

**PART II**

**Construction Management**

# Use of Linear Scheduling in Transportation Projects

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Current practices used to plan, schedule, and monitor transportation projects are reviewed. The results of a survey of state departments of transportation concerning the way contract durations are set and scheduling is practiced are presented. Project characteristics and appropriate scheduling methods are reviewed. One approach for linear scheduling of transportation projects, the repetitive activity scheduling procedure (RASP), is developed. The RASP approach is presented with an example project to illustrate its features. The process can be effective for monitoring and controlling projects that have a few highly repetitive yet interrelated activities. The system allows for a graphical depiction of both time and space in a format consistent with bar charts. Methods of project control and change management with the system are also detailed. The system fills a void between bar charts and critical path methods.

State and other transportation agencies need effective methods to plan and monitor highway construction projects. Approaches that will help promote workable schedules can provide many benefits by reducing overall costs, increasing safety, and shortening project duration. A shorter project duration increases public safety by allowing a highway to open earlier, thus reducing construction zone accident risk. The shorter durations reduce public use costs due to traffic interruptions and improved transportation system quality. Workable schedules promote construction efficiency while recognizing other important objectives for the projects.

Transportation projects vary in size and type to such an extent that it is not practical to use a single scheduling approach for all projects. Large bridge projects may lend themselves to the use of critical path method (CPM) approaches, whereas small projects may require only a bar chart to identify the controlling work items. Many of today's projects involving reconstruction of highways are sufficiently complex to require an approach beyond the bar chart. The CPM approach could be used, but it introduces rigid logic, which, in reality, does not exist. Determination of the best approach for scheduling a project from all of the methods available requires analysis of the project characteristics and needs for planning and control.

Many transportation construction projects are characterized by repetitive operations. Transportation construction projects are repetitive in nature, executed by a series of sequential operations repeated in each part or section along the length of the roadway. The projects are mostly horizontal rather than vertical, progressing along a centerline of the roadway in a linear fashion. We term these projects linear in nature. Typically they are made up of a few controlling or

critical work items whose criticality is determined by a combination of the inherent physical logic and the definition of quantity for a particular item of work.

Preliminary study identifies two promising approaches for scheduling projects with these characteristics. The approaches include the line-of-balance and linear scheduling method, which have been developed and used in several countries. Linear scheduling techniques are the most suitable methods for overall management of transportation projects (1). A preliminary survey of literature indicates that the use of linear scheduling for highway construction in the United States is very limited, and its use has not been well accepted as with CPM and bar chart (2,3).

Bar charts and the network appear to have several shortfalls when it comes to many transportation projects. An alternative is needed for transportation construction projects. It should be possible to simulate the effects of varying productivity rates and to measure the effects on the schedule. An approach with some logic between operations but with less rigid logic than is possible with CPM is needed.

On the basis of prior research by Herbsman, there is no one rigid scheduling technique that can be applied for every transportation project. Several different methods, including bar charts, CPM diagrams, and linear (line-of-balance) schedules, can be appropriate depending on the project characteristics. The scheduling procedures must be developed and tailored to each specific project according to its type, size, and complexity. The specification for scheduling should communicate the requirements that will ensure the timely information for control purposes and the information needed to effectively and fairly deal with schedule issues during the course of the project.

Recognizing that the current scheduling approaches are not ideal for all projects, this paper describes a scheduling procedure that combines the features of CPM, linear scheduling, and bar charts for scheduling and monitoring transportation projects. The procedure is called repetitive activity scheduling procedure (RASP). RASP allows the use of linear scheduling approaches to plan and control linked repetitive operations where matched production rates are critical.

## CURRENT PRACTICES

Several approaches have been reported for scheduling transportation projects. These range from simple bar chart to CPM networks and to some combinations of progress charts and linear scheduling techniques. A brief discussion of these techniques follows.

### Bar Chart

The bar chart or Gantt chart has been used since the early 1900s. The bar chart plots activities versus time with the activities listed vertically. The major feature of a bar chart is that it is simple and easy to understand and clearly indicates when an activity will start and finish. The bar chart is preferred for scheduling field operations because superintendents, foremen, and craft workers can easily understand and apply it (3–5). Although representation of linear activities is possible in a network, the additional complexity has discouraged some use of this method. As a result, contractors often prefer the simplicity of a bar chart (2). However, the bar chart only relates given activities to a time scale. There is no indication of activity interdependence or identification of critical activities. The bar chart does not give the overall schedule impact should an activity be delayed. Bar charts are cumbersome to update; thus, they become nearly useless when the plan is not followed and changes occur.

### Network Models

Network models, developed in the late 1950s and early 1960s, occur in one of two forms: as an activity on arrow (AOA) or an activity on node (AON) model. Both forms are CPMs. The CPM diagram illustrates the logical sequence of activities and shows the critical activities (i.e., those activities that cannot be delayed without delaying the project). Although the CPM has existed for more than 30 years, its application in transportation construction has been limited (3,6,7). There is evidence that contractors do not use networks in highly repetitive jobs (8). In transportation projects or projects consisting of repetitive activities, CPM requires the same activities to be repeated throughout the project's duration, resulting in a complex and cluttered network difficult to visualize. In addition, CPM does not guarantee the continuity of work and does not consider variable production rates. CPM's unrealistic assumptions of unlimited resources and independent activities that can be shifted freely between earliest start and latest finish creates a less-than-perfect model of reality that limits its use on linear and repetitive projects. This problem cannot be solved by resource allocation/leveling. Resource allocation, smoothing, or leveling procedures are incapable of ensuring full continuity for a production crew or process, which is the backbone of planning repetitive cases (6,9).

### Linear Models

Because of the difficulties with CPM in linear construction, various forms of linear scheduling have been proposed as an alternative. The origin of the linear scheduling method is not clear. In fact, there may have been multiple origins, possibly in different countries (8). Linear models include a multitude of variations. What they have in common is that they are all used for planning and controlling highly repetitive projects. They have different names: line of balance (LOB), vertical production method (VPM), combined PERT/LOB, time space diagram, stochastic approaches, or linear programming. In several articles, the linear scheduling method and LOB have

been described as synonymous. In fact, the linear scheduling method has some relationship to the LOB technique developed by the U.S. Navy in the early 1950s. The LOB technique was first applied in industrial manufacturing and production control to evaluate the flow rate of finished products in a production line (1). Any differentiation between linear scheduling and the LOB technique may only be a question of emphasis. In the usual application, the LOB technique is used to schedule or record the cumulative events of unit completion, whereas linear scheduling emphasizes planning or recording progress on multiple activities that are moving continuously in sequence along the length of a single project (2).

Although linear scheduling is used extensively in the Middle East (2), its use in the United States is very limited, and most of its applications to highway construction have been part of research or on a trial basis only (2,3,10). For example, in a survey involving more than 200 contractors working for the Illinois Department of Transportation, none used linear scheduling (8). There are major problems in the presentation of the information, and its success depends on the setting of production rates and more accurate estimates of work hours, because linear scheduling is sensitive to errors in these estimates (8).

### Survey of Scheduling Methods Used by Various Departments of Transportation

A survey has been conducted to examine approaches used by various state departments of transportation across the United States to establish contract durations, control time on construction projects, and schedule resources for the annual construction program. The survey was sent to the chief construction engineer, or equivalent, for each of the 50 states and the District of Columbia. Responses were received from 36 of those surveyed. This paper includes the results of this survey and previous research on related subjects by Johnson (2), Herbsman (3), Thomas (5), and Rowings (11). Results of the survey are given in Table 1.

From the results of Table 1, the following observations can be made.

In response to the question of contract duration, 44 percent of states determine the project duration on the basis of personal experience and judgment or the best guess, depending on project type, size, and complexity; 30 percent use standard production rates; and 22 percent use past projects and historical records. Only 4 percent use CPM to establish contract duration.

Furthermore, contract duration is established at the state level by the vast majority of states (88 percent). Forty-seven percent of the states do not use a schedule specification, 27 percent use various scheduling specifications for different project categories, 20 percent use one specification on all projects, and 7 percent mentioned other unspecified methods.

In response to the questions on computer hardware and software, 53 percent indicated they did not use computers. Of those using computers, 56 percent use microcomputers, 22 percent use minicomputers, and 22 percent use mainframes. Primavera and Supertrack were the software used. In addition, 50 percent require their contractors to use the same software program.

TABLE 1 Survey of Scheduling Procedures for Highway Construction Projects

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|   |  |                |                   |
|---|--|----------------|-------------------|
| 1. How do you determine contract durations?   |  |                |                   |
| [30%] Based on standard production rates  | [44%] Based on project type, size, complexity, etc.                        |                |                   |
| [4%] Based on a CPM schedule  | [22%] Based on historical records (past projects)                          |                |                   |
| 2. Is the contract duration established at the state or district level?   |  |                |                   |
| [88%] State   | [12%] District   |                |                   |
| 3. Do you include a standard scheduling specification in the construction bidding documents?  |  |                |                   |
| [20%] Use one scheduling specification on all projects  |  |                |                   |
| [27%] Use various scheduling specifications for different project categories  |  |                |                   |
| [47%] Do not use a standard scheduling specification  |  |                |                   |
| [7%] Other  |  |                |                   |
| 4. Do you use any computer hardware for scheduling purposes and project management?   |  |                |                   |
| [53%] No  | [22%] Minicomputer   |                |                   |
| [47%] Yes (If yes, specify hardware)  | [22%] Mainframe  |                |                   |
| [56%] Microcomputer   |  |                |                   |
| 5. What type of scheduling software do you use? Primavera; Supertrack.  |  |                |                   |
| 6. Do you require contractors to use the same software as above?  |  |                |                   |
| [50%] Yes   | [25%] Left open to contractors subject to the state or district's approval |                |                   |
| [25%] Not required  |  |                |                   |
| 7. What scheduling method do you require of contractors?  |  |                |                   |
| [15%] None  | [35%] Bar Chart  |                |                   |
| [40%] Critical Path Method  | [0%] Line of Balance Method  |                |                   |
| [5%] Progress Curve Method  | [5%] Other: Narrative Report   |                |                   |
| 8. Do you use CPM on all projects?  |  |                |                   |
| [0%] Yes on all projects  |  |                |                   |
| [53%] On selected project depending on size and complexity  |  |                |                   |
| [47%] No, we use Bar Chart or other methods on all projects   |  |                |                   |
| 9. Do you require contractors to "cost-load" their schedules? [100%] No   |  |                |                   |
| 10. Do you use cost/schedule integration? [80%] No [20%] Yes  |  |                |                   |
| 11. Do you attempt to use contractor's schedules to develop a multi-project schedule for your own inspection and contract administration activities? [73%] No [27%] Yes |  |                |                   |
| 12. How frequently do you require schedule updates?   |  |                |                   |
| [0%] Biweekly   | [13%] Monthly  | [7%] Quarterly | [13%] As required |
| [33%] Never   | [33%] Only when behind by 10 to 60 days or 20% of contract time            |                |                   |

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In response to what scheduling method is required of contractors, 40 percent indicated CPM, 35 percent bar chart, 5 percent narrative report, 5 percent progress curve, and 15 percent do not require any scheduling method. No one indicated use of LOB or linear scheduling techniques. As for CPM, 53 percent use it on selected projects, depending on size and complexity, whereas the rest use the bar chart. None of the states require their contractors to cost-load the schedules, and only 20 percent use cost/schedule integration.

In response to the question on multiproject schedules, 73 percent mentioned that they did not use contractor's schedules to develop multiproject schedules for inspection and contract administration activities. As for update frequency, 33 percent require schedule update when the project is behind 10 to 60 days or more than 20 percent of contract duration, 33 percent never update the schedule, 7 percent update the schedule quarterly, 13 percent update monthly, and 13 percent update only as required.

The results of this survey indicate some adoption of more sophisticated approaches for scheduling and control but not an overwhelming adoption of CPM or other approaches. Fur-

ther information is being gathered from the respondents concerning their reasons for their choice of approach. A survey of highway contractors to gain similar information is also under way.

#### RASP

There may be several reasons why there has been reluctance to use linear scheduling on transportation projects. Although it is fairly easy to plan transportation projects using linear scheduling methods, in practice, there are several problems with scheduling such projects using this method. Linear scheduling techniques are based on the assumption that the rate of output will be uniform. Construction productivity, in practice, varies substantially from day to day even if the assumed average figures are correct. The schedule, therefore, has to be corrected to minimize the interferences that occur when activities are delayed by more than the buffer time allowed (12). Furthermore, transportation projects are not always as linear as they appear. For example, projects involving large cuts and

fill are more difficult to schedule using linear scheduling than those in largely flat or gently rolling terrains (2). Earthwork activities do not necessarily move smoothly from station to station. Instead, an entire area is worked until subgrade is achieved.

Contractors prefer the bar chart because of its simplicity, high visibility, and ease of use. The user is directly involved, and the progress, even for complicated jobs, can be understood at a glance without the use of a computer and unaided by an elaborate scheduling approach. These features should be present in any schedule to be totally effective for updating and control. The fundamentals of project scheduling remain the same irrespective of the project size. A schedule is simply a road map of how its user intends to build the job within a given time frame. Therefore, the first objective of any type of project schedule is to communicate to its users and to reflect the planner's thoughts and intentions (13). RASP maintains the logic integrity of CPM, takes into considerations productivity fluctuations and activity interferences, and sustains the simplicity of the bar chart by combining all these features.

**Project Type and Scope**

The main conclusion of research conducted by Herbsman (3) is that transportation projects should be classified into four categories and that a different scheduling method be used for

each category. The first category consists of simple projects less than \$1 million in size and less than 6 months in duration. These projects will continue using detailed bar charts to plan and schedule the work. The second category consists of very complex projects, usually more than \$5 million in size and more than 12 months in duration. These projects should use detailed CPM. This leaves us with two other categories of typical highway projects: those ranging from \$1 to \$5 million in size and 6 to 12 months in duration as well as any unique or special projects of various sizes and durations. For these projects, a combination of bar chart, CPM, and linear scheduling can be recommended. Bennet (14) identifies five characteristics of construction projects from a management view. He mentions that construction projects vary in size, complexity, repetition, speed, and variability in productivity. Different combinations and different values of these five characteristics provide significantly different management decisions (14). The variation in these characteristics is so large that one single scheduling technique cannot be applied to all types of transportation projects. Using Herbsman and Bennet's research as a guide, the scheduling method selection guide shown in Figure 1 was developed to identify the appropriate techniques for various project characteristics. These include size, complexity, repetition, timing, and variability. Depending on a number of these factors, or a combination, several recommended scheduling techniques are listed on the right-hand side of Figure 1. These range from simple lists and bar charts

**PROJECT CHARACTERISTICS**

| SIZE    | COMPLEXITY  | REPETITION   | TIMING  | VARIABILITY  | RECOMMENDED SCHEDULING TECHNIQUE   |
|---------|---|--|---|--|--|
| <\$1 M  | SIMPLE/<br>STANDARD<br><br>SINGLE STAGE<br>SINGLE CONTRACTOR                                      | SEMI-<br>REPETITIVE<br><br>PERFORMING A<br>FEW FUNCTIONS<br>A FEW TIMES                                  | LOW SENSITIVITY<br><br>SHORT DURATION<br><6 MONTHS<br>FEW CRITICAL ITEMS<br>NO IMPOSED MILESTONE<br>DATES | NOT<br>VARIABLE IN<br>PRODUCTION<br><br>SINGLE SEASON                      | [ ] SIMPLE LIST OF DATES<br>[ ] SIMPLE BAR CHART<br>[ ] BAR CHART BASED ON PROD. RATES<br>[ ] PROGRESS CURVE METHOD<br>[ ] COMBINED PROGRESS CURVE/BAR CHART |
| \$1-5 M | TYPICAL<br>HIGHWAY<br>PROJECT   | VERY<br>REPETITIVE<br><br>PERFORMING A<br>FEW FUNCTIONS<br>MANY TIMES                                    | MEDIUM SENSITIVITY<br><br>6 - 12 MONTHS DUR.<br>MANY ACTIVITIES<br>CRITICAL OR NEAR<br>CRITICAL           | VERY<br>VARIABLE IN<br>PRODUCTION<br><br>SEASON LONG<br>LIMITED RESOURCES  | [ ] REPETITIVE ACTIVITY SCHEDULING<br>PROCEDURE ( R A S P )  |
| >\$5 M  | VERY<br>COMPLEX<br><br>MULTIPLE STAGES<br>MULTI-CONTRACTORS<br>HIGH TRAFFIC FLOW<br>IN URBAN AREA | NON-<br>REPETITIVE<br><br>PERFORMING<br>MANY FUNCTIONS<br>A FEW TIMES OR<br>MANY FUNCTIONS<br>MANY TIMES | HIGHLY SENSITIVE<br><br>LONG DURATIONS<br>>12 MONTHS<br>MOST ACTIVITIES<br>CRITICAL                       | SEMI-<br>VARIABLE IN<br>PRODUCTION<br><br>SEASON LONG<br>LIMITED RESOURCES | [ ] TRADITIONAL CPM METHOD<br>[ ] RASP/CPM COMBINED<br>[ ] PERT OR OTHER SIMULATION METHODS  |

FIGURE 1 Project characteristics versus method used.

to more sophisticated techniques, such as progress curves and CPM, to using RASP.

**Elements of RASP**

The survey of various departments of transportation indicates that most agencies in the United States let the contractors decide what scheduling method to use and, in most cases, require only a simple bar chart. In some states, CPM is required only on selected projects. It is obvious that an alternative scheduling procedure is needed for projects to which neither the bar chart nor CPM is appropriate. Any alternative scheduling method must be simple, flexible, easy to learn, and adaptable to various contractors and field personnel. RASP can meet this requirement. Several basic elements are crucial for a working understanding of RASP.

*Work Breakdown Structure*

The first step in the development of RASP is to separate the project into the constituent component processes by estab-

lishing the project's work breakdown structure (WBS). The WBS is the separation of a project into smaller tasks, or work packages, to aid in organizing, defining, and displaying the project. It is a framework for integrating the schedule and resources that provides a means to define the scope of work required to meet the project objectives. Figure 2 is an example WBS for a roadway construction project. The project consists of replacing and upgrading a portion of a roadway with a new road between stations 10+00 and 70+00, approximately 1.09 mi. The roadway contains approximately 150,000 yd<sup>3</sup> of excavation, most of which occurs between stations 10+00 and 30+00. An 8- × 10-ft reinforced concrete box culvert must be built at station 47+00 before earthwork can proceed in that area. Traffic must be maintained on all existing roads throughout the project duration. Therefore, the work will be accomplished in phases with three sections (STA 10+00 to 30+00, 40+00 to 55+00, and 63+00 to 70+00) completed in the first phase. Work between Stations 30+00 to 40+00 and 55+00 to 63+00, where the new road intersects the existing road, will be completed in the second phase. During the second phase, the work will be performed one lane at a time to keep the other lane open to traffic.

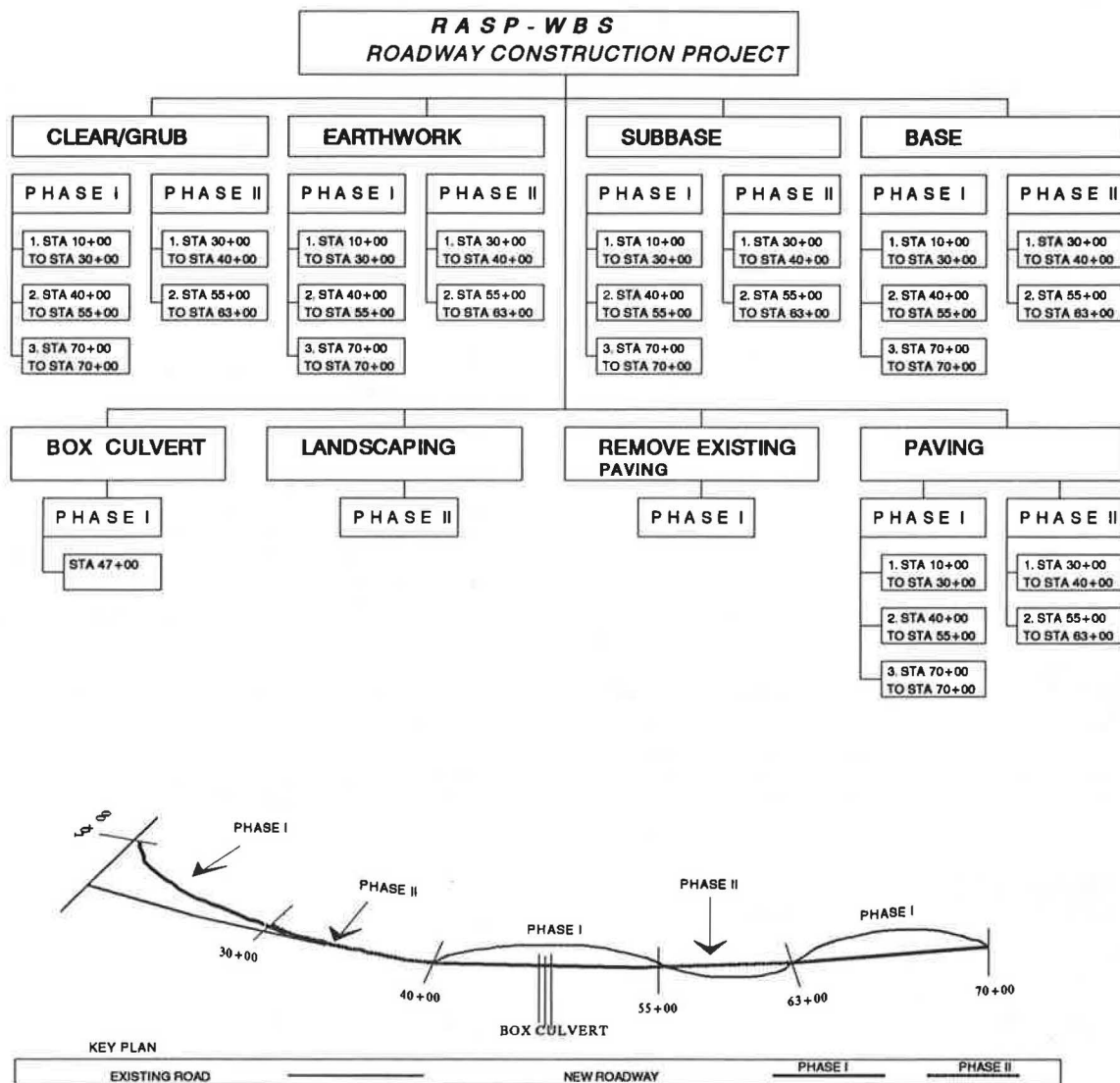


FIGURE 2 Example WBS for roadway construction project.



The WBS of Figure 2 shows eight major categories consisting of clear/grub, earthwork, box culvert, base, subbase, paving, pavement removal, and landscaping. These items are then further broken down by phases and those phases by phase. WBS levels are organized on the basis of the assumption that each group of activities is performed in a continuous production line.

RASP Worksheet

Figure 3 shows a sample RASP worksheet for Phase I of the example project. The worksheet is supplementary to the WBS and is essential to the development of the RASP schedule. All components of the WBS are listed in this worksheet. The RASP worksheet is used as an aid in calculating durations, planning resources, and identifying work stages and sequences. Contract time or contract duration has a major effect on the construction process. Severe time limitations placed on construction will result in high bidding prices and could lead to extensive claims (11). In repetitive types of work, duration is a function of crew sizes, equipment types, and production rates. CPM ignores these important factors when calculating durations (9). Using the RASP worksheet, the

project planner considers all possible resources and how they are to be used, establishes daily production rates, and calculates durations on the basis of these factors. An attempt is made to capture most schedule assumptions and the planning thought process on this worksheet. Furthermore, this worksheet is used to report progress and calculate the percentage of work complete. This information, interfaced with the RASP schedule, can also provide progress curves based on the quantity of work and unit rates. As with the WBS, a key plan showing project location and work segments is shown for maximum visual impact.

RASP Schedule Format

The graphical display of the project plan showing activities, time, and location all framed in one picture is the heart of this technique. Therefore, size and format are prominent bases in the development of RASP. Figure 4 shows the RASP schedule for Phase I of the example project. The format consists of two sections both drawn on 8.5- x 11-in. paper. The top section resembles a simple bar chart and shows all the project's main components as identified by the WBS. The lower section is a plot of time (x-axis) versus distance (y-axis). Using

| STATION -->            | CLEAR/GRUB  |             |             | EARTHWORK |          |             | BOX CULVERT            | SUBBASE  |          |          | BASE     |          |          | PAVING   |          |          |
|------------------------|-------------|-------------|-------------|-----------|----------|-------------|------------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
|                        | 10+00-30+00 | 40+00-55+00 | 63+00-70+00 | 10+00-30  | 40+00-55 | 63+00-70+00 | STA 47+00              | 10+00-30 | 40+00-55 | 63+00-70 | 10+00-30 | 40+00-55 | 63+00-70 | 10+00-30 | 40+00-55 | 63+00-70 |
| QUANTITY               | 1           | 1           | 1.5         | 40000     | 24000    | 18000       | 100                    | 5000     | 5000     | 5000     | 5000     | 5000     | 5000     | 5000     | 5000     | 5000     |
| UNIT                   | ACRES       | ACRES       | ACRES       | CYD       | CYD      | CYD         | FEET                   | SQYDS    | SQYDS    | SQYDS    | SQYDS    | SQYDS    | SQYDS    | SQYDS    | SQYDS    | SQYDS    |
| CONDITIONS AT SITE     | LIGHT TREES | LIGHT TREES | ROCK        | NORMAL    |          | ROCK        | 8 X 9' REINF. CONCRETE |          |          |          |          |          |          |          |          |          |
| <b>EQUIPMENT:</b>      |             |             |             |           |          |             |                        |          |          |          |          |          |          |          |          |          |
| FRONT END LOADER       | 2           | 1           | 1           | 1         | 1        | 1           | 1                      |          |          |          |          |          |          |          |          |          |
| BULLDOZER              | 2           | 1           | 1           | 1         | 1        | 1           |                        |          |          |          |          |          |          |          |          |          |
| DUMP TRKS              | 3           | 1           | 1           | 2         | 2        | 2           |                        |          |          |          |          |          |          |          |          |          |
| SCRAPER 16 CY          |             |             |             | 2         | 2        | 2           |                        |          |          |          |          |          |          |          |          |          |
| PAVER                  |             |             |             |           |          |             |                        |          |          |          |          |          |          |          |          |          |
| ROLLER                 |             |             |             |           |          |             |                        |          |          |          |          |          |          |          |          |          |
| HYDR. EXCAVATOR        |             |             |             | 1         | 1        | 1           | 1                      |          |          |          |          |          |          |          |          |          |
| <b>MANPOWER:</b>       |             |             |             |           |          |             |                        |          |          |          |          |          |          |          |          |          |
| LABOR                  | 7           | 7           | 7           |           |          |             |                        |          |          |          |          |          |          |          |          |          |
| TEAMSTERS              | 3           | 1           | 1           | 2         | 2        | 2           |                        |          |          |          |          |          |          |          |          |          |
| EQP OPER               | 4           | 2           | 2           | 6         | 6        | 6           |                        |          |          |          |          |          |          |          |          |          |
| CARPENTER              |             |             |             |           |          |             |                        |          |          |          |          |          |          |          |          |          |
| PAVER                  |             |             |             |           |          |             |                        |          |          |          |          |          |          |          |          |          |
| IRONWORKER             |             |             |             |           |          |             |                        |          |          |          |          |          |          |          |          |          |
| PIPELAYER              |             |             |             |           |          |             |                        |          |          |          |          |          |          |          |          |          |
| FINISHER               |             |             |             |           |          |             |                        |          |          |          |          |          |          |          |          |          |
| BUDGETED COST          |             |             |             |           |          |             |                        |          |          |          |          |          |          |          |          |          |
| BUDGETED MANHRS        |             |             |             |           |          |             |                        |          |          |          |          |          |          |          |          |          |
| DAILY PROD RATE        | 1           | 1           | 1.5         | 2000      | 2400     | 1200        | 5                      | 1000     | 1000     | 1000     | 1000     | 1000     | 1000     | 5000     | 5000     | 5000     |
| DURATION               | 5           | 5           | 5           | 20        | 10       | 15          | 20                     | 5        | 5        | 5        | 5        | 5        | 5        | 1        | 1        | 1        |
| <b>SCHEDULED DATES</b> |             |             |             |           |          |             |                        |          |          |          |          |          |          |          |          |          |
| TARGET START           | WK 1        | WK 2        | WK 3        | WK 2      | WK 6     | WK 9        | WK 2                   | WK 6     | WK 9     | WK 12    | WK 7     | WK 10    | WK 13    | WK 14    | WK 14    | WK 14    |
| TARGET FINISH          | WK 1        | WK 2        | WK 3        | WK 5      | WK 8     | WK 11       | WK 6                   | WK 6     | WK 9     | WK 12    | WK 7     | WK 10    | WK 13    | WK 14    | WK 14    | WK 14    |
| TOTAL FLOAT            | 0           | 0           | 5 WKS       | 1 WK      | 0        | 0           | 0                      | 2 WKS    | 2 WKS    | 0        | 2 WKS    | 0        | 0        | 0        | 0        | 0        |
| FCST START             |             |             |             | WK 7      | WK 10    |             |                        | WK 10    | WK 13    |          | WK 11    | WK 14    | WK 15    | WK 15    | WK 15    | WK 15    |
| FCST FINISH            |             |             |             | WK 9      | WK 12    |             | WK 7                   | WK 10    | WK 13    |          | WK 11    | WK 14    | WK 15    | WK 15    | WK 15    | WK 15    |
| FCST FLOAT             |             |             |             | -1        | -1       |             | -1                     | 1 WK     | -1       |          | 1 WK     | -1       | -1       | -1       | -1       | -1       |
| <b>PROGRESS UPDATE</b> |             |             |             |           |          |             |                        |          |          |          |          |          |          |          |          |          |
| ACTUAL QTY TODATE      |             |             |             | 40000     |          |             |                        |          |          |          |          |          |          |          |          |          |
| % COMPL                | 100         | 100         |             | 100       |          |             | 75                     | 100      |          |          | 100      |          |          |          |          |          |
| COST TODATE            |             |             |             |           |          |             |                        |          |          |          |          |          |          |          |          |          |
| MANHOURS TODATE        |             |             |             |           |          |             |                        |          |          |          |          |          |          |          |          |          |
| ACTUAL START DATE      | WK 1        | WK 2        |             | WK 2      |          |             | WK 3                   |          |          |          | WK 4     |          |          | WK 5     |          |          |
| ACTUAL FINISH DATE     | WK 2        | WK 2        |             | WK 5      |          |             |                        |          |          |          | WK 4     |          |          | WK 5     |          |          |
| ASSUMPTIONS/REMARKS:   |             |             |             |           |          |             |                        |          |          |          |          |          |          |          |          |          |

FIGURE 3 RASP worksheet.

# RASP

## Repetitive Activity Scheduling Procedure

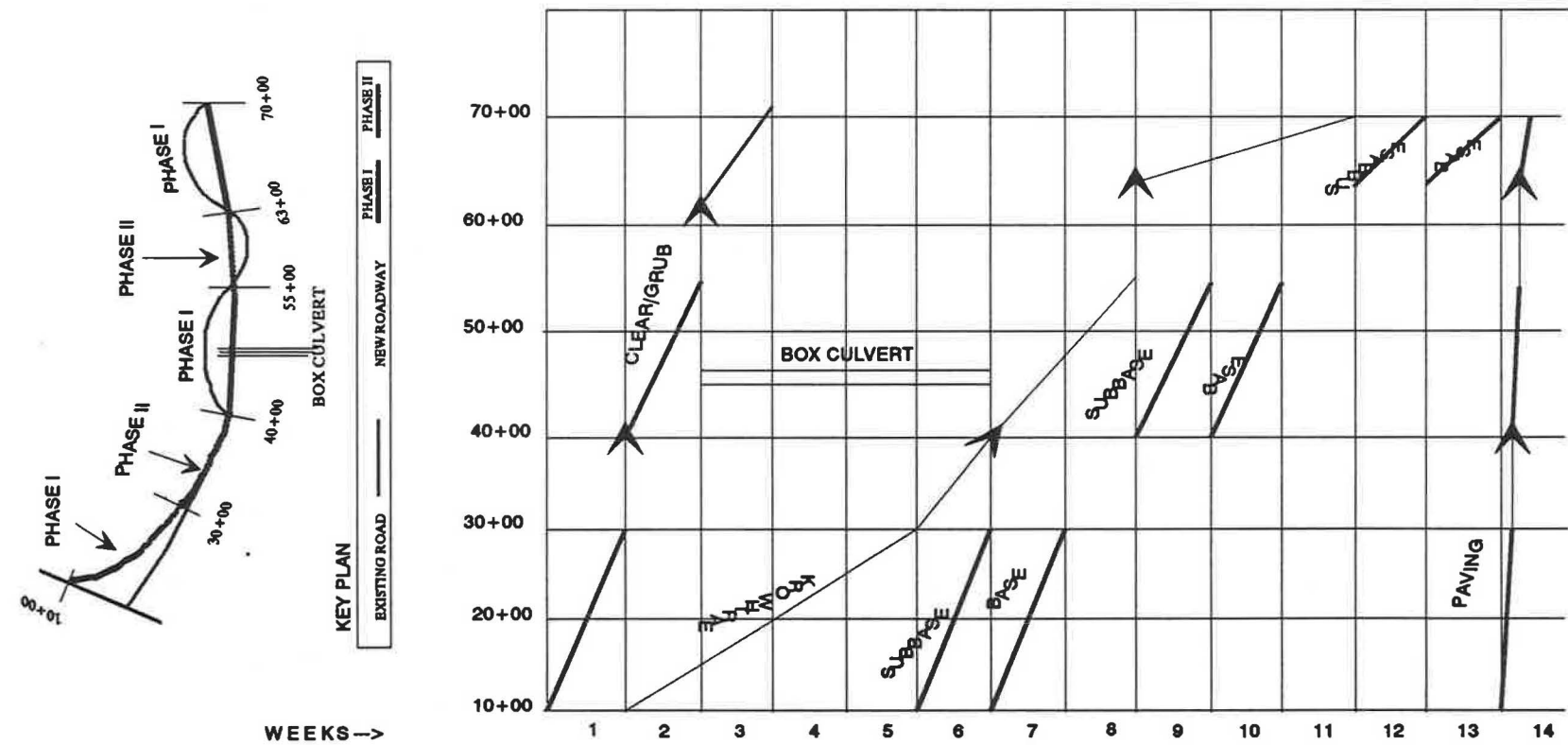
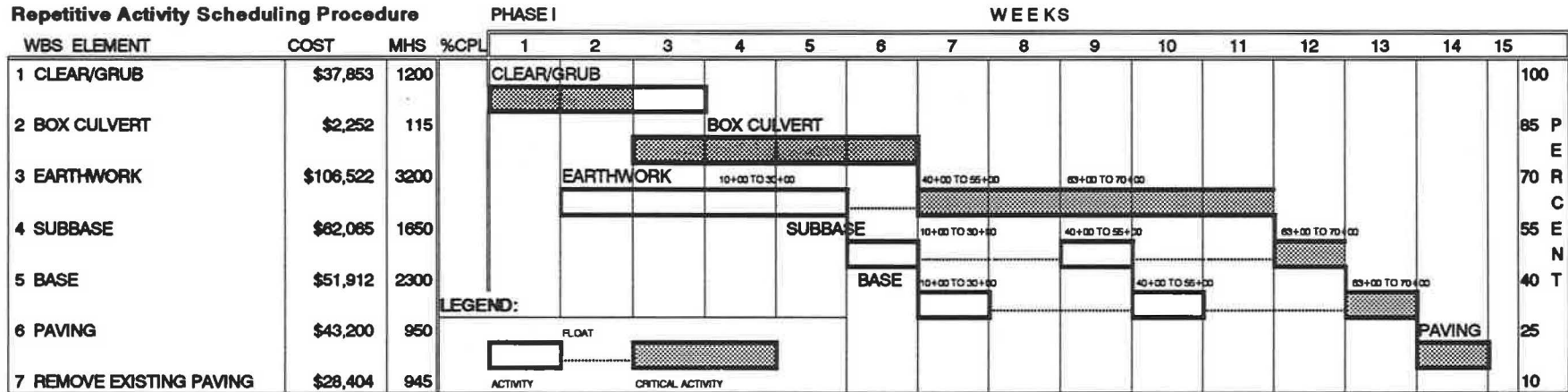


FIGURE 4 RASP schedule format.



the worksheet as a guide, the planner decides a starting place to begin the work. In this example, the work starts with clear/grub at Station 10+00. Clear/grub is then plotted on the lower section using the durations calculated on the worksheet. Each activity is a line whose slope and position are an indication of the planned work pace, productivity, and work area congestion. A vertical, dashed line indicates movement of a crew or resource from one section location to another, assuming there is no time loss in this movement. The arrowhead indicates the direction of the movement. A dashed line between activities expanding both vertically and horizontally indicates a delay in the start of the next activity. This may be due to a restraint, as indicated on earthwork between Sections 1 and 2. In this case, earthwork on Section 2 cannot start until the box culvert at STA 47+00 is completed. When there are no dashed lines between two identical items, float activity exists. Once the lower section is completed, the bar chart section can easily be drawn. The bar chart indicates the critical path as well as total and free float. Unlike the conventional CPM programs, with RASP the planner can see at all times where a project is headed. The planner can determine right away if the project can be done within a certain time frame. RASP is a flexible tool that guides the planner to be in control of the schedule.

#### CPM/RASP Combined

Although RASP can be developed without a CPM schedule, on more complex projects with substantial amounts of discrete activities it may be advantageous to develop RASP as a supplement to the CPM program. This can easily be accomplished with most software programs by downloading the semidiscrete or linear tasks and then performing the analysis using RASP.

#### Updating and Monitoring Progress

The ability to update a schedule in a few easy steps is one of the primary advantages of using RASP versus generic systems. This can be accomplished manually or by computer with minimal data entry compared with the time-consuming data reentry involved in generic systems. Figure 5 shows a RASP schedule updated through Week 6. The method in monitoring progress in RASP is similar to updating bar charts. On any specific date during the project, the working or calendar day can be marked with a line drawn vertically across the diagram. Progress on individual activities would be marked by location rather than time. Completed activities or activities in progress can be shaded, as shown in Figure 5. As long as the project is reasonably within the original or current target, there is no need to redraw the diagram. RASP is a dynamic scheduling tool that is quickly updated and can be more easily modified to reflect the project's changed conditions. The vertical status line provides the managers with a quick overview of the project's progress. When the project is significantly behind schedule or there are major revisions in the scope of work or operations, RASP will be revised and redrawn. Because of the simplicity of RASP, this rescheduling process is fairly easy.

#### Linear Scheduling and Progress Curves

According to the survey of scheduling procedures for highway construction projects, a number of agencies indicated the use of progress charts or progress curves. Progress charts display a two-dimensional representation of status and rate of progress (15). The horizontal axis shows time. The vertical axis can be used in a number of ways to show quantity, cost, or percentage of progress. Progress charts allow the managers to determine not only whether the project is ahead or behind schedule but also whether it is gaining or losing ground. Progress charts can easily be developed as a supplement of RASP. In fact, RASP and progress charts complement each other.

Since 1967, the U.S. Department of Defense and the Department of Energy have established what is known as the cost/schedule control systems criteria (C/SCSC) for control of selected federal projects. Although this system is primarily for use on large projects, certain useful features of this system may be applicable to transportation projects as well. The system, which uses the progress chart concept, consists of three major elements: budgets are time phased to provide a budgeted cost of work scheduled (BCWS); actual costs are captured as actual cost of work performed (ACWP); and the earned value concept is used to determine budgeted cost of work performed (BCWP). By a comparison of these three major elements, several conclusions about cost and schedule performance can be reached.

Earned value or achieved and accomplished value are terms used for determining overall percent completion of a combination of dissimilar work tasks or a complete project. Earned value techniques are applicable to both fixed and variable budgets, although there are differences in detail in applying these techniques. Performance against schedule is simply a comparison of what you planned to do against what you did, whereas performance against budget is measured by comparing what you did to what you have paid for. These ideas can be expressed as follows:

$$\text{Scheduled variance (SV)} = \text{BCWP} - \text{BCWS}$$

$$\text{Scheduled performance index (SPI)} = \text{BCWP}/\text{BCWS}$$

$$\text{Cost variance (CV)} = \text{BCWP} - \text{ACWP}$$

$$\text{Cost performance index (CPI)} = \text{BCWP}/\text{ACWP}$$

A positive variance and an index of 1.0 or greater is considered favorable performance. These calculations are used in determining forecast costs at completion.

Three basic methods are used:

- Method 1 assumes that work from this point forward will progress at planned rates whether or not these rates have prevailed to this point. This is expressed as

$$\text{EAC} = \text{ACWP} + \text{BAC} - \text{BCWP}$$

where

EAC = estimated at completion,  
ACWP = actual cost of work performed to date,

# RASP

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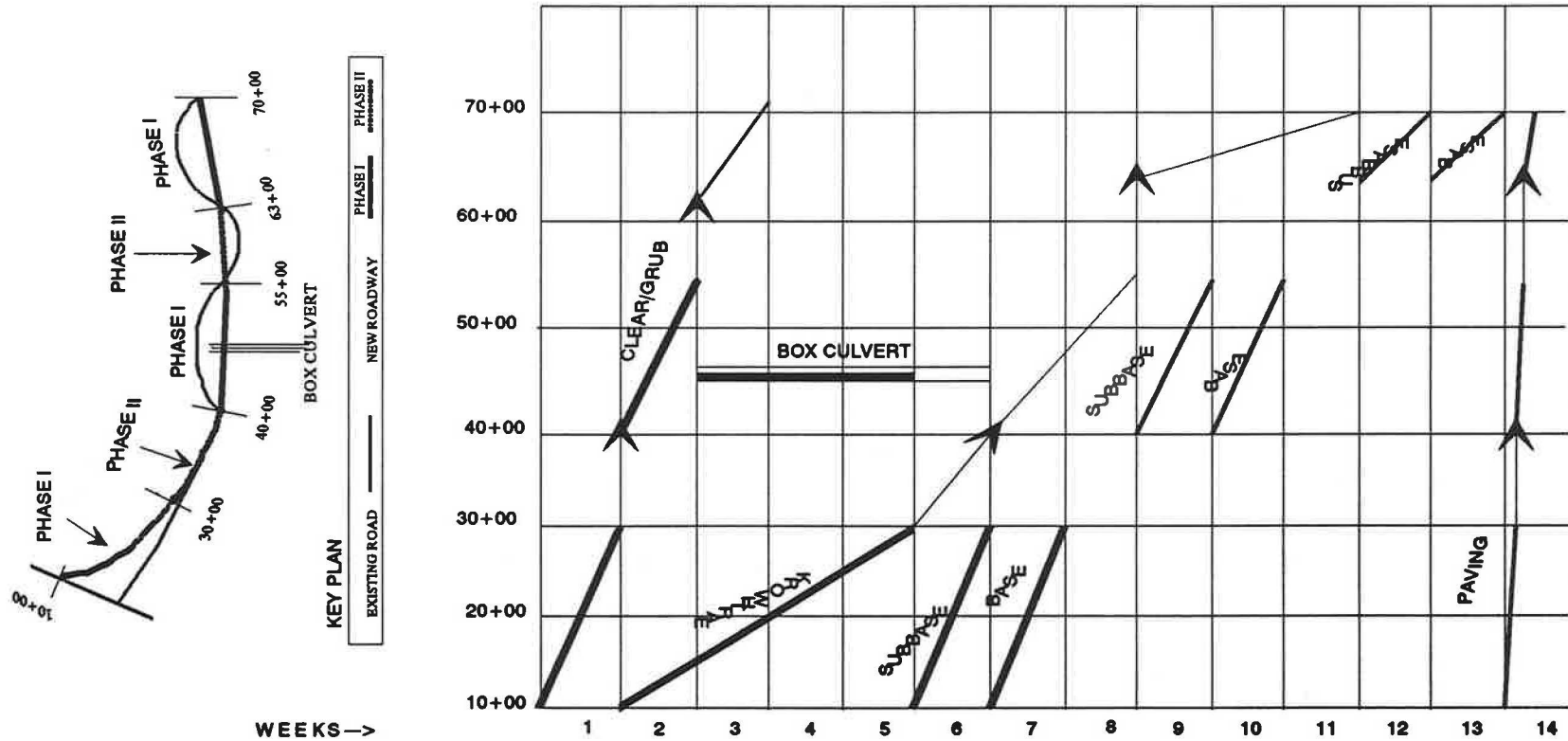
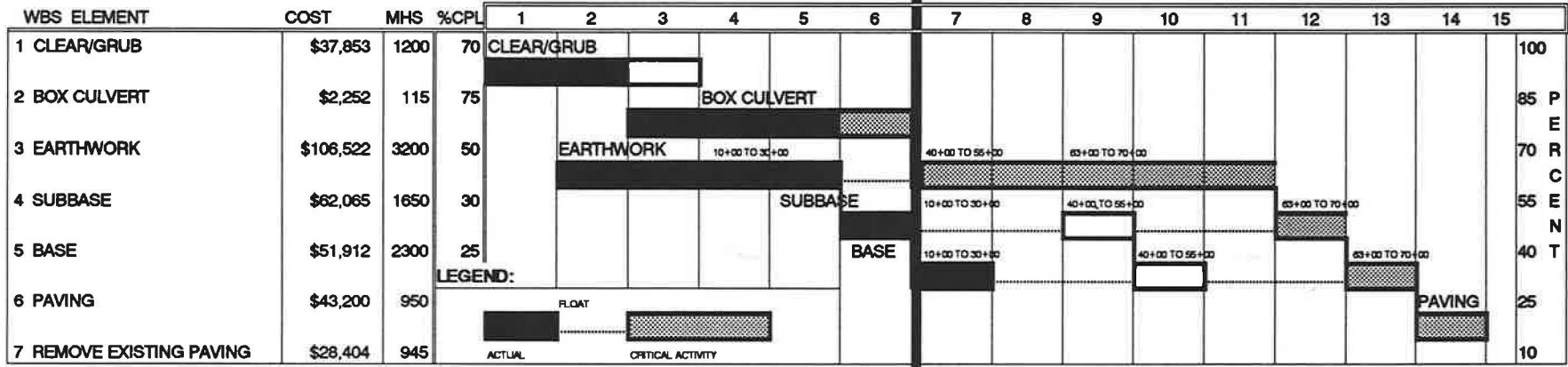


FIGURE 5 Updating RASP.

BAC = original budget at completion, and  
 BCWP = budgeted cost of work performed to date.

• Method 2 assumes that the rate of progress to date will continue to prevail and is expressed as

$$EAC = BAC/CPI = BAC * (ACWP/BCWP)$$

where CPI = cost performance index.

• Method 3 uses progress curves for forecasting as shown in Figure 6. Actual accomplishment—Point A—is plotted below the scheduled curve, indicating that the project is behind schedule. The actual amount can be determined by drawing or extending a horizontal line from Point A back to Point B on the schedule and measuring the schedule slippage. Likewise, the plotted cost—Point E—is located above the scheduled budget, but the amount of variation present in this parameter is not immediately apparent. The scheduled cost of the actual accomplishment must be determined rather than the cost listed for the current time frame. By extending a line vertically from Point B on the scheduled accomplishment until it meets the cumulative budget at Point C, we can determine what the cost for that accomplishment should have been. Continuing a horizontal line from there to Point D on the current time frame shows whether there is a cost overrun or underrun. In this case, the cost overrun is measured as the vertical difference between Points D and E.

It is recommended that no single forecasting method be used; rather, include a forecast by each of the preceding methods because they provide a range of possibilities.

**Software Status**

Although RASP can be developed without the use of a computer, it can easily be automated as required. RASP is an excellent candidate to be developed using spreadsheet programs combined with a graphics package. There are several commercial programs available from which to choose. Further research will provide guidelines for developing computerized RASP and its interface with other packages. In addition, RASP can easily be interfaced with CPM scheduling programs such as Primavera and others.

**SUMMARY AND CONCLUSION**

The scheduling approaches used today on transportation projects have many shortcomings for properly modeling the real world constraints and conditions that are encountered. A large number of projects exist whose characteristics dictate an approach different from the bar chart or CPM. An alternative approach, RASP, has been developed using the principles of the linear scheduling technique. The most obvious characteristic of RASP is its simplicity. The RASP schedule format and worksheet can easily convey detailed information that is comparable with what may be derived from an equivalent CPM schedule. RASP is a strategic planning tool that indicates the pace of work, allowing the planner to see how everything comes together and how the activities relate to each other. RASP provides an additional dimension not available with CPM or bar chart.

The technique requires a different form of data base than is currently kept to develop good estimates of production,

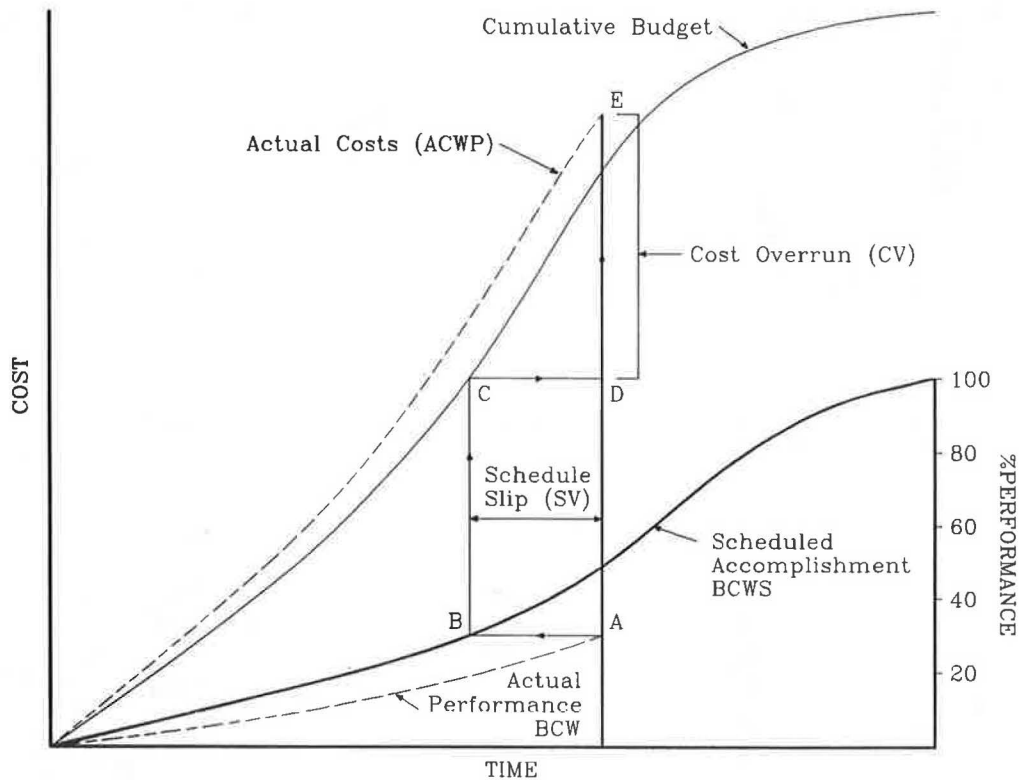


FIGURE 6 RASP and progress curve.

given certain resource combinations and working conditions. The system should offer an opportunity for improved planning and control of transportation projects.

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*Publication of this paper sponsored by Committee on Construction Management.*