J. E. Rowings, D. J. Harmelink, F. Rahbar

Final Report

A Multi-Project Scheduling Procedure for Transportation Projects

April 1993

Sponsored by the Iowa Department of Transportation
Highway Division and the Highway Research Advisory Board

Iowa DOT Project HR-339
ISU-ERI-Ames-93413

Iowa Department of Transportation

report

College of Engineering
Iowa State University

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Abstract

The Iowa Department Of Transportation started requiring Critical Path Method(CPM) schedules two years ago on some larger or more schedule sensitive projects. The specification which has been used has resulted in a variety of CPM approaches by contractors. Recognizing that the current procedures might not be adequate for all projects, the Iowa DOT sponsored a research project to explore the state-of-the-art in transportation scheduling and identify opportunities for improvement. This report proposes, that for certain types of highway construction projects undertaken by the Iowa Department of Transportation, a scheduling technique commonly referred to as linear scheduling may be more effective than the Critical Path Method scheduling technique that is currently being used. The types of projects that appear to be good candidates for the technique are those projects that have a strong linear orientation. Like a bar chart, this technique shows when an activity is scheduled to occur and like a CPM schedule it shows the sequence in which activities are expected to occur. During the 1992 construction season, the authors worked with an inlay project on Interstate 29 to demonstrate the linear scheduling technique to the Construction Office. The as-planned schedule was developed from the CPM schedule that the contractor had developed for the project. Therefore, this schedule represents what a linear representation of a CPM schedule would look like, and not necesssarily what a true linear schedule would look like if it had been only scheduling technique applied to the project.

There is a need to expand the current repertoire of scheduling techniques to address those projects for which the bar chart and CPM may not be appropriate either because of the lack of control information or due to overly complex process for the actual project characteristics. The scheduling approaches used today on transportation projects have many shortcomings for properly modeling the real world constraints and conditions which are encountered. Linear project's predilection for activities with variable production rates, a concept very difficult to handle with the critical path method, is easily handled and visualized with the linear technique.

It is recommended that work proceed with the refinement of the method of linear scheduling described above and the development of a microcomputer based system for use by the Iowa Department Of Transportation and contractors for its implementation. The system will be designed to provide the information needed to adjust schedules in a rational way for changes in quantities and scope of the projects. The system will provide a simple, understandable method for monitoring progress on the projects and alerting Iowa Department Of Transportation personnel when the contractor is deviating from the plan.

Introduction and Problem Statement

The state and local transportation agencies have been challenged from all sides to develop reasonable durations for the construction of transportation projects. The agencies strive to ensure that contractors develop workable schedules which are consistent with the time, cost, safety, and quality objectives. In the past, the Iowa Department of Transportation(IDOT) has used cash flow curves(progress charts) and has required the Critical Path Method (CPM) scheduling on a few projects based on complexity of the project. The Iowa DOT has recognized that the cash flow curve is merely an administrative document rather than a real schedule representing how the contractor plans to execute the project.

The Iowa DOT started requiring CPM methods last year on some larger or more schedule sensitive projects. The specification which has been used has resulted in a variety of CPM approaches by contractors. The total impact of applying CPM has not been formally evaluated. Recognizing that the current procedures might not be adequate for all projects, the Iowa DOT sponsored a research project to explore the state-of-the-art in transportation scheduling and identify opportunities for improvement. It is hoped that this study will assist with; (1) improving methods for determining contract durations, (2) making more accurate project updating and forecasts, and (3) providing a methodology for evaluation of the impact of scope changes and extra work.

Based on prior research by Herbsman , it was also recognized that 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 balance schedules could be appropriate depending on the project characteristics. This study involves a critical examination of the needs of the Iowa DOT for a schedule and an evaluation of all the possible methods and their suitability.

Objectives

The objectives of this research are:

(1) to evaluate the existing state-of-the-art scheduling techniques used by other states,

(2) to develop new or improved methods that will enable Iowa DOT to determine a reasonable contract duration,

(3) to develop a method to monitor the project progress more accurately,and

(4) to develop procedures to objectively evaluate the time impacts of changes and extra work.

Research Approach

The tasks identified at the outset to accomplish these objectives include: (1) A review of the scheduling specifications from other states to identify alternative approaches and scheduling methods. (2) A review of available scheduling techniques which might be appropriate for various types of transportation projects. (3) A review of the current bid items and the appropriate work breakdown structures for projects. (4) A review of the available scheduling software with respect to the requirements of the Iowa DOT. (5) Development of a scheduling specification which addresses the requirements of the Iowa DOT. (6) Development of a recommended procedure for estimating contract durations and documenting critical assumptions. (7) Development of a methodology for evaluating the reasonableness of contractors and their compliance with scheduling requirements. (8) Development of a guide system for change identification and develop procedures that objectively evaluate the time impacts of changes and extra work. (9) Development of a methodology for a multi-project control system(MPC). This system will be capable of providing information for the efficient use of DOT resources(3). (10) Providing training for Iowa DOT personnel on the use of any system developed.

At an interim point in the progress of this project, the researchers presented a report to the Office of Construction staff and the research board and which recommended that the work proceed with the refinement of the linear scheduling method and be tested on a project underway to determine the method's feasibility. The staff and board agreed that the development of the method and testing of the method should proceed before addressing the issue of multi-project scheduling. This report addresses only this modified scope of work.

Research Progress

This report represents the results of the first and second phases of the research. It includes a summary of the work performed to date and a recommendation for the tasks to be accomplished in the third phase. The third phase has been approved by the Iowa Department of Transportation, and is proceeding with application of the method to several projects of varied types around the State of Iowa.

Transportation Scheduling Background

State and other transportation agencies are in need of effective methods to plan and monitor highway construction projects. Approaches which will help promote workable schedules can provide many benefits as it reduces overall costs, increases safety, and shortens 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 while 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. To determine 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 these projects 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.

Based on 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, a methodology is needed to select the most appropriate method for the project circumstances.

Documented 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. Following is a brief discussion of these techniques.

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 the preferred tool for scheduling field operations as superintendents, foremen, and craft workers can easily understand and apply the bar chart (Herbsman, 1987;

Barrie, 1978; Thomas, 1986). Contractors prefer the simplicity of a bar chart (Johnson, 1981). However, the bar chart only relates given activities to a time scale. There is no indication of activity interdependence and the identification of the critical activities. The bar chart does not provide an answer to the question of what the overall schedule impact is if an activity is delayed. Bar charts are cumbersome to update; thus, 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 termed Critical Path Methods (CPM). The CPM diagram illustrates the logical sequence of activities, and shows the critical activities (i.e, those activities which can not be delayed without delaying the project). Although the CPM has existed for over 30 years, its application in transportation construction has been limited (Jaafari, 1984; Herbsman, 1987; Reda, 1990). There is evidence that contractors do not use networks in highly repetitive jobs (Arditi, 1986). 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 can not 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 (Peer, 1974; Jaafari, 1984).

Linear Models

Due to the difficulties with CPM in linear construction, various forms of linear scheduling have been proposed as an alternative. The origins of the linear scheduling method is not clear. In fact, there may have been multiple origins, possibly in different countries (Arditi, 1986). 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 are named differently: 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 the 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 to industrial manufacturing and production control with the object of evaluating the flow rate of finished products in a production line (Al Sarraj, 1990). Any differentiation between the 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 while linear scheduling puts emphasis on planning or recording progress on multiple activities that are moving continuously in sequence along the length of a single project (Johnson, 1981).

Although linear scheduling is used extensively in the Middle East (Johnson, 1981), its use in the United States is very limited, and most of its applications to highway construction has been part of research or on a trial basis only (Herbsman, 1987; Chrzanowski, 1986; Johnson, 1981). For example, in a survey involving over 200 contractors working for the Illinois Department of Transportation, none used linear scheduling (Arditi, 1986). There are major problems in the presentation of the information, and its success depends on the setting of production rates and a more accurate workhour estimates as linear scheduling is sensitive to errors in these estimates (Arditi, 1986).

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 (Harris, 1977). 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 (Johnson, 1981). Earthwork activities do not necessarily move smoothly from station to station. Instead, an entire area is worked until subgrade is achieved.

A preliminary survey of literature reveals that the use and knowledge 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 (Johnson, 1981; Herbsman, 1987). The greatest impediments to the use of this technique appear to be the lack of a computerized system for it's application and knowledge about the method.

Scheduling Practices of State DOT's

Survey of State DOT's

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 DOT 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 section includes the results of this survey and previous research on related subjects by Herbsman (1987), Thomas (1986), Johnson (1981), and Rowings (1980). Results of the survey are tabulated in Table 1. From the results of Table 1, the following observations are made:

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

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

In response to the questions on computer hardware/software, 53% indicated they did not utilize computers. Of those who do utilize computers, 56% use microcomputers, 22%

minicomputers, and 22% mainframes. Primavera and Supertrack were the software used. In addition, 50% require their contractors to use the same software program.

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

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

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

Review of State Scheduling Specifications

The standard and supplemental scheduling specifications from different states were reviewed to determine if they had any common characteristics in their sections related to scheduling. This section provides a summary of the review of those specifications and standards.

The specifications office at IDOT has a library of the current specification books for highway and bridge construction of all state DOT's. These books were examined to determine scheduling requirements used by other states in the country.

As shown in Appendix B, a large number of states have very brief scheduling clauses that typically require the contractor to furnish the Engineer with a "Progress Schedule" (or CPM) showing the order of the work and time required for the completion. This schedule would be used to establish major construction operations (or salient features or controlling items) and to check progress. The minor differences that do exist between these states are listed in Appendix B also.

	Bar Chart Schedule	Network Schedule	Cost-Loading	Written Narrative	Activity Duration	Number of Activities	Float Ownership	Schedule Updates	Progress Payments
Alabama	X								
Arizona								X	
Colorado	X			X				X	
Delaware								X	
Florida			X	X				X	X
Hawaii		X	X					X	
Mississippi	X								
New Jersey	X	X						X	
Oklahoma		X		X	X	X	X	X	X
Pennsylvania									
Washington								X	
West Virginia	X	X	X					X	

Figure 1. Scheduling Specification Summary

Twelve states had scheduling specifications that varied in one way or another from the group described in the preceding paragraph. The specifications of these states were typically more extensive and an analysis of them is included here. Figure 1. graphically shows states that included clauses in their specifications that relate to specific scheduling requirements.

Note that a description for each item identified in the figure is included in the following text:

Bar Chart schedule. Alabama requires a bar graph for projects with durations greater than 60 days. Colorado requires a "Comprehensive Bar Chart" with extra space for revisions and progress plots. Mississippi requires a bar chart. New Jersey requires a bar chart when the "Progress Schedule" is not a pay item. In West Virginia the contractor has the option to use a bar-graph type schedule.

Network schedule. Hawaii requires a CPM schedule for projects which have both a contract amount of one million dollars or more and a contract time of one hundred working days or more. New Jersey requires a schedule prepared by CPM, PERT, or a comparable network system for all projects when the item "Progress Schedule" is a pay item. Oklahoma requires a CPM schedule as presented in the AGC's manual "Use of CPM in Construction". Oklahoma further requires that the schedule be in the form of an arrow diagram (I-J node). West Virginia gives the contractor the option of using a network schedule. If the contractor elects to use a network schedule it will be by CPM, PERT, or other approved method.

Cost-Loading. Hawaii requires that progress schedules include a graphical representation of the relationship of working days to total earnings. Florida requires that each activity on the schedule shows a monetary value. West Virginia requires that the percent complete for each activity for each month, based on monetary value of the work, shall be listed in numbers above the bar graph.

Written Narrative. Colorado requires a detailed narrative description of the activities displayed in the "Comprehensive Bar Chart". Florida requires that the schedule be accompanied by a working plan, which is a concise written description of the Contractor's construction plan. Oklahoma requires that a written narrative describing the critical path and logic revisions or modifications to the schedule be included with the monthly progress reports.

Activity Durations. Oklahoma specifies that no activity duration shall be longer than 20 workdays without the Department's approval.

Number of Activities. Oklahoma specifies that the Department reserves the right to limit the number of activities on the schedule to between 50-500 activities.

Float Ownership. Oklahoma's specification states "It is understood by the Department that the Contractor float is a shared commodity".

Schedule Updates. Arizona requires a 2-week schedule including dates of major phases of the work and status of ongoing activities. Colorado requires, if requested by the Engineer, a bar chart showing the status of the work actually completed to date. Delaware requires the contractor to submit to the Engineer, on each Friday, a "Proposed Activity Schedule" for the following two week period. This activity schedule shall not be a duplication of the information shown of the "proposed work schedule" but rather shall provide specific details related to actual construction activities the contractor plans to have in progress during the reporting period. Florida specifies that the Contractor shall submit an updated Work Progress Schedule only when requested by the Engineer. Hawaii requires, that when requested by the Engineer, the Contractor shall submit supplementary progress schedules to reflect adjustments in the original progress schedule arising from changes in the progress of the work. New Jersey requires the Contractor to update the mathematical tabulation on a two month basis and to provide the Engineer with updated copies. The updated tabulations shall reflect the current status of activities as outlined on the network diagram. New Jersey further requires that conditions may develop which require network logic revisions to the original diagram. If during the progress of the work, major changes develop which necessitate changes in the original plan, the Contractor shall make such changes so as to depict the current mode of operation and shall provide the Engineer with a revised network diagram. Oklahoma requires that not later than the fifth day of each month of the project, the Contractor will submit four copies of an updated I node-J node including a written narrative describing the critical path and logic revisions or modifications to the schedule. No logic revisions or modifications shall be made without prior approval of the Department. The Contractor will further submit two copies of revised activity on arrow diagrams for the following: delay in completion of any critical activity; actual prosecution of the work which is, as determined by the Department, significantly different than that represented on the schedule; the addition, deletion, or revision of activities required by Contract modification; or any logic revisions or calendar revisions. The Contract completion time will be adjusted only for causes specified in this Contract. As determined by CPM analysis, only delays in activities which affect milestone dates, critical path, or Contract completion dates will be considered for a time extension. Washington requires the Contractor to submit supplemental progress schedules when requested by the Project Engineer.West Virginia specifies that the Contractor shall submit each month a report of actual progress of the work.

Progress Payments. Florida's specification states that failure to finalize either the initial or the revised schedule in the time specified will result in withholding of all contract payments until the schedule is approved. Oklahoma states that failure to submit the required monthly network analysis system updates will cause the Department to withhold the monthly progressive pay estimate until such time as the update is received by the Department.

The current scheduling specification used by the Iowa DOT was examined and compared with those of other states. The Iowa supplemental scheduling specification is similar to several other and provides only limited guidance as to format and content of the schedule. This open specification leads to a variety of approaches by contractors and can produce schedules with many different appearances. The specification does not specify the software to be used.

One of the tasks was to develop a new specification for scheduling. Based on the general belief that there is not one best scheduling approach for all projects it was decided to produce a specification that could be used with a variety of project types and would specify the best approach for the particular characteristics of the project. To that end draft specification for bar charts and CPM's were developed based on the review of other states' scheduling specifications and the input received from meetings with the Iowa DOT Construction Office staff. These are included in Appendix A. It is hoped that these will be applied and tested on actual projects in upcoming lettings to determine their effectiveness and usefulness. Until more development is done on the linear scheduling method it is not appropriate to develop a draft specification.

Work Breakdown Structure (WBS)

One of the tasks identified in the research plan was a review of the current bid item list to determine if it could be used as a work breakdown structure for scheduling. The first step in the development of any schedule is to separate the project into the constituent component processes by establishing the project's 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 provide a means to define the scope of work required to meet the project objectives.

The Iowa DOT bid item descriptions were reviewed for their suitability as a work breakdown structure for transportation project scheduling. It appears that the bid items, while appropriate for pay items are more detailed than would be needed for a project schedule in most cases. This level of detail would be cumbersome and would add complexity in the schedule which might inhibit it's usefulness. There are some instances where it would be possible to use the bid items as activities and many where it would be appropriate to combine bid items to define activities. Some thought should be given to developing more structure and a coding system for the bid item list. This would enhance its use for tracking and planning purposes.

Evaluation of the Procedure for Establishing Contract Durations

Currently the Iowa DOT establishes contract durations based on the judgement of the Contracts Office at the state level. This approach normally works fairly well with the tendency toward providing more than sufficient time to allow contractors with a variety of production capability to be able to bid the work. This provides the State an opportunity to have a larger number of bidders and thus with more competition it is reasoned that they will receive lower bid prices for the work. It was reported that there have been several instances where, even though the durations were set in one office, inconsistencies occurred and the duration established appeared unreasonable to the contractors. The result of this inconsistency is that the project must be pulled from the letting and then advertised again for a later time period. This may result in higher prices and delayed service to the eventual users of the project.

Several of today's projects involve rebuilding section of highway that have heavy traffic usage. On these projects it is critical that the duration be established based on a reasonable but very aggressive schedule. These projects require careful sequencing and staging to meet that objectives of safety,and schedule. Close consideration to production rates and sequences must be given in establishing contract durations. Each project is so unique that it is not possible to develop a reasonable yet aggressive contract duration without a systematic process of looking at the requirements of the project.

The contracts department has identified this area as one which should be addressed and has began collecting data on the actual durations of projects as well as the production rates on major time-consuming activities. This data collection has only begun recently and was not available as yet for this study. It is envisioned that this data will be used in the system eventually developed in this project.

Development of a Methodology for Scheduling

Contractors prefer the bar chart due to its simplicity, high visibility, and ease of use. The user is directly involved, and the progress, for even 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 (Rahbar, 1984).

John Bennet 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 (Bennet, 1985). The variation in these characteristics is so large that one single scheduling technique cannot be applied to all types of transportation projects. Using Bennet's research as a guide, the scheduling method selection draft guide shown in Figure 2 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

PROJECT CHARACTERISTICS

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

Figure 2. Project Characteristics v. Method Uses

of, several recommended scheduling techniques are listed on the right hand side of Figure 2. These range from simple lists and bar charts to more sophisticated techniques, such as Progress Curves and CPM, to using some form of linear scheduling. The survey of various DOTs indicates that most agencies in the United States leave it up to the contractors on what scheduling method to employ, and, in most cases, require only a simple bar chart. In some states, CPM is required only on selected projects. It seems that an alternative scheduling procedure is needed to address the needs of projects which are not appropriate for either the bar chart or CPM. Any alternative scheduling method must be simple, flexible, and easy to learn and adapt by various contractors and field personnel.

Linear Scheduling

This report proposes, that for certain types of highway construction projects undertaken by the Iowa Department of Transportation, a scheduling technique commonly referred to as linear scheduling may be more effective than the Critical Path Method scheduling technique that is currently being used. The types of projects that appear to be good candidates for the technique are those projects that have a strong linear orientation.

A linear project could be described as a project that has a linear nature such as a highway, a railroad, or a pipeline. Typically, these projects have a group of operations that progress along the course of the project and define the majority of the work associated with the completion of the work. For example, to reconstruct a paved highway, the existing pavement is removed, the new base for the road is prepared, and finally the new road is paved. When these activities have been completed at any specific location, the work is basically complete up to that point.

Linear scheduling is a scheduling technique that can capitalize on the linear aspect of these types of projects. Like a bar chart, this technique shows when an activity is scheduled to occur and like a CPM schedule it shows the sequence in which activities are expected to occur. Unlike other scheduling techniques, however, it also shows where an activity is to occur. This information is presented visually, using various graphical constructs to represent the types of activities. On linear type activities, the beginning location and time, the ending location and time, and the production rate relative to the physical location on the project are easily visualized.

CPM scheduling seems best suited to projects in which the logic is heavily constrained. The majority of the relationships between activities are of the finish-to-start type, as is common in buildings or other forms of vertical construction. In these situations the critical path method is a very powerful tool. Linear projects, however, are much less constrained by the hard logic of the project. Macro planning decisions are seldom constrained by more than a few negotiable technical constraints.

The authors discovered that a high percentage of the relationships described in linear projects were either start-to-start or finish-to-finish. These relationships would be used to model a group of activities that would traverse large distances across the projects, all moving at a constant rate. The critical path method focuses on modeling the beginning and ending points of the activities, when in fact it is usually the interaction between the activities as they progress along the coarse of the project that become important. The linear scheduling technique allows the planner to visualize the relationships between activities at any point along the project's path. The greatest value derived from the linear scheduling technique comes from its ability to plan and depict the planned use of space and time.

Graphical Constructs

The linear scheduling technique use a variety of graphical constructs and symbols to depict the various types of activities found in linear projects. The following discussion describes some of the typical symbolism found in linear schedules.

Axes

A linear schedule has a horizontal and a vertical axis. One axis is allocated to some measure of time and the other is related to a physical location or distance on the project. The typical orientation for highway construction projects, as shown in Figure 3, has placed time on the vertical axes and location or distance on the horizontal axes. The units for time are usually days and can be expressed in either calendar days or work days. The horizontal axis generally relates to stationing on the project. Scales need to be selected for the axes that allow for the schedule to be legible on whatever output media is used.

Project visual cues

Since the linear schedule is bound to physical aspects of the project it is possible to display other information. Figure 4 shows examples of how a plan and profile could be included in the linear schedule. Information such as this helps relate the schedule to the physical aspects of the project making the schedule easier to understand and comprehend. The types of graphical information and the amount of detail included in the graphics are limited only by the creativity of the person preparing the schedule and the physical aspects of

Figure 3

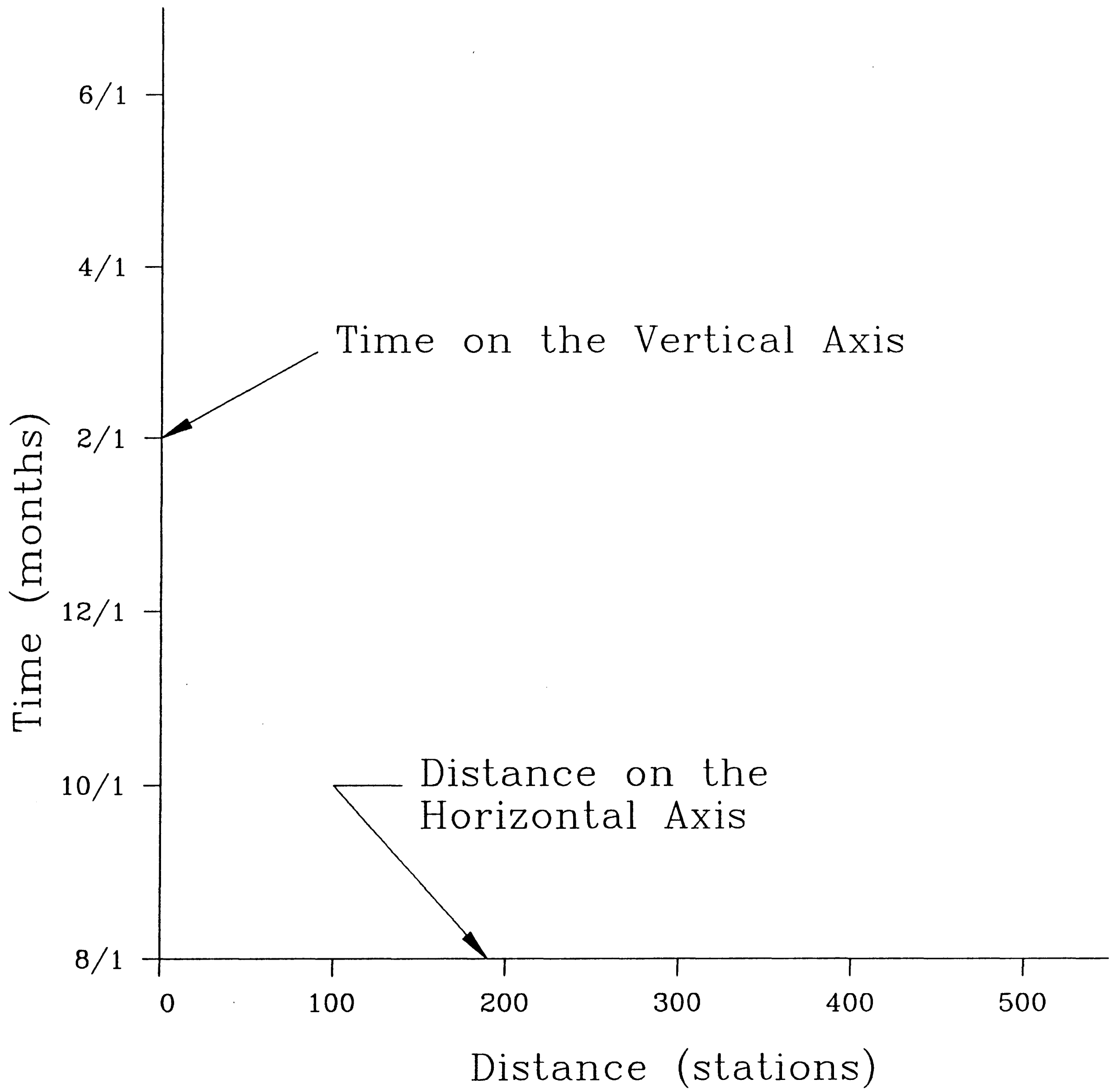
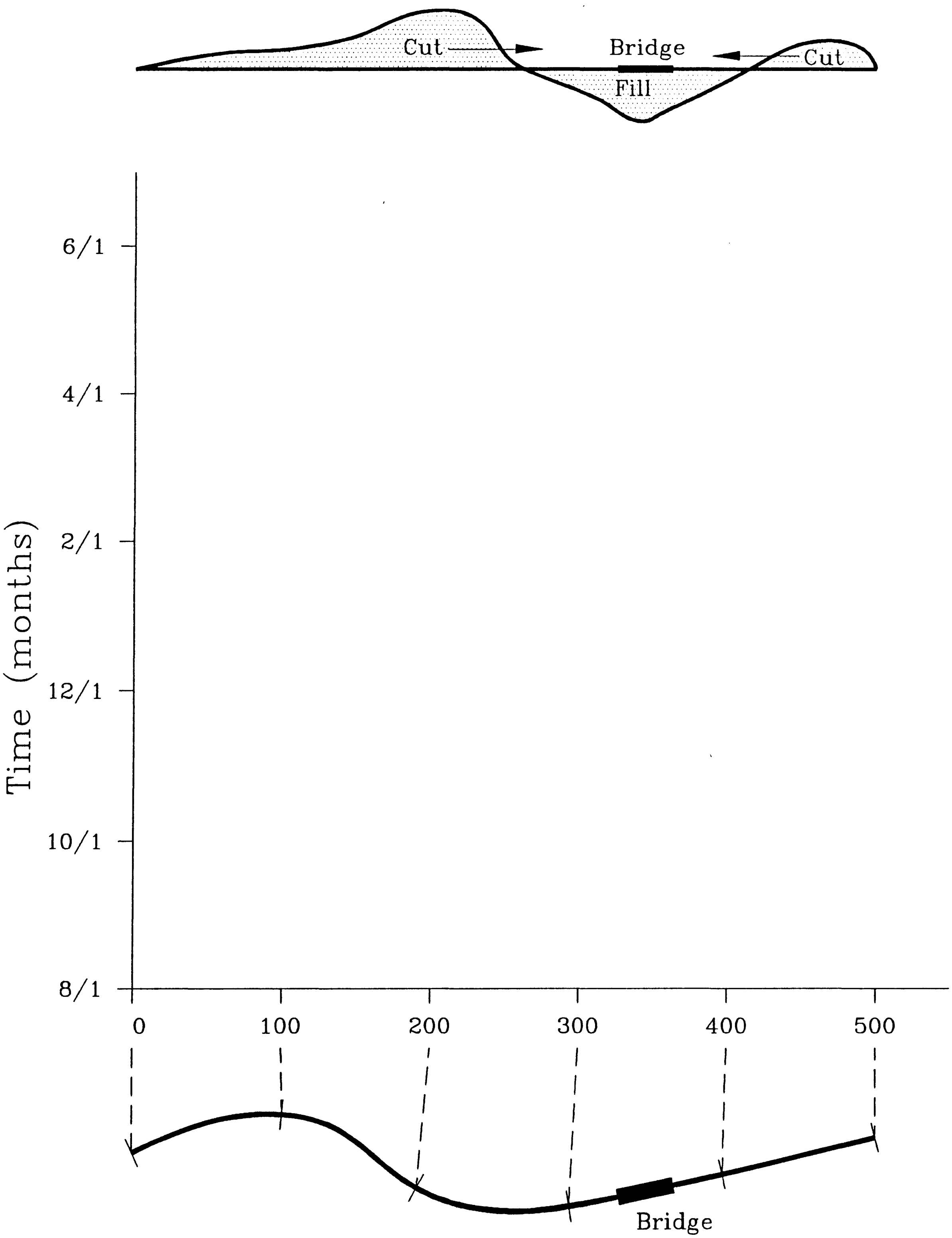

Time on the Vertical Axis
Distance on the Horizontal Axis
6/1
4/1
2/1
12/1
10/1
8/1
Time (months)
0
100
200
300
400
500
Distance (stations)

Figure 4



Cut
Bridge
Cut
Fill
6/1
4/1
2/1
12/1
10/1
8/1
Time (months)
0
100
200
300
400
500
Bridge

the project.

Accessibility

Areas of inaccessibility to the project or periods of nonwork are difficult to demonstrate with most scheduling techniques. Linear scheduling, however, can represent these periods very easily as Figure 5 indicates. Access to an area could be restricted for a period of time as the figure shows or events such as cold weather shutdown could be visually displayed.

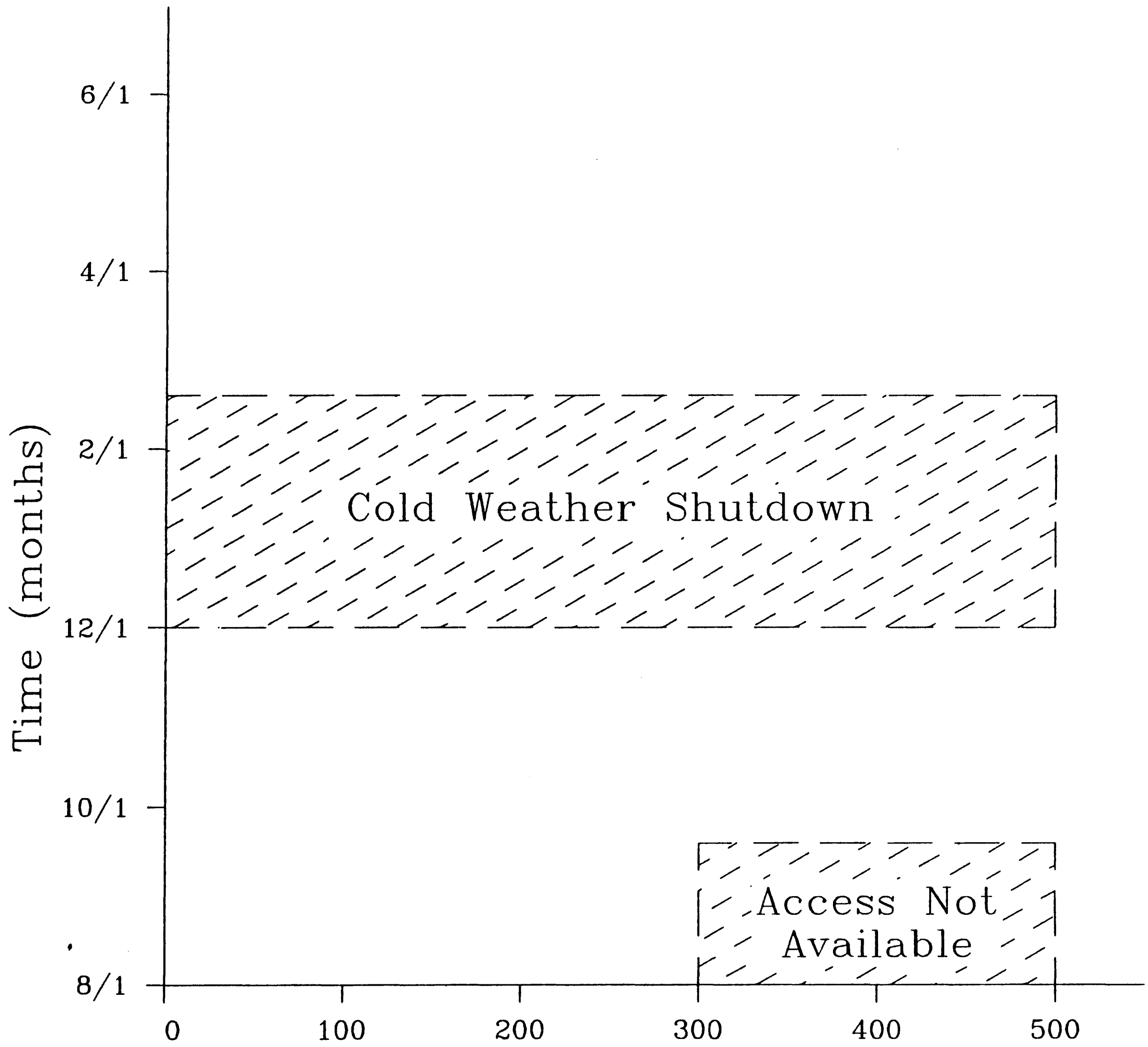
Lines

Most of the activities on a linear schedule will be represented as lines. A typical activity on a linear schedule represents an activity that progresses from one location to another such as a highway paving operation. An activity of this nature begins at an initial location and time and progresses to a new location at a later time. This information, as Figure 6 shows, can be represented as a line. It is also possible to represent variable rates of production for an individual activity. The upper portion of the line in the figure occurs at a different rate than the lower portion as indicated by the varying slopes of the line. In the orientation used in the figure the later portion of the activity occurs at a higher rate that the early part of the activity. In other words the later portion of the activity progress across 200 stations in less time than the early portion of the activity traversed 200 stations.

Bars

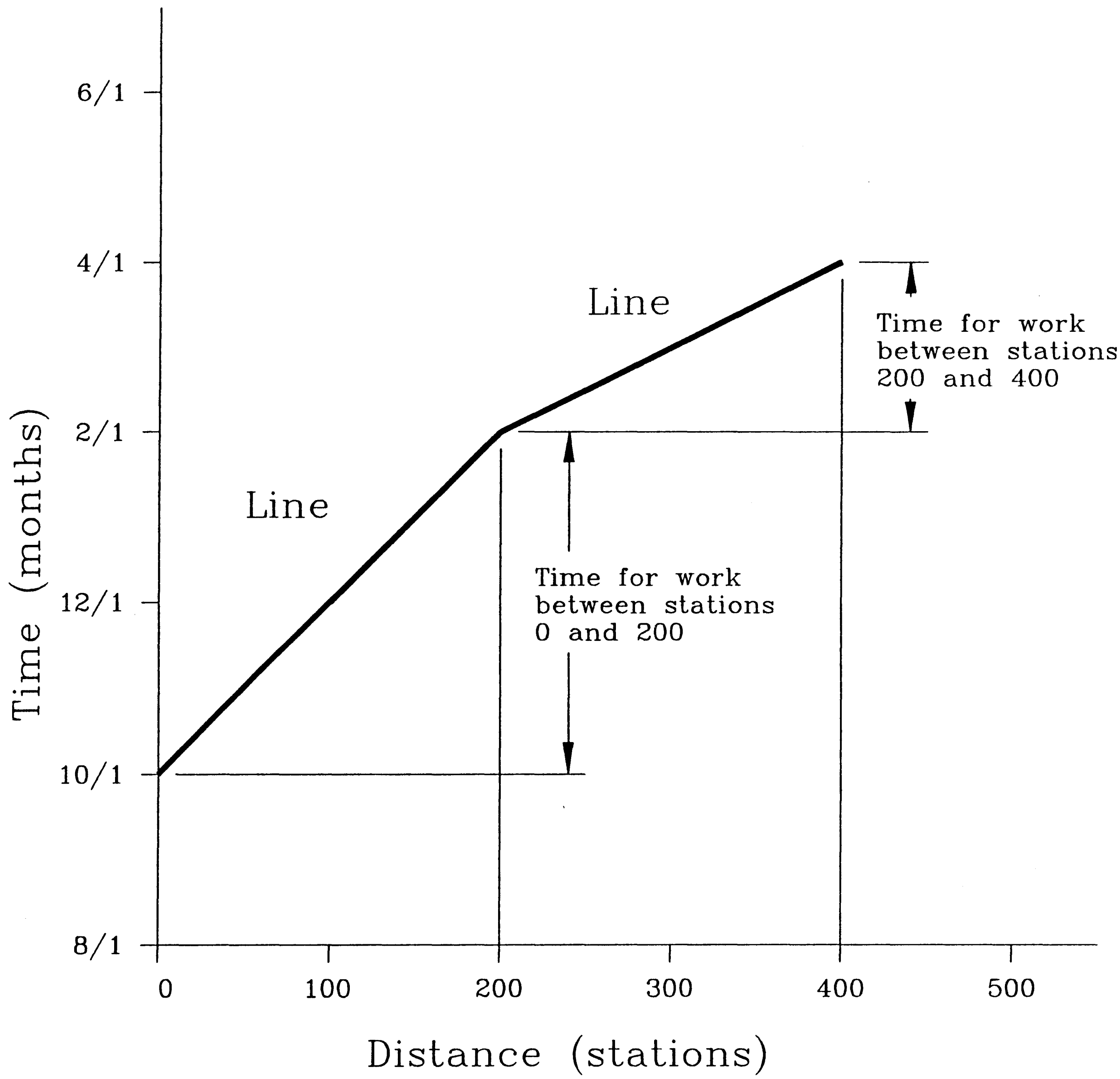
Most projects that have a linear nature will have numerous work items that are not necessarily linear in nature. For example, a highway reconstruction project may have bridge approach work that cannot be done with the mainline paving operations. In this example the

Figure 5



Time (months)
6/1
4/1
2/1
12/1
10/1
8/1
0
100
200
300
400
500
Cold Weather Shutdown
Access Not
Available

Figure 6



6/1
4/1
2/1
12/1
10/1
8/1
Time (months)
Line
Line
Time for work between stations 200 and 400
Time for work between stations 0 and 200
0
100
200
300
400
500
Distance (stations)

activities necessary to complete the bridge approach are the same as the mainline paving activities, but they all occur over a relatively short distance. Instead of portraying these activities as a group of very short lines segments it may be easier to understand if all of the activities necessary to complete this work item were included in a bar as shown in Figure 7.

Another case in which a bar may be used to represent an activity or group of activities may occur where an activity crosses the path of those represented on the linear schedule. An example would be the paving of a side street in conjunction with the paving of the main street. These activities would appear as bars on the mainline linear schedule and conversely the mainline activities would appear as bars on the side street linear schedules.

Blocks

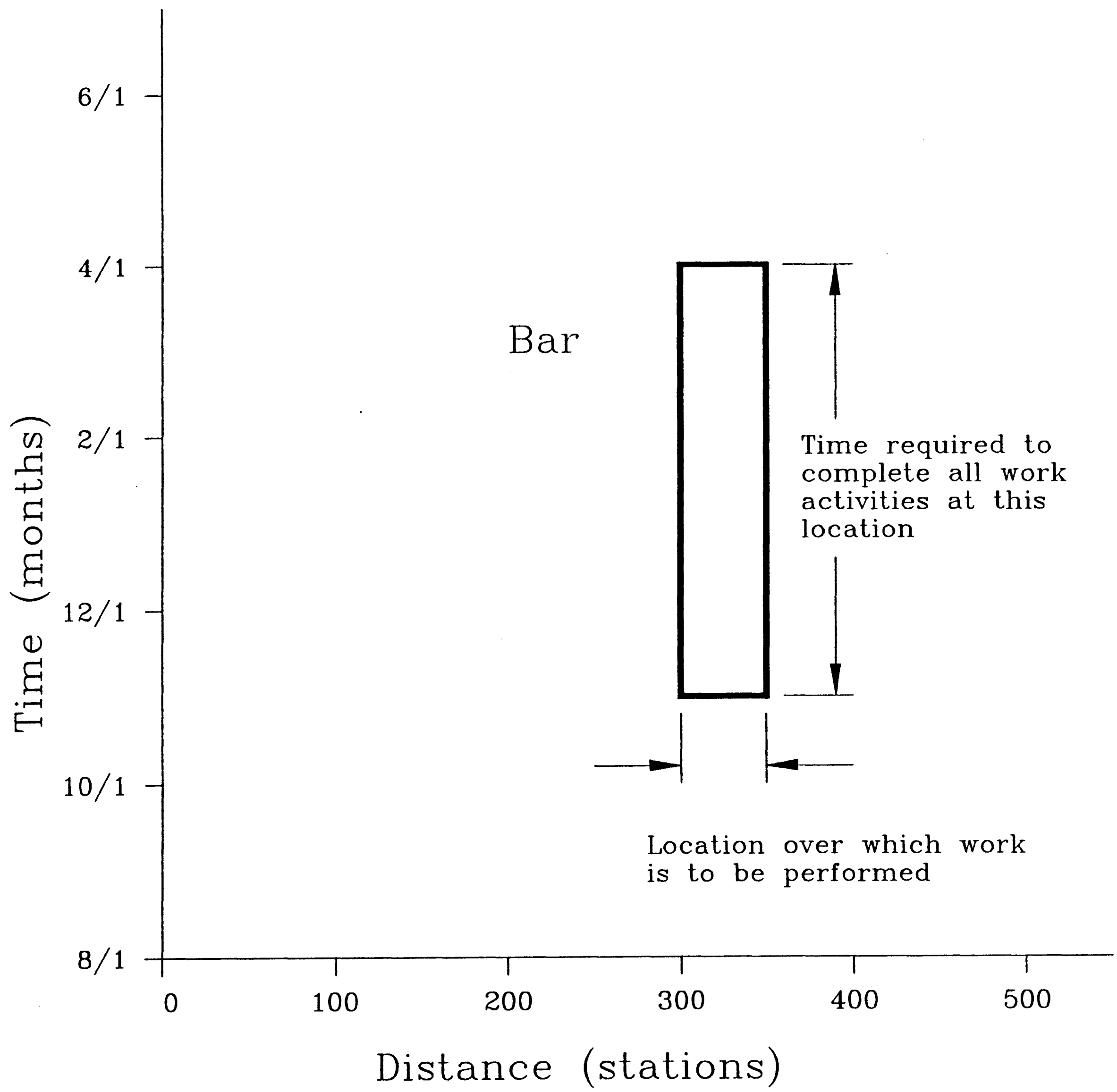
Blocks represent activities that cover significant areas of the project for some measurable amount of time. Earthwork activities, for example, occupy a balance for a period of time during which other activities cannot occur. These activities are best represented by a block as Figure 8 shows.

Figure 9 shows, simply, how the various parts of a linear schedule would look with respect to each other. Notice that it is possible to visually determine where activities represented as lines will begin and in what direction and rate they will progress. Activities on the linear schedule should not touch or cross each other. If they do there may be a conflict between them.

Linear Scheduling versus Critical Path Method

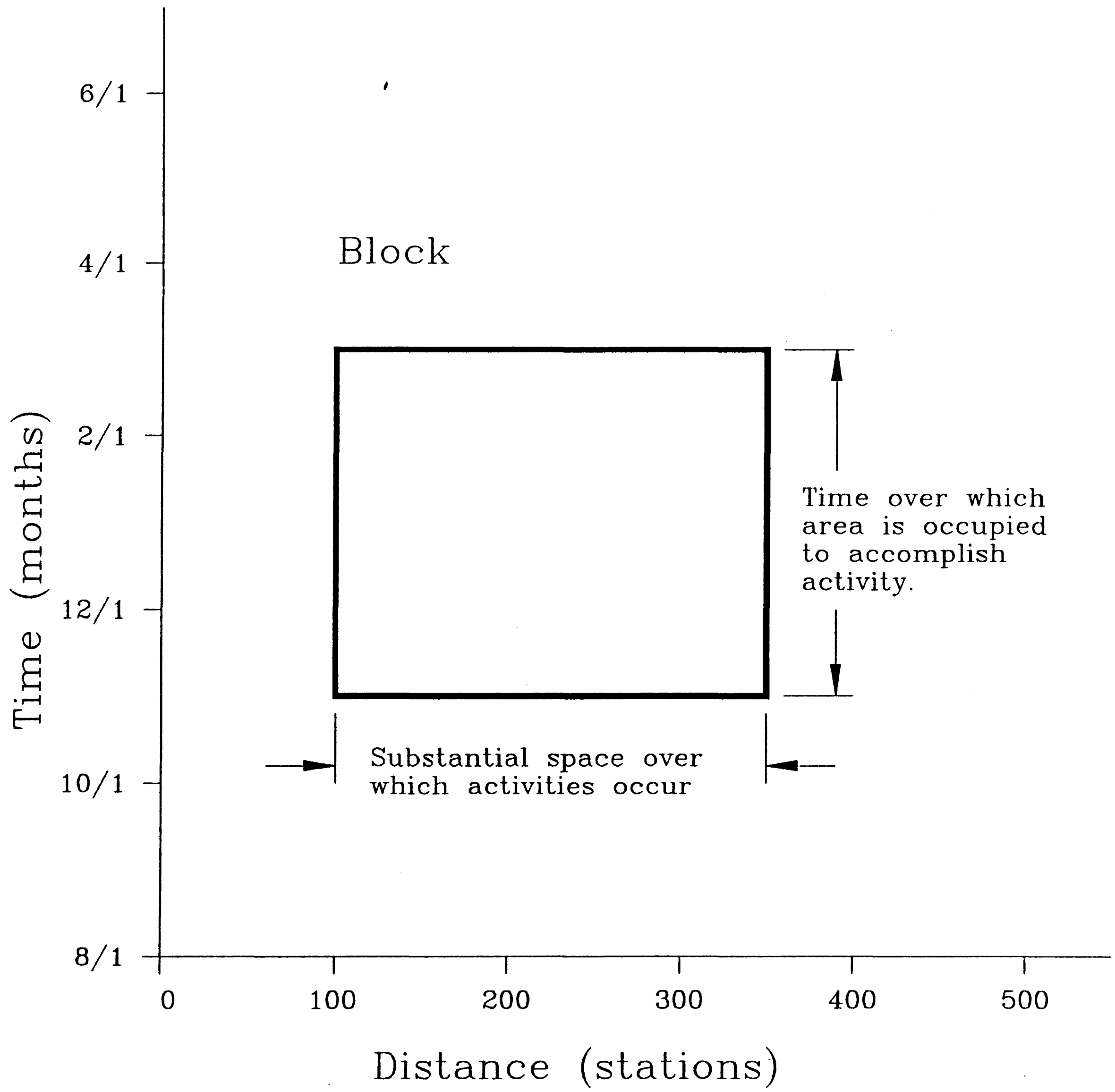
Figure 10 shows an example of a simple CPM logic diagram. The number in the

Figure 7



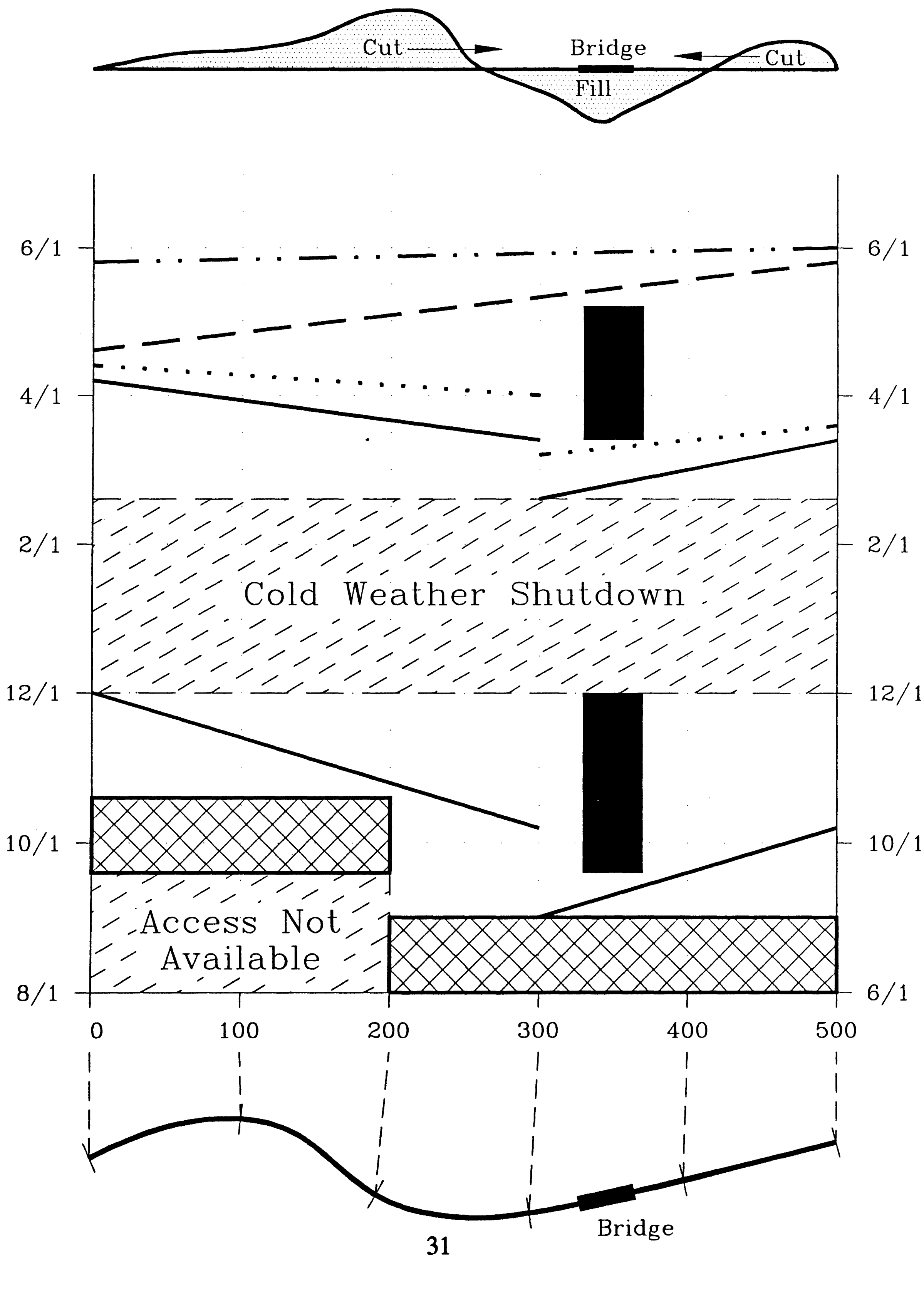
6/1
4/1
2/1
12/1
10/1
8/1
Time (months)
Bar
Time required to complete all work activities at this location
Location over which work is to be performed
0
100
200
300
400
500
Distance (stations)

Figure 8



6/1
4/1
2/1
12/1
10/1
8/1
Time (months)
Block
Time over which area is occupied to accomplish activity.
Substantial space over which activities occur
0
100
200
300
400
500
Distance (stations)

Figure 9


Cut
Bridge
Cut
Fill
6/1
4/1
2/1
12/1
10/1
8/1
6/1
4/1
2/1
12/1
10/1
6/1
Cold Weather Shutdown
Access Not Available
0
100
200
300
400
500
Bridge

lower center of each activity box is the duration. The diagram says that Activity B cannot start until Activity A is complete which will take 10 days. Activity C starts 5 days after Activity B and is completed before Activity E starts. Five days after Activity B ends Activity D can start and Activity E can end. Activity F cannot start until Activities D and E have both been completed. The numbers in the upper portion of the box indicate the early start and finish of each activity while the numbers in the lower corners indicate the late start and finish. The total duration for the project is 60 days and activities A, B, D, and F are on the critical path. Activities B and E have 10 days float as indicated by their early and late dates.

The relationships depicted in this logic diagram are typical of how activity relationships are represented in highway projects. It is common for activities all to start at a given location, each a few days apart, and progress along the coarse of the project. These activities will be represented with start-to-start relationships similar to the relationship between Activities B and C. To complete the logic, these activities are then joined by a finish-to-finish relationship as between Activities B and E. The number of start-to-start and finish-to-finish relationships, and the number of lag relationships versus the number of activities is usually disproportionately high when compared to CPM schedules of non-linear type projects. The ability of CPM to accurately model the project weakens as the number of these types of relationships increases.

Assuming that all of the activities in the example CPM cover the same portion of the project, Figure 11 could represent what this CPM may look like as a linear schedule. The added dimension is the stationing along the horizontal axis going from 0 to 1000 stations. Time is represented along the vertical axis and the end points of the line coincide with the

Figure 10

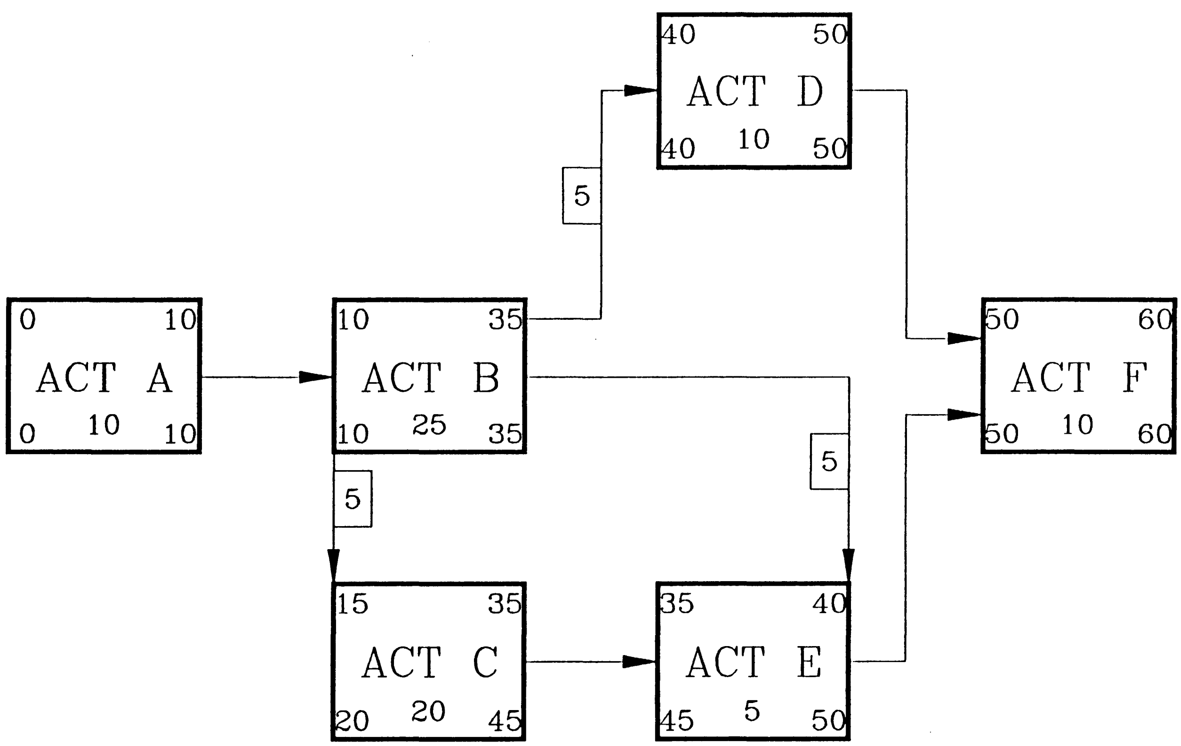
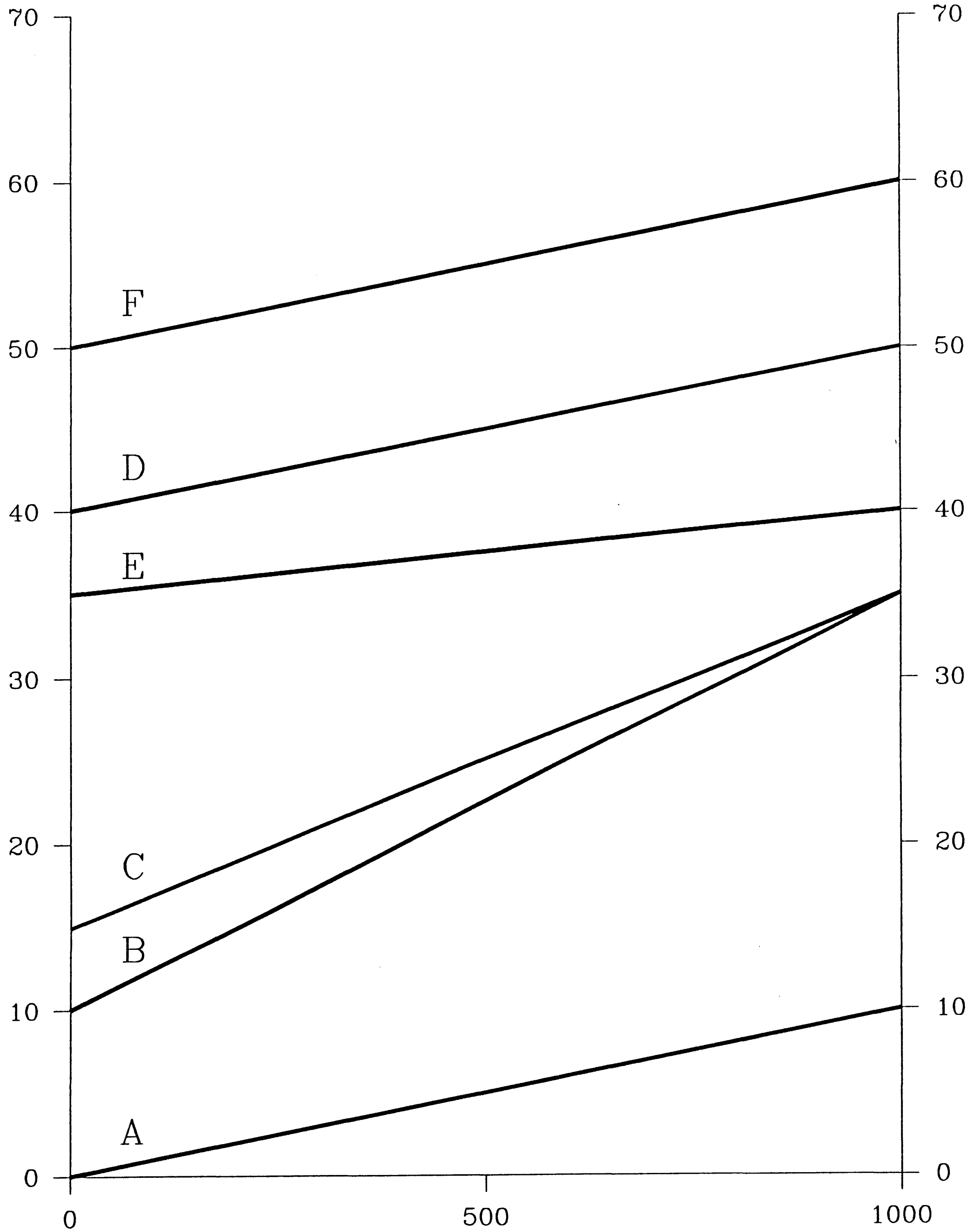

0
10
ACT A
0
10
10
10
35
ACT B
10
25
35
40
50
ACT D
40
10
50
5
5
5
15
35
ACT C
20
20
45
35
40
ACT E
45
5
50
50
60
ACT F
50
10
60

Figure 11



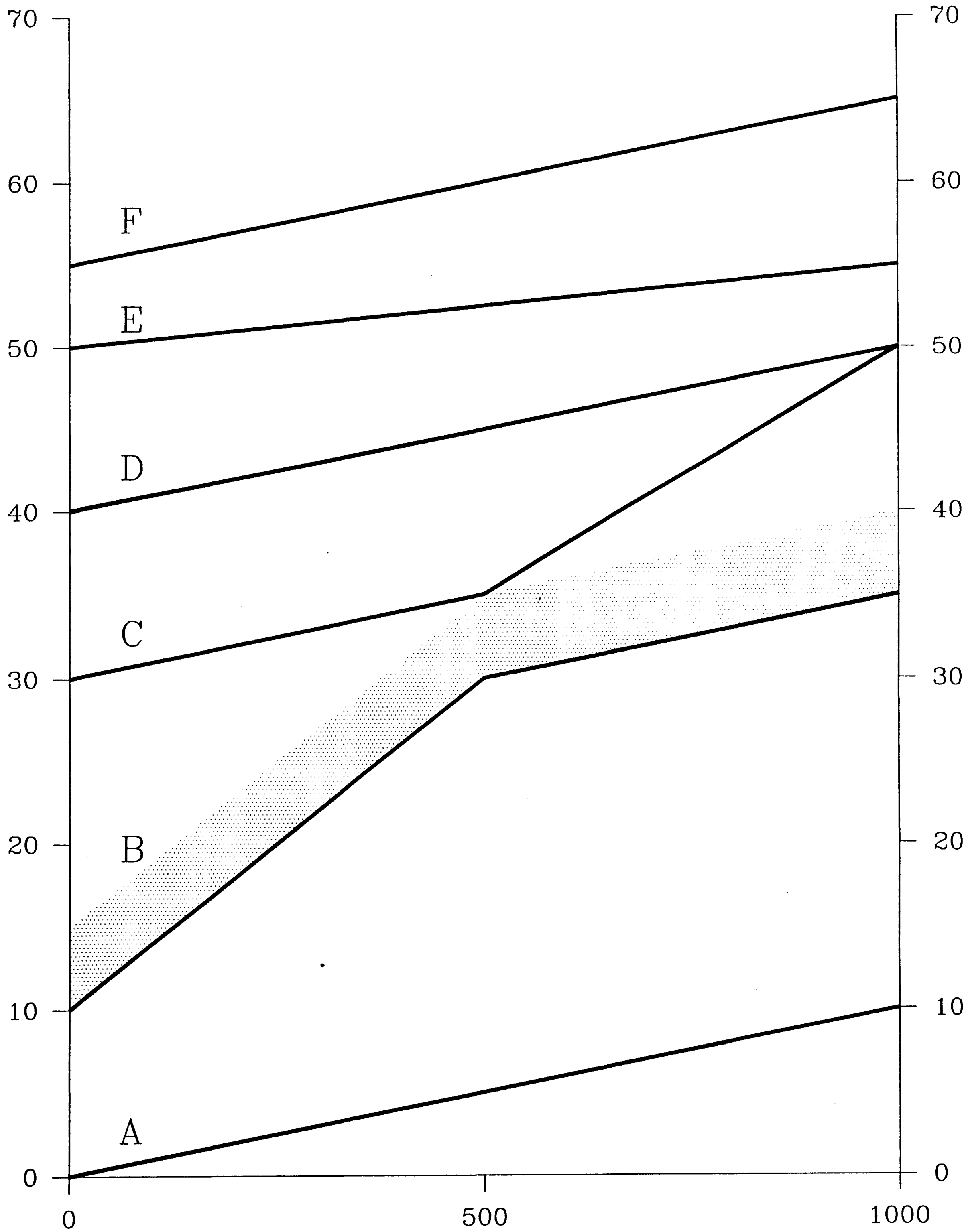
early start and finish dates indicated on the CPM. If we assume that this diagram represents the order in which activities will occur at any given point then the lines should never cross.

The first noticeable conflict between the two schedules involves Activity E. The CPM indicated that activities C and E had 10 days of float. In other words these activities could occur 10 days later than the early dates without affecting subsequent activities. However, the linear schedule indicates that the start of activity E can only be delayed by five days before it will delay the start of activity D. This apparent conflict is not ascertainable from the linear schedule.

The next area of concern involves the simultaneous completion of both activities B and C. It may not be reasonable to assume that the two activities can complete at the same time. For example, the five day lag between the start of activity B and activity C could represent a cure time on a pouring operation. This would mean that activity C cannot occur in less than five days anywhere along the coarse of the project, not just at the start of the activities.

To examine another aspect of the potential conflicts involved between linear activities consider the possibility that the production rates of the activities may not be constant. Figure 12 shows what could happen if the production rates of activities B and C were varied. Assume that activity B progresses at a rate of 25 stations per day for the first 500 stations and at 100 stations per day for the second 500 stations. Assume also that activity C has a production rate of 100 stations per day for the first 500 stations and 33.3 stations per day for the second 500 stations. Notice that the overall durations of the activities do not change from the initial durations of 25 days for activity B and 20 days for activity C. The shaded area above activity B indicates the 5 days of cure discussed previously. Even though the logic has

Figure 12



not changed and the activities were all completed within their allotted durations the project was delayed by five days.

The CPM schedule described earlier is completely acceptable with respect to how the critical path method is currently applied to linear type projects. However, unless the person scheduling the project is very cognizant of the affects of variable production rates, and the consequences of representing logic with relationship other than finish-to-start, the problems described above will only serve to disillusion managers as to the effectiveness of the critical path method on projects with a linear orientation.

Pilot Project

During the 1992 construction season, the authors worked with an inlay project on Interstate 29 to demonstrate the linear scheduling technique to the Construction Office. Figures 13 and 14 show the as-planned and the as-built linear schedules for this project respectively. The as-planned schedule was developed from the CPM schedule that the contractor had developed for the project. Therefore, this schedule represents what a linear representation of a CPM schedule would look like, and not necesssarily what a true linear schedule would look like if it had been only scheduling technique applied to the project. Much of the as-built schedule was developed from the updated linear schedule as well. However, it was possible to obtain fairly accurate daily production data for a group of activities. These activities are represented by the lines that have the varying slopes in the center portion of the chart.

Six activities, pavement removal, grade ready, dirt trim, special backfill, special

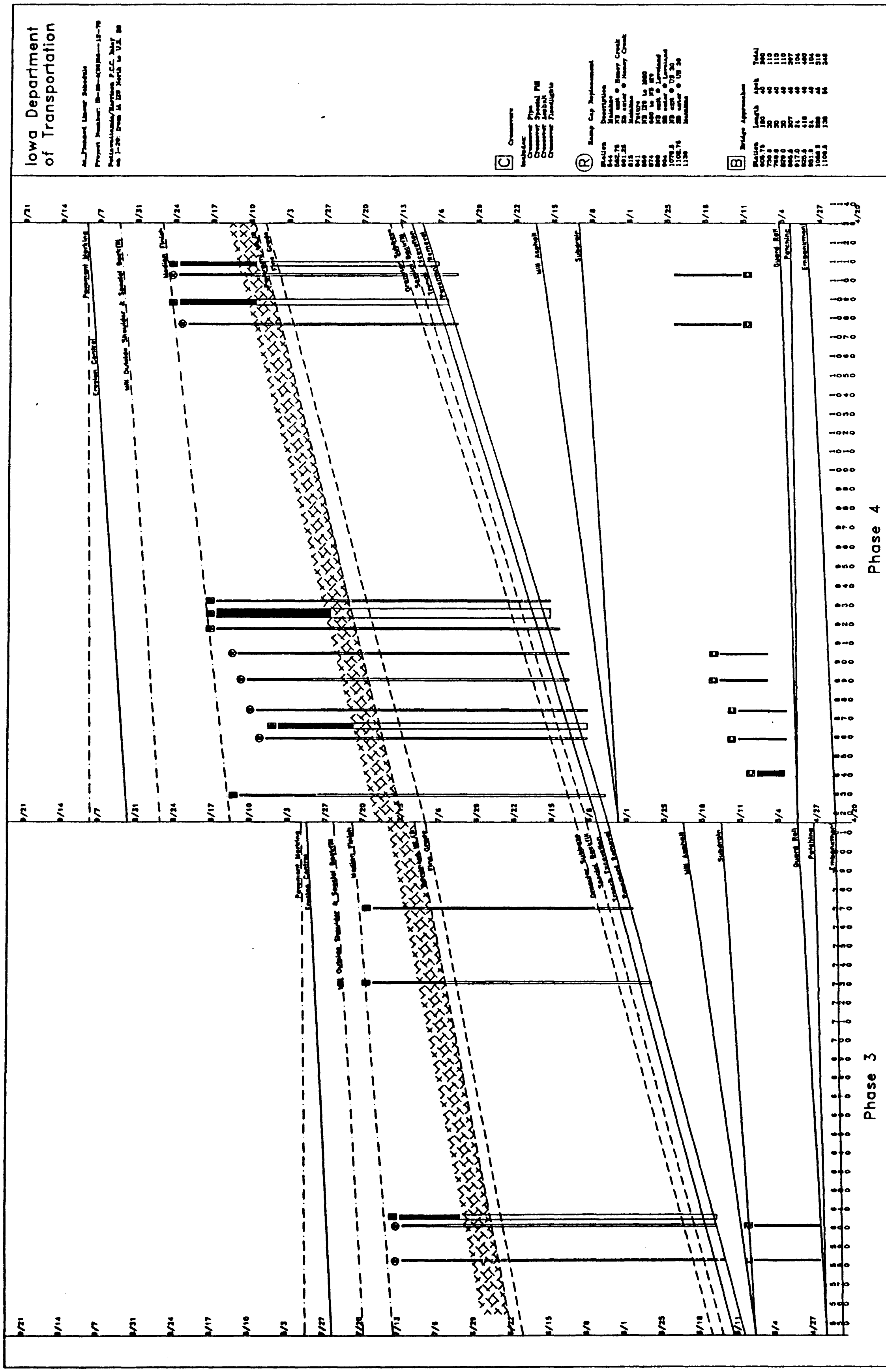


Figure 13

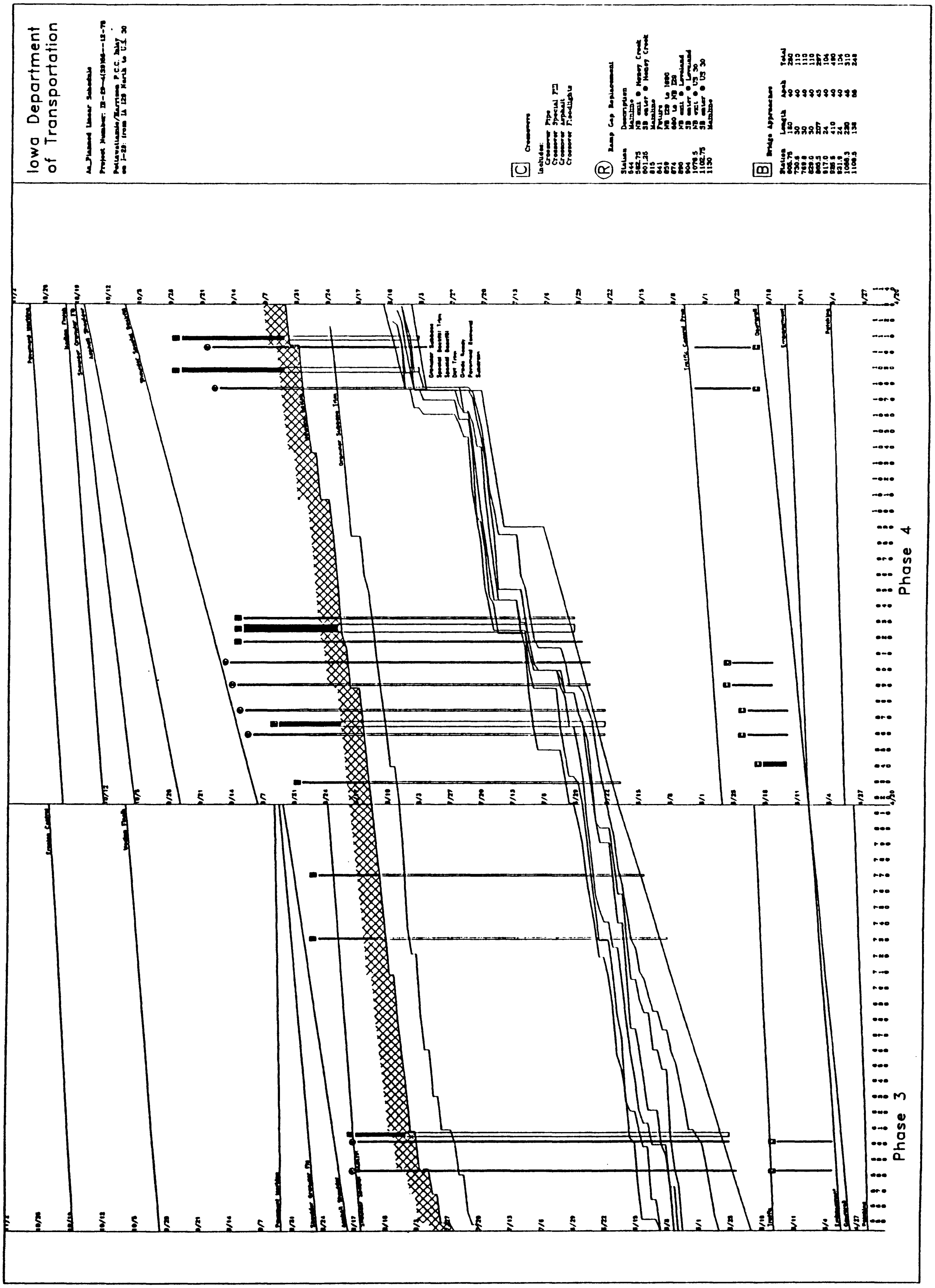


Figure 14

backfill trim, and granular subbase, on the as-built schedule correspond to four activities, pavement removal, trench excavation, special backfill, and granular subbase, on the as-planned schedule. Notice that the durations between the start of activities on the as-built schedule are considerably longer than on the as-planned schedule. These activities also finished much closer together than the two days between each activity as depicted on the as-planned schedule. The as-built schedule graphically depicts the daily production rate of each of the six activities. During periods of time when the lines are all vertical the project was delayed by weather. During these periods time has elapsed but no work has been accomplished, hence the line is vertical. Conversely, the closer the slope of an activity line is to horizontal the higher the production rate for that period.

Conclusions and Recommendations

Conclusions

There is a need to expand the current repertoire of scheduling techniques to address those projects for which the bar chart and CPM may not be appropriate either because of the lack of control information or due to overly complex process for the actual project characteristics.

The scheduling approaches used today on transportation projects have many shortcomings for properly modeling the real world constraints and conditions which are encountered. A large number of projects exist whose characteristics dictate a different approach than the Bar Chart and CPM. An alternative approach, should be developed using the principles of the linear scheduling technique. The most obvious characteristic required is simplicity. The schedule format and medium should easily convey detailed information that is comparable to what may be derived from an equivalent CPM schedule. This system could be an operational planning tool that indicates the pace of work allowing the DOT to see how everything comes together and how the activities relate to each other. The system would provide additional monitoring and control information not available with the CPM or bar chart.

It was evident from the pilot project that the linear scheduling technique provides a visual link between the schedule and the actual work. This visual cue provides the information that makes the application of the critical path method difficult to apply to linear projects. It allows scheduling information to be displayed in a format that is easily understood by all parties involved in the project. Linear project's predilection for activities with variable production rates, a concept very difficult to handle with the critical path method, is easily handled and visualized with the linear technique. Attempting to discern the effects between activities caused by delays or variable production rates of linear activities using the critical path method can be frustrating at best.

Recommendations

It is recommended that work proceed with the refinement of the method of linear scheduling described above and the development of a microcomputer based system for use by the Iowa DOT and contractors for its implementation. The system will be designed to provide the information needed to adjust schedules in a rational way for changes in quantities and scope of the projects. The system will provide a simple, understandable method for monitoring progress on the projects and alerting Iowa DOT personnel when the contractor is deviating from the plan.

The system will be applied to a project and the results documented. A draft linear scheduling specification section will be developed to fit with the previous specification sections for bar charts and CPM. These will be field tested if possible. A guide for application of the various scheduling approaches will be developed. training materials will be developed for the system.

The level of effort required to produce a workable system will be significant. After consultation with Tom Cackler, Chief Construction Engineer,Iowa DOT Construction Office, it has been suggested that our first efforts be focused on the development of the linear scheduling system. This would be needed before a method for multi-project scheduling would be addressed. If time permits, the multi-projects scheduling need will be addressed.

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APPENDIX A
IOWA DEPARTMENT OF TRANSPORTATION
SCHEDULING SPECIFICATION

GENERAL - For each contract awarded the contractor shall submit a progress schedule of the construction activities. The progress schedule shall be used for coordination and monitoring the work of the contractor, the subcontractors, the suppliers, and others with responsibilities under the contract between the Iowa Department of Transportation and the contractor. This schedule shall represent the contractor's plan for organization and execution of the work.
The schedule shall be the basis for evaluation of progress and for evaluation of the time impact of changes to the contract. The method of scheduling will be determined by the Office of Contracts to meet the specific characteristics of the project. The schedule requirements may call for development of one of several types of schedules, bar chart, critical path method, or linear schedule. The requirements for each are provided below.

SUBMITTAL - The successful bidder for a project must furnish 5 copies of an initial schedule to the Contracts Engineer with the signed contract. The schedule will be reviewed for compliance with the intended work. The contracting Authority will notify the Contractor within 10 calendar days after receiving the schedule if the schedule is acceptable to begin work with or if corrections or revisions are required. If corrections or revisions are needed, the contractor shall revise the schedule document and submit 3 copies of the revised schedule to the Project Engineer at least 10 days before the preconstruction conference. The schedule will be reviewed during the preconstruction conference. The Project Engineer will review the schedule to ensure that the schedule represents a reasonable plan to execute the work, is in conformance with the intended work and meets the requirements of a document suitable for monitoring the work and making adjustments to the plan or contract accurately, fairly, and efficiently.
Failure to follow the above procedures may result in suspension of bidder qualifications in accordance with article 1102.03 A of the Standard Specifications.

BAR CHART SCHEDULE SPECIFICATION

REQUIREMENTS FOR A BAR CHART SCHEDULE - The progress schedule submitted shall be a bar chart which accurately and clearly depicts the contractor's plan for completion of the specified work. The bar chart must show all of the discreet controlling items of work. The bar chart shall also show other items of work which could impact the controlling items or become controlling items shall changes or delays occur in the execution of the work. All items of work specified in the contract shall be accounted for in the bar chart schedule. The controlling logic shall be shown graphically or with a written narrative submitted with the bar chart. The production rates for each major controlling item or activity shall also be provided. For each item on the bar chart a narrative description of the scope and content of the item shall be provided.

USE OF THE SCHEDULE - No contract work will be done without an accepted progress schedule. The bar chart schedule shall be used to represent the plan for the project for purposes of monitoring the progress of the contractor, for determining the controlling items of work, and for making time adjustments to the contract based on changes. Unless otherwise stated each bar represents a period of uniform production from the beginning point to the end point for progress monitoring purposes.
During the life of the project, the Contractor shall review the schedule with the Project Engineer bi-weekly unless otherwise specified. The contractor shall submit a revised schedule within 5 working days if it is determined that the project is behind schedule or if the plan has been modified. All of the revised schedules must be reviewed and accepted by the Project Engineer. For each revised schedule the Contractor must submit 3 copies to the project engineer. Payment may be withheld if the contractor deviates from the current accepted plan and fails to provide a current representation of the plan in an acceptable form to the project engineer.

BAR CHART STANDARDS - The bar chart shall be prepared in a neat and clearly legible style to the project engineer. The chart should list the items of work on the left side and have the time scale in appropriate units across the top. A legend describing all symbols and notations used on the chart should be provided. The schedule for the entire project shall not exceed the specified contract period. No individual item shall have a duration longer than 20 work days unless specified in the contract proposal or by the Contracting Authority.

METHOD OF MEASUREMENT AND BASIS OF PAYMENT - The cost of preparing and revising the schedule shall be included in the bid item for mobilization. The current specifications for mobilization shall apply.

CPM SCHEDULE SPECIFICATION

REQUIREMENTS FOR THE C.P.M. PROGRESS SCHEDULE. The C.P.M. progress schedule submitted shall be a network diagram with a numerical tabulation for each activity.

A. Network Diagram. The network diagram shall show a logical sequence and quantities of the required work. The network diagram shall also show the order and interdependence of activities. The Contractor shall prepare the network diagram making use of the crew hour estimates and material delivery schedules so that the project or tied projects are completed within the specified contract period. The Contractor shall take account in the network diagram for any critical closure periods and limitations of operations specified in Article 1108.03, the contract proposal, or the plans.

The basic concept of network scheduling shall be followed to show how the start of a given activity is dependent on completion of preceding activities and how its completion may affect the start of following activities. The network diagram shall include the following:

- Activity description
- activity duration (work days)
- intended production rates
- any activity done by a subcontractor denoted (the subcontractor identified)
- location of activity
- critical path denoted
- event nodes numbered
- all restraints noted
- slack "or float" for each activity (work days)
- work days calendar which extends for the length of the Contract plus 25 percent additional time.
- dummy paths denoted
- start/completion dates

B. Numerical Tabulation. The Contractor shall include a numerical tabulation for each activity shown on the detailed network diagram. The following information shall be furnished as a minimum for each activity on this tabulation:

- event nodes numbered
- activity description
- activity location
- if activity done by subcontractor (identify the subcontractor)
- estimate duration (work days)
- earliest start date (calendar date)
- earliest completion date (calendar date)
- latest start date (calendar date)
- latest completion date (calendar date)
- Contractor's intended start date (calendar date)
- Contractor's intended completion date (calendar date)

slack or float for each activity (work days)
quantities involved on each activity based on Contractor's intended start and completion dates

This numerical tabulation can be either a computer printout or prepared manually. There shall be a column for each of the above requirements.

C. Other Specific Requirements. The construction time, as determined by the C.P.M. progress schedule, for the entire project or any milestones shall not exceed the specific contract period. No individual activity duration shall be longer than 20 work days unless specified in the contract proposal or by the Contracting Authority. A unique activity numbering system shall be used to identify activities by bid items, work items, areas, procurements or subcontractors. If sub-networks are used, no two activities shall bear the same activity number or description.

There shall be a legend with the C.P.M. progress schedule defining only abbreviations, terms, or symbols used.

USE OF C.P.M. PROGRESS SCHEDULE IN CONSTRUCTION OPERATIONS. No contract work will be done without a C.P.M. progress schedule approved by the Engineer. The items in the activities for the denoted critical path will determine the controlling operations of the work for the charging of working days.

During the life of the project, The Contractor shall review the C.P.M. progress schedule with the Engineer bi-weekly unless otherwise specified. The Contractor shall submit a revised C.P.M. progress schedule within 5 working days of the review meeting if the Contractor is behind schedule or if the schedule has been modified. All revised C.P.M. progress schedules must be approved by the Engineer. For each revised C.P.M. progress schedule, the Contractor shall submit 3 copies to the Engineer.

If the Contractor deviates from the current approved C.P.M. progress schedule by doing activities not in the logical sequence of the critical path, payment will be withheld for the pay items for the affected activities until the Contractor submits a revised C.P.M. progress schedule and this schedule is approved by the Engineer.

A revised C.P.M. progress schedule shall be required if the controlling operation falls 10 working days behind schedule, the Engineer then may take steps specified in Article 1108.02G to insure satisfactory completion of the project. If the controlling operations falls 20 working days behind schedule and it appears that the completion of the project in the specified time is in jeopardy, the Contracting Authority may take action described in Article 1102.03B and Article 1103.01 and may take further action described in Article 1108.02G.

METHOD OF MEASUREMENT AND BASIS OF PAYMENT. The cost of preparing and revising the C.P.M. Progress Schedule shall be included in the bid item of Mobilization. The current specification for Mobilization shall apply.

LINEAR SCHEDULING SPECIFICATION

REQUIREMENTS FOR A LINEAR SCHEDULE - The progress schedule submitted shall be a linear schedule which accurately and clearly depicts the contractor's plan for completion of the specified work. The linear schedule must show all of the controlling work items. The bar chart shall also show other items of work which could impact the controlling items or become controlling items should changes or delays occur in the execution of the work. All items of work specified in the contract shall be accounted for in the linear schedule. The controlling logic shall be shown graphically or with a written narrative submitted with the linear schedule. The production rates for each major controlling item or activity shall also be provided. For each item on the linear schedule a narrative description of the scope and content of the item shall be provided.

USE OF THE SCHEDULE - No contract work will be done without an accepted progress schedule. The linear schedule shall be used to represent the plan for the project for purposes of monitoring the progress of the contractor, for determining the controlling items of work, and for making time adjustments to the contract based on changes. Unless otherwise stated each solid line represents continuous production from the beginning location and point in time to the ending location and point in time for progress monitoring purposes.

During the life of the project, the Contractor shall review the schedule with the Project Engineer bi-weekly unless otherwise specified. The contractor shall submit a revised schedule within 5 working days if it is determined that the project is behind schedule or if the plan has been modified. All of the revised schedules must be reviewed and accepted by the Project Engineer. For each revised schedule the Contractor must submit 3 copies to the project engineer. Payment may be withheld if the contractor deviates from the current accepted plan and fails to provide a current representation of the plan in an acceptable form to the project engineer.

LINEAR SCHEDULE STANDARDS - The linear schedule shall be prepared in a neat and clearly legible style to the project engineer. The linear schedule should identify the time units(dates or work days) on the left side and have the location(station number) scale in appropriate units across the bottom. A legend describing all symbols and notations used on the chart should be provided. At a minimum, each activity shall be represented by a diagonal line(the slope of which, represents the rate of progress), a bar, or a block. For typical activities that represent an activity that progresses from one location to another the diagonal line will be used. For activities that occur at one location and consume time, a vertical bar will be used. Blocks will be used to represent activities that consume significant areas of the project for periods of time. The schedule for the entire project shall not exceed the specified contract period. No individual item shall have a duration longer than 20 work days unless specified in the contract proposal or by the Contracting Authority. Notation to differentiate between planned and actual progress shall be clear and noted in the legend.

METHOD OF MEASUREMENT AND BASIS OF PAYMENT - The cost of preparing and revising the schedule shall be included in the bid item for mobilization. The current specifications for mobilization shall apply.

APPENDIX B

A large group of states with similar specifications were found. These specifications typically required the contractor to furnish the Engineer with a "Progress Schedule" (or CPM) showing the order of the work and time required for the completion. This schedule would be used to establish major construction operations (or salient features or controlling items) and to check progress. The states that used language similar to this are:

Alaska-88 (include list of procurement dates for material and equipment),

California-88 (no progress payments before submission of satisfactory schedule),

Georgia-83 (prepared of furnished form or acceptable CPM),

Idaho-90 (on furnished form, indicate multishift work),

Illinois-88 (show intended rate of production for controlling items),

Kansas-90 (when required by Engineer),

Kentucky-91,

Louisiana-82 (supplied bar graph form submitted to Project Control Section),

Maine-90 (include detail schedule of operations involving utilities),

Maryland-82,

Massachusetts-88,

Minnesota-88 (show intended rate of production for controlling items),

Missouri (at request of Engineer),

Nevada-76,

New Hampshire-90 (include erosion control schedule), New Mexico-76

New York-85 (submit outline to Regional Director),

North Carolina-84,

Ohio-91 (approved form, show proposed prosecution of work),

Oregon-84 (emphasize first 30 days, submit comprehensive schedule within 30 days),

Rhode Island-71 (show early and late start, early and late finish, free and total float)

Texas-82,

Utah-79 (show cumulative % of contract at 20, 40, 60, 80, and 100 % of time),

Virginia-91,

Vermont-90,

Wyoming-80.

A number of states were found that had specifications significantly different enough from the previous group to warrant separate treatment. A summary of the specifications, particularly, items that differ from the typical specifications listed above, is presented for each state.

Alabama-89. Submit a bar graph for projects with durations greater that 60 working days. Include start and completion dates for each bar and the overall project. A CPM schedule may be required in the proposal.

Arizona-90. Submit a 2-week schedule to the Engineer at weekly meetings including dates of major phases of the work and status of ongoing activities. Submit a progress schedule at the preconstruction conference including the order of activities, start dates for salient features including materials and equipment, drawings, submittals, inspection of structural steel fabrication, and completion dates.

Colorado-91. The Contractor shall submit a Progress Schedule within 10 days of the date construction is authorized to proceed. The Contractor shall revise the Progress Schedule to show any substantial change within 10 days of the Engineer's written request. Failure to submit a revised schedule will result in withholding progress payments.

The Progress Schedule may be submitted on Contractor furnished forms or on forms supplied by the Division. The Progress Schedules shall consist of a Comprehensive Bar Chart and a Methods Statement, each on a separate report.

(a) The Comprehensive Bar Chart shall show, as a minimum, the following:

1. The salient features, as listed in the special provisions, listed in the order in which the Contractor proposes to carry out the work.

2. Any feature not listed in the special provisions that the Contractor considers a controlling factor for timely completion.

3. The time span of construction activities for each salient feature, and its relationship in time to other salient features.

4. The total anticipated time necessary to complete all work required under the Contract.

5. Sufficient space for each salient feature to permit additional plots parallel to the original time span, one for a revision of the planned time span, and one showing time spans achieved.

(b) The Methods Statement shall be a narrative description of the activities displayed in the Comprehensive Bar Chart. It shall contain details as follows:

1. A description of the activities within each salient feature including methods to be employed.

2. A description of activities within each salient feature, related to the location of or off of the project where these activities will occur.

3. An estimate of the time during which a salient feature is inactive or partially inactive. This estimate shall show the beginning and ending dates of the reduced production or inactivity.

4. The anticipated delivery dates for equipment or materials in any salient feature that can affect timely completion of the project.

5. Critical completion dates for any activity within and salient feature to maintain the progress indicated in the Progress Schedule.

All information on the Methods Statement is proprietary and will be kept confidential....

Delaware-85. The Contractor, prior to the "notice to proceed", will be required to submit for the Engineer's approval his/her proposed work schedule in detail, including proposed dates for ordering and receiving construction materials and similar items which control the items of work....

In all cases, upon submission of a revised work schedule, the contractor shall be required to state in writing the reason(s) for the changes. Any documentation in support thereof must also be submitted.

The accumulative number of working days shall be reviewed, verified, and signed by the contractor's representative, and the Engineer's inspector, at the end of each two week period; the accumulative working days also will be shown on the contractor's estimates for partial and final payments....

The contractor shall be required to submit to the Engineer, on each Friday, a "Proposed Activity Schedule" for the following two week period. This activity schedule shall not be a duplication of the information shown of the "proposed work schedule" but rather shall provide specific details related to actual construction activities the contractor plans to have in progress during the reporting period....

Florida-91. ....Each activity shall show a beginning work date, a duration, and a monetary value. Activities will include procurement time for materials, plant and equipment and review time of shop drawings where they are appropriate and essential to the timely completion of the project. The list of activities will include milestones when required by the plans or special provisions. In a project with more than one phase, each phase and its completions date will be adequately identified and no activity will span more than one phase....

The schedule shall be accompanied by a working plan, which is a concise written description of the Contractor's construction plan....

The Contractor shall submit an updated Work Progress Schedule only when requested by the Engineer...

Failure to finalize either the initial or a revised schedule in the time specified will result in withholding of all contract payments until the schedule is approved.

Hawaii-85. For contracts less than One Million Dollars or calling for contract time of less than one hundred working days, the contractor shall submit....a progress schedule similar in format to the sample furnished by the Department for the Engineer's approval.. ...He shall also show the relationship of working days to total earnings by graphical representation....

For contracts which have both a contract amount of One Million Dollars or more and call for contract time of one hundred working days or more, The Contractor shall submit....a progress schedule for the Engineer's approval. The progress schedule shall be prepared on the basis of the critical path method of scheduling acceptable to the Engineer. ...The progress schedule shall also include a graphical representation of the relationship of working days to total earnings.

Mississippi-90. The Department will furnish the schedule or the Contractor may submit his own proposed schedule on the same form. The bar graph shall indicate controlling phases of the work with start and finish times for each phase. One phase begins no later than the beginning contract date and one phase will be shown in progress until work is scheduled to be completed.

New Jersey-83. *(c) Intent, Responsibility and Time.* Scheduling of the construction is the responsibility of the Contractor. Therefore, it shall be the Contractor's responsibility to determine the most feasible order of work commensurate with the Contractor's abilities and the Contract Document. The requirement for the progress agrees that it is responsible in all respects or that the progress schedule, if followed, will result in timely completion of the Project. The parties agree that the progress schedule is not part of the Contract. ...

(e) Types of Progress Schedules. All progress schedules are to comply with the foregoing provisions of this Subsection. The progress schedule shall be one of the following types depending on whether the Contract requires the progress schedule as a Contract Item or not.

(1) Progress Schedule When the Item "Progress Schedule" is a Pay Item. The progress schedule shall be prepared by the Critical Path Method (CPM), Project Evaluation and Review Technique (PERT), or a comparable network system conforming with the requirements hereinafter prescribed. ...

The network shall include, as a minimum, one activity for each discrete component part of each Pay Item scheduled in the Proposal. The Engineer may allow for grouping of similar Pay Items. The system shall consist of network diagrams and accompanying mathematical tabulations as described hereinafter.

Diagrams shall show the order and interdependence of activities and the sequence and quantities in which the work is to be accomplished as planned by the Contractor. The basic concept of network scheduling shall be followed to show how the start of a given activity is dependent on the completion of preceding activities and how its completion may affect the start of following activities. The critical path shall be distinguished from other paths on the network. The network shall include the following:

(i) activity description

(ii) activity duration (work days)

(iii) critical path denoted

(iv) event nodes numbered

(v) all restraints noted

(vi) slack or float for each activity

(vii) work days calendar which extends for the length of the Contract plus 25 percent additional time.

In additional to construction activities, network activities shall include the following: (1) the submittal and approval of samples of materials and shop drawings, and (2) fabrication of special materials. All activities of the Department that affect progress and any special Contract required dates shall be shown.

The mathematical tabulation of the network diagram shall include a tabulation of each activity shown on the detailed network diagram. The following information shall be furnished as a minimum for each activity on this tabulation.

(i) event nodes numbered

(ii) activity description

(iii) estimate duration

(iv) earliest start date (calendar date)

(v) earliest finish date (calendar date)

(vi) latest start date (calendar date)

(vii) latest finish date (calendar date)

(viii) Contractor's intended start date

(ix) Contractor's intended completion date

(x) slack or float for each activity

(xi) quantities involved on each activity based on Contractor's intended start and completion dates

(xii) percentages of activity completed

(xiii) critical path activities denoted

This mathematical tabulation can be either a computer printout if a computer is utilized in computations, or one manually prepared by the Contractor, with a column for each of the above requirements. The Contractor shall update the mathematical tabulation on a two month basis and shall provide the Engineer with updated copies of the computer printout or manual tabulation, whichever is utilized. The updated tabulations shall reflect the current status of activities as outlined on the network diagram. If any delays have occurred, these shall be noted for time consideration, the updated tabulation sheet shall reflect all changes in dates, durations, and float time.

Conditions may develop which require network logic revisions to the original diagram. If during the progress of the work, major changes develop which necessitate changes in the original plan, the Contractor shall make such changes so as to depict the current mode of operation and shall provide the Engineer with a revised network diagram.

The accepted progress schedule will be paid for at the lump sum price bid for the schedule completed as specified including all necessary updating. Twenty-five of the lump sum bid will be payable upon approval of the initial submission with the balance paid upon approval of updates at a prorated sum based upon the number of anticipated updates to be submitted during the Contract Time. Payment will be made under:

Pay Item	Pay Unit
Progress Schedule	Lump Sum

(2) Progress Schedule When the "Progress Schedule" is Not a Pay Item. This type of progress schedule shall be submitted to the Engineer within 15 days after execution of the Contract by the Commissioner. The progress schedule shall be in the form approved by the Engineer and may be of the bar chart or similar type. The schedule shall be in a suitable scale as to indicate the percentage of work scheduled for completion at any time. The Contractor shall update the progress schedule when Project conditions have changes such to invalidate the current schedule.

Oklahoma-88. The Contractor's progress schedule prepared pursuant to this Subsection shall employ a network analysis system as described below when specified on the Plans or in the Contract. Implementing this system for the planning and scheduling of construction shall be the responsibility of the Contractor. As a minimum, the network analysis system shall be prepared in accordance with the Critical Path Method (CPM) as presented in the Associated General Contractor's Manual "Use of CPM in Construction." Scheduling methods, other than CPM, will not be acceptable.

The system shall consist of arrow diagrams, computer mathematical analysis, calendar, and narration.

The arrow diagram shall show the order and interdependence of activities and the sequence in which the work is to be accomplished as planned by the Contractor in accordance with all Subcontractors and other prime Contractors. The basic concept of the arrow diagram shall be followed to show how the start of a given activity is dependent on the completion of preceding activities and its completion restricts the start of following activities.

The detailed network activities shall include, in addition to construction activities, the submittal, approval of materials and shop drawings, procurement, installation and testing of materials and equipment that are on the critical path. The system shall show early completion of certain portions of the project as specified herein.

No activity duration shall be longer than 20 workdays without the Department's approval. The Department reserves the right to limit the number of activities on the schedule to between 50-500 activities. Detailed networks shall show a continuous low from left to right and be drafted on paper 24 inches in width and 36 inched in length. The drafted network diagram alphanumeric characters (numbers and letters) shall be large enough to be easily read. The network diagram arrangement shall allow sufficient room between diagram paths for "red line" modification of existing activity and/or diagram arrangement. The following information shall be shown on diagrams for each activity: Preceding and following event number, description of the activity, and activity duration in work days. The critical path shall be highlighted in order to be distinguished from the other diagram paths.

The initial and monthly update program or means in making the mathematical computation used in making the sort or schedule shall be capable of compiling all completed and partially completed activities. The program shall be capable of accepting revised completion dates as modified by approved time adjustments and recomputations of all tabulation dates and total float accordingly.

The program shall list the activities in sorts of schedules as follows:

(1) I.J. or node sort, by the preceding event number lowest to highest and then in order of the succeeding event number.

(2) Total float sort, by the amount of total float then in order of preceding event number.

The mathematical analysis of the network diagram shall be updated monthly unless waived by the Resident Engineer in writing.....

Not later than the fifth day of each month of the project, the Contractor will submit four copies of an updated I node-J node and Total Float Computer sort illustrating verified progress. Included shall be a written narrative describing the critical path and logic revisions or modifications to the schedule, including, but not limited to, changes in the method or manner of the work, changes in specifications, extra work, changes in duration, etc. No logic revisions or modifications shall be made without prior approval of the

Department. Failure to submit the required monthly network analysis system updates will cause the Department to withhold the monthly progressive pay estimate until such time as the update is received by the Department.

The Contractor will further submit two copies of revised activity on arrow diagrams for the following: delay in completion of any critical activity; actual prosecution of the work which is, as determined by the Department, significantly different than that represented on the schedule; the addition, deletion, or revision of activities required by Contract modification; or any logic revisions or calendar revisions. The Contract completion time will be adjusted only for causes specified in this Contract.

As determined by CPM analysis, only delays in activities which affect milestone dates, critical path, or Contract completion dates will be considered for a time extension under Subsection 108.07..

...It is understood by the Department that the Contractor float is a shared commodity.

Pennsylvania-90. The Department will furnish a form designated "Distribution of Contract Time." This form will show:

the total contract time allowed for the completion of all work on the project;

a list of the various operations to be performed on the project; and

a schedule of time estimates during which the Department suggests each operation can be performed.

At the preconstruction meeting, present for approval by the Chief Engineer, Highway Administration, a detailed construction schedule showing completion of all work at or before the time allowed by the contract. Show all sequencing and all other aspects of how work on the project will be scheduled and performed. Information may be submitted on available Department Forms....

Washington-91. ... The Contractor shall submit a progress schedule (total working days) to the Engineer ... This schedule and any supplemental schedule shall show: (1) completion of all work within the specified contract time, (2) the proposed order of the work, and (3) projected starting and completion times for major phases of the work and for the total project. The schedule shall be developed by a critical path method....

The Contracting Agency allocates its resources to a contract based on the total time allowed in the contract. The Contracting Agency will accept a progress schedule indicating an early completion but cannot guarantee the Contracting Agency's resources will be available to meet the accelerated schedule. No additional compensation will be allowed if the Contractor is not able to meet the accelerated schedule due to the unavailability of Contracting Agency's resources of for other reasons beyond the Contracting Agency's control....

West Virginia-86 ...The Contractor shall furnish a schedule showing how he proposes to prosecute the work to complete the project by the date set for completion. The schedule shall be either a bar-graph type conforming to the requirements of 108.3.2 or a network schedule conforming to the requirements of 108.3.3. Progress schedules will