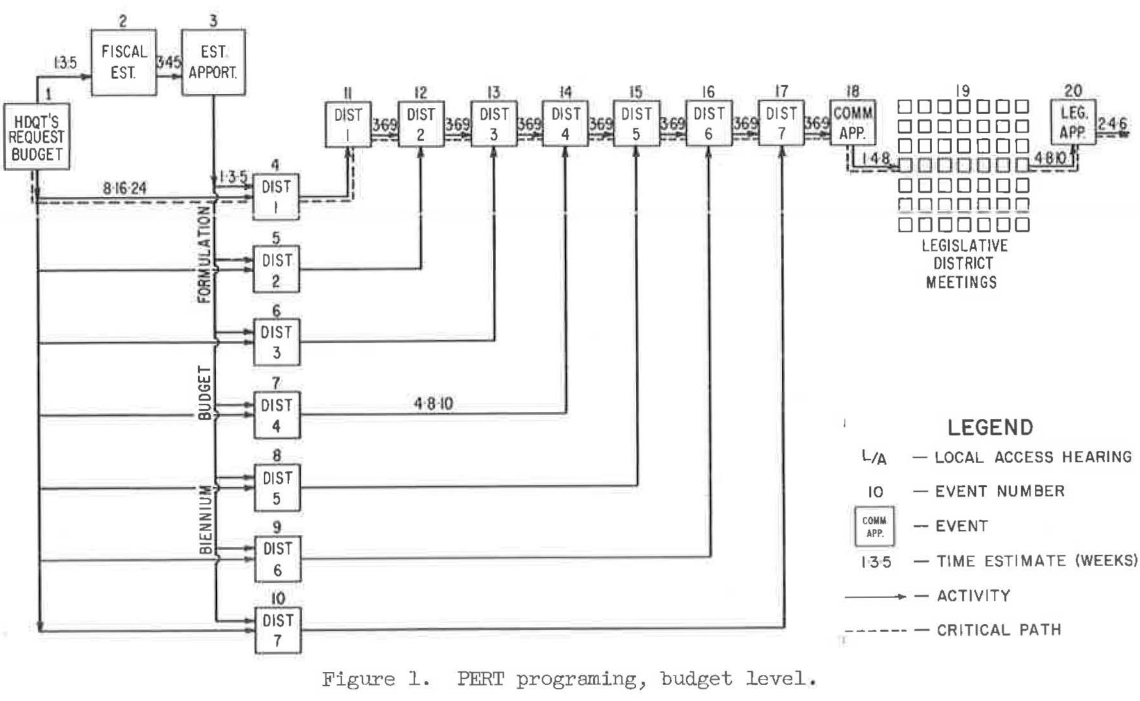

Figure 1. PERT programing, budget level.

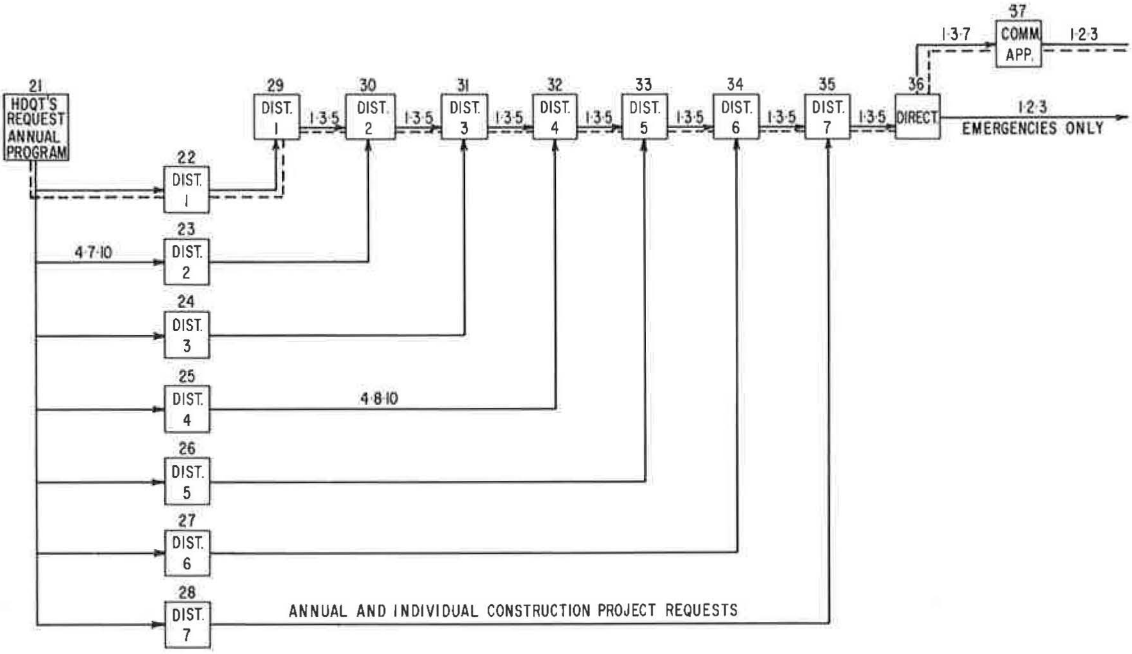

Figure 2. PERT programing, construction program.

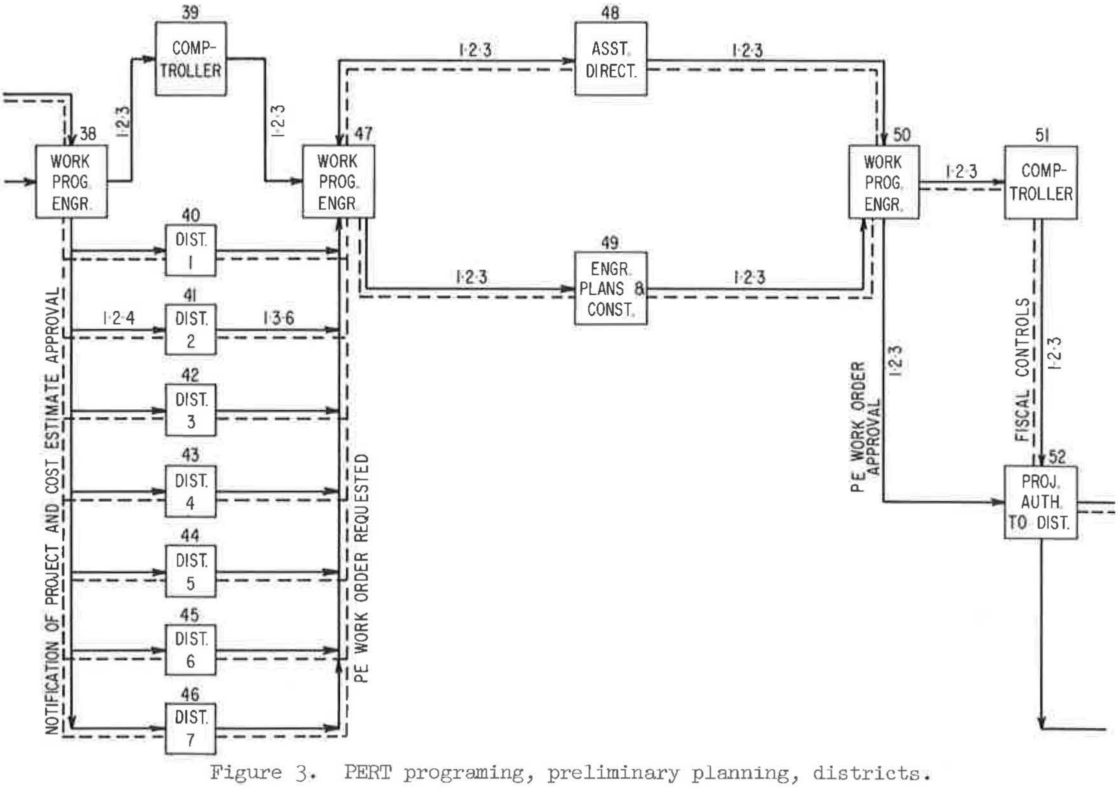

Figure 3. PERT programing, preliminary planning, districts.

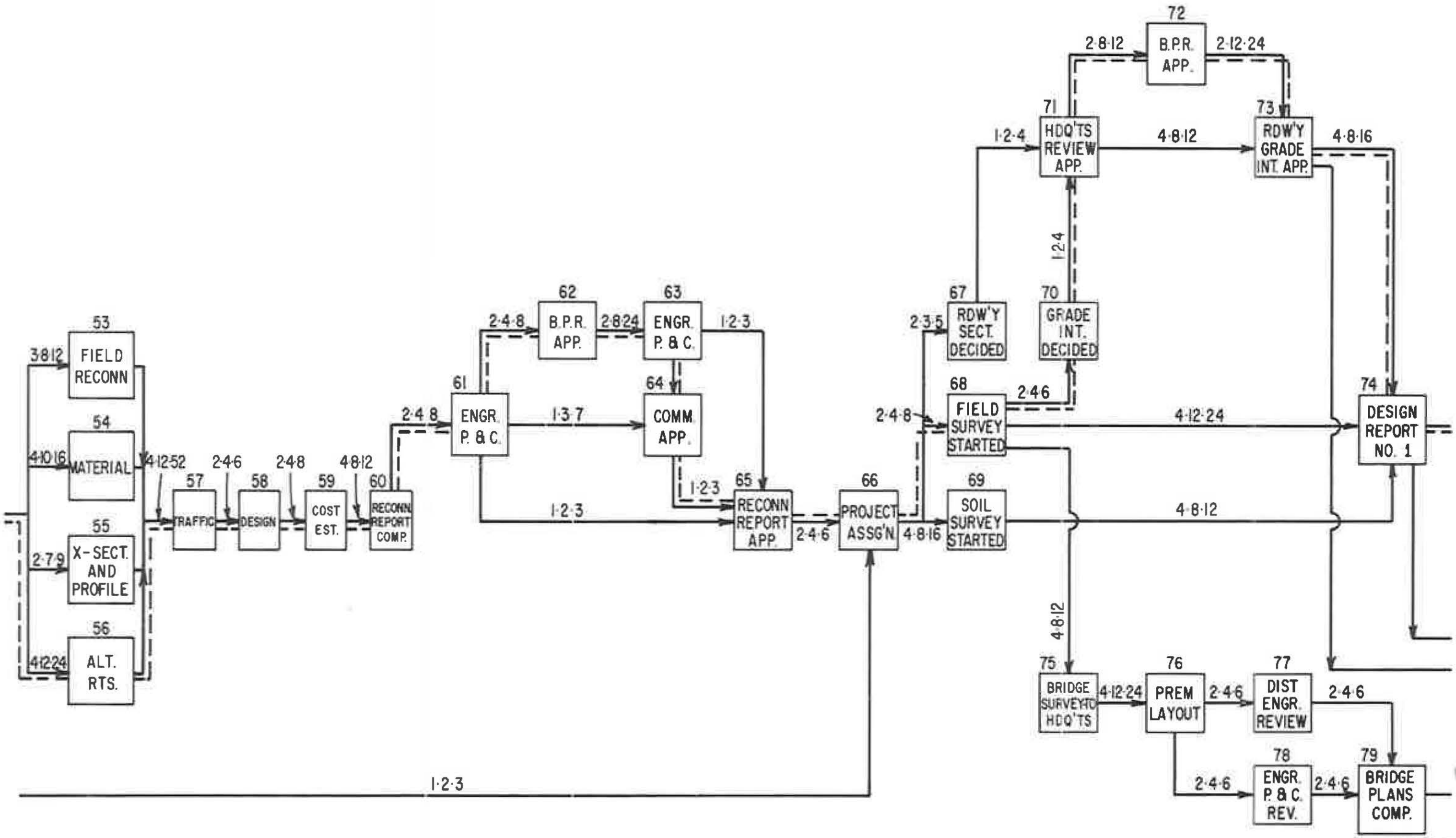

Figure 4. PERT programing, preliminary engineering and design.

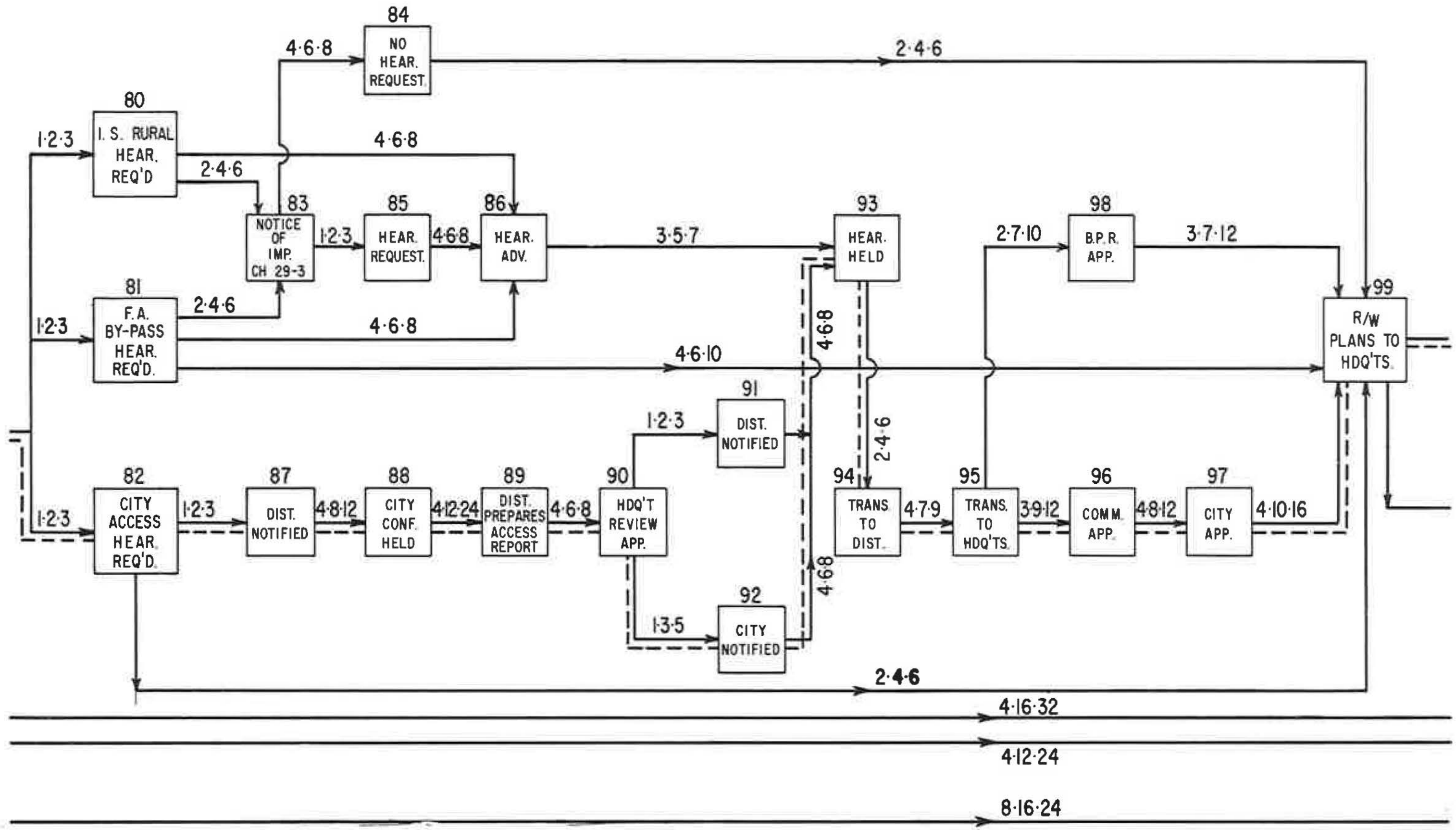

Figure 5. PERT programing, highway and right-of-way plans.

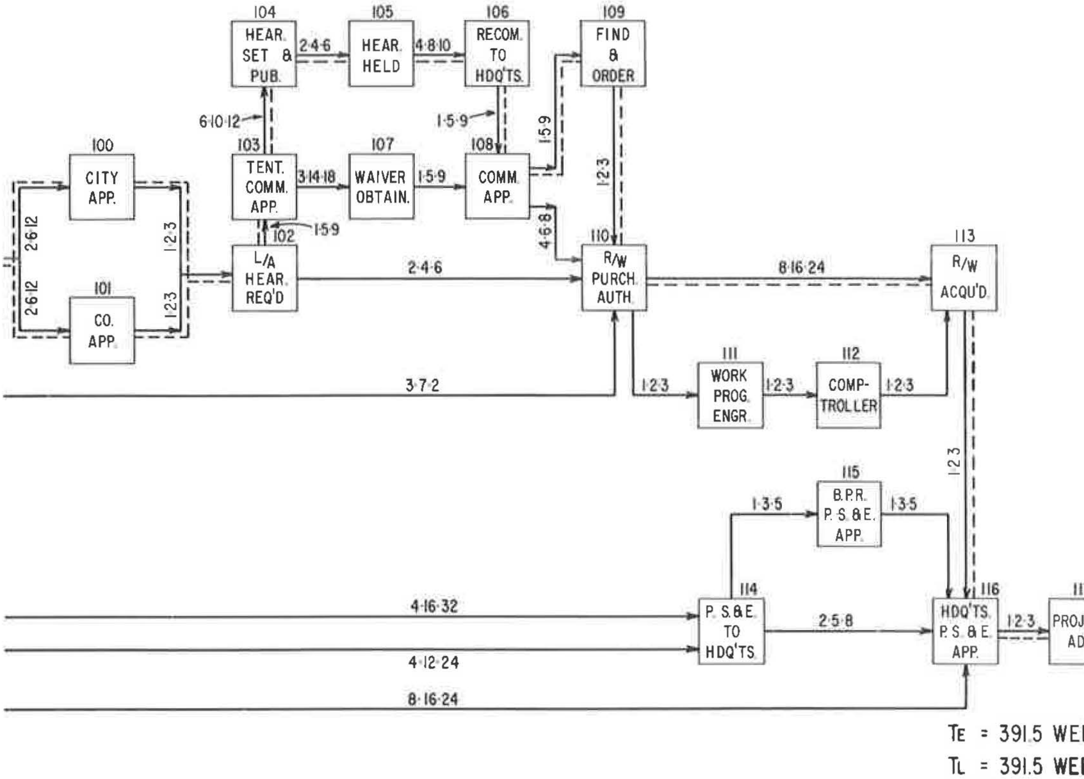

Figure 6. PERT programing, project approval and advertising.

project was advertised for construction. The Department also provided the three time estimates necessary to produce each event. ASF staff then produced a network diagram of the events and activities. Originally the network diagram was continuous, but for purposes of reproduction in this paper it is subdivided into six sections (Figs. 1 through 6).

The network diagram may take almost any form, as long as the events are shown in their proper sequence and give the impression of a normal flow. Events that can be done simultaneously are shown in a vertical array. Those which are dependent on completion of a previous event are shown in a horizontal array. It is both unnecessary and impractical to attempt to show events in relation to a horizontal time scale. Time estimates are placed on each activity line. For purposes of identification, each event is described and numbered. The sequence of numbers may start from either end, but it is usually simpler to have the preceding event with the lower number.

The network shown in Figures 1 through 6 starts the process with event 1, "Headquarters Requests Biennium Budget," and ends with event 117, "Project Advertised." All of the events and activities required to produce the end result are not shown, but they are in sufficient detail to portray the scope and complexity of the problem.

The next process is to compute the expected activity time to produce each event and summarize these items along the progression to obtain the earliest expected time, T_E, required to meet the total objective or any point along the network. For purposes of illustration only, time estimates to produce each activity were computed for a single project in this network, slack times were determined, and the critical path is shown by the dashed line on the network. The computed times are given in Figure 7. For the 117 events illustrated, the earliest expected time to reach "Project Advertisement" is 391.5 weeks, or 7.5 years.

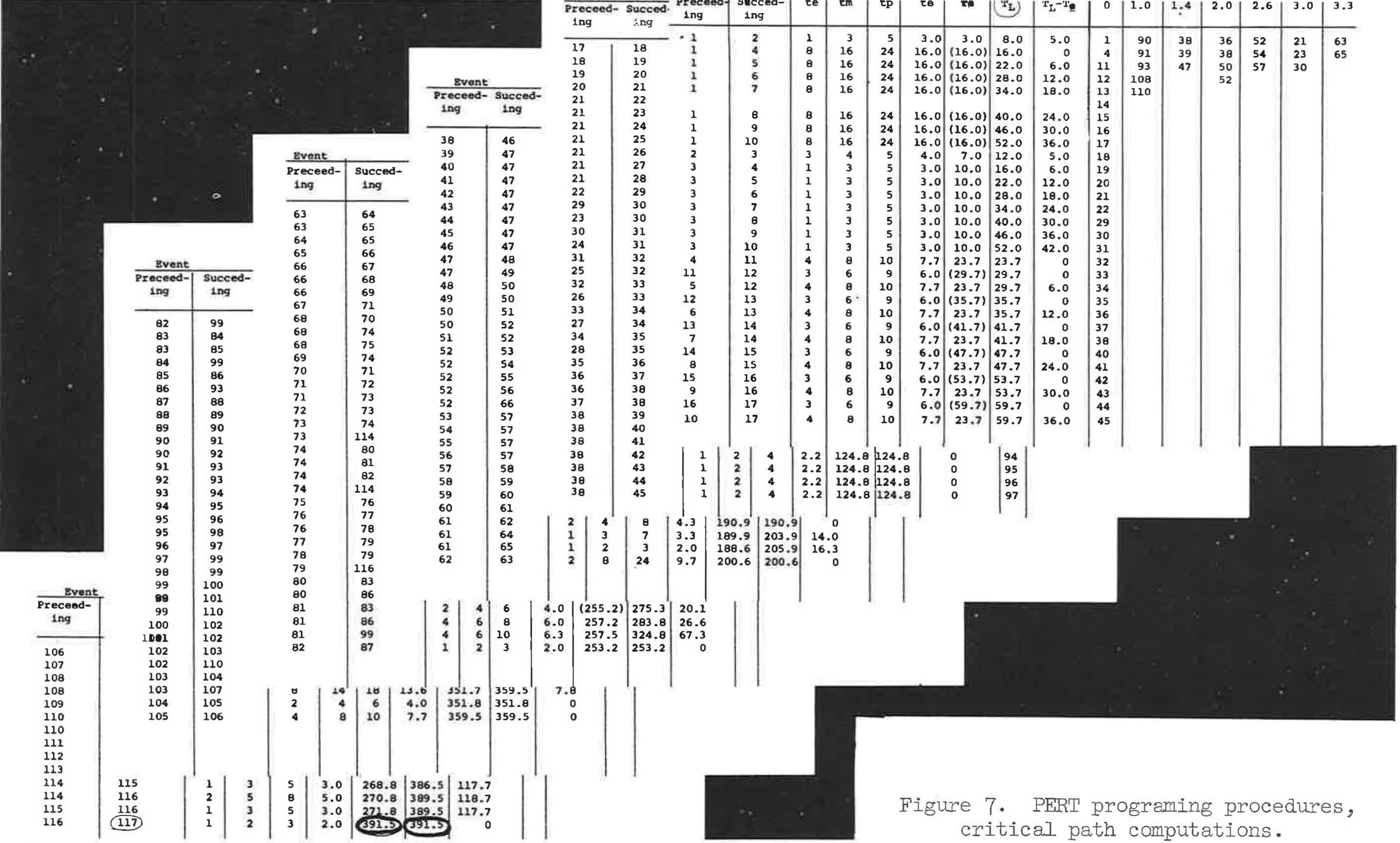

Figure 7. PERT programing procedures, critical path computations.

If the latest time required to meet the objective and if all events along the network were known, management would then know what events and activities would require attention. Also those events and activities which are not critical would be known, as well as the degree to which they are not critical.

The earliest time, T_E, to meet the advertising date is 391.5 weeks. This is also the latest time, T_L, needed to meet the requirements. Starting with event 117 and working backward to event 1, the latest time necessary to reach each event can be computed. This has been done in Figure 7, Col. T_L. The difference between the latest time and the earliest time ($T_L - T_E$) is then the amount of activity slack available for each event in the total network.

Those activities with zero slack are critical and the ones management should concentrate on to hold the plan on schedule. Zero activity slacks are noted in Figure 7 under zero column of critical path. These are from events 1, 4, 11, 12, etc., to 117. The zero slacks are also shown in Figures 1 through 6 by a dashed line. This is known as the critical path and points up those events and activities that should be accomplished on time.

The network diagram, the critical path and the calculations provide management with a basic tool to hold the plan on schedule. This tool also provides management with a means of making reliable decisions that have a known probability of success.

PERT BY TYPE OF PROJECT

Obviously, the total lapsed time of 7.5 years to produce the project shown along the critical path is one of the most complex types, involving reconnaissance reports, design reports, city assess hearings, purchase of right-of-way, local access hearings, and several Federal-aid and commission approvals. Only a very few projects would be processed by all of these steps. A review of the network in Figures 1 through 6 indicates that the type of project greatly influences the number of events and the activity times required to reach the end objective.

The network also indicates that there are many combinations of types of projects that can be produced. Some of these are with or without reconnaissance reports; with or without Federal aid; with or without a design report in combination with or without bridges and Federal aid. Some projects may require no hearings at all or as many as four, and may or may not involve rights-of-way.

Supposedly, no project can officially start until the project request is authorized to the district (event 52 and a total lapsed time from conception to inclusion in the biennium budget of 2.6 years). In other words, no project within the current biennium budget can be expected to officially begin until six months into the succeeding biennium budget. From this point on, the advertising date depends on the type of project.

PROGRAM FORMULATION

A review of activities leading up to event 52, the project authorization, is in order. The network diagram for these events and activities is shown in Figures 1 through 3.

Activities to produce events 1 through 20 (Fig. 1) all deal with the formulation, review and approval of the biennium budget. This requires an estimated total time of 77.6 weeks (1.5 years). This same process, except for legislative approval, is again repeated in the formulation, review and approval of the annual construction program. These are the activities to produce events 21 through 37 (Fig. 2) and require an estimated additional lapsed time of 43 weeks (11 months).

This is the first time PERT procedures have been attempted in highway programing and, admittedly, the time estimates could be reviewed. However, the process exists and there appears to be a duplication of effort. Top management may wish to review their process of approving programs with a view toward accepting the biennium budget projects as a biennium construction program.

Another hard look by top management should be the activity times required to produce events 1 to 4 through 10, the combining of project selection and estimated apportionments for each district's biennium budget. The average time required for the project selection is 16 weeks, whereas the estimated time for the apportionments to reach the districts is 10 weeks. The project selection process could be speeded up if each district had an array of projects based on good programing technique for a six-year rolling program. Then, as soon as their biennium apportionment was made known, the projects in the array immediately could be adjusted to the anticipated funds and the program firmed.

PROJECT DEVELOPMENT

There were more than 400 projects (exclusive of channelization and traffic control) in the 1961-63 biennium budget. The types of projects and complexity of work involved may be summarized in total, and between districts, as in Table 1. For purposes of scheduling work loads within and between districts, reporting progress to several levels of management, and making adjustments to keep the total program on time, these projects could be reduced to their basic components, as described in Table 2. The total

TABLE 1

PERCENTAGE DISTRIBUTION OF PROJECTS IN 1961-63 BIENNIUM BUDGET BY TYPE OF PROJECT FOR SIX DISTRICT OFFICES[1]

Type of Project	Distribution (%)						
	Dist. 1	Dist. 2	Dist. 3	Dist. 4	Dist. 5	Dist. 6	Total
Preliminary engineering	4	2	3	3	3	4	19
Right-of-way	1	*	None	None	None	2	3
P/E and R/W	2	1	2	2	1	1	9
P/E, R/W, grading, paving	2	1	1	*	1	*	5
P/E, R/W, grading, paving, bridges	2	1	*	None	*	1	4
P/E, grading, paving	3	1	1	1	2	2	10
P/E, paving	5	2	3	3	3	2	18
P/E, grading	3	1	6	3	1	1	15
P/E, bridges	4	*	3	2	None	*	9
P/E, grading, paving, bridges	2	*	None	1	1	2	6
P/E, grading, bridges	None	*	*	*	None	2	2
Total	28	9	19	15	12	17	100

*Less than 0.5 percent.
[1] District 7 is for Interstate projects in Seattle area and is not broken out in biennium budget.

TABLE 2

RATE OF OCCURRENCE OF PROJECT COMPONENTS IN THE 1961-63 BIENNIUM BUDGET FOR SIX DISTRICT OFFICES

Project Component		Rate of Occurrence (%)						
Type	Descr.	Dist. 1	Dist. 2	Dist. 3	Dist. 4	Dist. 5	Dist. 6	Total
A	Prelim. engineering	27	9	19	15	12	15	97
B	Right-of-way	7	3	3	2	2	4	21
C	Grading	3	1	6	3	1	3	17
D	Paving	5	2	3	3	3	2	18
E	Grading and paving	9	3	2	2	4	5	25
F	Bridges	8	1	3	3	1	5	21

work load in the total program could be determined by project components. Once these components are known, time estimates for each can be made, lead times determined, and project development scheduled.

The rate of occurrence of project components of the projects in the 1961-63 biennium budget is given in Table 2 for six district offices. Ninety-seven out of 100 projects involve some preliminary engineering. The end product for preliminary engineering on the network diagram showing events and activities from authorization could either be event 73 or 74, depending on the necessity for a roadway section, grade intersection, or design report No. 1 approval.

The beginning point on the network diagram is event 52, "Project Authorized to District" (see Fig. 4). The paths to reach the end result (event 73 or 74) vary with the number of events to be accomplished. For instance, if no reconnaissance report is required, the work flow would be from event 52 directly to event 66. If only a roadway section is required, and it is not a Federal-aid project (no BPR approval), the flow would continue from events 66 through events 71 to 73 or 74. In other words, the flow through the network diagram depends on decisions as to whether or not the project involves Federal aid and how it shall conform to state laws and department rules and regulations.

The minimum and maximum times to reach the end objective for each component can be reliably estimated from the critical path computations (Fig. 7). For Type A, preliminary engineering, these time estimates to reach event 74 are 24.1 weeks minimum and 113.2 weeks maximum.

Twenty-one out of 100 projects involve right-of-way. The end objective is event 113 (Right-of-Way Acquired). The beginning may be at several points along the network path: event 110 (Right-of-Way Authorized), or event 99 (Right-of-Way Plans to Headquarters). If the type and location of any of the 21 projects require hearings, a decision has to be made as to the type of hearing and the beginning point is set forward to events 80, 81, or 82. The starting date, except for the three projects involving right-of-way only, cannot be set until event 74 (Design Report No. 1) is completed.

The time estimates for Type B, right-of-way component, could be broken down as follows:

Function	Events Involved	Estimated Time (wk)	
		Min.	Max.
Type B, R/W component	99 to 113	23.2	62.7
Interstate hearing	74 to 99	16.0	55.0
FA by-pass hearing	74 to 99	8.3	55.0
City access hearing	74 to 99	6.0	75.6

Seventeen out of 100 projects involve grading only, 18 paving only, and 25 grading and paving combined. The network as diagrammed does not readily distinguish between the activity times to produce construction plans of each of these separate components. However, these would be from events 73 or 74 to event 116 (Headquarters PS & E Approval). The time estimates to reach this objective after events 73 or 74 have been completed are 17.6 weeks minimum and 22.6 weeks maximum.

Twenty-one out of 100 projects involve bridges. Bridge plans cannot be started until sufficient field surveys (event 68) have been completed. The estimated time to complete bridge plans and to forward them to headquarters for approval in the PS & E is 44.6 weeks. Event 116 (Headquarters Approval of PS & E) cannot be attained until the component parts (right-of-way, roadway, and bridge plans) are brought together. The longest time involved is with projects that include right-of-way. The time variances for the types of projects would be summarized as in Table 3.

TABLE 3

MINIMUM AND MAXIMUM TIMES TO COMPLETE ACTIVITIES BY TYPE OF PROJECT

Type of Project	Number per 100 Projects	Preceding Event to Be Completed	Events Included		Activity Time (wk)	
			From	To	Min.	Max.
Preliminary engineering	19	52	52	73-74	24.1	113.2
Right-of-way	3	74	74	116	31.2	140.3
P/E and R/W	9	52	52	116	55.3	253.5
P/E, R/W, grading, paving	5	52	52	116	55.3	253.5
P/E, R/W, grading, paving, bridges	4	52	52	116	55.3	253.5
P/E, grading, paving	10	52	52	116	41.7	135.8
P/E, paving	18	52	52	116	41.7	135.8
P/E, grading	15	52	52	116	41.7	135.8
P/E, bridges	9	52	52	116	50.9	122.8
P/E, grading, paving, bridges	6	52	52	116	50.9	135.8
P/E, grading, bridges	2	52	52	116	50.9	135.8

LEAD TIME AND SCHEDULING

Probable activity times for each type of project should be used to produce the lead times to determine what component of the project should be started and when. If the work is to be completed on time, it must be started on time.

Projects involving preliminary engineering and rights-of-way require 55.3 to 253.5 weeks, depending largely on whether or not hearings are required. Right-of-way is the controlling feature. If grading, paving and bridges are included in the right-of-way type of project, the construction plans for the roadway could be delayed from 13.6 to 117.7 weeks. If bridges were also included, bridge plans could be delayed from 4.4 to 103.7 weeks. On the other hand, if the right-of-way can be obtained in the minimum time of 55.3 weeks, the production of roadway construction plans control as much as 120.5 weeks.

Decisions are needed at the outset for each type of project as to Federal aid and conformance with state laws, and department rules and regulations. Once these decisions have been made, firmer activity times can be determined and the project "starts" and the estimated completion dates can be scheduled.

The schedules should be developed at district level and combined for all districts at headquarters. For every 100 projects in the 1961-63 biennium budget "starts" have to be made for 97 preliminary engineering, 21 right-of-way, 17 grading, 18 paving, 25 grading and paving, and 21 bridge components. In District 2, these are 9, 3, 1, 2, 3, 1, respectively (Table 2).

The 9 projects per 100 in the total biennium budget for District 2 may be used for sample scheduling, as shown in Figure 8. It has been decided that it is possible to complete these projects by the shortest activity path (minimum time) through the network diagram, except for project 1, which will require a reconnaissance report.

Obviously, the three projects involving rights-of-way should be started as early as possible, because this component requires the greatest time to complete. Other projects may then be interspersed to distribute the work load as evenly as possible.

Figure 8 is only for 9 projects in 100 and for one biennium. Complete schedules would include some projects not finished in the previous biennium and all projects would not be confined to the minimum time through the network diagram.

Further adjustments in the schedule would need to be made to adhere to fiscal restrictions. The Washington State Highway Department operates on anticipated receipts. Salaries of regular employees are estimated by headquarters from past experience and estimated expenditures are distributed by months to the districts. These limitations are known in each district.

Anticipated right-of-way expenditures are more difficult to achieve, but headquarters has worked out a system. The present method may be improved, however, if work schedules for each district were made and adhered to.

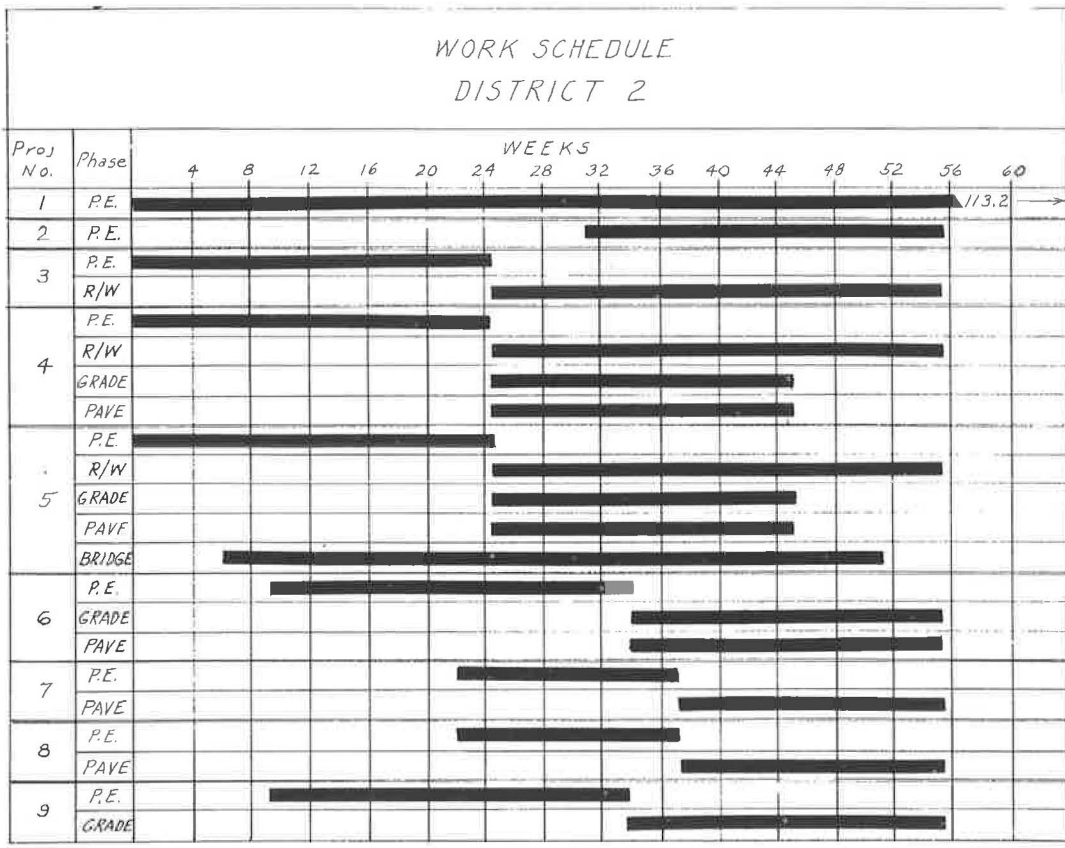

Figure 8. Sample work schedule.

LEVEL OF INDENTURE

Figures 1 through 6 contain some networks that do not logically belong in a diagram to be used in headquarters. These might be the development of the reconnaissance report, events from 52 to 60, which should go down to the project engineer level. Others would be relegated to the district level, as in events 82 and 87 through 92 of the hearing sequence. Other networks, such as the development of bridge plans, should be expanded by the bridge division.

Each management level should develop its own network and confine it only to those details and areas of interest where the management level can exert some influence and action. The number of networks should be equal to and confined to the managers who have responsibility and can make decisions. The networks should be developed by the person who can make use of them.

What is needed is a flow of information from the lowest level of management upward, so that action can be taken at the proper level to direct the action downward. This might be considered as a pyramid and symbolized as shown in Figure 9.

PERT sources estimate that a network size of more than 500 activities is too much for one manager to handle. A range of about 100 to 500 is more nearly right for drafting, reporting, and making calculations. The calculations made for one project in Figure 7 were done manually and took one man about three hours. Computer programs are available for these calculations and reporting if deemed to be necessary. PERT sources also estimate that about 80 to 90 percent of the total time is consumed in network diagramming.

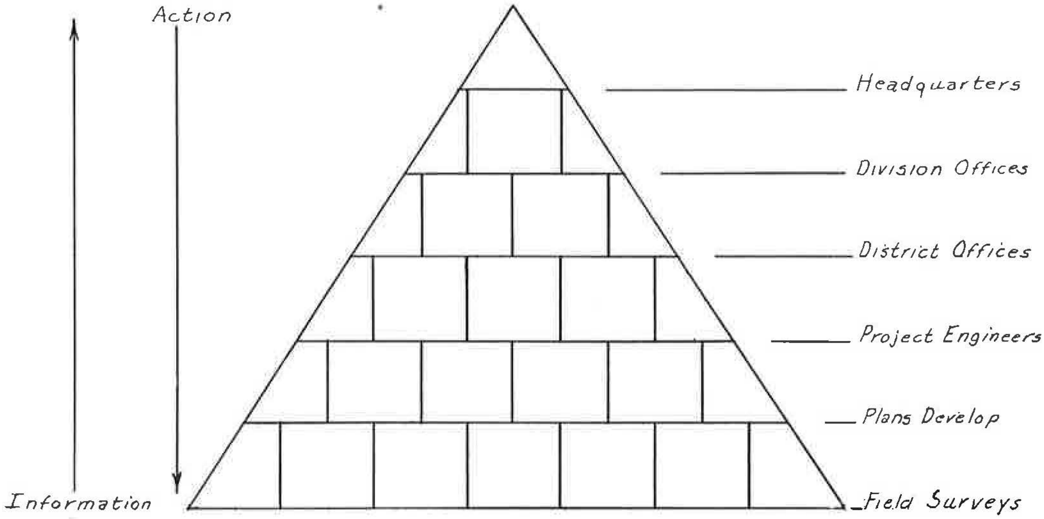

Figure 9. Level of indenture.

The headquarters office would be concerned only with certain aspects of the network in Figures 1 through 6. Events 1 through 52 (Figs. 1, 2 and 3) deal with biennium budgets, annual construction programs, and project authorizations. These would remain in a headquarter's PERT network. From event 52 on, only certain things are significant to headquarters and the network could be reduced to below that shown in Figures 4, 5 and 6. The part omitted would be developed at division or district levels or below.

Networks for each of the basic components should be developed in detail necessary for each management level. Combinations of components to reflect the total program can be made. Estimated completion times can be determined and starting dates instituted which would have a probability of being completed on time.

Once the networks have been developed for each level of management, the processes of reporting from one level to another are not difficult. The computations, which can be done by tabulating equipment if necessary, should be keyed to the network event number and the activity times determined.

Initially, the report for project 1 in District 2 would take the form shown in Table 4, an estimated 113.2 weeks with a completion date of August 4, 1964. Successive reports would then show activities completed, revised activity estimates if they are necessary, and new estimates of a probable date of completion.

Table 5 is an example of a progress report after eight weeks have lapsed. The field reconnaissance (event 53) has been completed as well as cross-sections and profiles (event 55). There has been a delay in the materials surveys (event 54) and the project engineer has re-estimated these items as 3.7.9, or a probability of completion of 6.7 weeks from date of this report.

In addition, the traffic (event 57) is to be completed sooner than expected and revised time of 4.10.16 has been made.

According to the network diagram, traffic cannot be used until events 53, 54, 55 and 56 are all completed. The net result is that the critical path has been changed to events 52.54.57 and the expected completion date for the reconnaissance report (event 60) has been reduced to 33.0 weeks from date, instead of 46.3 reported eight weeks ago, or a net saving of 5.3 weeks

Also, decisions have been made that neither Bureau of Public Roads nor commission approval is necessary and events 62, 63, 64 and 72 can be eliminated. Therefore, total lapsed time to reach event 74 is 70.5 weeks, rather than the previously reported 113.2 weeks. The estimated completion date is now October 9, 1963.

TABLE 4

BI-WEEKLY REPORT
DISTRICT 2
PERIOD ENDING JUNE 1, 1962

Project Number 1 — Estimated Completion Aug. 4, 1964

Event Preceed-ing	Succed-ing	Activity to	tm	tp	te	T_E	T_L	T_L-T_E
52	53	3	8	12	7.8	7.8	12.6	4.8
52	54	4	10	16	10.0	10.0	12.6	2.6
52	55	2	7	9	6.5	6.5	12.6	6.1
52	56	4	12	24	12.6	12.6	12.6	0
53	57	4	12	52	17.4	25.2	30.0	4.8
54	57	4	12	52	17.4	27.4	30.0	2.6
55	57	4	12	52	17.4	23.9	30.0	6.1
56	57	4	12	52	17.4	(30.0)	30.0	0
57	58	2	4	6	4.0	34.0	34.0	0
58	59	2	4	8	4.3	38.3	38.3	0
59	60	4	8	12	8.0	46.3	46.3	0
60	61	2	4	8	4.3	50.6	50.6	0
61	62	2	4	8	4.3	54.9	54.9	0
61	64	1	3	7	3.3	53.9	67.9	14.0
61	65	1	2	3	2.0	52.6	69.9	17.3
62	63	2	8	24	9.7	64.6	64.6	0
63	64	1	3	7	3.3	67.9	67.9	0
63	65	1	2	3	2.0	66.6	69.9	3.3
64	65	1	2	3	2.0	(69.9)	69.9	0
65	66	2	4	6	4.0	73.9	73.9	0
66	67	2	3	5	3.2	77.1	82.2	5.1
66	68	2	4	8	4.3	78.2	78.2	0
66	69	4	8	16	8.7	82.6	105.2	22.6
67	71	1	2	4	2.2	79.3	84.4	5.1
68	70	2	4	6	4.0	82.2	82.2	0
68	74	4	12	24	12.7	90.9	113.2	22.4
69	74	4	8	12	8.0	90.6	113.2	22.6
70	71	1	2	4	2.2	(84.4)	84.4	0
71	72	2	8	12	7.7	92.1	92.1	0
71	73	4	8	12	8.0	92.4	104.5	12.1
72	73	2	12	24	12.4	(104.5)	104.5	0
73	74	4	8	16	8.7	113.2	113.2	0

0	2.6	3.3	4.8	5.1	6.1	12.
52	52	63	52	66	52	71
56	54	65	53	67	55	73
57	57		57	71	57	
58						
59						
60			14.0	17.3	22.6	22.4
61			61	61	66	68
62			64	65	69	74
63					74	
64						
65						
66						
68						
70						
71						
72						
73						
74						

The project engineer would report to the district engineer on event 60. The district engineer would report to headquarters regarding activities for events 52, 60, 65, 66 and 73. Headquarters might make revised estimates for events 61 and 65.

Reporting should be timely to permit decision-making by the manager responsible, on whether to speed up, slow down or hold the estimated schedule. The slack in the critical paths is the clue. Should some phase be lagging, one solution would be to shift personnel from a phase that has the most slack time. This might be in a district or between districts. Normally, reporting should be done every two to four weeks.

MANAGEMENT

The success of the PERT system, as in any management system, is the coordination at top level. If this is not done, no system will work. It should be remembered that PERT is a tool to be used in narrowing judgment, flagging critical situations in time for the manager to take proper corrective measures. The manager makes the decisions—PERT only assists him.

One coordinator at top staff level can handle the situation. However, he must have authority to implement his decisions. The coordinator would be assisted by a very small staff of clerks, one draftsman to revise networks and have access to a computer, if found necessary.

TABLE 5

BI-WEEKLY REPORT
DISTRICT 2
PERIOD ENDING JULY 20, 1962

Project Number 1. Estimated Completion Oct. 9, 1963

Event		Activity							Critical Path				
ceed-ng	Succed-ing	te	tm	tp	te	T_E	T_L	T_L-T_E	0	2.1	5.1	10.2	10.5
2	53	completed											
2	54	3	7	9	6.7	6.7	6.7	0	52	52	66	68	66
2	55	completed											
2	56	3	4	9	4.6	4.6	6.7	2.1	54	56	67	74	69
3	57	completed											
4	57	4	10	16	10.0	(16.7)	16.7	0	57	57	71		74
5	57	completed											
6	57	4	10	16	10.0	14.6	16.7	2.1	58				
7	58	2	4	6	4.0	20.7	20.7	0					
8	59	2	4	8	4.3	25.0	25.0	0	59				
9	60	4	8	12	8.0	33.0	33.0	0					
0	61	2	4	8	4.3	37.3	37.3	0	60				
1	62	N.A.											
1	64	N.A.							61				
1	65	1	2	3	2.0	39.3	39.3	0					
2	63	N.A.							65				
3	64	N.A.											
3	65	N.A.							66				
4	65	N.A.											
5	66	2	4	6	4.0	43.3	43.3	0	68				
6	67	2	3	5	3.2	46.5	51.6	5.1					
6	68	2	4	8	4.3	47.6	47.6	0	70				
6	69	4	8	16	8.7	(52.0)	62.5	10.5					
7	71	1	2	4	2.2	48.7	53.8	5.1	71				
8	70	2	4	6	4.0	51.6	51.6	0					
8	74	4	12	24	12.7	60.3	70.5	10.2	73				
9	74	4	8	12	8.0	60.0	70.5	10.5					
0	71	1	2	4	2.2	(53.8)	53.8	0	74				
1	72	N.A.											
1	73	4	8	12	8.0	61.8	61.8	0					
2	73	N.A.											
3	74	4	8	16	8.7	(70.5)	70.5	0					

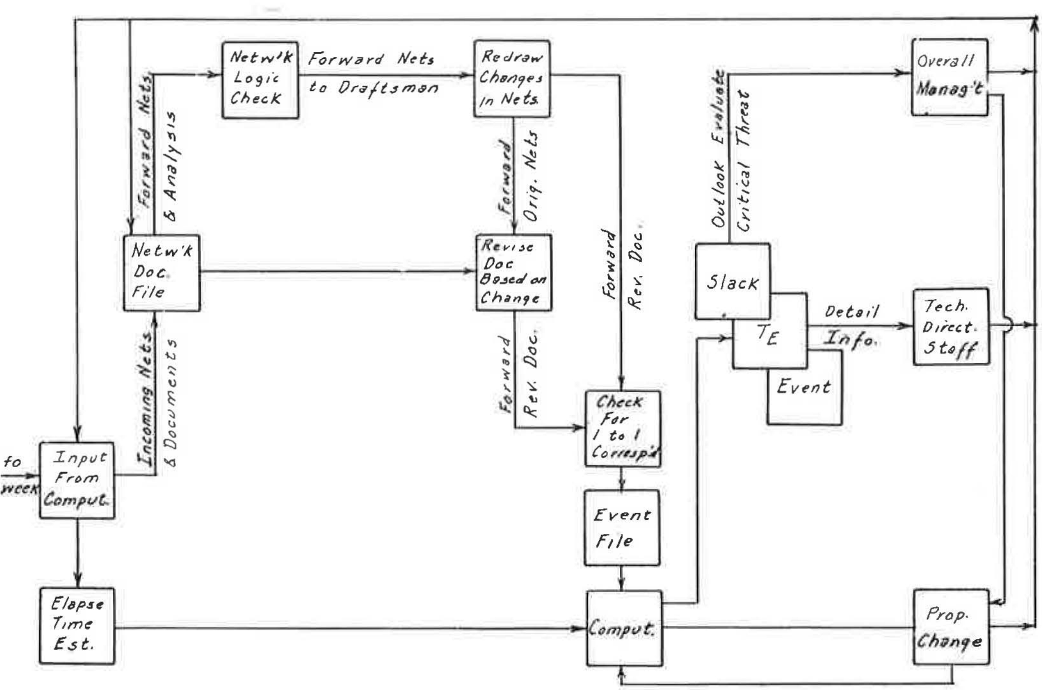

Figure 10. A suggested PERT control and revision procedure.

A flow diagram suggesting PERT control and revision procedure is shown in Figure 10.

COSTS

As previously mentioned, 80 to 90 percent of the time spent on PERT systems is in preparation of the networks. The remaining time is consumed in keeping it operative.

Estimated operating costs (rule of thumb) for industry are 0.1 percent to 1.0 percent of the total construction costs. Breakdown of these costs have been estimated as 15 percent engineering, 25 percent computations, and 60 percent administrative.

Computer programs are commercially available for IBM equipment.

SUMMARY

It is obvious from the study reported herein that the events, their sequence, and the activity time estimates need more review. Also, the networks shown are only preliminary and need revision.

More research is needed to explore other possible routes of application. The area covered extends from the conception of the biennium budget to the date of advertisement. It should be extended to include completion of construction.

The ultimate proof, of course, would be to place PERT in operation in a highway department. However, certain conclusions appear evident as a result of this endeavor:

1. Management tools such as PERT have been successful on application to a single project with one objective. It can be applied to a group of isolated projects which comprise a single annual continuing objective, such as a highway program.
2. Development of the network is important to show the interrelationship of a phase of work to the entire amount of work to be produced. If nothing more was done, this alone is beneficial to top management for organizational and planning purposes.
3. A breakdown of projects by components enables a better determination to be made of the total work load in the total program. Manpower and physical resources can be scheduled more efficiently.
4. Reliable estimates of activity times required to produce necessary events enable management to determine lead times. If the objective is to be reached on time it must be started on time.
5. Responsibilities can be placed more accurately. It may be advisable to place responsibilities at more than one level of organization.
6. Where responsibility is designated, the one in charge must have authority to make decisions and act.
7. PERT, as a management tool, alerts management as to areas where the program is off schedule, and provides a means for decision-making that has a known probability of success.
8. Reporting processes required provide an excellent means of communication.
9. PERT will not do the thinking; now will it, by itself, produce the end result. Decision will have to be made.
10. It is adaptable to computer programing but not essential.
11. The cost of operation is minor and would only require a small staff.

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