PERTing a Transportation Study

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•DURING the past ten years, organizations known as transportation studies have been created to prepare long-range, comprehensive transportation plans. Because the need for such planning is great (one index of need is the tremendous state and national investment in new transportation facilities), these studies have been well financed. Their budgets frequently run in excess of $1 million, and they employ hundreds of persons. Their size and cost create substantial management problems.

Size alone, however, is not the most pressing problem. Transportation plans must be produced rapidly. Road-building programs advance with considerable speed, although this may not always be apparent to the man on the street. Decisions to build are made far in advance, often on a project-by-project basis without any review against a comprehensive plan. Decisions then become salted down with investments in detailed plans, estimates, hearings, and public announcements. Each piece of construction and each commitment begets another. The building program is thus often fixed for five years into the future. Rapid production of plans for entire systems of transportation facilities is, therefore, a great need.

Size and speed demand skilled management, but many things make effective management unusually difficult. These difficulties may be grouped under three headings:

1. The number of different operations necessary for the completion of comprehensive plans. These include data gathering for land use, transportation facilities, and trip making; the coding of this information; machine processing; contingency checking; computing; analysis; specification of goals and planning principles; plan making; plan testing; and, the writing of reports.
2. The number of skills involved. To complete these operations, a wide variety of skills must be employed. These include economics, statistics, mathematics, city planning, traffic engineering, design engineering, sociology, geography, supervision of interviewers and coders, management of data processing machines, computer programming, supply procurement, accounting, typing, and the writing and production of reports.
3. The interdependency of work. The tasks which sum up to a completed transportation planning program are interdependent to an unusual degree. (See Fig. 8.)

All these things point to the need for new management tools which will permit a person or a management team to maintain control and direction over a project, rather than floating with the project and reacting to the pressures of events. This paper has to do with one such technique, Program Evaluation and Review Technique (PERT) also called the Critical Path Method.

PERT — AN AID TO MANAGEMENT

PERT is a programming device, designed to aid in the allocation of time, manpower, and skills to the various activities which constitute some larger work program. It consists of five basic steps: specifying events (the end products of each small part of a larger program); developing a network describing the relationships between events; estimating the time needed to accomplish each link in this network; determining the critical path; and, reviewing and revising the program.

Paper sponsored by Committee on Origin and Destination.

The essence of the PERT process is the use of a network diagram to describe a large number of products (events) and their relationships to one another. It would be extremely difficult and tedious to describe these events and their relationships in English. The PERT notation, like mathematical notation, is terse and clear; it is highly economical. It has, furthermore, the quality of being readily translated into computer notation so that some of the programming can be done by computer.

Although the basic idea of PERT is very simple and straightforward, actually doing the work is difficult. One reason for the difficulty — but a major advantage of the system — is that PERT requires a thorough and complete thinking-through of a major work program from beginning to end. PERT does not allow any pretense about what is to be done at each stage along the way. A second difficulty is that, despite its terse form and the precision of its statement of the problem, diagramming a complex production or research task can never be wholly complete. Some relationships must be left out, some tasks not included. The problem is to select the main elements with care, but to include all of these.

Specification of Events

The first requirement of PERT is the complete and exact specification of events which are to be programmed. An event is defined as the product or result of some kind of action. It may be a table, a set of specifications, a physical product, or a computer program. But the event is distinctly not the action or process which produced it.

Here there is a sharp contrast between PERT and the normal programming of research or planning work. Normally a planner thinks in terms of processes; for example, six months of O-D survey work, four months of coding, or two months for analysis of trip generation. By contrast, under PERT planning, these things would only be considered in terms of their outputs; for example, 20,000 completed home-interview forms, or a specific table of trip generation rates.

Concentration on product is especially important in research and planning work, where the process, for instance, the process of analyzing trip making, has tended to dominate the product. Analysis, research, and planning can very easily become nebulous operations. Hence the tough-minded approach of accenting the product is peculiarly important in this field.

Network Construction

Events can be listed, and then posted to boxes or circles drawn on a large sheet of paper or a blackboard (Fig. 1). The order of posting is not important, but the point of beginning is generally kept to the far left, the conclusion to the far right.

Once the events are posted, they must be connected by a series of lines which describe the relationships between events (Fig. 2). If, for example, a map is needed prior to field list, the map event must be at the base of the arrow which points from the map to the field list.

The preparation of lists of events and the placing and studying of the interrelationships between the events is best done by a small team consisting of those persons who will be doing the work. This enables them to participate in the project; it also produces a more complete specification of needs. Although group work is extremely helpful, there is always need for strong direction of the PERTing activity. Single direction provides a unifying element and the necessary decisiveness.

Time Estimating and Cost Estimating

Once the diagram of interrelationships has been prepared, time estimates of each activity must be prepared. The activity is represented by the line (arrow) connecting events; it is, in short, the work necessary to produce the event.

Single or multiple time estimates can be prepared. One manual recommends that three time estimates should be prepared, a shortest possible time, a "best" estimate, and a very conservative time estimate. The average value (computed by weighting the shortest time once, the best estimate four times, and the most conservative estimate

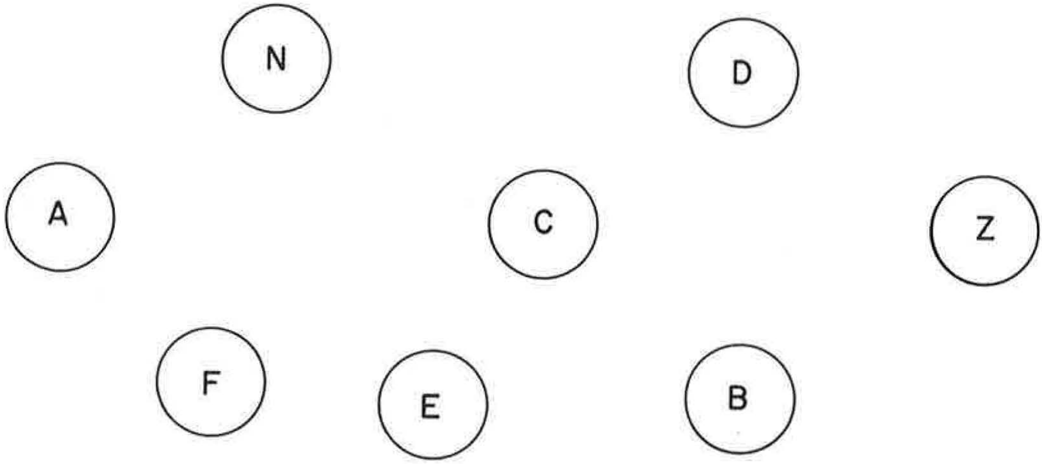

Figure 1. Events — a series of N events must be completed before final objective Z is achieved. Each event is defined.

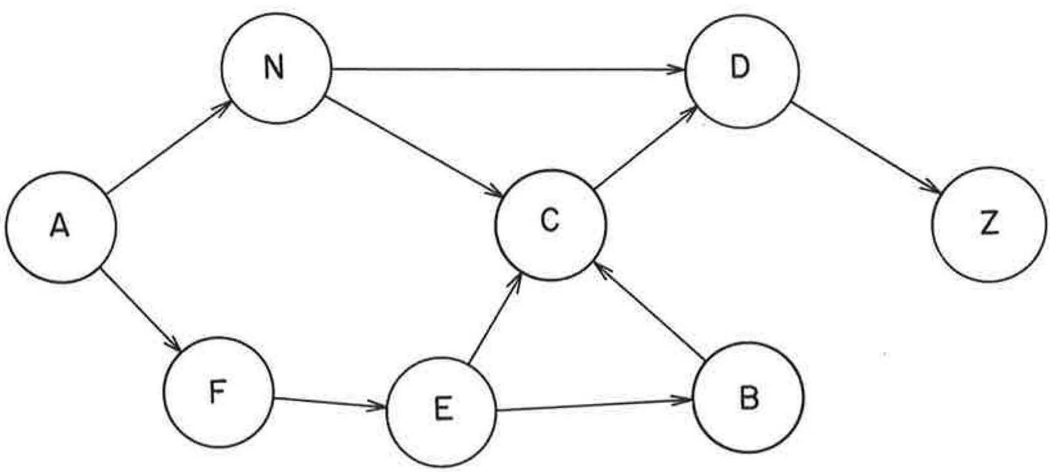

Figure 2. Relationships defined by network — lines are activities necessary to produce events; each event is an output of one activity and/or the input to another.

once) is posted on the "activity" line, below the other estimates (Fig. 3). It is desirable to make estimates randomly, so that there is less tendency to think of scheduling at the time the time estimates are made.

Determining the Critical Path

Once the time estimates have been made, the next step is to determine the critical path (Fig. 4). The critical path is simply the longest time path between the start of the project and its completion.

For networks of 100 or 200 nodes the critical path can readily be determined by hand. This is done using a hand posting technique developed from Moore's algorithm (1). The procedure is to start at the beginning of the network, posting the accumulated time at each node. At each node, a small arrow is placed, pointing backwards toward the origin along the longest time path to that point. Where two or more activities ter-

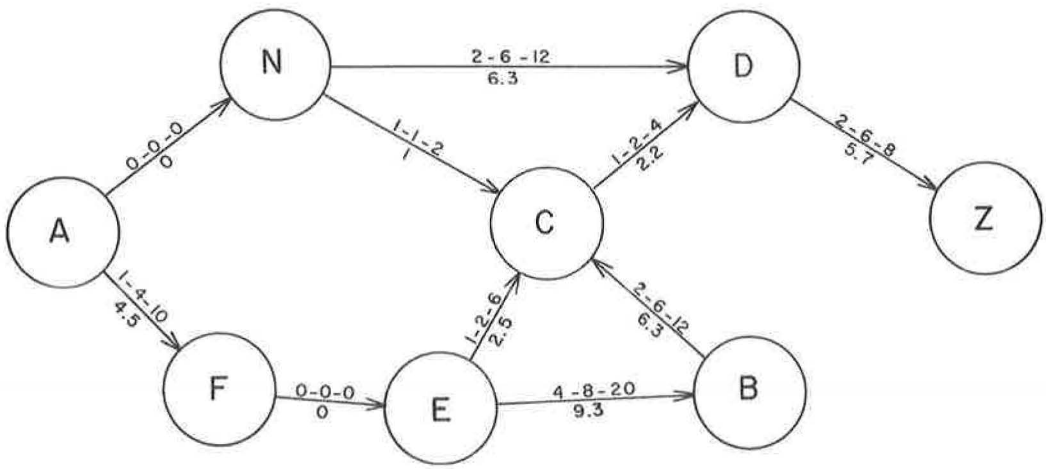

Figure 3. Times estimated — minimum, best estimate, and maximum time estimates are made for each link (e.g., 2-6-20); these time estimates are averaged for a working estimate (under line).

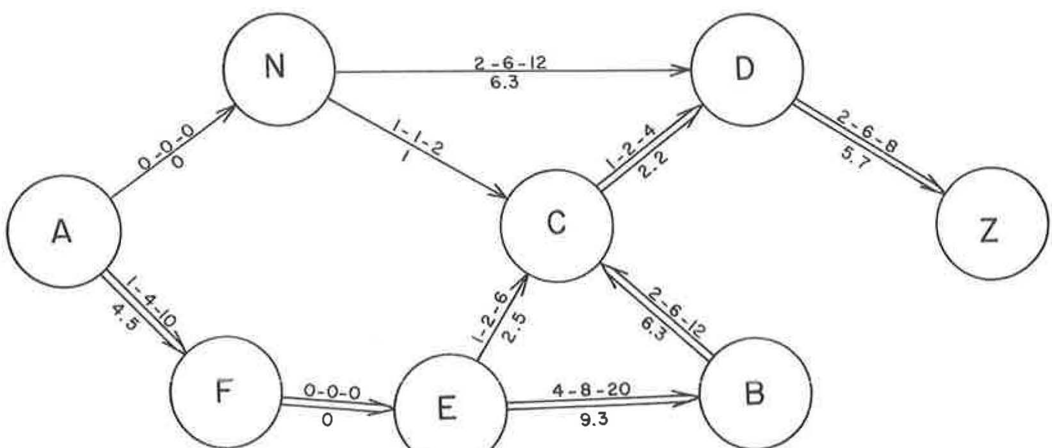

Figure 4. Critical path chosen — the critical path is that which takes the longest to achieve.

minate at a given node a choice must be made; the maximum accumulation of time to that node is noted, together with an arrow pointing backwards along the maximum time path. This can be done easily in one hour.

Computers can also be used to select the critical path. There are "canned" programs for this on a number of machines. The computers do many things besides calculate the critical path; they indicate earliest and latest start times for each activity, and calculate "float" times.

Review

Once the critical path has been determined, a review must be made to see where changes can be made to improve the situation. The review is the point where executive decision making is brought to bear. Methods or schedules can be changed, additional resources brought forward, or slowdowns ordered.

AN EXAMPLE OF PERT

A survey to measure and identify floor area in the central business district of Buffalo was conducted as part of the Niagara Frontier Transportation Study in August and September 1962. This survey was a small affair, involving direct costs of about $2, 500. Nevertheless, it is a good example of the complexity of survey operations. It was decided to PERT this survey, and the final diagram, completed prior to the start of the survey, is shown as Figure 5.

One normally thinks of survey or inventory operations as consisting of field work and the coding of the results. As the PERT diagram forcefully shows, this is only part of the task. The critical path, far from being the direct line of making a study design, hiring and training people, and doing the inventory, actually winds far afield. In this survey, 15 percent of the total time along the critical path was spent in survey design, 23 percent in pre-survey work, 37 percent in the field work, and 25 percent in coding and other post-survey work.

Having prepared the PERT diagram in committee, decisions on several fronts were made in rapid order. Necessary card forms and supplies were procured, and their time requirements were understood immediately by the administrative personnel. Processes for control of records were set up, and key control points were noted.

If the survey had been longer, review of the PERT diagram would have indicated the desirability of running one or more operations in parallel; e. g., coding the early field work results before the whole field work had been completed.

Arraying PERT Diagrams by Organization and by Time

The basic PERT diagram can be redrawn to aid administrative decision making. Two forms and a combined form are possible.

The first form (Fig. 6) is to divide the presentation area by horizontal lines, each representing the area of responsibility of a particular group within a larger organization. It is easy, using this technique, for each responsible section or division head to see what projects are his, and how they key in with the work of other divisions or sections.

The second form (not illustrated) is to divide the presentation area by vertical lines, each representing a week or other time unit on a calendar. The events can then be arrayed in their chronological sequence. The placement of each event may be fixed (as in the case of events on the critical path) or there may be some degrees of freedom. Here is where earliest and latest "start" times, as calculated by a computer, can be of great advantage. It can be seen that the placement of events having degrees of freedom can be dictated by some new criterion, such as the minimization of cost or the desire to minimize changes in employment.

A third form (not illustrated) would be a combination of both the preceding two forms.

Diagramming Technique

There appear to be two different diagramming techniques which can be used for PERT or the Critical Path Method. In one technique (used in this report) the event is the point of emphasis and the event's title is posted within a circle or box. In the other, the process is the point of emphasis and its title is posted along the arrow which represents the work activity leading to an event (2). In both cases event (node) numbering is the same and critical path computations by hand or computer would appear to be identical.

Although either technique could be used, the one employed throughout this paper was selected because of its focus on the event or product. It also appears to have some advantages of neatness, and undoubtedly has greater flexibility of presentation. However, a review of the CBD Survey PERT diagram (reproduced here in its form of August-September, 1962) led to a modified diagramming technique. The purpose of the change is to increase clarity and reduce the possibility of making mistakes.

The technique illustrated in the CBD Survey problem places an event in every node (represented by a circle). This leads to the certainty that two or more arrows — each

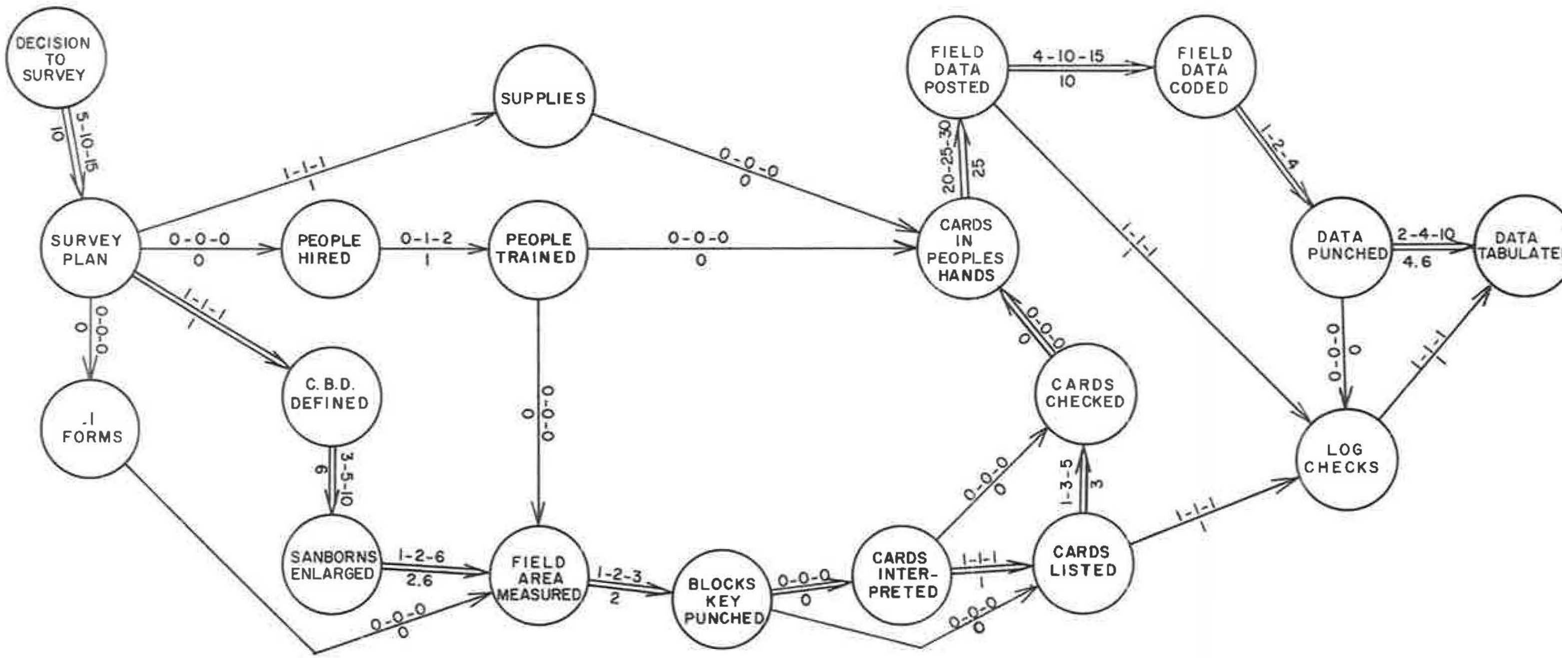

Figure 5. PERT program for CBD survey (all time estimates in days).

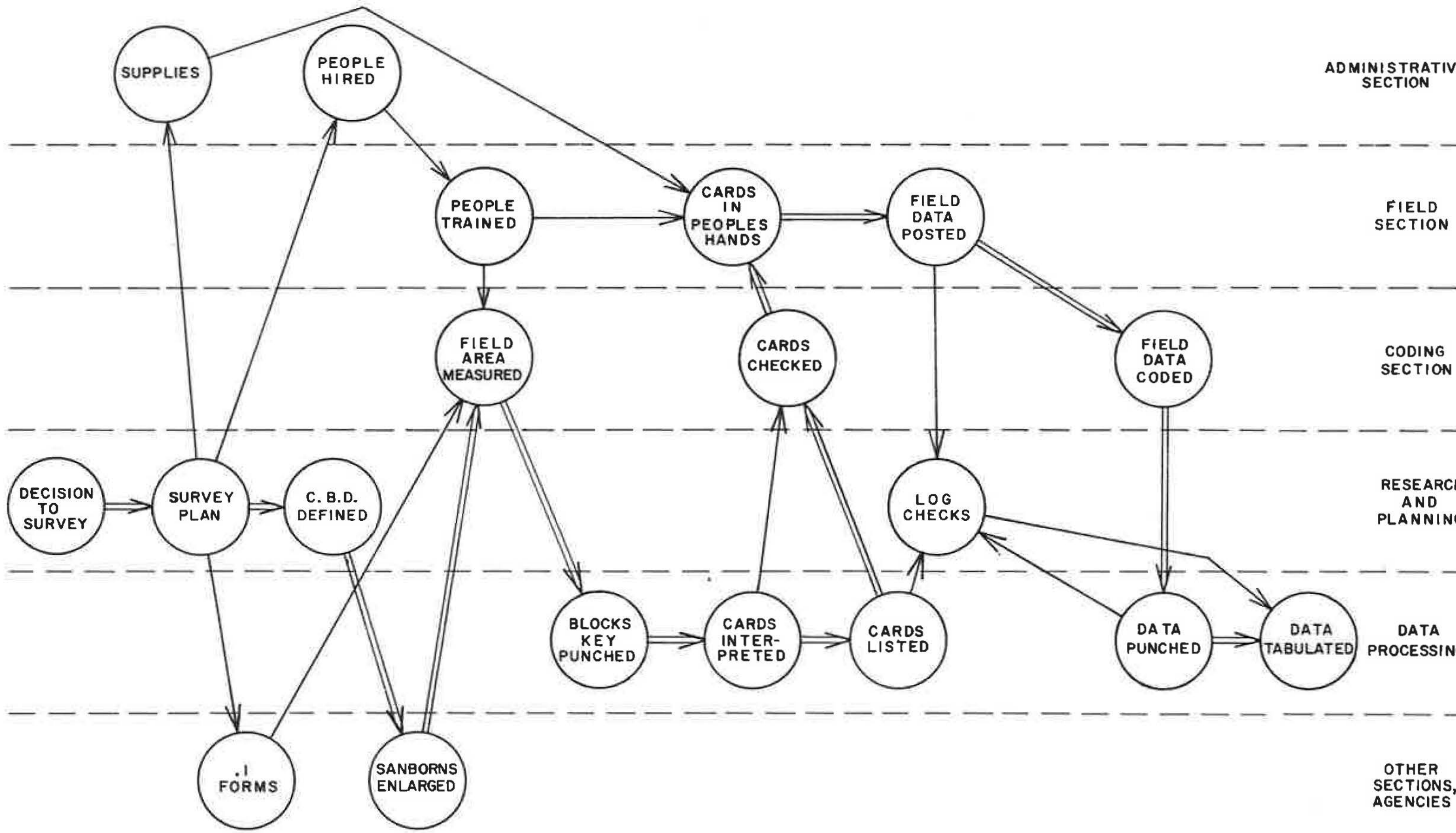

Figure 6. PERT program for CBD survey arrayed by section responsible for events.

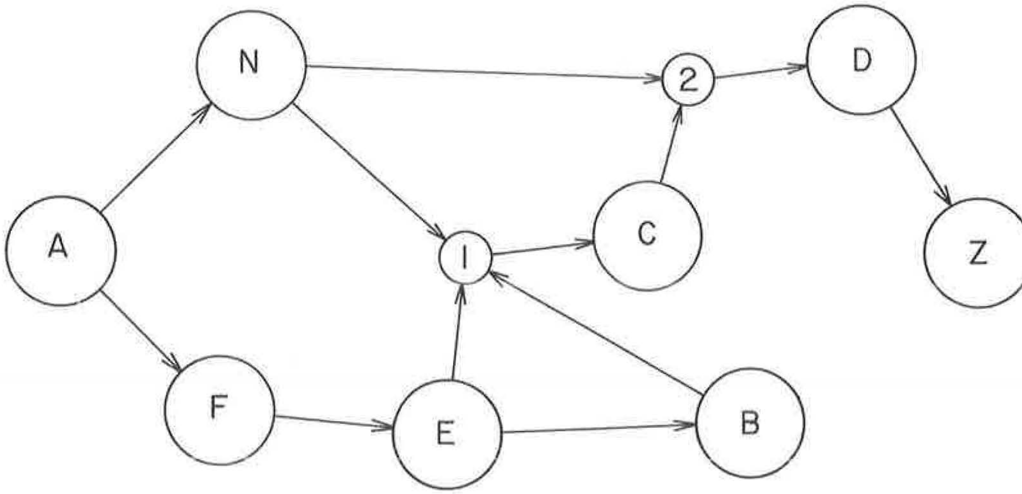

Figure 7. Modified diagramming technique — numbered nodes are assembly nodes; lettered nodes are event nodes. Only one activity (arrow) may lead to an event node. Assembly nodes indicate required availability of two or more events before a new activity may begin.

representing an activity — will terminate in a single event. It does not seem logical for two activities to have a single product.

To get around this problem, the author has used, in subsequent PERT diagrams, two types of node symbols. The first, called an "event node," is diagrammed using a large circle. Such event nodes can only be the terminal of a single arrow representing a single activity. The second type of node is called an "assembly node" or "dummy node" and is used as a junction point where two or more previously completed events are brought together so that a new operation or activity may commence (Fig. 7).

This diagramming technique adds perhaps a third more nodes, but increases clarity and diagramming ease. It has been used subsequently in the PERT diagram for the entire transportation planning process.

PERTING A COMPREHENSIVE TRANSPORTATION STUDY

A PERT diagram for an entire comprehensive transportation study is shown in Figure 8. This diagram, although prepared specifically for a transportation study for the Rochester (N.Y.) metropolitan area, is sufficiently general so that it could be used in any major metropolitan area.

A list of events, with minimum requirements for each, is given in Table 1. Numbering of the events corresponds with the numbers on the block diagram.

The diagram and its accompanying list of events has evolved through about six drafts, with many minor amendments. The nature of the PERT process dictates that it will continue to be subject to constant change and amendment. Figure 7, therefore, cannot be considered final.

In all, 150 events are diagrammed in Figure 8. Of these, 31 are "assembly nodes" and 119 are "event nodes." Over 200 activity lines or arrows connect these nodes; about 40 percent of the arrows are dummy activities, with zero times. Not counting zero activities, the median duration of each activity is between three and four weeks. This appears to be a reasonable unit for management and reporting purposes in a transportation planning program.

Major Work Areas and the Critical Path

As the PERT diagram for the entire transportation planning process was prepared, the various events began to fall into a series of major work areas. This was partly

TABLE 1

EVENTS AND MINIMUM REQUIREMENTS FOR COMPREHENSIVE TRANSPORTATION STUDY

Node Number	Title	Minimum Requirements
1	Study design	Report describing surveys, analyses, forecasts, objectives, planning and testing processes, together with organization, time, cost, manpower, space and equipment requirements.
2	Transit study design	A plan describing methods for mass transportation survey and planning operations.
3	Travel survey design	A report describing the time, duration, sample size, and other features of the travel inventories to be undertaken including the home interview, the truck-taxi, and the external surveys.
4	Contractor hired	A firm retained on contract to undertake all, or portions of, the home interview, the truck-taxi and the external surveys.
5	Administrative procedures	The steps necessary to obtain (a) interviewing personnel and to train them, (b) field office, (c) payment procedures, (d) vehicles, and (e) incidental equipment.
6	Arterial selection criteria	A set of criteria for determining which roads shall be included in the network of arterial streets to be coded and used for planning purposes and computer assignment.
7	Land-use manual	A plan for obtaining land-use data using one or a combination of (a) existing data, (b) assessors files, (c) air photos, and (d) field list. This includes a plan for parcel and block numbering.
8	Map resource list	List giving coverage, scale, date, and contents of all maps and aerial photographs available for the study area.
9	Census tracts and political units maps	Maps showing up-to-date political unit and census tract boundaries.
10	Gridded regional map	Map showing study area with precise location of a half-mile grid with CBD at point x = 500, y = 500.
12	Zones and districts	The mapped location of analysis zones, which are the area units into which the study area is divided for planning purposes. Zones are grouped into districts which combine into rings or sectors arrayed by distance and direction from the CBD of the urban area.
13	Arterial numbering manual	A plan for numbering the arterial network.

TABLE 1 (continued)

Node Number	Title	Minimum Requirements
14	Home-interview manual	A manual describing in precise terms how the home-interview survey is to be conducted.
15	Truck-taxi manual	A manual describing in precise terms how the truck-taxi survey is to be conducted.
16	External manual	A manual describing in precise terms how the external survey is to be conducted.
17	Truck-taxi sample	A sample of truck registration numbers drawn from official registration sources, keypunched, and printed on interviewers' daily work sheets, together with letters to truck owners and operators.
18	Transit maps and schedules	Maps of all mass transportation systems in the metropolitan area showing route locations together with schedules for buses and rail rapid transit trains.
19	Coded transit network	The transit network coded for computer representation including length, seating capacity, service and other characteristics of each segment of the network.
23	Land-use data source	All available sources giving existing land use. May be existing land-use maps, assessors' cards, field lists, or aerial photographs.
24	Assessors' files	A card or tape copy of assessors' files including (a) account number, (b) address, (c) area of land, (d) land-use code (if available), and (e) other data.
25	Large-scale maps with grid and block numbers	Maps at 800 ft = 1 in. to 2,000 ft = 1 in. with grid and all block numbers added.
27	Selected arterial system	A map showing all streets divided into three classes (a) local streets, (b) expressways and (c) arterials.
29	Parcels identified	All parcels of land, as defined, numbered within or referenced to each block.
30	List of blocks	A list of each block in the study area, numbered by its x-y position.
31	Field list	A list, or a corrected list, of addresses within numbered blocks showing (a) number and location of each dwelling place and (b) land use.
32	Block list keypunched	Keypunched list of all blocks in study area, numbered with x-y notation.
33	Streets numbered	A list of all streets in the study area with a four digit number for each.

TABLE 1 (continued)

Node Number	Title	Minimum Requirements
34	Arterials numbered	Each segment of the arterial network within the study area, plus existing expressways, numbered to permit its being represented in a computer.
35	Street list key-punched	The street list in punched card form.
36	Block list checked	Block list checked against maps to insure completeness.
38	Sample selected	A sample of addresses, properly stratified and day-dated, printed on interview assignment forms and printed on "dear householder" letters.
40	Street address guide	A printed address guide, giving address ranges for each block face in the study area, and the proper block and street numbers pertaining thereto.
41	Screenline counted	Mechanical and hand traffic counts made on each crossing of one or more screenlines dividing the study area.
42	Transit network tabulated	Bus and other mass transportation service summarized to provide, as a minimum, seat miles of service by route segment.
43	Arterial network keypunched	The arterial network keypunched.
44	Arterials contingency checked	Contingency checks performed on the arterial network to insure completeness of the network.
46	Land use identified	Land use of each parcel coded onto forms or mark sensed on cards. Includes reference to street face identified by number.
47	Screenline data summarized	Summarizations of screenline crossing by vehicle type, by hour of day.
48	Transit computer program	A computer assignment program permitting transit trips to be assigned over a mass transportation network, simulating zone-to-zone movements.
49	External survey completed	All interviews completed on the cordon line surrounding the study area.
50	Truck-taxi survey completed	Interviews completed for all truck and taxi sample registrations.
51	Home interview completed	All home-interview sample addresses interviewed.

TABLE 1 (continued)

Node Number	Title	Minimum Requirements
52	Road network survey	The following data, as a minimum, coded and keypunched for each arterial street: length, speed limit, pavement width, right-of-way width, type of cross-section.
53	Sample of streets	A sample of local and arterial streets selected for machine or manual counting.
54	Land use measured	Each parcel measured and noted on forms or mark sensed on cards. Includes street areas.
58	Sample of buses	A sample of buses selected from schedules to permit a sample survey to be conducted of person miles of travel.
59	Person miles of travel survey	A survey conducted on bus and (if in operation) rail rapid transit systems to ascertain the volumes of passengers using each segment of the transit network.
60	Person miles of travel data coded	Data obtained in the person miles of travel survey, coded and keypunched.
61	External survey coded	All external interview forms coded and ready for keypunch.
62	Truck-taxi survey coded	All truck-taxi forms coded and ready for keypunch.
63	Home interview coded	All home-interview schedules coded geographically and numerically.
64	Road network coded, punched	All data for the arterial network punched and contingency checked.
65	Road volume counts made	Counts (either short-count manual or machine) made of traffic volumes on sampled arterials and local streets.
66	Contingency check on person miles of travel data	Person miles of travel surveys checked and corrected.
68	External travel survey keypunched	Coded travel survey data keypunched.
69	Truck-taxi survey keypunched	Coded truck-taxi data keypunched.
70	Home-interview survey data keypunched	Coded data from the home-interview survey keypunched.
71	Land use keypunched	Land-use data keypunched.

TABLE 1 (continued)

Node Number	Title	Minimum Requirements
73	Land-use contingency checks completed	Land-use contingency checks completed. Includes (a) block list check for completeness, (b) area checks for scale correction, (c) map printouts, and (d) miscellaneous checks.
74	Volume data coded and punched	Manual or machine counts coded and keypunched.
75	Road network contingency checked	Contingency checks performed on the road network and corrections made so as to insure a perfect file.
76	External contingency checks	Contingency checks performed on all external survey data and corrections made.
77	Truck-taxi contingency check	Contingency checks performed on all truck and taxi cards and corrections made.
78	Home-interview contingency checked	All home-interview cards machine contingency checked and corrections made.
80	Person miles of travel tabulations	Tabulations of person miles of travel giving, as a minimum, the volumes on each segment of the mass transportation network and person miles of travel by analysis zone.
81	Volume data contingency checks	Contingency checks data performed on volume cards.
83	Land-use tabs	As a minimum, area totals for each major land-use type by analysis zone.
84	Zoning data	Existing zoning measured, as a minimum, for commercial, residential and industrial categories, for each analysis zone. (It may be desired to incorporate this within the land-use survey.)
85	Land-use forecast model	A computer program, based on a reasonable theory which will (a) distribute population, labor force, and vehicle ownership to analysis zones by 5-yr increments, and (b) indicate future uses of land in each analysis zone.
86	Travel data factored	Home interview, truck-taxi and external travel data factored.
87	Travel tabulations	Tabulations of travel data obtained from the home interview, truck-taxi, and external survey giving, as a minimum, person and vehicle trips by purpose and separately by land use by analysis zone. Also, standard Bureau of Public Roads tables of population and zone-to-zone trip movements.

TABLE 1 (continued)

Node Number	Title	Minimum Requirements
88	Person trip data	Tabulations of person trips by mode within land use, by analysis zone.
90	Transit computer assignment	An assignment of current transit trips to the existing transit network to determine whether current travel over bus and rapid transit network can be simulated reliably.
91	Volume and vehicle miles of travel data	Volume data presented, at a minimum, in flow diagram form; VMT data by street type by analysis zone.
92	Road network data tabbed	Tabulations of network data including, as a minimum, arterial and expressway capacity, mean speed, and length, by analysis zone.
94	Historic PEV data	Historic data on population, economic growth, and vehicle ownership of the study area.
95	Independent trip generation data	Trip generation data from other cities obtained for the purpose of simulating trip making independently from travel survey data.
97	Simulated trip data	Person trip and vehicle trips simulated by applying trip generation rates from other cities against current land-use data.
98	PEV forecast model	A computer program for estimating aggregate population, economic, and vehicle growth for the study area, by 5-yr increments.
99	PEV forecast	An estimate of (a) aggregate population for the study area, (b) labor force, by industry type, (c) income, (d) industrial output, and (e) vehicle registrations, all by 5-yr increments.
101	Vehicle trip data	Tabulations of vehicle trips giving, as a minimum, automobile and truck trip destinations by land use and separately by purpose, for each analysis zone.
102	PEV data	Tabulations of population, economic, and vehicle ownership data obtained from travel surveys giving, as a minimum, population for each analysis zone with breakdowns by age group, by income, and by vehicle ownership for each district.
103	Land-use forecast	An estimate, by 5-yr increments, of the distribution of population, labor force and vehicle ownership and of the uses of land, in each analysis zone.
104	Trip forecast model	A computer program which will estimate future truck trips, automobile trips, and person trips made by mass transportation, for each analysis zone, by 5-yr increments.

TABLE 1 (continued)

Node Number	Title	Minimum Requirements
105	Trip generation rates	As a minimum, person and vehicle trip generation rates per acre by major type of land use, within district.
106	Road computer program	A computer assignment program capable of estimating zone-to-zone movements and assigning them over a road network with the option of restraining traffic flows by relating volume to street capacity.
108	Actual assignment	A computer assignment performed using trip data recorded from the travel surveys and assigned over the existing network.
109	Transit assignment evaluated	The assignment of transit trips compared with volumes measured on each link of the mass transportation network as measured by the PMT survey.
111	Simulated assignment (roads)	An assignment of vehicle trips to the existing network using simulated trip ends.
112	Transit sketch plans	One or more plans for mass transportation facilities.
113	Coded transit plans	Transit plans coded for computer assignment.
114	Trip forecast	An estimate of truck trips, automobile trips, and person trips by transit for each analysis zone for each 5-yr planning period.
115	PMT survey and mass transportation network report	A published report giving the amount and distribution of service provided by mass transportation systems together with the use which is made of these systems.
117	Assignment evaluated	Actual and simulated assignments compared with data on traffic flows and vehicle-miles of travel so as to calibrate the computer program to reproduce present traffic flows reliably.
118	Revised transit computer program	The transit computer program calibrated.
119	Physical factors	Mapped locations of both physical (topographic) and cultural (expressways, rail lines, housing developments, cemeteries, parks, etc.) features which influence the planning of future transportation facilities.
120	Objectives	A statement of the objectives and values which are to be sought in urban planning, with particular focus on transportation objectives. These objectives are to be used as a basis for measuring the performance of each plan.

TABLE 1 (continued)

Node Number	Title	Minimum Requirements
121	Planning guides	A statement giving general guides or principles for the planning of transit, rail, and road networks.
122	Optimum spacing	Formulas for estimating, in preliminary fashion, the best spacing of future road systems.
125	Arterial plans	A set of plans giving the proposed locations and numbers of lanes of arterial (major) streets, taking into account future trip making, physical factors, planning guides and optimum spacing.
126	Expressway plans	One or more plans giving the proposed generalized locations of expressways to serve travel demands of a future population.
128	Sketch road plans	The combination of expressway and arterial plans.
130	Revised computer program (roads)	The computer program revised and calibrated as a result of the evaluation of actual and simulated assignments.
131	Coded road plans	One or more road network plans coded for computer assignment.
134	Transit computer assignment	An assignment of future transit trips to a transit plan.
135	Road computer	A computer assignment using future estimated trips over a planned road network.
136	Transit evaluation	An evaluation of more than one transit plan including, as a minimum, estimates of (a) construction costs, (b) operating revenues, (c) passenger time, and (d) other evaluations in light of the objectives.
137	Road plan evaluation	A review and study of the computer assignment resulting in (a) estimate of construction and operating costs, (b) a list of portions of the network which are overloaded and underloaded, and (c) a general evaluation of the network in light of the objectives.
138	Final road plan	A road plan adopted as a result of the review of assignments to a number of plans.
139	Final transit plan	A final plan for mass transportation facilities indicating recommended locations for bus and rail lines and estimated use of each such line.
141	Final plan	A final, comprehensive transportation plan showing recommended locations for new arterials, new express roads, additional bus service, and additional transit lines as required.

TABLE 1 (continued)

Node Number	Title	Minimum Requirements
142	Schedule	A recommended schedule of priorities for the construction of new transportation facilities and for the operation of new transit services, by 5-yr increments.
143	Financial study	A study indicating the relationship between the costs of constructing and operating new transportation facilities and the ability of the Federal, state, and local governments to pay for such improvements.
144	Final report	A report containing the final plan, the justification for this plan and a recommended schedule for its construction.
145	Trip forecast report	A published report giving the estimated numbers and locations of truck trips, automobile trips, and mass transportation trips.
146	Land-use forecast report	A published report giving estimates of the distribution of population, vehicle ownership, and land use for the target year.
147	Road network and volume report	A published report giving the results of the surveys of road facilities and the use made of these facilities.
148	Travel report	A published report giving the findings obtained from the surveys of travel.
149	Land-use report	A published report on the distribution of land use by type within the study area.
150	Stop	

the influence of previous experience and partly the result of the evolution of the diagram as it was drawn. (Much of the diagram was drawn backwards, starting from the final plan and asking the question "what do I need to have on hand to produce this particular event?")

Nine major areas of work evolved:

1. Mapping and listing controls;
2. Land-use survey;
3. Road facilities and use survey;
4. Travel survey;
5. Transit facilities and use survey;
6. Land use and trip forecasting;
7. Assignment calibration;
8. Planning and testing; and
9. Final reports.

One major work area has been omitted: the study of goods movement. A program for this is now being developed by the UNYTS staff for the Niagara Frontier Transportation Study. It will be fitted into the overall diagram at an early date.

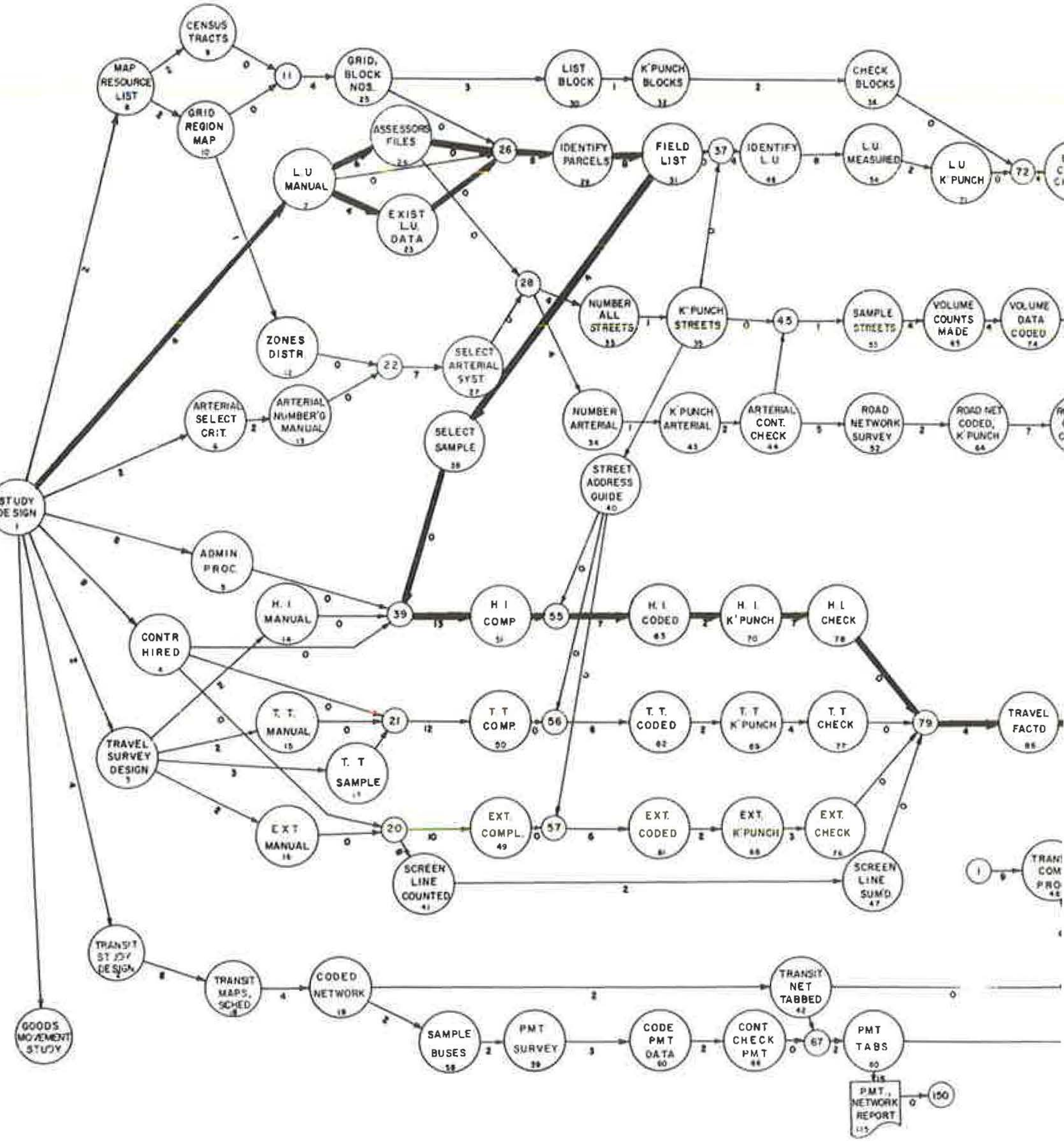

Figure 8. PERT diagram for a comprehensive transportation st

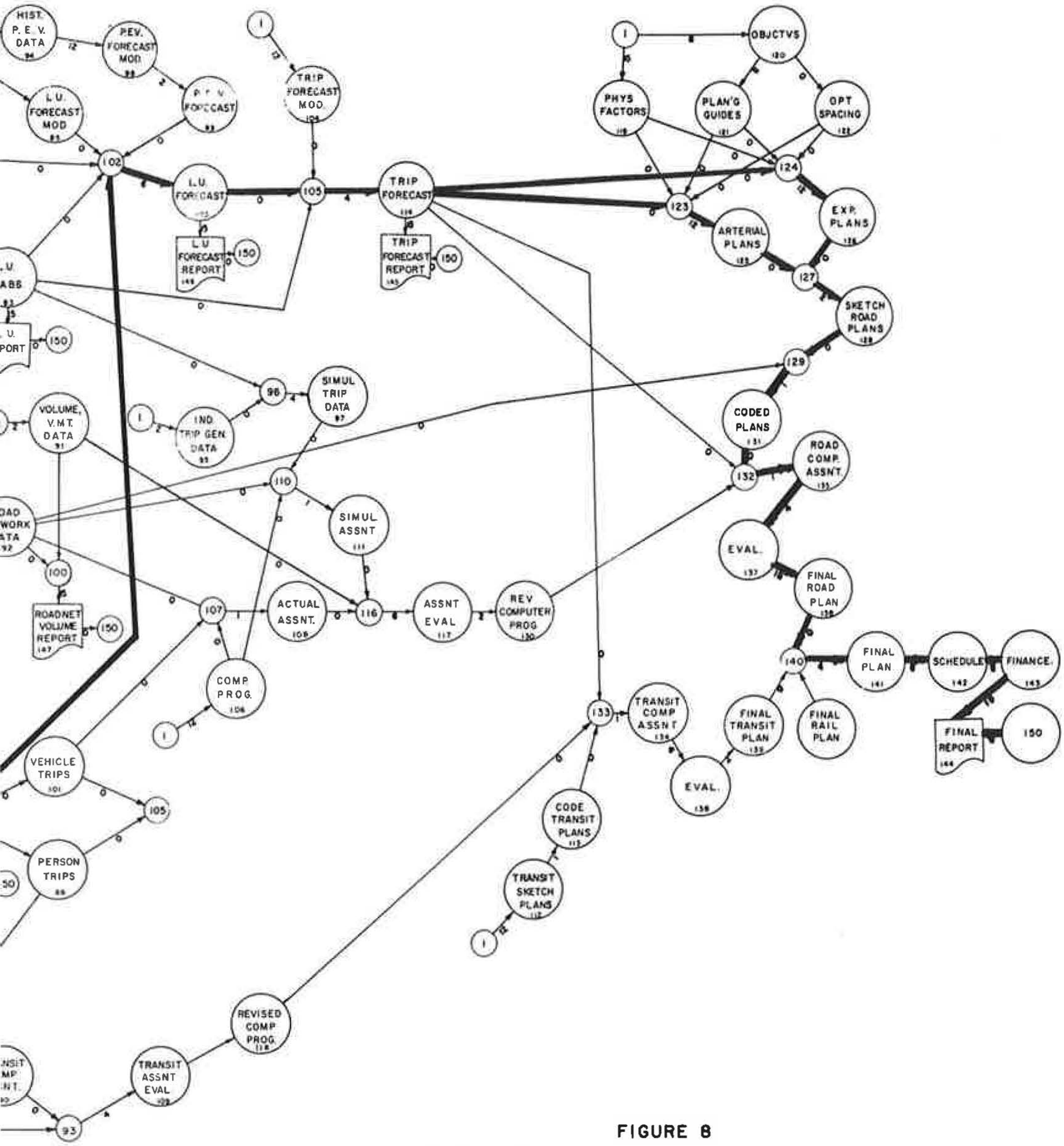

FIGURE 8

PERT DIAGRAM FOR A COMPREHENSIVE TRANSPORTATION STUDY

TIME IN WEEKS — CRITICAL PATH

gures on lines represent time in weeks; heavy lines, critical path.

The critical path runs through (1) mapping and listing, (4) travel surveys, (6) land use and trip forecasting, (8) planning and testing and (9) final reports.

The critical paths, determined objectively on the basis of time estimates prepared randomly (so as to be influenced as little as possible by previous scheduling), turn out to be very much the way one would expect.

The critical path, as estimated from this diagram, is 148 weeks, or 2. 8 years. This length of time can undoubtedly be reduced, but probably not much under two years. The breakdown of this critical path is as follows:

From Start Event	To End Event	Duration
Go	Sample selected	28 weeks
Sample selected	Travel tabs	37 weeks
Travel tabs	Trip forecast	10 weeks
Trip forecast	Final road plan	38 weeks
Final road plan	Final report — Stop	35 weeks
Total		148 weeks

The two final sections of the critical path (from final road plan to final report — stop) can be shortened. Much of the planning work will be done ahead of the time when trip forecasts have been made. Also, studies of scheduling and financing the plan can be undertaken ahead of time, and not in series as shown on the diagram.

Evaluation for Time Reductions

Having displayed the transportation study process in PERT diagram form, the obvious question is "How can the planning process be modified to reduce time and/or cost?" This is a proper question, provided that one is assuming a constant quality of plan output. It would certainly be unwise to conduct a race to see who could conduct transportation studies the fastest, because a major plan takes time to mature and its quality must be very high.

One must insert the precaution that the time estimates shown in Figure 8 are based on given manpower, machine power, and experience. The UNYTS staff now has the experience of data gathering for one major metropolitan area. Manuals have already been prepared which, with slight modification, are ready to be used in other metropolitan surveys. An inexperienced staff would naturally take much longer to do the same job.

There are certain obvious ways in which to make reductions in time, not necessarily derived from the PERT process. Some of these have already been put into practice in the Niagara Frontier study, others will be used in the Rochester study.

1. Cut interviewing time to 3 or 4 months. Indications are that urban travel is sufficiently regular so that long interviewing periods are no longer necessary.
2. Increase manpower in coding operations. Provided that good coding instruments (coding guides, maps, and generator files) are available, and within the limitations of management capability, it is worthwhile to increase the number of coders, since an hour's coding work costs as much one month as it does the next.
3. Increase machine power. High-speed data processing equipment probably costs less per unit of output than low-speed equipment, even including programming time.

In terms of delivering a product sooner there is no comparison. Hence more powerful machines provide a clear way toward cutting time.

4. Running operations in parallel. Within the limitation of the time of the professional staff, it is naturally desirable to run operations in parallel rather than in series. In the Niagara study this has been accomplished by starting the formal planning work at an early date — working out statements of objectives (Event 120), planning guidelines (Event 121) and preparing maps of the key physical factors (e.g., topography, land uses, transportation facilities) which influence planning. Traffic assignment computer programs are available which will be ready in time to run, and these have, in fact, been tested so that there is a proven capability for computer assignment.

Besides these more obvious means of reducing the total time of a transportation study, examination of the PERT diagram (Fig. 8) leads to other possible ways.

1. Increased use of simulation techniques. A large part of the critical path (23 weeks) is employed in testing and re-testing plans (Events 131 to 138). Plans can be prepared almost from the start of a study, but the problem is how to test them without the availability of travel data. The answer lies in improved simulation of trips and improved forecasting techniques — both made completely dependent on the computer. The only new data needed (at least for preliminary testing purposes) would be the results of the land-use survey.

2. Improved maps and field list data. A large part of the work needed to get ready for surveys of travel and land use is absorbed in preparing adequate maps and lists of houses. Numbering of blocks and obtaining reliable land-use data are also lengthy tasks. Such activities may require 12 to 15 weeks, assuming that one is willing to get by with less than the best. A sure way of reducing the time needed for such preparatory work is to have the data already available in the proper form. An excellent combination of source data appears to be assessors' data combined with land-use data from the city planning commission, with both of these keyed to accurate photogrammetric maps. Such data, organized on punched cards or on magnetic tape, can greatly reduce land use, block numbering, sample selection, and other costs and time expenditures.

3. Shortening the forecasting operations. Much of the time required to make forecasts is eaten up in the preparation of models for forecasting population, economic growth, vehicle registrations, land use, and trips. Once these models have been prepared, in sufficiently generalized form so that they can be applied in more than one metropolitan area, there will be a considerable reduction in the overall planning processes.

4. Shortening the planning operations. Whereas survey work for comprehensive transportation studies is well understood, this same situation does not obtain in the field of plan preparation. Currently it is a major effort to select and assemble the key factors influencing a transportation plan for roads, mass transportation and good movement, and to use these in molding a plan. Hopefully this work, which has tended to be highly intuitive and individual, will become sufficiently regularized so that it will not take so long.

Goals

A PERT diagram proceeds from a start point to a single ending point, and thus carries with it the danger that the single destination may become a fixation, to the exclusion of all other goals. The single goal in Figure 8 is a comprehensive transportation plan, embracing roads, mass transportation systems and other forms of transportation as may be required.

This single plan, however, must be viewed along with other goals. These include the conduct of successful research work, the development of increased public understanding, and the accomplishment of the plan itself. Accomplishing a plan depends, of course, both on the existence of a careful and responsible plan and on public understanding of the plan and its means of development.

Of the three additional goals, only one makes its way into the block diagram describing the transportation study. This is the development of increased public understanding — through the reports which the study staff must prepare. These reports are shown by standard report symbols which take off from certain events on the diagram. There are six such reports which can be prepared and distributed in the second year of a transportation study's life.

Clearly, the additional goals besides the goal of the plan itself must be kept constantly in mind. They must, moreover, be acted upon if the fullest use is to be made of the plan once it has been prepared.

CONCLUSION

PERT offers the manager or management team of a transportation study a number of substantial advantages in return for the investment in time which the technique requires. Several of these advantages are as follows:

1. Accurately defined work targets.
2. A concise means of representing processes that are too complicated to store in one's head.
3. A technique which helps to remove bias from time estimating.
4. A technique that objectively points out the critical work areas.

This paper has shown how the PERT process is being applied to a comprehensive transportation study. A diagram and a list of events have been presented. Several implications have been drawn from this evidence — ways in which transportation studies can be shortened, and critical areas where work is needed in the development of new methods.

It is clear, however, that a great deal more can be done with PERT. Three areas of possible improvement are as follows.

1. Computer display. It is quite possible (if it has not already been done) to program a computer so that the output of the PERT problem is not merely a list, but a diagram like the original input, with the events positioned according to certain rules. One rule would be to position each event vertically according to the organization doing the work and horizontally according to, say, the earliest possible start time.
2. Computer scheduling. It should be possible for the computer to consider the events and the size of the organization involved and to schedule the work according to various rules. One rule might be to minimize changes in employment; that is, to keep the work load as even as possible, within a given overall project time.
3. Cost considerations. PERT/COST is a technique which brings cost as well as time into the picture. This should be applied to transportation studies, since the trade-off of time for money can assume large proportions.

Any management work requires a considerable investment of time and skill. PERT is no exception to this rule. PERTing a comprehensive transportation study takes, initially, a month of concentrated work, and beyond that many hours of drafting, coding, and checking before it can be put on a computer. Constant revisions and corrections must be made. The return lies in increased certainty and speed and this outweighs the investment.

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