Multiple Project Scheduling of Preconstruction Engineering Activities

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Systematic methods for scheduling the preconstruction engineering and right-of-way activities of the various state highway programs are revealed in several approaches. In each approach the schedules are arrived at by allocating the assumed fixed pool of classified manpower resources to a priority array of programed projects.

The "balance-period approach" is a theoretical procedure which outlines a set of rules that is applied in an iterative manner for the entire highway program period. Each repeat of the procedures is for a predetermined time interval or balance period. During the balance period the entire pool of fixed manner resources is applied to the priority array of projects. Network diagrams of each project and critical path methods are utilized to allocate the resources and thus create a schedule of preconstruction activities.

The application of the balance-period method, along with several correlating rules for activity continuity, produces a schedule that is based on project priority and the availability of manpower resources. Furthermore, the balance-period method is mechanical and thus suitable to be written as a computer program.

The similarities and differences between RAMPS and RPSM were explored by testing sample problems with each program. The practical aspects of using either the theoretical balance-period approach, the RAMPS program, or the RPSM program are presented. Highway department policies and operating methods have substantial effects on the feasibility of these approaches. Numerous technical problems must be solved to achieve fully objectives of highway program administrators.

•RESEARCH was initiated in 1963 by the staff of the Automotive Safety Foundation in the "execution phase" of highway programing. Specifically, the work has been confined to studies of the schedule and control of preconstruction activities for the multiplicity of projects that comprise the state highway programs.

This area was set apart for attention due to results of a cooperative survey conducted by the U. S. Bureau of Public Roads and the Automotive Safety Foundation for the Highway Programming Committee of the Highway Research Board. The objective of the survey was to investigate the methods used by 35 states to schedule precontract activities and to make available for general use any significant findings. In summary, the conclusions reveal a wide diversity in the extent and degree to which work schedules

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are planned in advance, and more importantly, the various work schedules devised were not the result of clearly defined, systematic procedures that related the work required to the availability of manpower resources.

The Regional Conference on improved Highway Engineering Productivity, held by the AASHO Committee on Electronics in April 1963, indicated the progress several states had made in the application of the Critical Path Method (CPM) to the highway program. Of the six states that reported their activities in this area, two states had used CPM to schedule various construction projects, three states were applying CPM to preconstruction engineering, and one state was engaged in both research and indoctrination of personnel on the possible application of CPM. Since this conference, it has become apparent that other highway departments are making use of critical path theory and associated computer programs to schedule both construction contracts and preconstruction engineering.

The value of the CPM to the scheduling of single projects that draw on unlimited resources has been well demonstrated in many engineering fields. However, the possible extension of this technique to a multiplicity of projects that rely on a limited manpower pool has not been widely explored.

Research was first begun in theoretical areas, and then in study of practical application of procedures that attempt to allocate more efficiently the available manpower to establish a realistic highway program schedule.

The theoretical balance-period approach to multiple project scheduling is discussed first. It is anticipated that this research could lead to procedures that would be reiterated periodically to provide an effective method for monitoring the precontract phases of the various programed projects.

While studying the theoretical approach, it became apparent that other organizations had been successful in developing multiple-project scheduling methods for other industries. Several of these techniques and some of the aspects of practical application of any one of these methods are discussed.

BALANCE-PERIOD APPROACH TO MULTIPLE-PROJECT SCHEDULING

The balance-period approach was developed to offer a theoretical solution to the problem of scheduling the preconstruction engineering and right-of-way activities of state highway programs. It is based on the premise that the availability of manpower and the priority ranking of projects are the critical features that determine the schedule. The principle involved is that for standard units of time, herein referred to as balance periods, the entire manpower pool is allocated to the programed projects. The allocation procedure is repeated for each balance period until the manpower requirements of every programed project are met. The result is a schedule.

Hypotheses

To detail the approach more specifically, it is necessary to establish the frame of reference on which the balance-period approach is founded. Five assumptions are made:

1. A program of specified projects exists.
2. The programed projects are ranked in relative order of priority or urgency. (It is not pertinent to this study to decide how this should be done.)
3. Funds will be available during the program period to finance all preconstruction activities of the programed projects.
4. The highway departments have a limited pool of available personnel that may be assigned to preconstruction engineering and right-of-way tasks. This pool is fixed and will remain so within the program period.
5. The network or arrow diagraming process is of benefit in the planning of preconstruction activities, and thus, it is feasible to portray all programed projects in network diagram form.

It is recognized that modification, additions, or deletions are necessary to accommodate a specific highway department's scheduling problem. However, it is on these five particular features that the theory of the balance-period method has been designed.

Objectives

Within this framework and without further guidelines, the principle of balancing manpower and projects within standard units of time could be accomplished. However, to establish systematic procedures, the balancing process should have specific goals to accomplish at each iteration. After considering a range of possibilities, the following three objectives were established as being reasonable goals for highway scheduling:

1. The procedures must schedule the projects based on the relative priority ranking;
2. The procedures must make maximum utilization of the fixed manpower pool; and
3. The procedures must schedule each project to completion in the minimum possible time.

Other objectives, such as scheduling projects to meet predetermined advertising, were not included in this preliminary search for systematic scheduling techniques.

Network Diagrams

The type of network diagram used in the balance-period approach is shown in Figure 1. This is simply the type of diagram used in normal CPM operations for single project schedules. The arrows indicate the activities and the nodes represent events or the instants in time that an activity or group of activities originates or ends. Dummy activities that show a dependency or time relationship between events are indicated by dashed arrows. The events are designated by numbers and the activities are described by the event numbers that directly precede and follow the activity. By way of illustration, event 3 might be "final highway design complete," and activity 3-5 might represent the work required to prepare the project's contract plans. Event 5 might indicate the completion of the preconstruction engineering and right-of-way activities necessary to offer the contract for bid advertising. The dashed dummy activity 2-4 indicates that activity 4-5 cannot commence until the completion of activity 1-2.

Sample Problem Solution

A hypothetical and very simplified problem was designed to develop the balance-period method. The problem employs but four projects that involve only 24 activities; however, it should suffice to illustrate the method. The projects are shown in network diagram form on the right side of Figure 2. Each diagram, at first glance, looks like all others; closer examination reveals the differences between projects.

To proceed with the scheduling of the sample problem, certain basic information must be provided.

1. The programed projects must be identified and arranged in priority sequence. For the problem, the project number indicates the priority. Project No. 1 is the most urgently needed project.

2. Manpower available for assignment must be classified and tabulated according to skill. For the sample problem, only two skills and a total of three men are available to accomplish the work of the problem. The skills are R and B. There is one R skill and two B skills.

3. The skills required of each activity must be determined. The letter designation R or B along the arrows describes the skill necessary to perform the activity. Event and activity names are disregarded for the sample problem.

4. The work required in each project must be estimated in terms of basic time

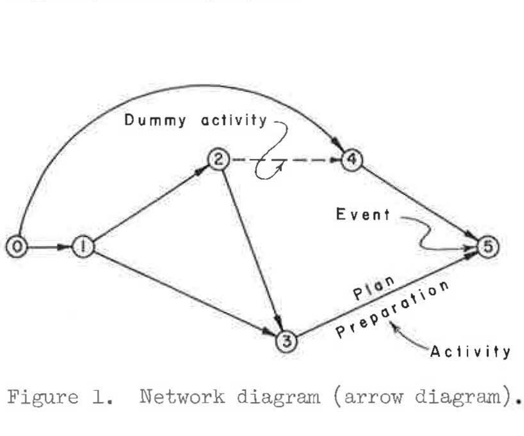


Figure 1. Network diagram (arrow diagram).

Project	Balance Period	Man	Activity	Work	Time Units	Work Remaining	Man	Activity	Work	Time Units	Work Remaining
		MANPOWER	ALLOCATION								
1	0					19					21
	1	R_1	1 - 2	8		11	B_1	1 - 3	8		13
							B_2	0 - 4	4		9
	2	R_1	2 - 3	6		5	B_1	4 - 5	8		1
		R_1	3 - 5	2		3					
	3	R_1	3 - 5	3		0	B_1	4 - 5	1		0
2	0					13					27
	1						B_2	1 - 2	4		23
	2						B_2	1 - 2	4		19
							B_2	1 - 3	4		15
	3	R_1	0 - 4	4		9	B_2	1 - 3	4		11
		R_1	4 - 5	1		8	B_1	2 - 3	6		5
							B_1	3 - 5	1		4
	4	R_1	4 - 5	8		0	B_1	3 - 5	4		0
3	0					4					36
	3						B_2	1 - 2	4		32
	4						B_2	1 - 2	4		28
							B_1	1 - 3	4		24
							B_2	2 - 3	4		20
	5	R_1	0 - 4	4		0	B_1	1 - 3	4		16
							B_2	2 - 3	2		14
							B_2	4 - 5	4		10
							B_1	3 - 5	4		6
	6						B_2	4 - 5	5		1
							B_1	3 - 5	1		0
4	0					12					12
	5	R_1	1 - 3	4		8	B_2	0 - 4	2		10
	6	R_1	1 - 3	5		3	B_1	1 - 2	2		8
		R_1	3 - 5	3		0	B_1	2 - 3	2		6
							B_2	4 - 5	3		3
	7						B_2	4 - 5	3		0

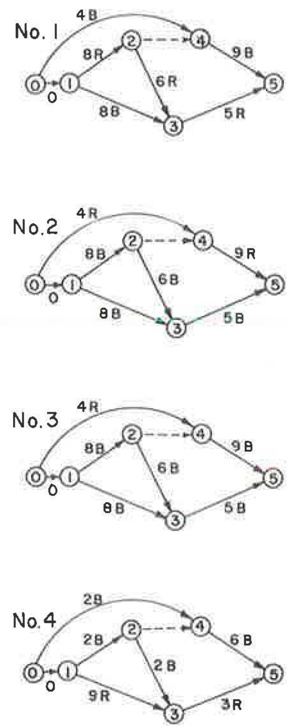


Figure 2. Chart of balance-period method.

units. The number beside the arrows of the network diagrams indicates the work required to accomplish the activity. Thus, for activity 1-2 of project No. 1, the figure "8" represents the fact that 8 time units are required to complete the activity. For the sample problem only one man may be utilized to accomplish an activity.

5. The smallest indivisible time unit that is practical to schedule is chosen as the basic time unit. This might be hours, days, weeks, or months, depending on whether the schedule is to be utilized at the production level or at a higher management stratum.

6. A logical accumulation of basic time units determines the balance period. For example, if the basic time unit is a day, then the logical balance period is a week. The balance period comprises eight basic time units in the sample problem.

With this information and suitable charts, the scheduling process begins. Personnel are allocated, within the balance periods, to the highest priority, uncompleted projects. Where the network diagram indicates that some personnel cannot be utilized in the highest priority, uncompleted project, they are assigned to the next-to-the-highest priority project or to the first project in the descending list of projects that can utilize these people. All personnel are allocated before proceeding to the next balance period.

The primary importance of the network diagram is disclosed in the allocation process. The diagram portrays the activities that can be started and the activities that must be held off until an uncompleted activity is finished. This importance is further amplified in the case of the activity that depends upon the completion of two or more activities.

The priority ranking of projects is also vital to the balance-period method. It is this feature that allows a mechanical allocation of personnel between projects. For each balance period, all activities that compete for the men of a specified skill are ranked in order of their project priority, and allocation is made according to this priority ranking.

But the translation of project priority to activity priority does not take into account the case in which several activities of the same project are competing for the same man. Both activities would have the same priority, and thus critical path procedures are relied on to determine which activity the resource is to be assigned.

In the first balance period, it is shown on the network diagrams that all resources can be scheduled to start work on Project 1. R_1 is assigned to activity 1-2, B_1 is scheduled for activity 1-3, and B_2 is scheduled for activity 0-4. R_1 and B_1 will be occupied for the entire balance period on their activities, but B_2 completes activity 0-4 in the first four basic time units.

In the search for an assignment for B_2, in the latter four basic time units of the balance period, it is noted that the first project requires a B skill to accomplish activity 4-5. But the network diagram indicates a dependency between 4-5 and both 0-4 and 1-2. This dependency precludes the scheduling of work on 4-5 until both 0-4 and 1-2 are complete. Since 1-2 will not be finished until the end of the first balance period, and our objective is to make maximum utilization of available men, B_2 is scheduled to work on Project 2 for the remaining four basic time units of the first balance period.

A choice is now presented on whether to schedule activity 1-2 or 1-3 of the second project. Critical path analysis is relied on for the decision. A check of all time paths through the project reveals that path 1-2-3-5 requires 19 time units while 1-3-5 requires 13 time units. In an effort to complete the project in the earliest possible time, B_2 is assigned to the activity that lies on the longest path. Thus, B_2 is scheduled for the last four time units of the first balance period to activity 1-2 of Project 2.

In scheduling the second balance period, attention is still applied to Project 1—the highest priority, uncompleted project. It is realized that activities 0-4, 1-2, and 1-3 are completed and that 2-3, 3-5, and 4-5 will have precedence over activities of other projects. R_1 is assigned to 2-3 for the first six time units, and for the last two time units R_1 is scheduled to start 3-5. B_1 is scheduled to work on 4-5 for the entire eight-unit balance period. There remains one time unit of work in Project 1 that requires a B skill. This is the ninth unit of the work required on activity 4-5 and thus cannot be scheduled for the second balance period. Therefore, B_2 must be allocated again to Project 2.

A choice still exists on assignment of B_2 to 1-2 or 1-3 of Project 2; but in an attempt not to break the continuity of an activity, the choice is obviated and B_2 is therefore scheduled for the first four time units to complete activity 1-2.

Faced with the choice of assignment of B_2 to 1-3 or 2-3 for the last four time units of the balance period, the time paths of the uncompleted activities are again checked to aid in the decision. Activity 2-3 is on the path 2-3-5 and requires 6 + 5 or 11 time units to complete. Activity 1-3 is on the path 1-3-5 and requires 8 + 5 or 13 time units to complete. B_2 is, therefore, assigned to the longest path or to activity 1-3 for the latter four time units of the balance period.

At this point, with the principles of the balance-period method demonstrated, the remainder of the problem is not discussed.

In summary, the CPM, the network diagrams, the priority ranking of projects and the fixed pool of manpower resources form the elements of the theory utilized in the balance-period approach to scheduling. This schedule is a calendar time allocation of each resource to activities each can do, when it can be done, and in sequence of project priority.

The fixed pool of resources has a major bearing on the schedule. For each balance period, the entire manpower pool is applied to the priority array of projects. With the aid of network diagrams, a search is made for activities that can utilize the manpower. The search descends through the project array. The men are allocated to the highest priority project possible. When an allocation choice exists, the time paths through the project are checked and the man is allocated to the activity on the longest path. This conforms to the critical path method of scheduling.

Iterative Procedures

The sample problem is enormously simplified and could be solved without the aid of a computer. However, when 500 to 1,000 projects are involved with an even larger number of engineers, technicians, draftsmen, right-of-way specialists, etc., the problem probably requires solution by electronic computer. Furthermore, several variations of the problem should be solved and analyzed prior to adopting any schedule.

Therefore, the balance-period approach is more explicitly described in a five-step procedure that is to be repeated for each balance period.

1. Determine the initial critical path of each project. This is accomplished by examining all paths through the project to determine the path that requires a maximum of time to accomplish. Assuming manpower is available during all time periods, the critical path establishes the total time necessary to accomplish the project.
2. Assign personnel to the critical path of highest priority project not yet completed.
3. For the highest priority uncompleted project, examine the remaining time paths to complete the project and assign available personnel. Where activities compete for a resource, precedence is given to the activity on the longest path.
4. Personnel not assigned to the highest priority, uncompleted project are then available for assignment to the next highest priority, uncompleted project. The time paths are examined and personnel are assigned in the same manner as in the prior project. The resources are applied down through the priority list in like manner until all resources are exhausted.
5. Proceed to the next balance period and iterate steps 1 through 5. In the second and all subsequent iterations, the assignment must be somewhat altered. This is done to preserve activity continuity, and is accomplished by inserting the statement that once an activity has commenced, work should proceed until the activity is accomplished. To this rule there is one exception: in the case where a man has been scheduled in the previous balance period to a secondary project but is now needed on the critical path of the highest priority project, he is shifted so that he can be scheduled on the priority project—thus the continuity of his original assignment is broken. Activity continuity of the priority project is never disturbed—not even for assignment to the critical path.

The problem and schedule (Fig. 3) demonstrate the exceptional case that calls for activity interruption. For the first balance period on this problem, R_1 was scheduled to work on activity 1-2 of Project 2. This was done because Project 1 activity requiring an R skill cannot be scheduled until the B work on activity 1-2 of Project 1 has been completed. Proceeding to the second balance period, activity 2-4 of Project 1 is on the critical path and requires the assignment of an R skill. The continuity of activity 1-2 of Project 2 is thus broken to schedule the R skill to activity 2-4 of Project 1.

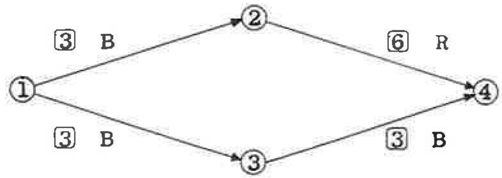
The purpose of interrupting the continuity of an activity is also seen in the problem and schedule of Figure 3. Had activity 1-2 of Project 2 been scheduled in the second balance, Project 1 could not be scheduled to completion until the end of time period 12. This delay would be contrary to our basic objective of bringing projects to completion in a minimum possible time.

While on the subject of activity continuity, it is pertinent to note the other cases where activity splitting is a possibility but is, in general, an unacceptable procedure.

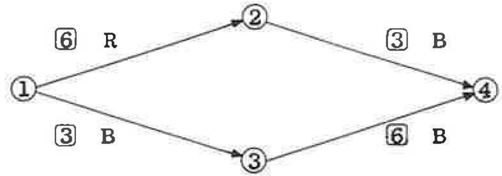
1. An activity of the highest priority project is not broken in order to schedule the critical path of this or any other project. Although such a practice might bring the project to completion in shorter time, the relatively greater number of activity splits that results probably does not warrant the savings in time. Figure 4 illustrates what would happen if activity continuity were ignored and the schedule planned according to strict critical path methods. (Only the activities indicated by solid lines scheduled.)

With the balance period equal to the basic time unit, the critical path shifts at every change in time. Manpower is allocated to activities that lie on the two highest time paths. The resultant schedule of the three activities shows activity 1-3 broken for a two-week period and activity 1-4 interrupted for one week.

Project 1
First Priority



Project 2
Second Priority

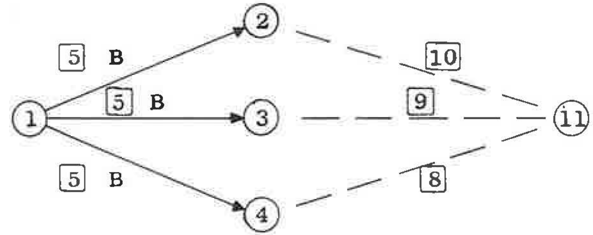


Manpower Pool: 2 B Skills
1 R Skill

Balance Period: 3 weeks
Basic Time Units: week

Project	Activity	SCHEDULE — Basic Time Units: 0–3	3–6	6–9	9–12	12–15
1	1-2	B_1				
	1-3	B_2				
	2-4		R_1	R_1		
	3-4		B_1			
2	1-2	R_1			R_1	
	1-3		B_2			
	2-4			B_1		
	3-4			B_2	B_2	

Figure 3. Continuity analysis.



Manpower Pool: 2 B Skills

Balance Period: 1 week

Basic Time Units: weeks

Project	Activity	SCHEDULE* — Time Periods: 1	2	3	4	5	6	7	8
	1-2	B_1	B_1	B_1	B_1	B_1			
	1-3	B_2	B_2			B_2	B_2	B_2	
	1-4			B_2	B_2		B_1	B_1	B_1

* For first three activities only.

Figure 4. Critical path scheduling.

The schedule that does not allow activity interruption is as follows:

activity 1-2—time periods 1 through 5
activity 1-3—time periods 1 through 5
activity 1-4—time periods 6 through 10.

This latter case results in an overall increase of two weeks to complete activities 1-2, 1-3, and 1-4.

2. An activity of a secondary project is not broken to allow the scheduling of a non-critical activity in a higher priority project. This is based on the premise that the critical path, and thus project duration, would not be shortened in the higher priority project; and therefore, there is no warrant for interrupting an activity.

Evaluation

This evaluation is directed toward the quality of the schedule that results from utilization of the balance-period method. Limitations are also discussed, but remarks in regard to problems of practical application are taken up later.

Figure 5 represents the schedule of activities and the manpower utilization that pertain to the hypothetical sample problem in Figure 2.

Examination of Figure 5 along with the project network diagrams of Figure 2, shows a fundamental feature of the balance-period approach to scheduling. It appears that, with due consideration for available manpower, project priority, time paths, and activity continuity, activities are scheduled at the earliest possible start time. The network diagram for Project 1 indicates that at time zero the critical path is 1-2-3-5. Therefore, the activities 1-2, 2-3, 3-5 have no float; but 0-4, 4-5, and 1-3 all possess float. In other words, the activities with float could be scheduled within a range of time units without altering overall project duration. Activity 0-4 could be scheduled to commence in either the first, second, third, or fourth time units of the first balance period without changing the project completion date. Thus, activity 0-4 has four time units of float. By the same reasoning, activity 1-3 has six time units of float, and activity 4-5 has two time units of float.

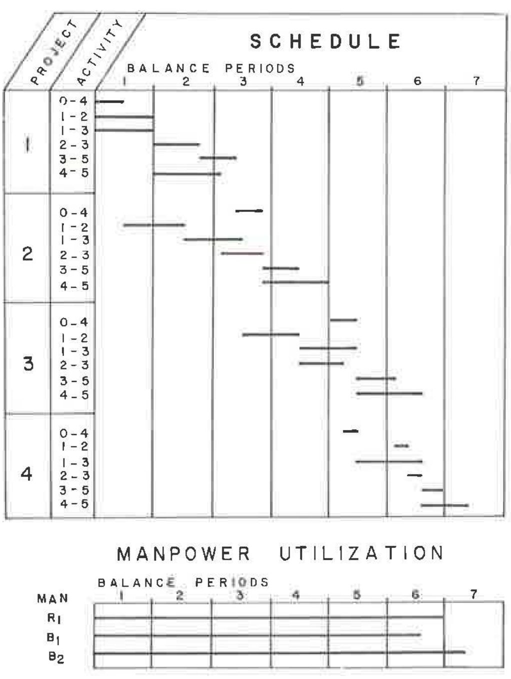


Figure 5. Schedule and manpower usage chart.

Although the balance-period method discriminates between the activities with float and the critical path activities, the method gives no consideration for the amount of float. The activities with float are scheduled at the earliest possible time. Therefore, the schedule may not be an optimum. The optimum schedule might be approached by sliding to the right on the bar chart some of the activities with float. This might allow the commencement of some critical activities at an earlier time than allowed by the balance-period method. This process would be used to reduce project completion dates of priority projects. Such a procedure has not been incorporated into the balance-period approach and is subject to further research.

The balance-period approach uses the project priority as key information in the scheduling procedure; project completion dates are merely end products. Thus, in order to arrive at a predetermined set of completion dates, several trial arrays of project priority must be analyzed. Adaptations of the balance-period method that utilize completion dates rather than project priorities are also the subject of future research.

But within these possible limitations, the balance-period method does provide a schedule of multiple projects that may meet the requirements of highway departments. Further, it appears that the procedure is mechanical and is suitable to be programed on high-speed computers.

OTHER APPROACHES TO MULTIPLE-PROJECT SCHEDULING

The ultimate goal is to develop systematic procedures to schedule the preconstruction phases of the highway program. The balance-period method established that such a goal is realistic. The balance period represents the joining of several paramount aspects of the highway program with the recently developed principles of network diagraming and critical path scheduling. The resultant schedules meet some of the requirements of the highway industry.

The real significance of the balance-period approach is that it is possible to develop systematic procedures for manpower allocation and multiple-project scheduling. It is of secondary importance that the balance-period method does not, perhaps, embrace all requirements for scheduling the preconstruction phases of the highway program.

To proceed in the research of systematic scheduling procedures, two alternative paths were possible. On the one hand, a computer program could have been developed for the balance-period method. This would have led to further testing of the approach and possibly a practical application. On the other hand, a search for parallel ideas in various industries might uncover superior approaches to the goal. A cursory study revealed that operational computer programs were available, thus possibly obviating the requirement for a new computer program. Therefore, the latter alternative was deemed most useful at the time, with the further objective of studying what revisions, if any, might be needed in existing computer programs to meet needs of highway departments.

Through contact with highway departments, the Bureau of Public Roads, universities, computer "hardware" and "software" firms, management consultants, the U. S. Navy and others, the following organizations appeared to have advanced their research of manpower allocation and multiple project scheduling to a point where computer programs were either operational or very close to operational:

Organization	Computer Program
Carnegie Institute of Technology	$(MS)^2$: Multiship, Multishop, Workload-Smoothing
C-E-I-R, Inc.	RAMPS: Resource Allocation and Multi-project Scheduling
General Electric Co.	
IBM, Inc.	Man-Scheduling Program
Mauchly Associates, Inc.	RPSM: Resource Planning and Scheduling Methods

Another firm, Management Studies, Inc., has an analog computer mechanical approach that is a very definite contribution. Other firms and researchers may have made progress unknown to the authors.

Available computer systems were reviewed. A decision was made to test the RPSM and the RAMPS programs with a sample problem. The $(MS)^2$, the Man-Scheduling, and the GE programs did not (at the time of these studies) appear to be at a point where tests would be useful.

It is essential to outline some of the basic similarities and differences between the balance-period method and the RAMPS and RPSM systems. The three objectives of the balance-period method were previously discussed. Identified in an abbreviated form, the first two objectives are to schedule according to (a) project priorities and (b) limited manpower pool.

Investigation of possible objectives for scheduling with either the RPSM or RAMPS program adds the following three items: (a) unlimited manpower pool, (b) project start dates, and (c) project completion dates.

These five items can be combined into optional sets of objectives. Each set will provide a unique schedule. The objective which calls for scheduling each project to completion in a minimum possible time is not listed. It is, in varying degrees, basic to all schedules that are the result of the balance-period method, RPSM program or the RAMPS program. In describing the sets of schedule objectives, it is obvious that either unlimited manpower resources or limited manpower resources must be specified. Time and manpower are dependent variables that determine the schedule. The limiting of one precludes the limiting of the other.

This is the actual case with RPSM. However, in the RAMPS program, the incorporation of a "project delay penalty" (in the form of \$/day of delay beyond a specified completion date) allows both resources and project duration (time) to be specified. The resource limits will never be exceeded, but the time limitation may be prolonged at an added project cost.

Should manpower be limited, then it is not feasible to specify both project start and completion dates. Conversely, with unlimited manpower resources, both dates can be accommodated. Project priorities, identified collectively as an independent variable, may be utilized in any situation, but must be used when project start or completion dates are not specified.

Thus, RPSM or RAMPS will design a meaningful schedule according to any of the following optional sets of objectives:

Unlimited manpower pool
Project start dates
Project priorities

Limited manpower pool
Project start dates
Project priorities

Unlimited manpower pool
Project completion dates
Project priorities

Limited manpower pool
Project completion dates
Project priorities

Unlimited manpower pool
Project priorities

Limited manpower pool
Project priorities

Unlimited manpower pool
Project start and completion dates

Unlimited manpower pool
Project start and completion dates
Project priorities

Individual characteristics of both RPSM and RAMPS allow for other management objectives. However, the objectives listed appear to be the most useful for the scheduling of preconstruction activities of state highway department programs.

It is quickly recognized that RPSM and RAMPS will provide schedules according to a variety of objectives, while the balance-period method is restricted at this time to a schedule that relies on a limited manpower pool and project priorities. But of the seven other objectives, five rely on the restricted supposition that manpower is unlimited. Small alteration to the balance-period method would provide a realistic schedule for the limited manpower-project start dates-project priorities set of objectives. Major alterations would be required to schedule according to the remaining set which provides for project completion dates.

Like the balance-period method, both RPSM and RAMPS employ the networking method of project planning and the critical path concept of work scheduling. Basic input information required is similar to the balance-period method:

______name of activities within each project,
______estimate of time and type of resources needed to complete each activity, and
______specified quantities of each available resource.

However, project priorities, start dates or completion dates may be supplied in the RPSM or RAMPS program, depending on management objectives.

The proprietary nature of both the RPSM and RAMPS programs precludes a detailed discussion of the procedure for scheduling each basic time unit. It is possible, however, to relate the procedures generally.

The problem is divided into time periods of an hour, day, month or any predetermined length of time. For each period, RPSM or RAMPS computes a combination of scheduled, delayed or interrupted activities according to resource availability and management objectives.

Beginning with the first time period, reanalyzing remainder after each time period, and continuing until all activities are scheduled, the RAMPS program performs the following steps to schedule each time period:

1. Computes the critical path in each project to determine critical activities
2. Computes the earliest start times and the latest completion times for activities to determine the possibilities for delay or interruption
3. Determines the activities available for scheduling during the current period, including activities scheduled earlier
4. Computes the resource requirements of each available activity
5. Generates a variety of possible schedules for the time period
6. Evaluates each possible schedule according to the degree to which it conforms to the desired scheduling objectives of management
7. Selects the best schedule according to the algorithms involved.

The RPSM computational procedures are not known other than the fact that critical path methods are employed.

The RAMPS program is processed on the IBM 7090 computer and has the capacity of approximately 700 activities. The RPSM program is processed on the IBM 1620 and is capable of handling approximately 1,400 activities. The capabilities of both are dependent on the variety of resource skills specified.

A sample problem was designed to test the RAMPS and RPSM programs. It is shown in network-diagram form in Figure 6. Twelve projects arrayed in priority sequence comprise the problem. A limited manpower pool (32 men) of six skill classifications was randomly established (see Figs. 14 and 15). The objective was to provide schedules based on the use of a limited manpower pool and project priorities.

Samples of the computer output are shown in Figures 7 through 11. The problem was originally designed in the highway context. Thus, "typical" highway activities were designated, i.e., "location," and "preliminary survey." The skill classifications were likewise typical highway designations: H - highway designers; S - survey crews; T - traffic engineers; P - highway planning engineers; B - bridge engineers; R - ROW engineers.

The actual schedules and manpower usage charts are shown in Figures 12 through 15. Comparison of the schedules (Figs. 12 and 13) yields the following observations:

______the RPSM program utilized a total problem time of 96 periods and the RAMPS program 88 periods
______only project 3 had identical project completion times in both programs
______the RAMPS program split nine activities
______the spread between project start and finish increased as project priority diminished

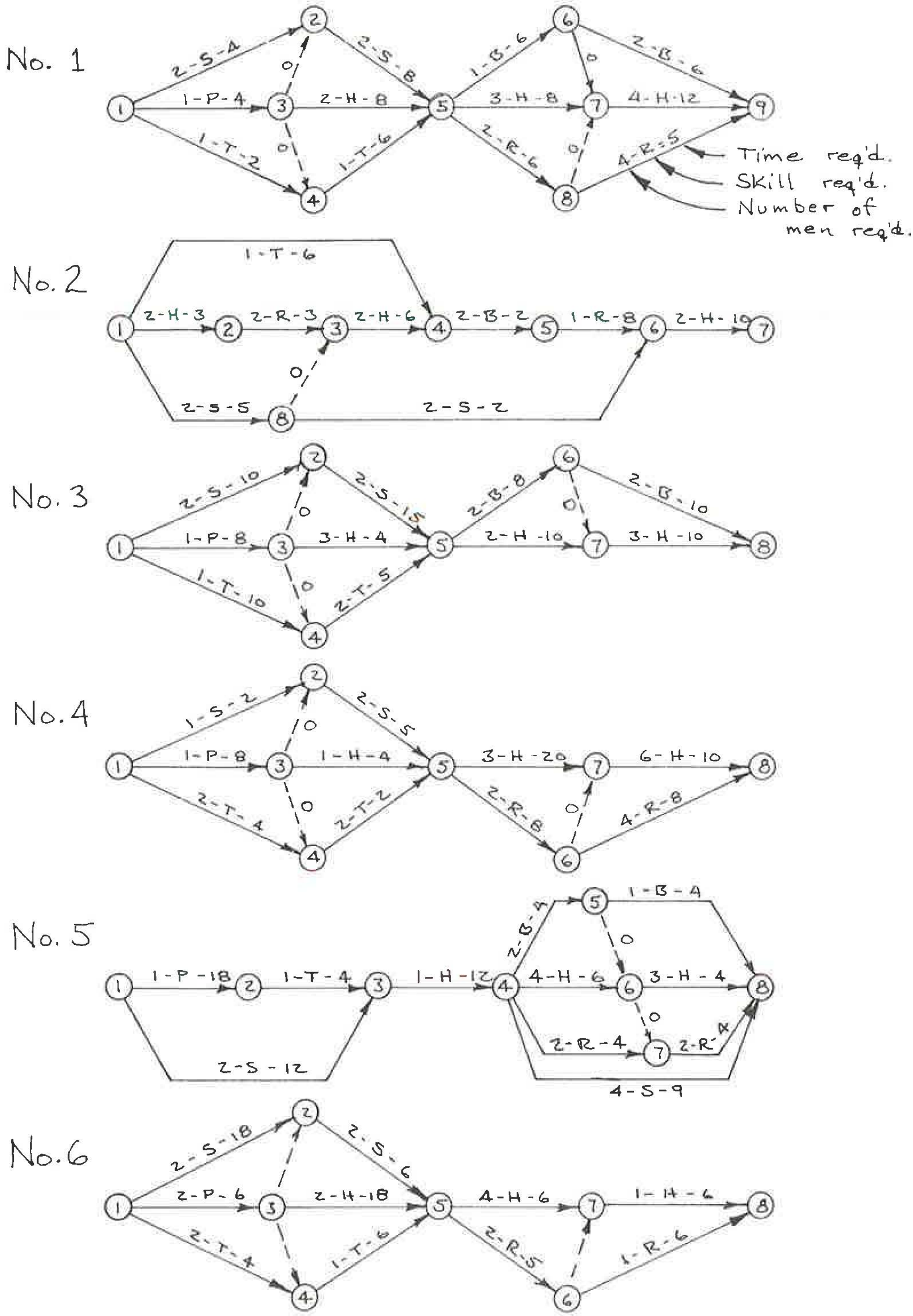


Figure 6. Sample problem.

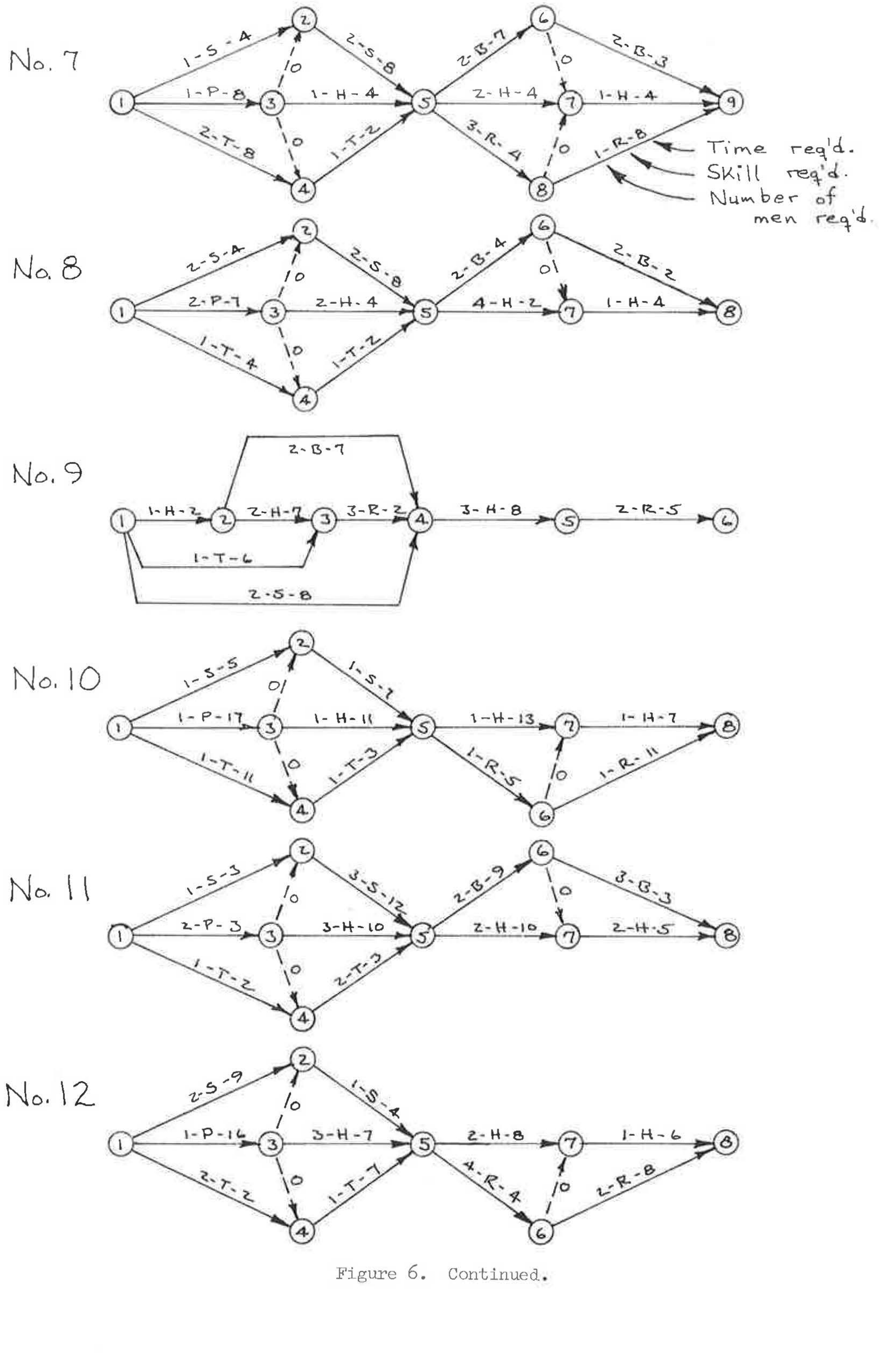


Figure 6. Continued.

AUTOMOTIVE SAFETY FOUNDATION
STUDY PROBLEM 201
AUGUST 20,1963
RPSM SIMULATIONS BY
MAUCHLY ASSOCIATES,INCORPORATED
FORT WASHINGTON,PENNSYLVANIA
RESOURCES LIMITED RUN
TIME UNITS ARE IN WEEKS

I	J	DUR.	COST	DESCRIPTION	START		END	--CODES--			
1	13	4	640	LOCATION	1	1	4	P	1		
1	12	4	5600	PRELIM SURVEY	1	1	4	S	2		
1	14	2	320	TRAFFIC EVALUATION	1	1	2	T	1		
13	12			DUMMY	1	5	4				
12	15	8	11200	FINAL SURVEY	1	5	12	S	2		
13	15	8	4560	PRELIM DESIGN	1	5	12	H	2	D	2
13	14			DUMMY	1	5	4				
14	15	6	960	TRAFFIC ASSIGN	1	5	10	T	1		
15	17	8	6840	HIGHWAY DESIGN	1	13	20	H	3	D	3
15	16	6	1710	STRUCTURAL DESIGN	1	13	18	B	1	D	1
15	18	6	3420	ROW PLAN PREPARATION	1	13	18	R	2	D	2

Figure 7. Example of RPSM output—activity schedule.

AUTOMOTIVE SAFETY FOUNDATION
STUDY PROBLEM 201
AUGUST 20,1963
RPSM SIMULATIONS BY
MAUCHLY ASSOCIATES,INCORPORATED
FORT WASHINGTON,PENNSYLVANIA
RESOURCES LIMITED RUN
TIME UNITS ARE IN WEEKS

RESOURCE USAGE TABLE

IME		B	D	H	P	R	S	T
1	U		4	3	2		7	2
2	U		4	3	2		7	2
3	U	2	6	4	2		8	2
4	U	2	6	2	2	2	8	2
5	U	2	8	4	2	2	8	2
6	U	2	8	4	2	2	8	2
7	U	2	4	6	2		8	2
8	U	2	4	6	2		8	2
9	U	2	7	9	2		8	2
10	U		5	7	2		8	2
11	U		5	7	2		8	2
12	U		5	7	2		8	2

Figure 8. Example of RPSM output—resource usage table.

AUTOMOTIVE SAFETY FOUNDATION
STUDY PROBLEM 201
AUGUST 20,1963
RPSM SIMULATIONS BY
MAUCHLY ASSOCIATES,INCORPORATED
FORT WASHINGTON,PENNSYLVANIA
RESOURCES LIMITED RUN
TIME UNITS ARE IN WEEKS

RESOURCES REMAINING TABLE

TIME		B	D	H	P	R	S	T
1	R	3	26	10		4	1	
2	R	3	26	10		4	1	
3	R	1	24	9		4		
4	R	1	24	11		2		
5	R	1	22	9		2		
6	R	1	22	9		2		
7	R	1	26	7		4		
8	R	1	26	7		4		
9	R	1	23	4		4		
10	R	3	25	6		4		
11	R	3	25	6		4		
12	R	3	25	6		4		

Figure 9. Example of RPSM output—resource remaining table.

P A1 STATE HWY DESIGN PROJ

AVAILABLE START TIME= 1
DESIRED COMPLETION TIME= 5
SCHEDULED COMPLETION TIME= 39
DELAY COST AT $ 120000=$ 4080000

TASK	ACCOUNT NO. / RESOURCE TEAM	RATES		WORK	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	PREL SURVEY			8																								
1	2 SURVEY	2	20		2	2	2	2																				
	TRAFFIC EVAL			2																								
1	4 TRAFEN	1	10		1	1																						
	LOCATION			4																								
1	3 PLANNE	1	10		1	1	1	1																				
	FINAL SURVEY			16																								
2	5 SURVEY	2	20						2	2	2	2	2	2	2	2												
	TRAF ASSIGN			6																								
4	5 TRAFEN	1	10								1	1	1	1	1	1												
	PREL DESIGN			16																								
3	5 HWYDES	2	20						2	2	2	2	2	2	2	2												
3	5 DRAFTS	2	20						2	2	2	2	2	2	2	2												

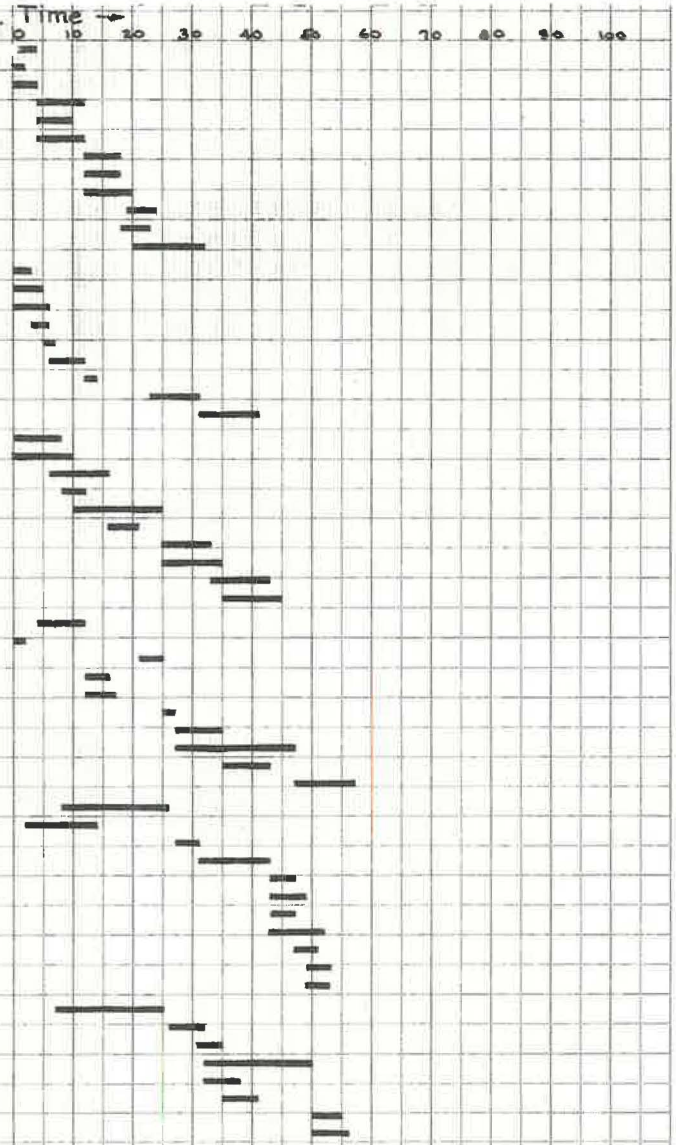
Figure 10. Example of RAMPS output—activity schedule.

RESOURCE SURVEYORS

PROJECT	TASK	ACCOUNT NO.	IDENTIFICATION	WORK	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
P A3	1	2	PREL SURVEY	20	2	2	2	2	2	2	2	2	2	2														
P A4	1	2	PREL SURVEY	2	1	1																						
P A2	1	8	PREL SURVEY	10	2	2	2	2	2																			
P A1	1	2	PREL SURVEY	8	2	2	2	2																				
P A11	1	2	PREL SURVEY	3	1		1	1																				
P A7	1	2	PREL SURVEY	4		1	1	1	1																			
P A10	1	2	PREL SURVEY	5					1																			
P A1	2	5	FINAL SURVEY	16					2	2	2	2	2	2	2	2												
P A2	8	6	FINAL SURVEY	40						2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
P A9	1	4	SURVEY	16						2	2	2	2	2	2	2	2											
P A3	2	5	FINAL SURVEY	30											2	2	2	2	2	2	2	2	2	2	2	2	2	2
P A4	2	5	FINAL SURVEY	10													2	2	2	2	2							
P A6	1	2	PREL SURVEY	36														2	2	2	2	2	2	2	2	2	2	2
P A5	1	3	PREL SURVEY	24																		2	2	2				
P A7	2	5	FINAL SURVEY	16																					2	2	2	2
	TOTAL REQUIRED				8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
	TOTAL AVAILABLE				8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
	TOTAL IDLE (-ACQ.)																											

Figure 11. Example of RAMPS output—resource usage table.

Project	Activity	Resource	Number
1	1-2	S	2
	1-4	T	1
	1-3	P	1
	2-5	S	2
	4-5	T	1
	3-5	H	2
	5-6	B	1
	5-8	R	2
	5-7	H	3
	6-9	B	2
	8-9	R	4
	7-9	H	4
2	1-2	H	2
	1-3	S	2
	1-4	T	1
	2-3	R	2
	3-6	S	2
	3-4	H	2
	4-5	B	2
	5-6	R	1
	6-7	H	2
3	1-3	P	1
	1-2	S	2
	1-4	T	1
	3-5	H	3
	2-5	S	2
	4-5	T	2
	5-6	B	2
	5-7	H	2
	6-8	B	2
	7-8	H	3
4	1-3	P	1
	1-2	S	1
	1-4	T	2
	3-5	H	1
	2-5	S	2
	4-5	T	2
	5-6	R	2
	5-7	H	3
	6-8	R	4
	7-8	H	6
5	1-2	P	1
	1-3	S	2
	2-3	T	1
	3-4	H	1
	4-5	B	2
	4-6	H	4
	4-7	R	2
	4-8	S	4
	5-8	B	1
	6-8	H	3
	7-8	R	2
6	1-2	S	2
	1-3	P	2
	1-4	T	2
	3-5	P	2
	2-5	S	2
	4-5	T	1
	5-6	R	2
	5-7	H	4



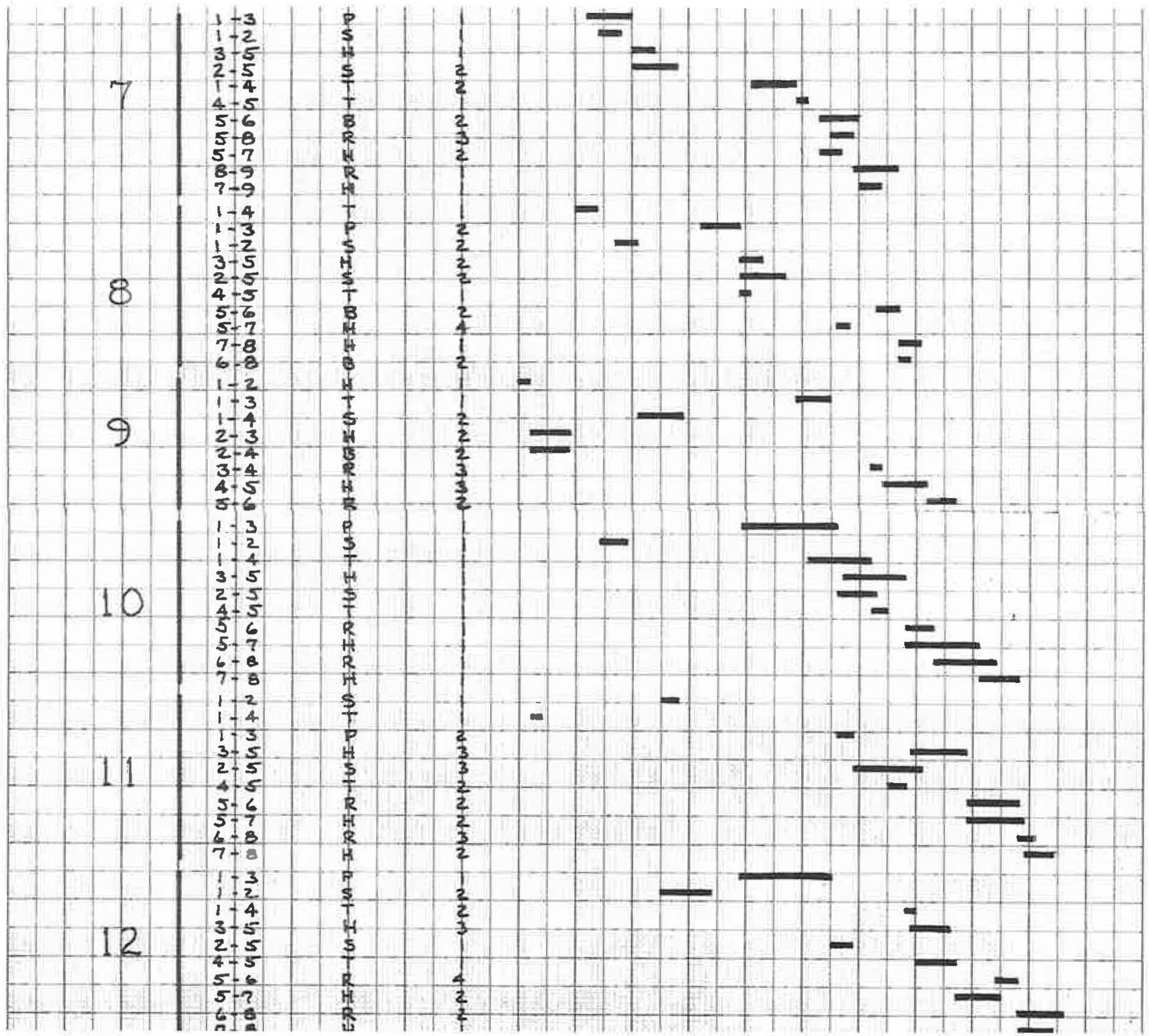
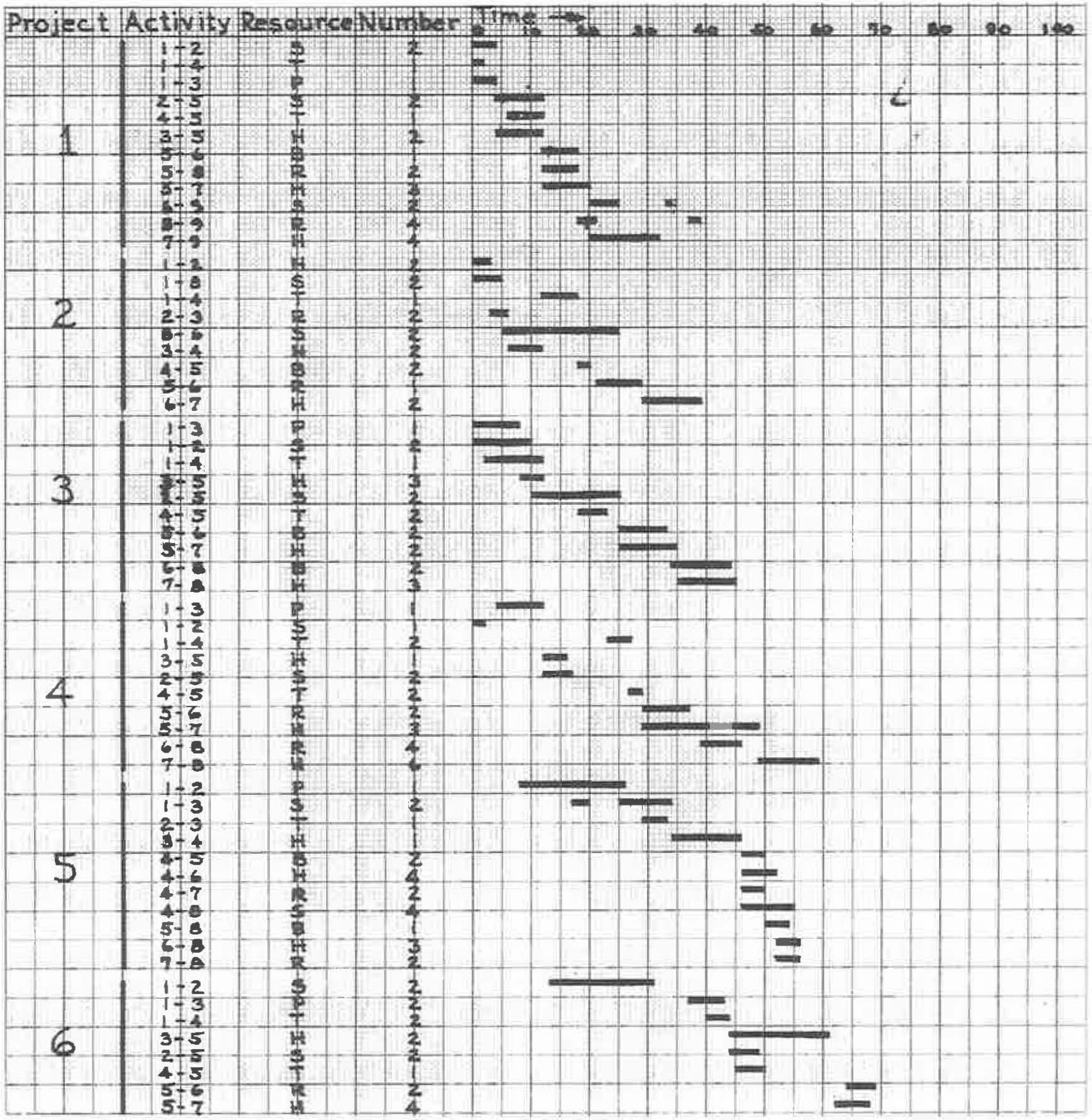


Figure 12. RPSM schedule chart.


Project
Activity
Resource
Number
Time
1
2
3
4
5
6

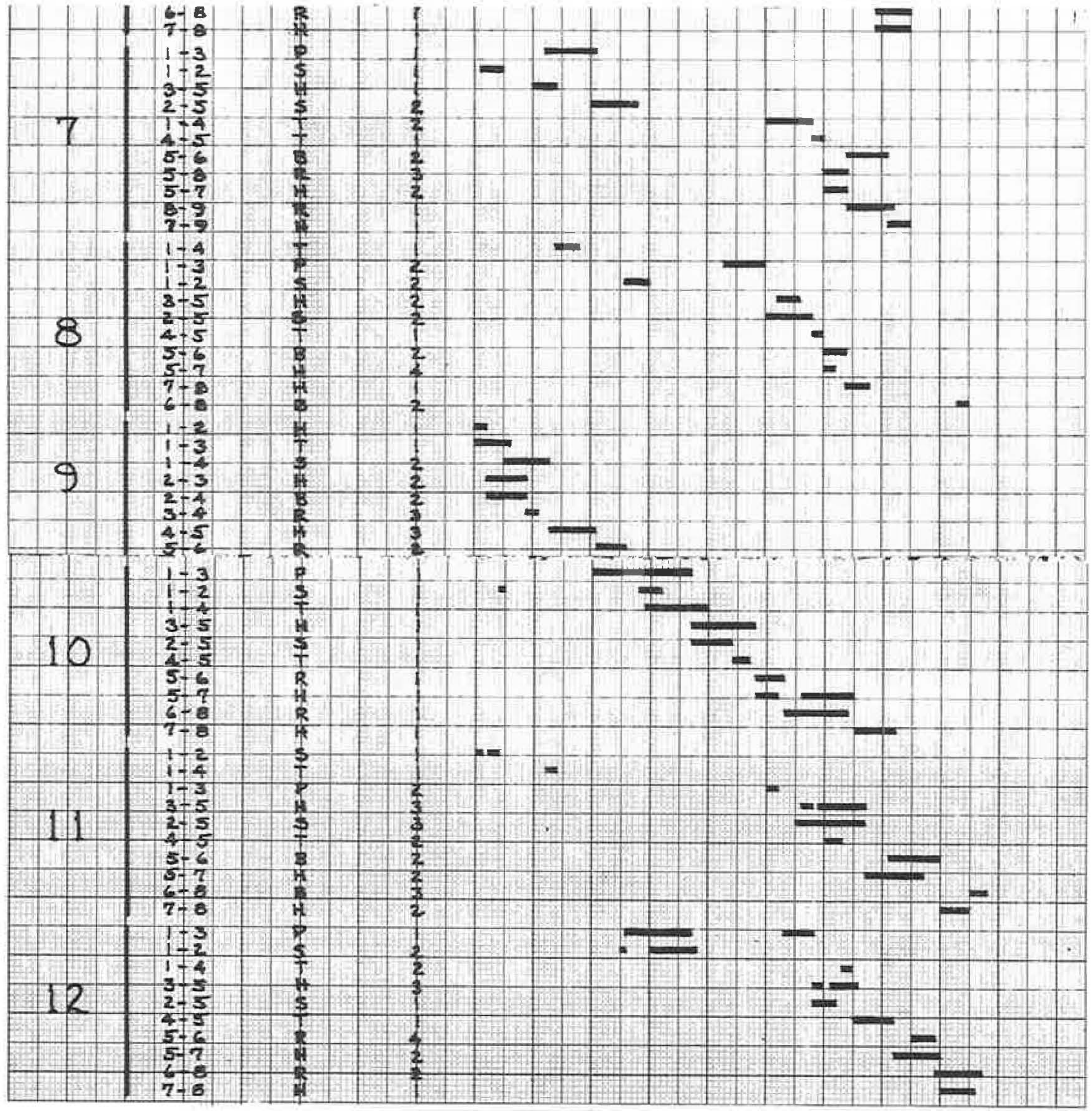


Figure 13. RAMPS schedule chart.

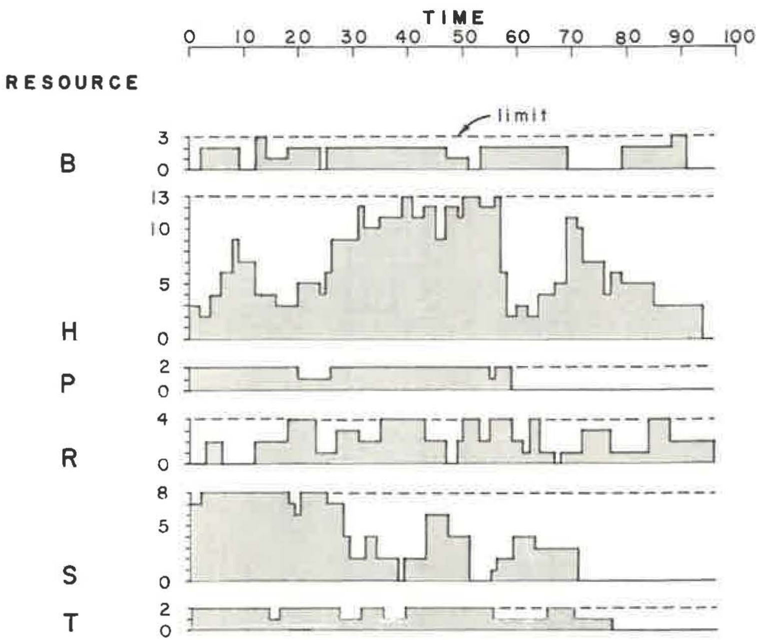


Figure 14. RPSM resource usage chart.

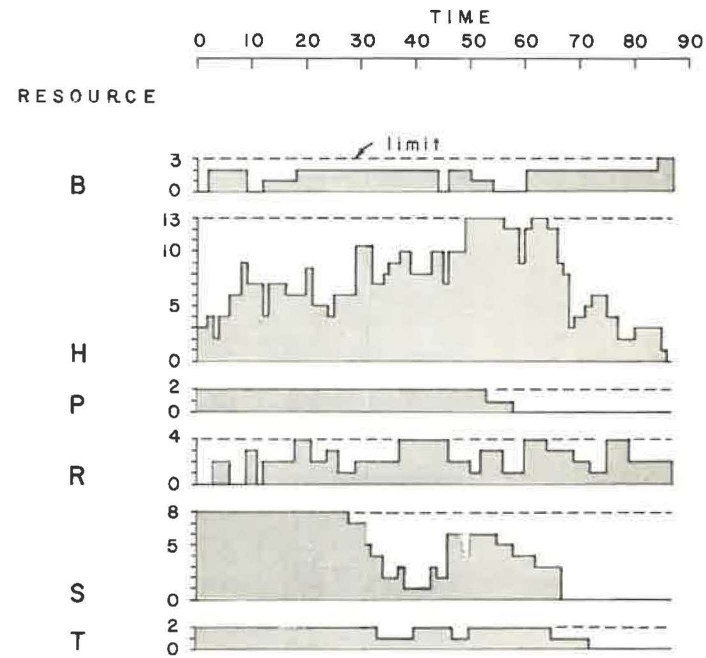


Figure 15. RAMPS resource usage chart.

- ______the RAMPS program expedited project 9 (completed in time period 26) with apparent disregard for its relatively low priority
- ______with the exception of project 9 in the RAMPS schedule, all other projects appear to be scheduled according to priority.

The resource usage charts (Figs. 14 and 15) indicate the amount of each skill classification that was allocated at each time period to form the schedule. In examining the charts, it must be recognized that this sample problem is set in a wholly unrealistic background. There are no projects under way prior to time zero and the problem contains only 12 projects. Furthermore, the projects involve the application of P, S and T skills, along with a limited number of H skills, to only the early half of each project. Conversely, the latter half of each project requires B, R and many H skilled personnel. Therefore, it is to be expected that maximum utility of P, S and T skills will be made in the early portions of the total problem duration, and maximum utility of B and R skills in the later portions of the duration. In this situation (problem), therefore, it is impossible to achieve full utilization of all skills, as suggested in the different problem used to describe the balance-period method.

Even considering the fact that the charts do not present a realistic situation, their ragged nature indicates either:

- ______the problem was not designed to allow maximum utilization of manpower, or
- ______that neither computer program emphasizes a manpower leveling feature.

It is, however, safe to assume that analysis of the charts and subsequent changes in the manpower limitations and/or project priorities will provide more even manpower utilization. Further research will be directed toward evaluating and testing the manpower leveling capabilities of both programs.

In regard to the RAMPS program, it is known that various "weightings" of manpower leveling and several other "management controls" are available. The weights applicable are from 0 to 100, but a standard weight of one was established for the sample problem. A higher weight applied to "manpower leveling" would probably smooth the resource usage charts at a level somewhat below the maximums shown in Figure 15, but problem duration, and thus project completion dates, would probably be extended.

It is pointed out that to schedule this problem by the manual, balance-period method would be extremely tedious. For this reason, no comparative analysis of a balance-period schedule can be made at this time.

There are other ramifications available with the RAMPS and RPSM programs, for example:

- ______cost analysis
- ______teaming of resources
- ______optional activity work rates (RAMPS only)
- ______management controls.

Some of these items have important contributions to make to the theory of scheduling. However, the authors believe that further explanation and exposition of these items would not add materially, at this time, to the general applicability of these programs to the highway program.

The SMD PLANALOG as developed by Management Studies, Inc., is a device that can be manually manipulated to plan and schedule single or multiple projects. The PLANALOG is a grooved metal board. The grooves are designed to engage a variety of plastic blocks and to allow lateral movement of the blocks. A time scale is taped to the boards.

The blocks represent project activities and are of various lengths to express different activity time durations. They can be color-coded to portray the skill required to accomplish the activity. Cost information and varying manpower rates can also be placed on the blocks.

Serrated metal plates called "fences" are provided. These fit transversely across the board to indicate the instant in time when several project activities may commence or end. The fences provide the interrelationships between the activities and perform the computing and forecasting function for the PLANALOG.

In general, a multiplicity of projects can be described on a series of the boards. From examination of the color codes and employment of manpower usage charts, various schedules that meet a variety of management objectives can be portrayed. This device appears useful for scheduling and resource allocation of:

______single projects of 20 to 1,000 activities
______a large number of simple (5 to 100 activities) projects
______several complex projects totaling 1,000 activities
______a large number of complex projects that are reduced to simple form.

Further research is necessary to evaluate the SMD PLANALOG adequately. Management Studies reports that SMD PLANALOG has been successfully field tested with regards to multiple-project scheduling.

ASPECTS OF PRACTICAL APPLICATION

Policies and operating methods of highway departments have substantial effects on feasibility and methods of scheduling and control of preconstruction activities. In addition, there are numerous technical problems that remain to be solved to achieve objectives of highway program administrators.

Principles and methods previously described offer some hope that present procedures can be improved, but only if some prerequisites are fixed:

1. Projects are identified and priority is established;
2. A complete and adequate network diagram for each project is prepared;
3. Realistic time and resource estimates are provided for each activity; and
4. An adequate reporting system is in operation, in order to permit periodic schedule revisions.

This paper also is based on only a few of management's objectives:

1. Available manpower resources shall be assigned first to the top priority project and to its most critical activity. Subsequent assignments are to be made in sequence of project priority and criticality of activities.
2. All available manpower shall be used productively, in line with the preceding objective.
3. Each project shall be completed, ready for contract award, in the least possible time and preferably in priority sequence.

Prerequisites for Systematic Scheduling

1(a). Project Identification. "Projects" may be described differently at different stages of their development. What ends as a specific location, design and length, often has begun as part of a broad area-wide study, progresses through several alternatives, and ends as only a portion of what may have been conceived initially.

1(b). Project Priority. This is easier said than done, especially with any reasonable degree of stability. Many factors must be considered, and priority may vary logically (or illogically) from time to time. It should be obvious to management, however, that instability of decisions reduces, in direct proportion, the adequacy of any advance scheduling method. Project priority is affected by methods of determining relative needs, availability of funds, requirements of stage construction or continuity of design, agreements with other agencies of government (or their action or inaction), political decisions and other factors.

2. Network Diagrams. The requirements, even for single project scheduling, are subjects of much literature. Problems are multiplied when considering requirements of multiproject scheduling. Resource (manpower) allocation may require very complete diagrams in order to account for all tasks. (See item 3, following.) However, as the level of management interest rises from that concerned with a single project, to top levels concerned with numerous projects and long-range operations, details become less essential. The nature of detail required for general management objectives remains to be studied to determine whether meaningful scheduling can be accomplished with a minimum of complexity. Moreover, the diagraming will vary, depending on nature of the project and on its stage of development, as mentioned in item 1(a).

3. Time and Resource Estimates. Necessity for and problems of establishing realistic time estimates for each activity have been discussed in numerous other papers. When considering resources (manpower) allocation, the methods discussed in this paper seem to require indivisible units of manpower and time. To meet the condensed or simplified needs of top management as pointed out in item 2, broader terms are desirable, but these must account for time and manpower requirements if basic schedules are to be derived there-from.

For example, a broad activity identified as "design" (part of a condensed diagram for a specific project) involves work by design personnel, but certain phases of the design work may depend upon completion of assignments by soils, traffic, bridge, and computer personnel over which the responsible originator of the identified design activity has little or no control. The originator of this activity, however, must produce an estimate of the time required for its completion. The problem of how to establish the time estimate, and what method can best portray resources required and their allocation to a series of projects, remains to be resolved.

Some clues may be available in computer programs that include "leading" and "trailing" resources—the latter being dependent on allocation and time of the leading resource. However, the application of this procedure to the problem of condensing networks is not clear.

When estimating time and resource individual projects, it is assumed that manpower and funds will be available in efficient or normal quantities for each activity. However, the pool from which manpower is drawn for a group of competing projects is not unlimited. Therefore, that pool must be determined, and may have to be divided into parts (such as highway districts and categories of projects, e.g., Interstate) before the total pool available to work on particular groups of projects is established.

4. Reporting System. Initial schedules may be produced as indicated herein, but they must remain flexible and subject to quick revision to account for the numerous changes that will occur. Therefore, any procedure that is devised should consider the essential reporting procedures required to provide flexible, accurate control and revision. Questions that need study include:

a. What methods and frequency of reporting are required?
b. Are the scheduling techniques adaptable to a uniform reporting procedure?
c. Can revisions be assimilated, analyzed and a revised schedule produced within a reasonable amount of time?
d. Do all projects require the same degree or level of control and reporting frequency to insure compliance with schedules? To provide for revisions?

e. If outside agencies (public or private) are involved, can their terminology and working procedures be adapted to the method and frequency of reporting?

Limited Management Objectives

1. Priority Assignment of Resources. Although this is basically desirable, there will be numerous variations with which to contend. It was previously suggested that project priority may be assigned within categories or classes of projects, rather than on a statewide basis. If this is done, then resource pools must be allocated to each category before manpower allocation methods become useful.

Another problem relates to time requirements for total completion of single projects. For example, if the first priority project requires three years to complete all precontract activities, it is not realistic to allocate all possible manpower to that project—to the exclusion of work on some projects of short duration, even though of lesser priority. Completion of projects must be considered, as well as starting times.

2. Manpower Utilization. Techniques discussed in this paper do not provide for any pool of "unallocated" work. Some experience suggests that this is necessary to provide productive work when planned assignments are temporarily interrupted. Theoretically, the procedure would indicate the next most likely project, but it must provide for the basic problem of emergency assignments.

Of greater importance is the need for careful management analysis of adequacy or inadequacy of the manpower pool, in relation to its required work. The pool may be badly unbalanced with lack of critical skills or, conversely, an excess of noncritical personnel. In the latter event, scheduled assignments would tend to result in work on projects of least priority, long before it was essential.

Other related questions may be asked, and should be studied:

a. Will geographic location of projects affect manpower utilization and the application of the suggested techniques of scheduling?
b. How far apart can projects be and permit an effective interchange of resources on an activity basis? On a project basis?
c. Can the techniques be adapted to give recognition to projects that must be worked on seasonally?
d. Is it practical to group projects geographically for scheduling purposes?
e. Will the type of organization (centralized or decentralized) have any effect on this possibility?
f. Is it reasonable to anticipate interchange of resources on a project activity basis, regardless of geographic location, or proximity to the resource pool?

3. Least Time Completion. This involves redetermination of the critical path at each time period, which may be impractical except with the most sophisticated computer techniques. Moreover, as previously suggested, completion in the least possible time may not always be compatible with other management objectives.

Other Management Objectives and Problems

1. Basic to any schedule of preconstruction activities is a schedule of construction based on required expenditures related to funds available over various calendar time periods. Presumably this schedule, calling for contract awards on specified dates, would have to be compared to a feasible preconstruction activity schedule. Thereupon, adjustments in one or the other, or both, will be needed. If the construction schedule must be held firm, then management can analyze feasibility through methods suggested here and take necessary action to increase (or decrease) the resource pool (or pools). This type of combination and relation between schedules controlled by different limitations may, some day, be subject to a more systematic analysis than appears available now.

To arrive at a workable schedule, adjustments may be required to conform with stage construction, outside agency construction schedules, management desires, policy decisions, statutory controls and funds. Questions raised include:

a. Are the techniques discussed sufficiently flexible to produce alternatives for these conditions?
b. Can the alternatives be analyzed and combined to produce a schedule more nearly compatible with all desires?

2. Can the operating procedures of agencies outside a highway department be adapted to the scheduling techniques discussed? Such agencies include consultants, public utilities, private utilities, railroads, courts, title companies, and all other agencies (cities, counties, etc.) which have an effect on preconstruction activities.

3. Will the techniques described, or to be developed, provide adequate control of operations by each division head, district engineer, etc., responsible for major phases of the program? Perhaps some adaptation would give better internal control of manpower, and provide top management with a better overall view of program operation and forecasted achievements.

Must this, or any similar system, be centrally controlled, or may it be divided successfully into components? If so, what are they, and how would they be combined or condensed to meet overall management needs?

4. Would these techniques, if successfully developed, best be implemented a step at a time, e.g., by systems, and districts? What type of training program would be required, and how might it be instituted? What would be the cost of developing, installing and operating?

The application of a systematic technique of scheduling which will produce a smooth flow of projects to the contract stage has many advantages. Moreover, any procedure developed that can cope with the problems in this area probably has much to contribute to the scheduling and control of construction engineering operations.

Many benefits can be foreseen by applying the techniques discussed. The authors have also endeavored to focus attention on some of the operational problems that exist in the application of any scheduling technique. The theory advanced is believed to be sufficiently flexible to cope with many of them. However, it is recognized and acknowledged that the majority of the questions remain unanswered.

They have been posed with the thought that, through continued efforts of collective exchange, development, and research of this problem of scheduling and control, a technique can be developed to provide a solution to the majority of the very complicated problems associated with this phase of highway programing operations.

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4. Levy, F. K., Thompson, G. I., and Weist, J. D. MS^2: Multiship, Multishop, Workload-Smoothing Program. Graduate School of Industrial Administration Reprint No. 96, Carnegie Institute of Technology, 1962.
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Discussion

PALMER N. STEARNS, JR., Bureau of Public Roads—The mechanics of scheduling should be placed in proper perspective as related to the overall function of a highway department. An important development in the last few years in aiding management to accomplish its objectives has been the trend toward the integrated management information and control system. This system is aimed at improving the enterprise as a whole rather than the operation of one particular unit or endeavor within the enterprise. The system is designed to better inform management at the decision-making levels and to enable management to control entire projects by concentrating its efforts on 10 to 20 percent of the activities in the projects. The system is designed to channel information to appropriate individuals at each administrative level.

Network diagraming and computer analysis have been important tools in developing these information and control systems. However, these tools are a means to an end. Improved network diagraming methods and machines with faster speeds and bigger memories do not automatically provide a better information and control system. In fact, if adopted unnecessarily, they could impede the efficiency of the system. It is important that the system be analyzed first to determine what information management needs at each level for decision making and what feedback information is necessary for monitoring purposes. Only then, will a dollar spent be returned in a sound investment manner.

There appear to be certain peculiarities in the RAMPS and RPSM programs and the balance-period method which warrant further discussion, particularly relating to the practicability of controlling individual manpower skills with specific job tasks and the manner in which individuals are transferred from job to job.

The authors attempt to set up individual work assignments for professional personnel on an assembly-line basis looking only for production. It appears that the authors have carried network diagraming to an extreme. To attempt to control progress in the manner advocated would tend to decrease the quality of performance of the professional engineers and technicians whose responsibilities and duties cannot be compared with factory workers whose operations are repetitive and predictable. For instance, if a little more thought and imagination than estimated is required on a complex design problem or if a little more time than estimated is required to acquire a right-of-way parcel in an urban area at a reasonable price, there would be a tendency for the individuals responsible to place a greater degree of emphasis on meeting the predetermined schedule progress than would necessarily be justified from a quality standpoint.

The assignment of individual manpower and skills to specific job tasks would tend to indicate that low echelon operations have been very carefully studied and analyzed. This means that the supervisor or individual who must make the assignments must involve himself with a vast amount of detail and devote a large amount of his time to this work; that is, if any degree of accuracy is to result from the estimates. Events not previously scheduled could occur—illnesses, conferences, resignations, errors in calculation, etc.—and of course, a difference in the rate of progress from that estimated would occur for many jobs. As soon as the actual progress differs from the estimated progress, it would be necessary to reschedule the uncompleted work. Each time a rescheduling operation occurred, individual manpower skills would be reapportioned to many of the uncompleted jobs. The resulting consequence of breaking job continuity and jumping individuals from job to job could become costly and inefficient. To complete a certain task partially, then to begin work on another task, then to finish another uncompleted task before returning to the partially completed task could cause more time lost than under conventional supervisory methods. Each time the work is changed, the individual must reorient himself with the work at hand. Furthermore, the supervisor would be incessantly burdened with reanalyzing and reapportioning manpower and skills to the uncompleted jobs.

Pertaining to the aforementioned criticism, however, I do feel that the methods or similar methods proposed in the paper could be used for forecasting manpower and other resource requirements. The machine output would be in the form of summations of resource requirements at specified intervals in time rather than an individual manpower and skill assignment to tasks. The forecasts, of course, must be updated as frequently as necessary to maintain a current realistic picture in light of policy changes, obsolescence of methods or any unforeseeable changes that could alter the resource situation. These forecasts would provide management with a decision-making tool that would permit timely action in acquiring new resources or in reprograming available resources.

I do not mean to discount the value of network diagraming as a tool for the first line supervisor. It is excellent for providing a time reference for activities and showing the interdependency of activities. However, control of individual job assignments is something different. This should be handled through the skill of the supervisor. After all, in a highway department small groups under a first-line supervisor handle particular work assignments; i.e., squads handle design assignments, survey parties handle surveying assignments and soil crews handle soils investigation assignments. Members of these small units are not so specialized that they cannot perform many duties necessary to the completion of an assignment. At the level of the first-line supervisor, intuitive supervision accomplishes the job cheaper.

Effective scheduling procedures and methods should deal with a large amount of detail and confirmation of target dates for preletting activities in the initial portion of the project. The degree of detail and the preciseness of target dates should involve less detail on the later parts of projects as adjustments between theoretical and actual performance will generally be necessary. This will prevent wasted and unnecessary work. The authors did not mention how far ahead they intended the scheduling process to carry and still conform to their proposed mechanical methods. This is an important factor that is overlooked in RAMPS, RPSM, and the balance-period method.

An important subject related to multiple project scheduling that was not mentioned deals with the volume and complexity of data that a highway department must have in order to receive advantages from balancing resources and scheduling by machine methods.

The authors stated: "The ultimate goal is to develop systematic procedures to schedule the preconstruction phases of a highway program." Certainly this objective has significant merit in developing realistic schedules and in achieving optimum efficiency for highway department operations, especially in the face of today's ever growing complexities and problems. However, the authors immediately proceed to develop their subject apparently assuming that the "systematic procedures" must consist of a computer analysis of such sophistication that the input will be processed in a manner that will produce an output solution that will solve the resource and coordination problems connected with preconstruction work.

Certainly, any operation that may be accomplished by machine methods may also be accomplished by manual methods. Therefore, it would seem that there is a point of diminishing returns involved in the process of converting from manual to machine methods. In order to analyze where this point of diminishing returns should be, it is necessary to explore the advantages associated with the computerizing of manual methods and to derive some type of approach in weighing the benefits of each.

A computer cannot tell management what decisions to make, how to use the data, or what data for the computer to utilize. The quality of those decisions remains for the responsible individuals in management. Therefore, the advantages that an electronic computer can give to a highway department lie in the quickness of supplying decision-making data or the speed of calculation, the accuracy of the data, and the lesser cost of processing the larger amount of data.

Possibly some highway departments could profit by the use of a computer program in the nature of a modified version of either RAMPS, RPSM, or the balance-period method. However, there are other highway departments which do not posses the volume or complexity of data that would justify these types of programs. It would be difficult to establish quantitative criteria that would show when benefits would accrue if computer analysis of resource allocation and multi-project scheduling was adopted. A qualitative approach would be more in line. This approach would involve questioning each element in the computer operation and questioning the entire computer operation as related to the total management process of programing and scheduling in the highway department. Some of the important steps that a manager should do in considering the shift to computer analysis are as follows:

1. Define the objectives of the highway department.
2. Determine the information that is needed to accomplish the objectives.
3. Evaluate the present system of scheduling operations to determine its adequacy in providing the necessary information and accomplishing the objectives.
4. Determine if computer assistance in resource balancing and scheduling will provide better management information for decision making and aid in accomplishing the objectives.
5. Make sure the total cost and cost of operation will be justified and that the new system will work out more satisfactorily than the old method. Insure that the new system can be fixed with sufficient stability.

Another point of significance in the paper that is of concern is the character of the man-machine relationship that is engendered from computer programs of the RAMPS and RPSM nature. A programing and scheduling process utilizing machine assistance should adapt the machine to the man, rather than the man to the machine. It should use the machine to improve the speed, accuracy, and quality of performance of the man. Of utmost importance, the process should be flexible enough to consider the human ingenuity involved in programing and scheduling.

The RAMPS and RPSM programs are designed to produce output solutions that carry through the entire scheduling function uninterrupted. All logic pertaining to the scheduling of manpower availability, starting and completion dates, and project priorities has been preestablished and is contained in the coded instructions of the program. How does management know that this preestablished logic will apply under all types of conditions? What about decisions that favor courses of action, such as over or under staffing, awarding overtime or subcontracting? Is it practical to handle these decisions through a set of predetermined quantitative rules?

Even if many run-throughs of a problem were made to explore the alternative plans for the rearrangement of resources and projects and the different assignment of objectives, an awkward analysis would still result because of the difficulty in identifying the areas of critical decision that take place within the machine. In other words, it appears that the methodology of these proprietary programs is directed towards accepting the machine "printout" as a schedule and is not conducive to the flexibility and imagination that management personnel should possess and use.

When any program is written for a computer, it is necessary to transfer thought processes into rules that can be written mathematically. Consequently, one frequently does not look for or make use of all the facts, but looks instead for a formula or limiting formulas. The skill associated with decision-making includes the ability to determine all the facts that are needed as well as the ability to consider the relative importance of the facts that are available. Therefore, one must be careful that the decision rules programed into a computer are explicit and steadfast, and the decision rules that are not explicit and steadfast are left to management's judgment.

For the present stage of development in automatic data processing, a computer program should end at the point where management judgment must be exercised, and a new program should begin at the point where preconceived computation or routine processing must be accomplished prior to the next phase of management judgment. In this regard, certain phases of resource allocation and multi-project scheduling could be computerized. Gaps would remain between programs so that judgment could be exercised. Of utmost importance, the programs should be designed to supply the ammunition for decision making—not to perform the act of decision making.