J. E. Rowings, D. J. Harmelink

Final Report Part II

A Multi-Project Scheduling Procedure for Transportation Projects

March 1994

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 (IDOT) has been requiring Critical Path Method (CPM) schedules on some larger or more schedule sensitive projects. The Office of Construction's expectations for enhanced project control and improved communication of project objectives have not been fully met by the use of CPM. Recognizing that the current procedures might not be adequate for all projects, IDOT sponsored a research project to explore the state-of-the-art in transportation scheduling and identify opportunities for improvement. The first phase of this project identified a technique known as the Linear Scheduling Method (LSM) as an alternative to CPM on certain highway construction projects. LSM graphically displays the construction process with respect to the location and the time in which each activity occurs. The current phase of this project was implemented to allow the research team the opportunity to evaluate LSM on all small group of diverse projects. Unlike the first phase of the project, the research team was closely involved in the project from early in the planning phase throughout the completion of the projects.

The research strongly suggests that the linear scheduling technique has great potential as a project management tool for both contractors and IDOT personnel. However, before this technique can become a viable weapon in the project management arsenal, a software application needs to be developed. This application should bring to linear scheduling a degree of functionality as rich and as comprehensive as that found in micro computer based CPM software on the market today. The research team recommends that the IDOT extend this research effort to include the development of a linear scheduling application.

Introduction

The Iowa Department of Transportation (IDOT) has been requiring Critical Path Method (CPM) schedules on some larger or more schedule sensitive projects. The Office of Construction's expectations for enhanced project control and improved communication of project objectives have not been fully met by the use of CPM. Recognizing that the current procedures might not be adequate for all projects, IDOT sponsored a research project to explore the state-of-the-art in transportation scheduling and identify opportunities for improvement. This report covers the second phase of this research effort.

Background

The first phase of this project identified a technique known as the Linear Scheduling Method (LSM) as an alternative to CPM on certain highway construction projects. LSM graphically displays the construction process with respect to the location and the time in which each activity occurs. The finding of the first phase of the project are reported in HR-339, "A Multi-Project Scheduling Procedure for Transportation Projects", Final Report, April 1993.

In the initial phase of the project, the linear scheduling technique was applied to a highway construction project that was currently in progress. As-planned and as-built data was obtained for some of the major activities and a prototype linear schedule was developed. The results of this effort indicated that the LSM technique merited further investigation.

The current phase of this project was implemented to allow the research team the opportunity to evaluate LSM on all small group of diverse projects. Unlike the first phase of the project, the research team was closely involved in the project from early in the planning phase throughout the completion of the projects. Three projects were ultimately selected. LSM as-planned and as-built schedules and CPM schedules were created for all three projects.

Objectives

The objective of this phase of the research was to identify a group of highway construction projects to which the linear scheduling method (LSM) described in the report for the first phase of this project could be applied. It was anticipated, that by applying LSM to several projects from early in the planning phase through the construction of the project that the technique could be refined to meet the needs of the users in the following ways:

1. The benefits LSM may present for Iowa Department of Transportation (IDOT) personnel in the areas of understanding the contractors "plan of attack" and also being able to monitor actual work progress would be identified.
2. A determination of how construction managers would use LSM to manage their projects would be made. The necessary information, and form of the information, required by managers to function effectively would be identified.
3. A consistent set of symbols to describe the various types of activities involved in a typical highway construction project would be developed.
4. A comparison of how CPM is used by Contractors and IDOT currently with how LSM may be used would be made.

The Plan

The IDOT construction department was responsible for identifying a group of projects on which the linear scheduling technique could be used. The contractors involved with these projects did so on a voluntary basis, and were still responsible for meeting any schedule requirements in their contracts. The research team worked with the contractors to refine their initial Critical Path Method (CPM) schedules and then developed linear schedules to visually tie the initial plan to the project site. These schedules were updated regularly and presented at job site progress meetings whenever possible. Through this process of providing and maintaining linear schedules for actual projects in progress it was expected that situations would arise in which the use of linear schedules could be compared with how CPM schedules are used. Another expected outcome of the field application was that a consistent format and set of symbols could be developed that would aid a user's ability to recognize and understand the linear schedule symbology.

The Projects

This phase of the research involved developing linear schedules for a group of selected highway construction projects. Initial linear schedules were developed for three projects. Progress schedules were also developed as the work progressed and presented weekly at project meetings throughout the summer. The three projects involved in the research effort were:

Project I

Project No:	IM-80-7(59)247--13-52
County:	Johnson/Cedar
Type:	P.C.C. Inlay
Location:	On I-80: From west of the Iowa 965 interchange, easterly to 2 miles west of County Road X-40 interchange in Cedar County.
Miles:	17.607
Start Date:	04/01/93
Working Days:	210
Closure Days:	185
Schedule:	CPM required
Contractor:	Fred Carlson Co., Inc.

Project II

Project No:	HES-92-5(27)--26-91
County:	Warren
Type:	Grade and P.C.C. Pave
Location:	On Iowa 92 from the end of the existing four lane east of the junction of U.S. 65 / U.S. 69 in the city of Indianola, easterly approximately 1.8 miles.
Miles:	1.813
Start Date:	04/01/93

Working Days: 65

Schedule: None required

Contractor: Cedar Valley Corp.

Project III

Project No: NHS-28-2(9)--19-77

County: Polk

Type: Grade, Drainage and P.C.C. Paving

Location: On Iowa 28 (63rd Street) from Park Avenue, North to Grand Avenue in the cities of Des Moines and West Des Moines.

Miles: 1.85

Start Date: 05/03/93

Working Days: 160

Schedule: CPM required

Contractor: M. Peterson Construction Co.

The Baseline Schedules

The research team worked with the contractors to refine their plan to include all of the linear activities that could be tracked on a linear schedule. A linear activity could be thought of as an activity that progresses along a path, from one location to another, and at any position along that path the activity is complete. For example, consider the activity concrete removal, at any point along the road bed, if the concrete has been removed the activity is complete since this activity will not occur in this location again. Several other types of activities can also be described with linear schedules. For a review of the various symbols used in linear scheduling, see Appendix A. Appendix A is an excerpt from the first phase of this project (HR-339, "A Multi-Project Scheduling Procedure for Transportation Projects").

Once the CPM schedules were developed, linear schedules were prepared using appropriate data from the CPM schedule. Information that could be used from the CPM schedules included activity descriptions and start and end dates. In order to prepare the linear schedule however, another dimension of information needed to be added to the data from the CPM schedule, the physical locations in which the activities were to occur. An activity on the linear schedule required, at a minimum, a start date and starting location plus an end date and an ending location.

Project I

Figures 1, 1A, and 1B, show the baseline linear schedule for Project I. For reference, a portion of the timescaled logic diagram developed from the CPM schedule can be seen in Figure 2. This project consisted of 10 miles of inlay on I-80 in Johnson and Cedar counties. The schedule only shows activities during the head-to-head traffic period of the project. The schedule in Figure 2 is not the original plan, but is a revised plan after a crossover was added that would allow work to proceed in an area that otherwise would have not have been available. The original plan called for the west section of the eastbound lanes to be closed first. This can be seen on the linear schedule as the area from station 1106 to 1355. Station 1106 is the west end of the project. As the breaking operation finished in the western section

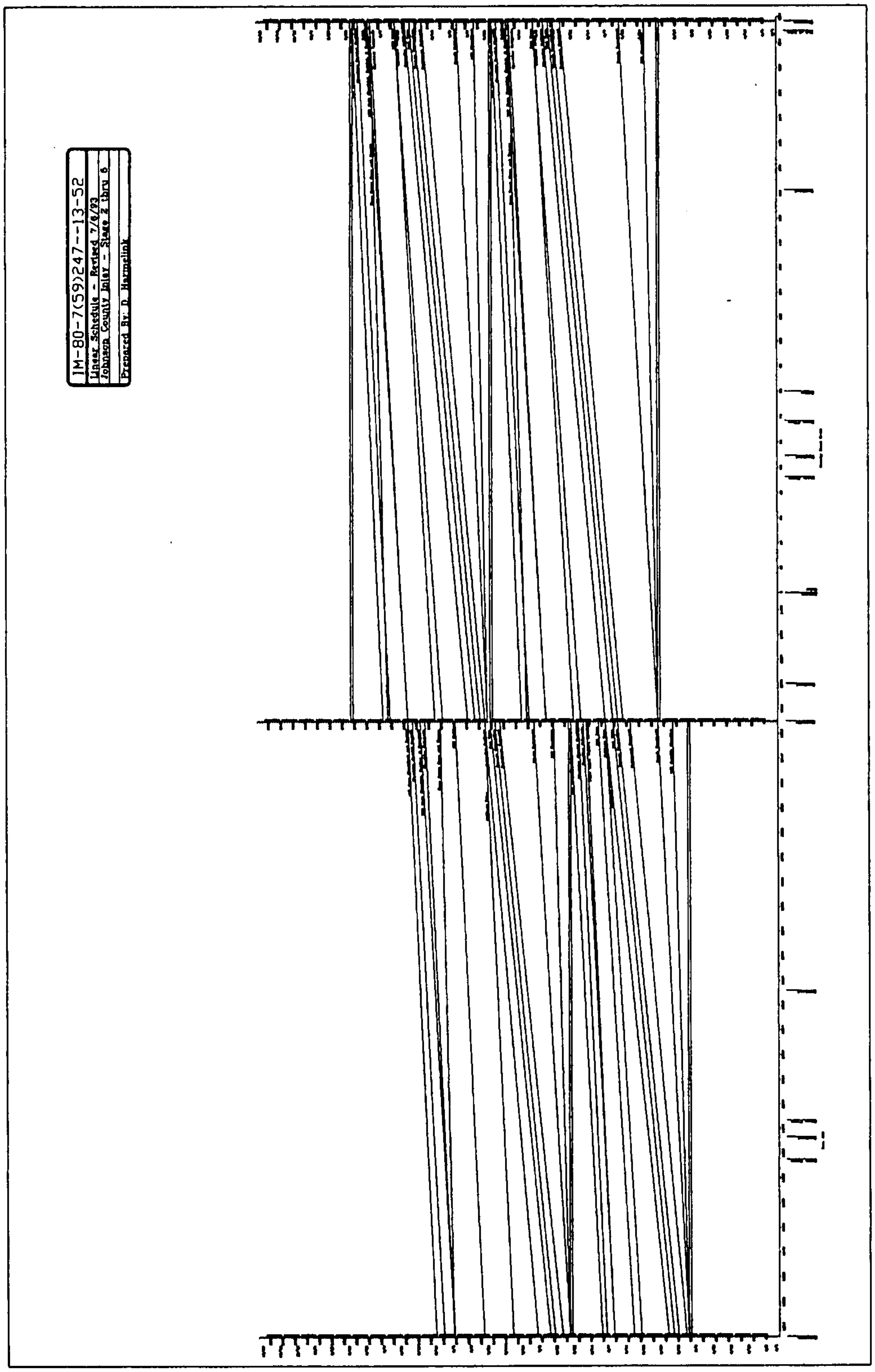

Figure 1 - Project I Linear Schedule

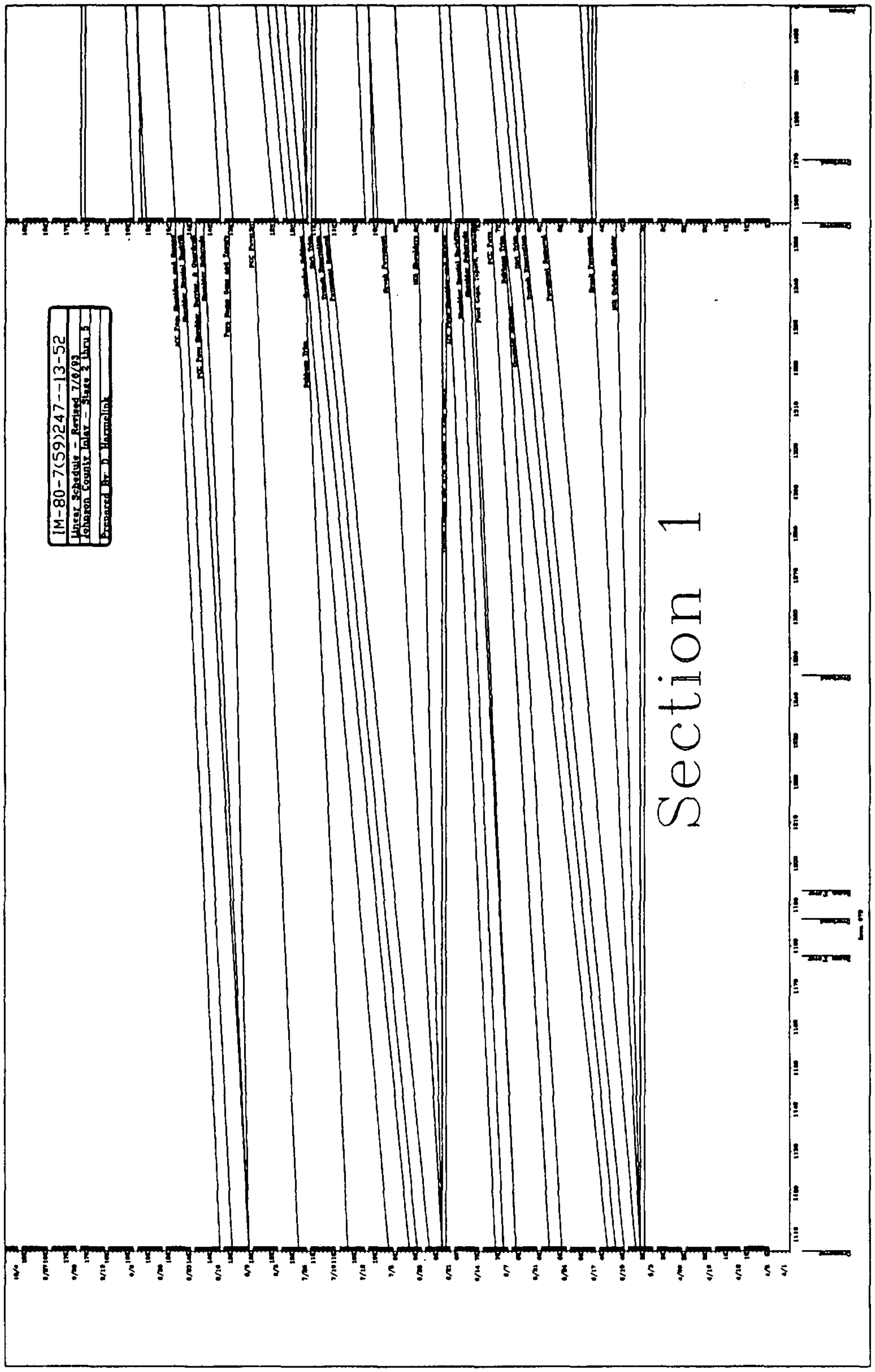

Figure 1A - Project I, Section 1, Linear Schedule

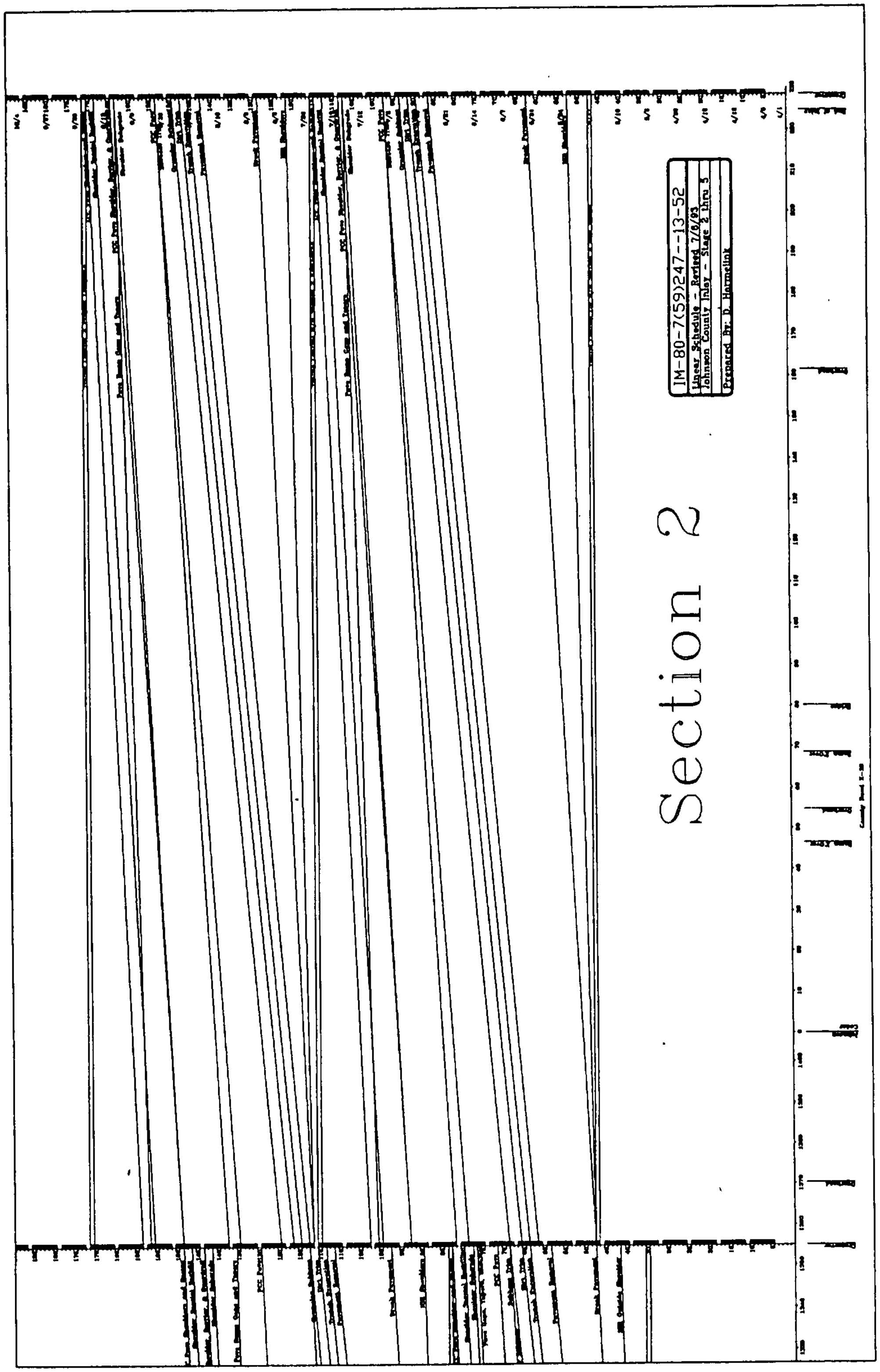

Figure 1B - Project I, Section 2, Linear Schedule

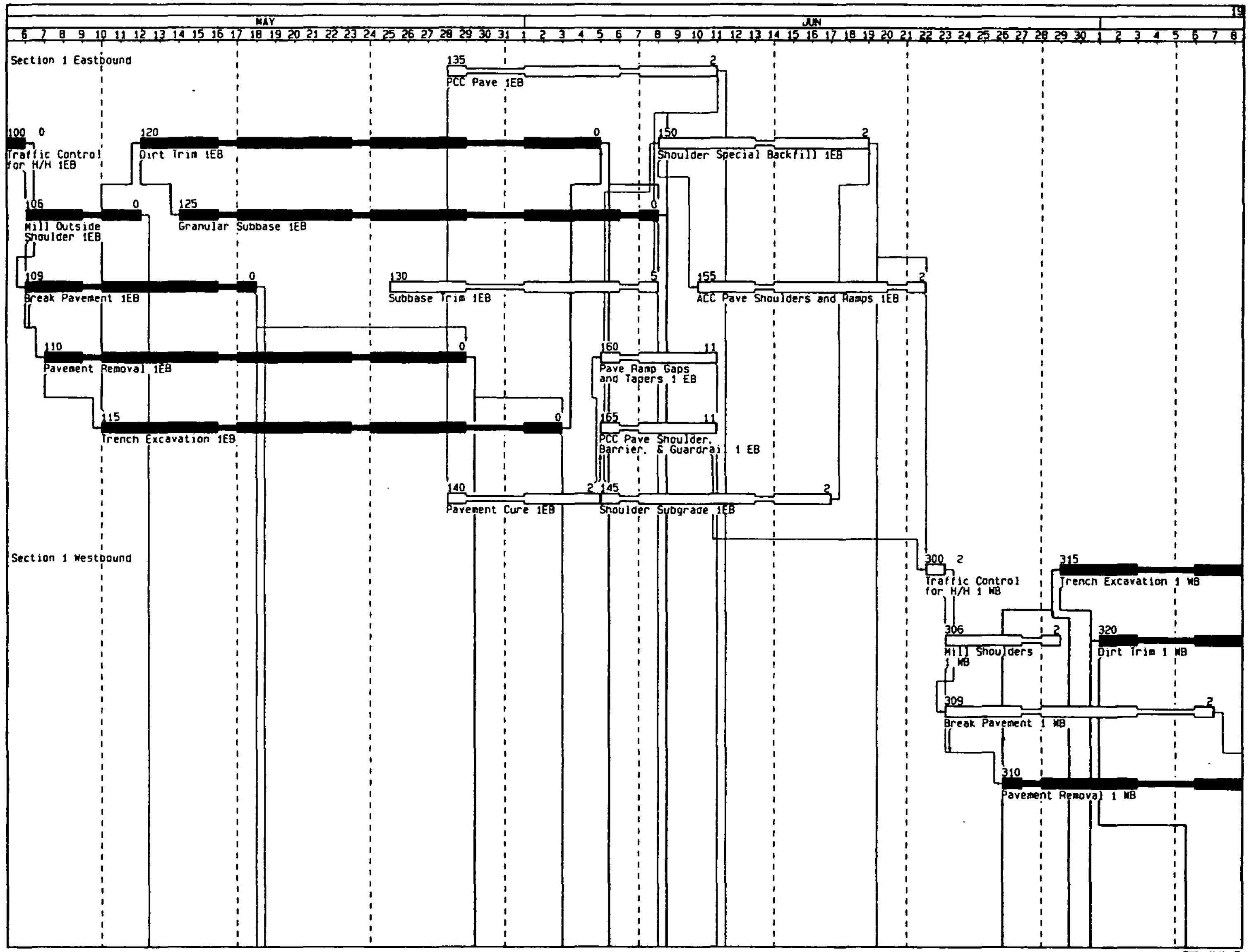

Figure 2 - Project I Partial Time Scaled Logic Diagram

and was ready to proceed into the eastern section of the eastbound lanes this area was closed to traffic as well. At this point the entire project was head-to-head on the westbound lanes.

The original plan called for the eastbound lanes to be completed and opened for traffic before the westbound lanes could be started. This schedule shows that west end of the westbound section was started before the eastbound lanes were to be completed. This change was accomplished by the addition of another crossover directly to the east of the existing crossover at station 1355. This extra crossover allowed for the head-to-head lanes on the westbound side to both be moved over to the eastbound lanes one lane at a time using the two adjacent crossovers.

When the east section of the eastbound lanes were completed they could then be opened to traffic and work could progress into the east section of the westbound lanes, the last section of the project to be completed.

Project II

Figure 3 depicts the baseline linear schedule for Project II, the grade and pave of Iowa 92 near Indianola. Although a CPM schedule was not required for this project the contractor prepared one. After this schedule was refined and reviewed by both the contractor and the research team, the linear schedule was developed. For reference, a portion of the timescaled logic diagram developed from the CPM schedule can be seen in Figure 4. The CPM was organized around the earthwork balances on the project. The heavy lines indicate the critical activities and the horizontal dashed lines represent the relationships that connect the activities on the critical path. The schedule in Figure 3 has activities represented with symbols other

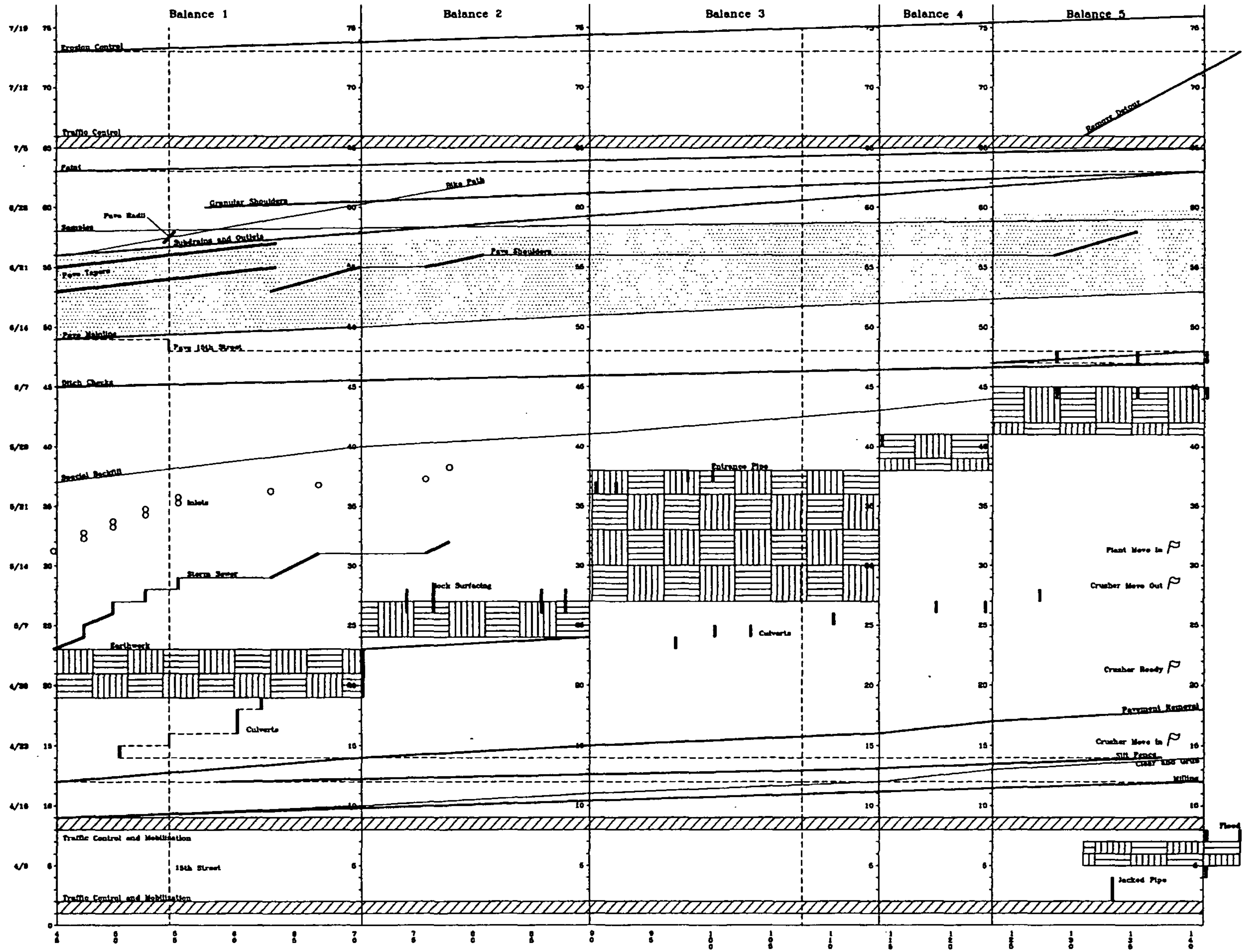

Figure 3 - Project II Linear Schedule

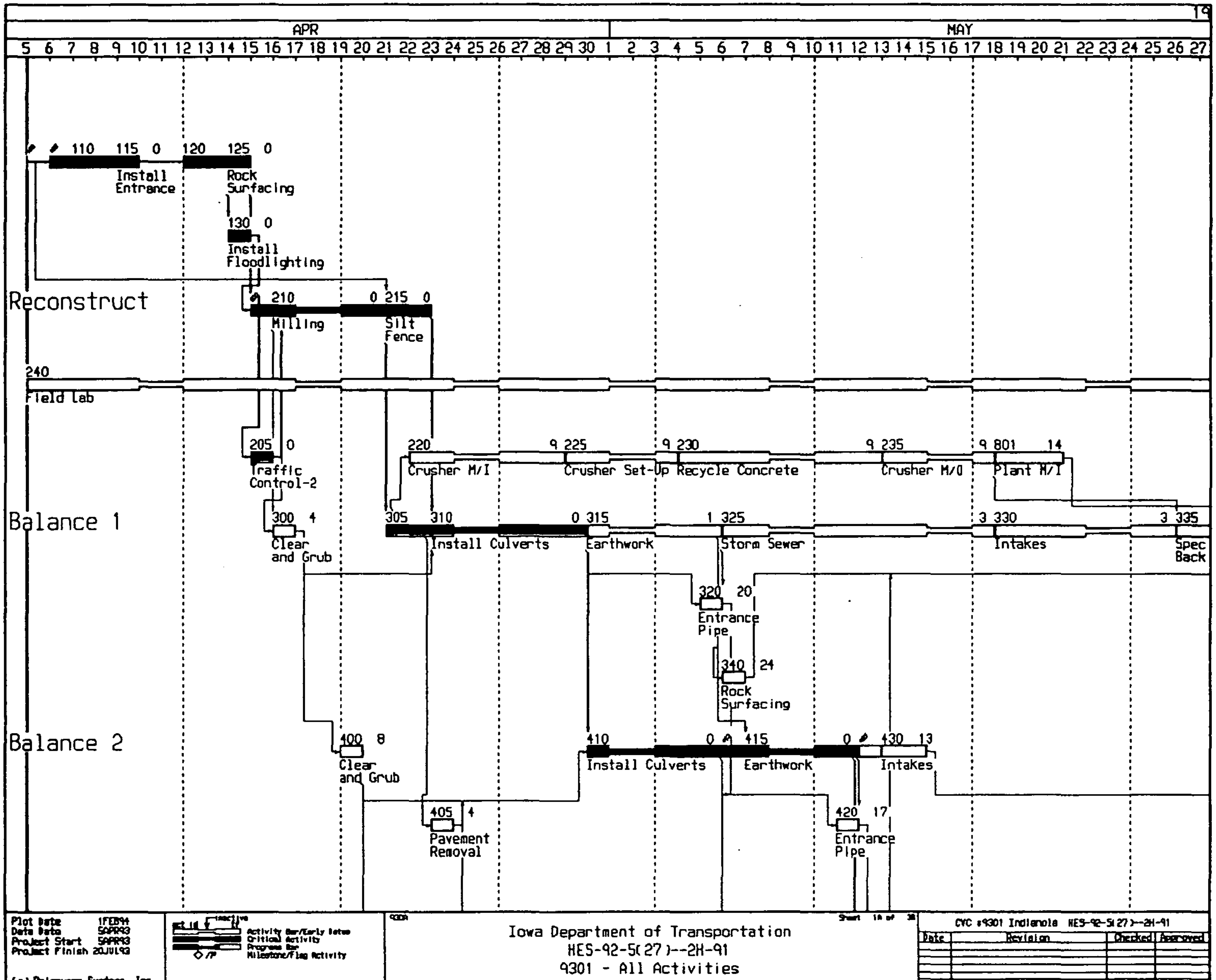

Figure 4 - Project II Partial Time Scaled Logic Diagram

than lines. The earthwork activities are shown as blocks, culverts and entrance pipes are shown as bars, and symbols are used to represent inlets and activities such as crusher and plant move-in.

The time scale used on Figure 3 only shows planned working days. The work plan was based on five work-day weeks, therefore, the schedule only includes five days out of each week. The data and day scales are aligned with the tick marks. This means that the end of the day falls on the tick mark. The calendar dates are Fridays, the last planned work day of the week. This method of showing dates did not prove to be very useful and was not used on any other schedules. The preferred method will be discussed later.

Project III

Project III is the grade and pave of 63rd Street on the boarder between Des Moines and West Des Moines. The initial linear schedule developed for the first stage of this project can be seen in Figure 5, and a corresponding portion of the CPM schedule is included in Figure 6. The linear schedule was developed somewhat independently of the CPM. After the CPM schedule was developed, more information was obtained from the contractors involved in the project to produce the linear schedule. The linear schedule shows the project divided into portions that correspond to natural features of the project. For example, the bridge at stations 50 to 55 provided a barrier to a number of operations. The CPM schedule fro this project, shown in Figure 6, does not subdivide the activities in this stage of the work.

Along the bottom of the linear schedule a simplified diagram of the project plan was included in order to provide a reference to identifiable landmarks on the project. Besides

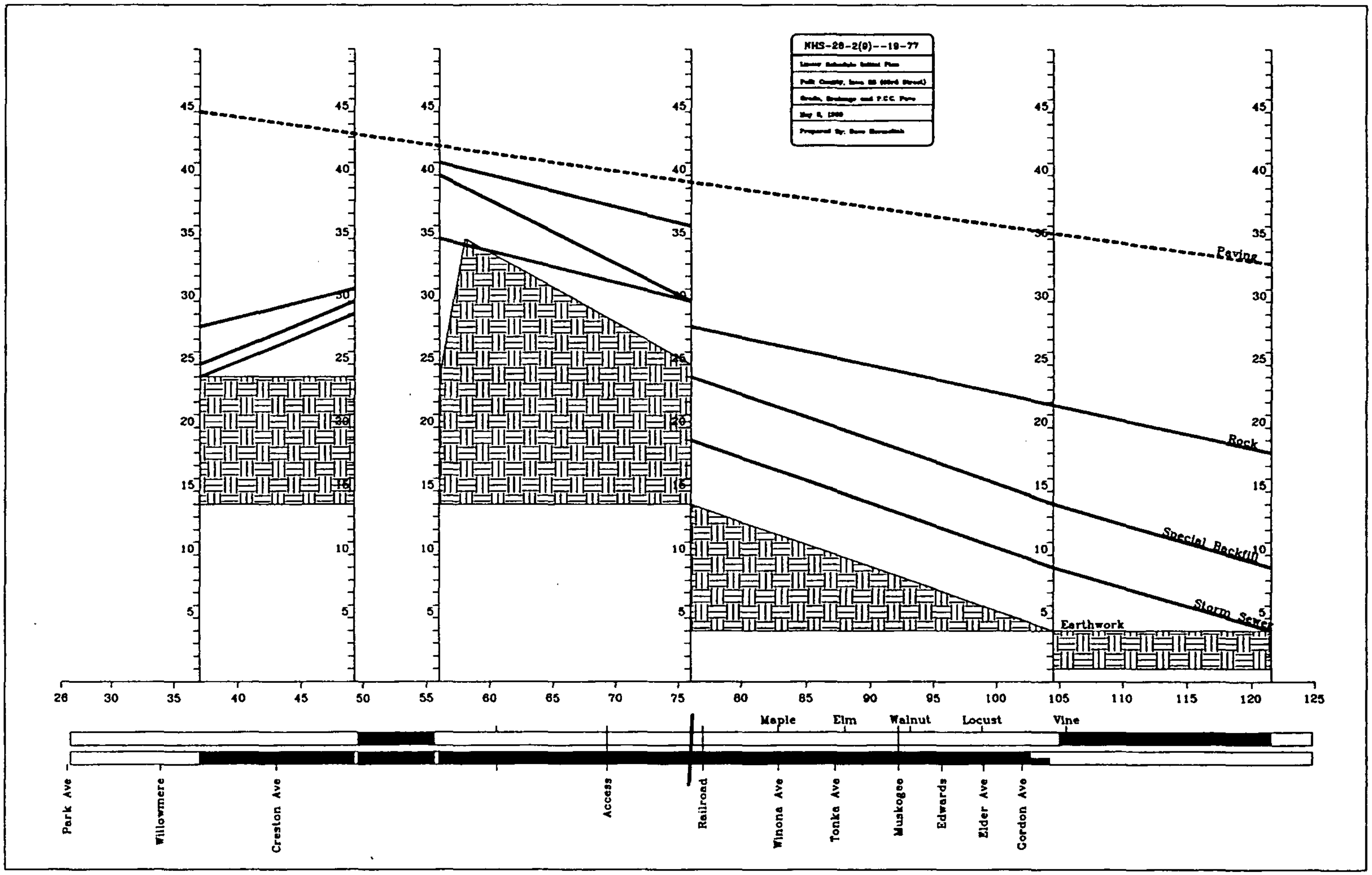

Figure 5 - Project III Linear Schedule

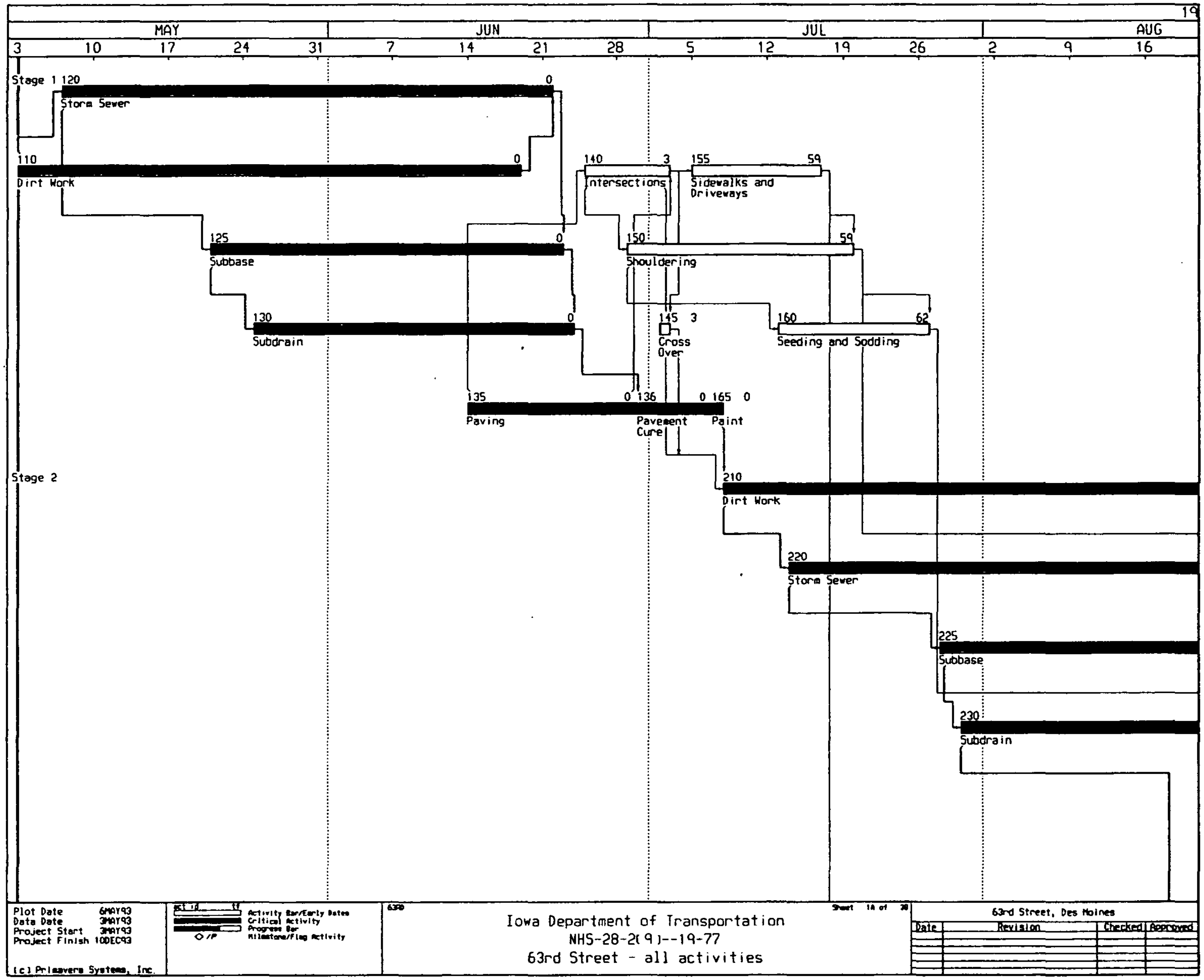

Figure 6 - Project III Partial Time Scaled Logic Diagram

providing a reference to landmarks, Figure 5 also identifies the areas of construction included in this stage of the project. The dark areas, other than the bridge, are the areas that the activities depicted in the linear schedule encompass. By this method, each stage of the project should has a separate diagram.

Notice that some of the earthwork activities are shown with shapes other than rectangles as on previous schedules. The earthwork operation between Vine and Railroad for example, is a triangle. The reason for this was that the operation was largely a cut beginning a Vine and progressing to Railroad with the extra material being used as fill north of the bridge. As the operation progressed the activity was complete at the current cut location. Therefore, instead of a rectangular block the upper portion has a slope to indicate the progressive completion of the activity.

Progress Meetings

Progress meetings were attended regularly for each of the projects throughout the second week in August. Progress schedules were presented at these meetings. Examples of project schedules are not presented here since the final as-built scheduled presented later, in essence, comprise progress schedules at any given date.

At each meeting current activity progress information was obtained from IDOT inspectors. This information came in the form of activity data sheets for two of the projects and daily log books for the third. Some necessary information was not always available form the inspectors data. For example, breaking pavement was not a pay item and therefore quantities are not typically recorded by inspectors. Information such as this was usually obtained easily from the contractor. On the I-80 project, however, the inspector agreed to track two activities that were not pay items, pavement breaking and rock subbase trim. This made the data collection process much easier and more consistent.

Project status was a topic that consistently came up at progress meetings. The question was "When can the project be expected to complete?" One attempt at answering this question involved plotting the planned linear schedule onto vellum. To status the project, the transparent vellum plan would be overlayed onto the current progress schedule. The plan would be positioned such that the progress of the current controlling operation intersected the line depicting the same activity on the plan. Any lines on the plan either above or beyond the current progress then became the projected plan, and projected activity dates could be determined from where the plan activities intersected reference axes on the progress schedule. This technique provided a simple visual means of statusing a project without the need for long calculations or computers.

In the course of the progress meetings, the linear schedules were often used to show parties not directly associated with the project how the work activity was to occur. For example, at the Iowa 92 progress meetings, there were almost always representatives from the city of Indianola, the Balloon Festival, and various utilities present. The linear schedule was often referred to as a tool to show the parties how the work on the project was expected to progress.

The linear schedule was used a couple of times on the I-80 Inlay project to resolve disagreements. One instance involved whether or not an activity was a controlling item and on another occasion the linear schedule helped determine if the contractor's daily productivity was less than their typical rate.

The As-Built Schedules

As-built schedules were created for all three projects and are presented in Figures 7 through 9 respectively. In the production of these schedules, an attempt was made to use a common set of elements. A discussion of these features follows:

Common Elements

Axes

In all of the diagrams, the x-axis represents the project site and denoted as stations, usually in increments of 5 or 10. The y-axes are always a measure of work periods, but they are also a means of reconciling the four individual measures of time included in these diagrams. The y-axes provide a correlation between actual calendar days and work periods. The CAD program used to represent these schedules needs numerical values for y coordinates, not calendar dates. The work period scale also provides a reference to elapsed days since the beginning of the project. The thick vertical lines either along the left-most y-axis or closest to the y-axis line indicate planned working days. These are days that the contractor plans on working and provide a calendar to establish planned activity dates. The thick vertical lines on the right-most axes indicates the charged working days. Each time period charged, in half-day increments, is indicated by a thick vertical line.

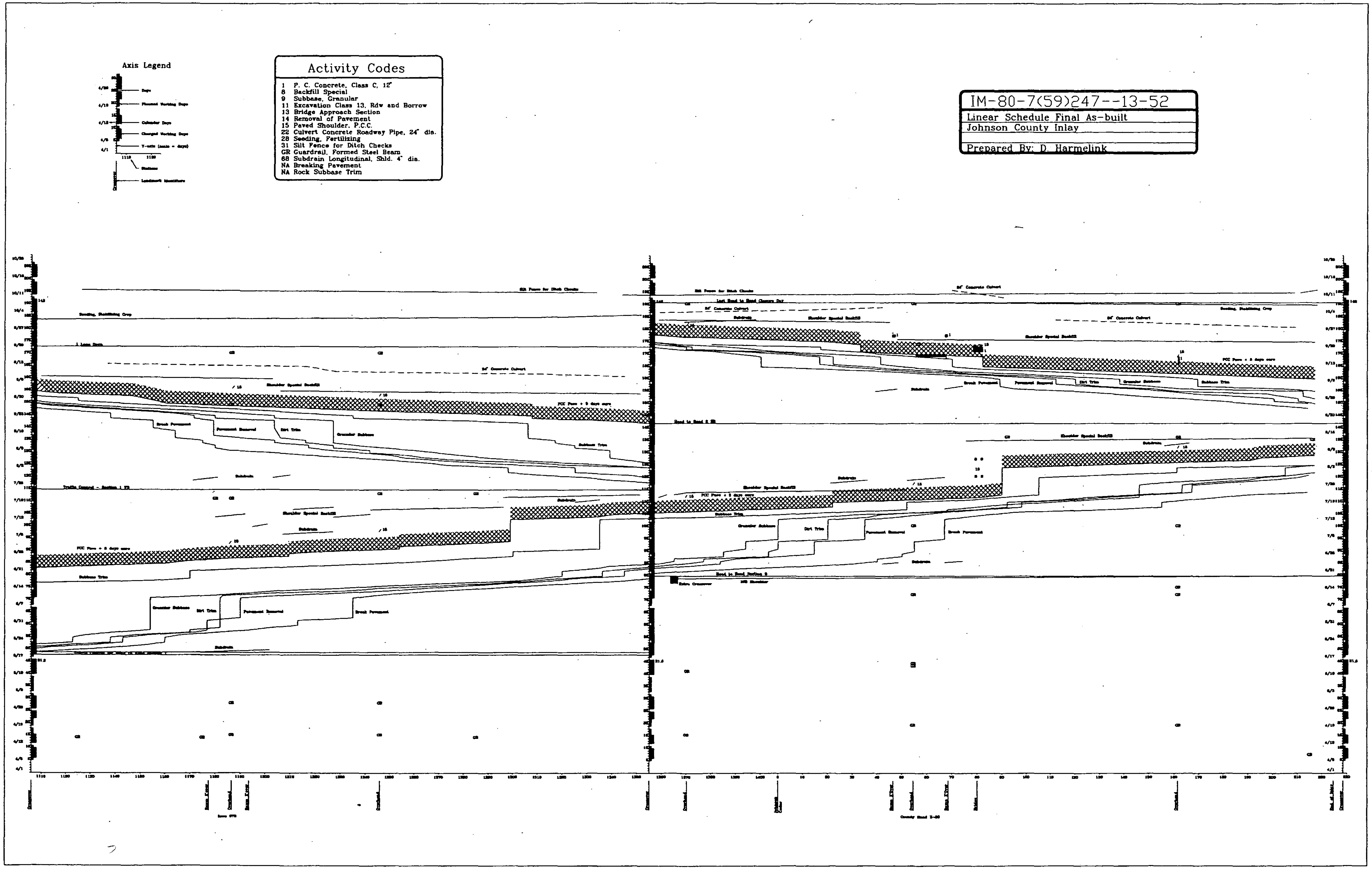

Figure 7 - Project I As-Built Linear Schedule

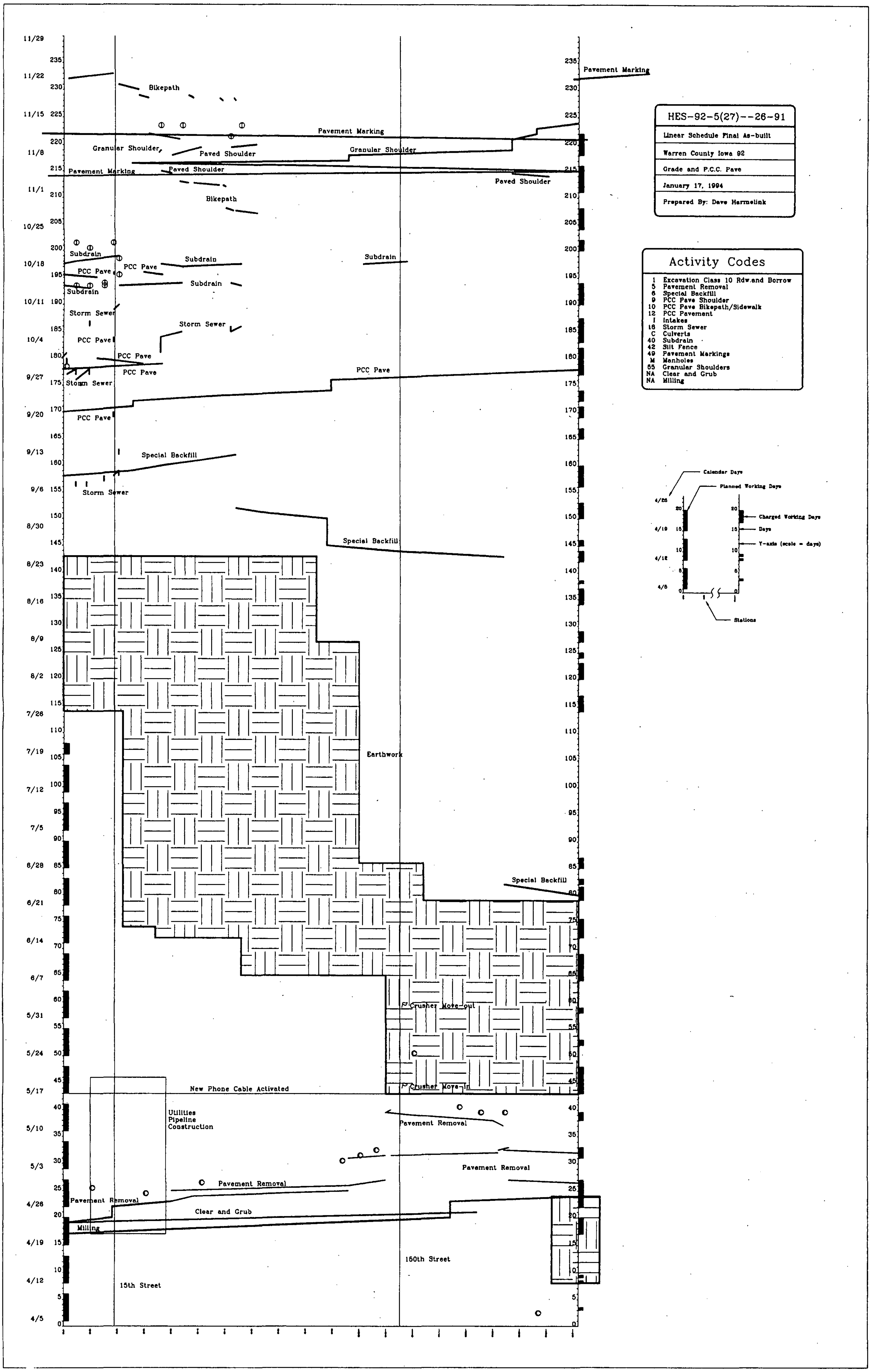

Figure 8 - Project II As-Built Linear Schedule

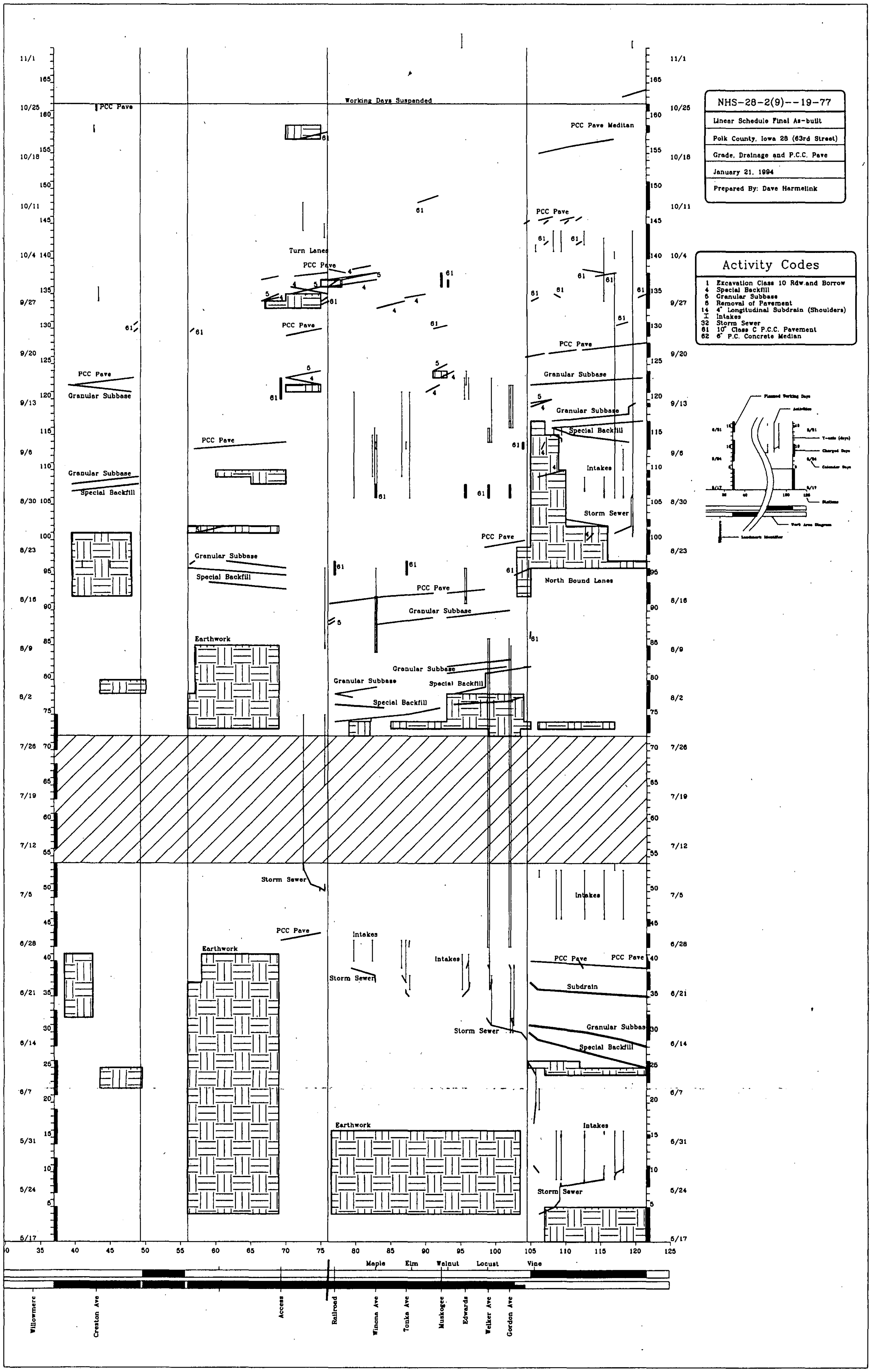

Figure 9 - Project III As-Built Linear Schedule

Activity Codes

A box with a list of activity descriptions and a number of symbol is included on each schedule. Whenever possible the code number corresponds to the number assigned to pay items in the project drawings. This number is also used to organize the quantity tabulation sheets recorded by the inspectors. This list also serves as a legend for identifying activities on the schedule. If limited space on the diagram does not allow the use of the activity description, the code number of symbol is used.

Axis Legend

There is an axis legend included on each as-built schedule that describes the items included on the axes.

Data Collection

Whenever possible, the data used in producing these schedules was developed from the sheets that the inspectors use to record daily quantities for pay items. Figure 10 shows an example of one of the inspectors sheets for Subbase, Granular. The data recorded on this sheet includes the date, the location in stations, the lane, and current and cumulative quantities. In order to plot an activity such as mainline paving, the appropriate information needs to be assembled from this sheet. The numbers in the left margin indicate the work period on which this date falls and were added by the researcher. For example, granular subbase was placed in the eastbound lane on 7/22/93, work period # 113, from station 126+00 to station 146+09. This information would plot as a line on the as-built schedule

Form 15

Item Description: Subbase, Granular Page 2 of

Item # 0090 Project # IM-80-7(59)247--13-52 Contract # 35197

	Date	Location Sta	to Sta	Side	Length	Width	Sq. Yds. Today	Sq. Yds. To date	Div
84	6-23-93	1338+45	1359+85	EB Mainline	2140.0	27.67	6579.31	77797.88	II
	6-24-93	1359+85	1365+00	EB Mainline	515.0	27.67	1583.34	79381.22	I
87	6-26-93	1365+00	1384+89	EB Mainline	1989.0	27.67	6115.07	85496.29	I
90	6-29-93	1384+89	1394+01	EB Mainline	912.0	27.67	2803.89	88300.18	I
94	7-03-93	1394+01	1407+14.7	EB Mainline	1313.7	27.67	4038.90	92339.08	I
		Equa. 1407+14.7 Bk = 0+00 Ahead							
103	7-12-93	0+00	16+50	EB Mainline	1650.0	27.67	5072.83	97411.91	II
104	7-13-93	EB 16+50	EB 31+00	EB Mainline	1450.0	27.67	4457.94	101869.85	II
105	7-14-93	EB 31+00	EB 40+00	EB MAINLINE	900	27.67	2767.00	104636.85	II
106	7-15-93	40+00	46+50	EB MAINLINE	650	27.67	1998.39	106635.24	II
106	7-15-93	48+00	67+50	EB MAINLINE	1950	27.67	5995.17	112630.41	II
		EB Exit Ramp West Branch							
107	7-16-93	41+50	47+50	EXIT Ramp	(See Page - of - Pavement Removal)		1229.17	113859.58	II
107	7-16-93	68+25	79+00	EB MAINLINE	1075	27.67	3305.03	117164.61	II
110	7-19-93	80+00	90+00	EB MAINLINE	1000	27.67	3074.44	120239.05	II
111	7-20-93	90+00	110+00	EB MAINLINE	2000	27.67	6148.89	126387.94	II
112	7-21-93	110+00	126+00	EB MAINLINE	1600	27.67	4919.11	131307.05	II
113	7-22-93	126+00	146+09	EB Mainline	2009	27.67	6176.56	137483.61	II
117	7-26-93	146+09	155+01	EB Mainline	892	27.67	2742.40	140226.01	II
		EB Entr. Ramp							
117	7-26-93	68+03	76+50	West Branch	See Page - of - Pavt. Removal		2395.89	142621.90	II

Quantity Awarded: 324852.000 Sq. Yds.

Quantity Authorized:

Quantity Paid:

Meas. & Insp. By: Larry Hotz Method of Measurement 2111.08

Checked By: Basis of Payment 2111.09

Figure 10 - Inspector's Data Sheet Example

with endpoint coordinates in the form of (x,y). The starting point of the line would be (126.00,113) and the endpoint of the line would be (146.09,114). The next time this activity progresses is on 7/26/93; work period #117. During the three day interval between the end of day 113 and the start of day 117, there was no progress recorded for the granular subbase activity. This plotted as a vertical line from (146.09,114) to (146.09,117).

A vertical section in an activity shown as a line on these schedules, usually indicates that there was not any progress recorded on this activity during this period of time. If the line indicating an activity was anything but vertical, progress has occurred, and the nearer the slope of this line is to horizontal, the higher the rate of progress. Keep in mind, however, that this measure of progress is in terms of stations along the roadway, and that actual quantities may vary along the course of the project.

Obviously, not all of the activities included on the as-built schedules are depicted as lines. A discussion of the symbology used on the individual schedules appears in the nest section.

Project I

The as-built schedule for the I-80 Inlay project can be seen in Figure 7. The actual rates of the six mainline activities are plotted for each of the four sections. These activities, in the order that they occur, are:

1. Break Pavement,
2. Pavement Removal,
3. Dirt Trim,

4. Granular Subbase,

5. Subbase Trim,

6. and PCC Pave + 5 days cure.

Shoulder Special Backfill, Subdrain, Seeding, 24"Concrete Culverts, and work on the bridge approaches are also shown. The miscellaneous paving, such as gaps and gore areas, was shown for the east section of the westbound lanes only. The activity of paving the asphalt shoulders was not included since the data recorded was in tons per day with no reference to stationing.

Notice the small block beginning on day 76 marked Extra Crossover between stations 1360 and 1370. This is the construction of the extra crossover that allowed work to progress into section 1, westbound, earlier than originally anticipated. On day 142, the head-to-head traffic was moved from the westbound to the eastbound lanes in section 2. Since section 1 of the westbound lane was closed to traffic on day 115 there was a potential gain in project duration of 27 days.

There are areas on the diagram where all of the activities currently in progress are shown as vertical lines. For example, all six mainline activities show no progress for days 95 through 102. This includes the dates 7/4/93 through 7/11. The first two days of this period were holidays which may be the reason that there was no progress, but excessive rainfall was certainly the reason for the rest of the delay. Care must be taken, however, not to assume that all vertical lines were unavoidable delays. Daily job records need to be consulted to make accurate determination from these diagrams.

Whenever the contract period is controlled by work days, the concept of "controlling activity" becomes important. From field observations and examination of the as-built linear schedule, it is apparent that the only critical activity from the beginning of head-to-head traffic until the end of day 174 is Pavement Removal. Only after the completion of Pavement Removal, did other activities which needed to be finished before the project was complete become critical.

It is apparent that in a few areas of the diagram, the lines representing various activities cross, indicating that one activity passed another activity. Since this was physically impossible, there likely was an error in recording the field data. If there was a need, a closer examination of the data would probably correct the situation.

Project II

The Iowa 92 project's as-built schedule is shown in Figure 8. Notice that this schedule does not bear much resemblance to the original plan. The extremely wet season had a dramatic impact on the completion of this project. As indicated by the right-most y-axis, there were a large number of days for which working days were not charged. The planned working day scale along the left y-axis illustrates the planned working days and when the project was expected to be completed.

The earthwork activity could not proceed until the phone cable was activated as shown on the diagram by the horizontal line at day 43. The existing phone cable, which interfered with the earthwork operation, could not be de-activated until the new cable was completely in place and operational. This type of information is ascertained through discussions with field personnel and is not available from the inspection quantity reports. It's inclusion on the linear schedule, however, can be very useful in understanding how the work on the project advanced.

To determine if an activity is "on-schedule" a comparison needs to made between the planned and charged working days for the specific activity. As an example, consider the earthwork operation for this project. The original linear schedule indicated that earthwork was scheduled to begin on day 19 and complete on day 44. The as-built schedule indicates that earthwork began on day 14 and was complete on day 47.5, according to the charged day scale. Therefore, the activity appears to have started 5 days ahead of schedule and it finished 3.5 days behind schedule. The original calendar date for completion of the activity was 5/18/93 and the actual calendar completion date was 8/24/93.

Figure 8 also includes some symbols for activities such as culverts and intakes. The placement of these symbols typically indicates the completion of the item as recorded in the quantity reports and may not give a very accurate indication of the duration of the activity. Project III will demonstrate another approach to identifying an activity such as intakes when more information is available.

Project III

Figure 9 shows the as-built schedule for the work that was accomplished on the 63rd Street project during the 1993 construction season. Of the three projects included in this report, this project was probably the most complicated, at least in terms of staging, access, and utilities. A cursory glance at the schedule seems to indicate much more congestion than the schedules for Projects I or II. The project included 5 stages of construction. The as-built schedule only shows Stage 1 and a portion of Stage 2. Public access to 63rd Street had to be maintained throughout the project as well as cross streets at Muskogee and Railroad. There were also several businesses along the street for which access needed to be maintained. Since this was a fully developed residential area, there were extensive utilities involved with the project.

The intakes on this schedule are displayed differently than they were on the schedule discussed previously, primarily due to the manner in which the data was recorded. The inspectors on this project still used field books to record information instead of the quantity sheets used on the other project in the study. The information recorded for intakes included four dates for each intake. These dates were the pour dates for the footing, the walls, the insert, and the top of RA-3, RA-5, and RA-8 intakes. RA-2 and RA-2 Utility Access intakes do not have an insert, so they only have three dates recorded. On the linear schedule, these dates were shown as vertical lines with a short horizontal line at each end of the vertical line. Each intake has two of these "I" shaped segments associated with it, one representing the dates the footings and walls were poured, and another to indicate when the insert and top were poured. The short horizontal lines indicate the respective dates. The reason that the intakes were shown in this manner is that after the footing and walls are poured, the mainline paving is done. After the paving is complete, the rest of the intake, the insert and the top, can be finished. If there was a cure period necessary for the footings and walls before the mainline paving could occur, it was not evident from the data. However, if this situation did exist, it could easily be portrayed on the diagram .

The large area of diagonal hatching between 7/10/93 and 7/26/93 indicates the time that the project was delayed due to the Des Moines flood. Although much of the project was under water, damage and rework was not extensive. The area activity in the upper right portion of the schedule from station 105 to 122 beginning on day 96 labeled North Bound Lanes is part of stage two. The work area diagram along the bottom of the schedule does not include this work. An area identified as Turn Lanes in the upper center portion of the schedule shows work on a double turn lane at Railroad Avenue. Working days were suspended on 10/25/93 as indicated by the horizontal line across the top of the diagram.

Observations

Baseline Schedules

The preparation of the linear schedule produced some interesting results. If there were any logic errors, conflicts in location, or omissions in the original CPM schedule they became immediately obvious in the linear schedule. In the preparation of the CPM schedule, the scheduler had to mentally visualize the relationships between activities. For the schedule to be accurate, all of the possible relationships had to be established. These relationships were, at times, very difficult to describe using CPM techniques. For example, consider a paving operation that required five days of cure time before subsequent activities could proceed. This was typically modeled as a start-start relationship between paving and cure time in the CPM. Let's assume that the paving operation covered several miles and occurred over a period of several days. The cure activity relationship said that subsequent activities could start five days after paving started, but since paving could span many days, the true relationship was that subsequent activities could not start until five days after paving had occurred at any point along the course of the paving operation. CPM was unable to correctly model an activity that occurred at any location other than the same point at which paving started or an activity that progresses at a faster rate than that of the paving operation. In either of these cases, CPM would allow subsequent activities to occur before the five days of cure had elapsed.

Refer back to the linear schedule for the Iowa 92 project shown in Figure 3. Notice that two activities, pave tapers and pave shoulders, are both shown as having occurred during the five days of cure depicted by the shading above the pave mainline operation. Since this schedule was prepared directly from the CPM schedule this indicated a logic error in the initial schedule. The contractor and the researcher spent a considerable amount of time and effort in the development of the CPM schedule, and only after it appeared to be accurate was the linear schedule produced. A simple visual check of the linear schedule indicated that there was a problem, a problem that was nearly impossible to detect from the original CPM schedule.

Output from CPM schedules can, at best, be difficult to understand. The contractor, typically delivers a logic diagram and a tabular report showing activity dates. From this information, DOT personnel try to discern if the contractors plan is accurate. As the previous discussion indicates, this was difficult even for those that were very intimate with the schedule. The format of the linear schedule seemed to overcome many of these problems. A user of the schedule can visualize the project construction plan. Apparent on the schedule, was the sequence of activities at any particular location on the project, the starting and ending date as well as the starting and ending location of all activities, and an indication of production for linear activities in terms of stationing. Any logic errors in the plan were clearly evident as interferences between the graphic entities depicting the activities on the schedule.

Presentation of the schedule at progress meetings, for the projects studied, supported the suggestion that it was much easier to convey the contractors plan for accomplishing the work using linear schedules than CPM schedules. The primary reason for this was that linear schedules add a very important dimension to the scheduling process, the location. In linear scheduling, *where* an activity occurred was equally important as *when* it occurred, as evidenced by the axes on the diagram. In projects with predominantly linear type activities, this was an extremely important attribute.

As-Built Schedules

One of the objectives of the research was to develop a format and set of symbols that would become a common set of elements on all linear schedules. Many different symbols and formats were tried in the development of these schedules. For example, one schedule showed only working days, while another showed all calendar days. The way items of work were displayed on the schedule varied as in the case with intakes. On the 63rd Street schedule, the inclusion of a work diagram to show work areas for a particular stage of the project seemed relevant , but its use on the other schedules would have added very little useful information.

The appearance of activities on the linear schedule was somewhat dependant on the what the scheduler was trying to depict and the form in which the as-built data was recorded. A logical approach to the creation of a consistent set of symbols, could be to develop a pallet of symbols from which the scheduler could choose appropriate elements. This method would present a finite set of elements, flexible enough to deal with variations among projects and districts, that could be used on all linear schedules.

Converting the information contained in the inspector's quantity reports into entities on the linear schedule was not a straight forward process. It was not possible to take every entry directly from the quantity reports and convert them into a schedule activity A considerable amount of interpretation and manipulation was required by the researchers.

All of the as-built schedules were produced manually with the use of AutoCAD. The major effort expended on the schedules was in drawing them, either from the CPM or from the quantity data.

Conclusions

This portion of the research indicates that the IDOT construction personnel increase their understanding of a contractors "plan of attack" on certain types of projects through the use of linear schedules. Currently, IDOT engineers receive CPM schedules in the form of logic diagrams and printed reports. The logic diagrams, usually printed on a large number of adjoining fan-fold sheets of paper, are, at best, cumbersome and difficult to comprehend. The logic diagrams only show the logic between activities and the dates generated by the forward and backward pass. The printed reports typically contain an activity description along with a duration, early and late dates, and an indication of float for each activity in the logic diagram, basically, a tabular report of the information contained on the logic diagram.

A linear schedule contains a much richer set of information than the CPM schedules. It contains information on the planned sequence of activities at any specific location on the project. A vertical line, extended upward from any location on the x-axis, intersects all of the activities that will occur at that location. The intersection points indicate dates on which the activity is planned to occur as well as the order in which the activities will occur. This provides clear communication of the sequence at any point along the centerline of the project.

The linear schedule also shows all of the work activity that should be in progress at any time during the duration of the project. A horizontal line extended across the path of the project at any specific point in time intersects all of the activities that are planned to be underway as well as the specific location to which the activity should have progressed. If an activity on the linear schedule is a linear activity, a line, the slope of the line is an indication of the planned rate of production for that activity with respect to the units specified on the location axis. Since the units on the location axis are typically stations, the rate of production can be expressed in stations or lineal feet per day directly from the linear schedule.

The linear schedule visually demonstrates that all of the work activities necessary to complete a project have been accounted for, and that there is time and space available to accomplish them, assuming that the contractor can maintain the planned production rates. Progress can be plotted on the linear schedule and a visual comparison can be made of planned progress versus actual progress. Production rates, at least in terms of units per station, are graphically portrayed by the slope of the line indicating a linear activity. A comparison of planned rates versus actual progress rates can be used to anticipate delay, and determine if adjustments are warranted.

The process of creating a CPM schedule can be quite complex, even for schedules with a relatively small number of activities as highway projects. The scheduler first should decide what the activities are going to be. Then, based on a production rate and quantity, the scheduler should determine a duration for each activity. Once this is done, a network can be developed by logically connecting the activities. For example, the box culvert must be complete before the roadway preparation that crosses it can begin.

The scheduler should attempt to model all of the relationships between activities while keeping in mind what effect the location has on the logical relationships. Imagine the box culvert just mentioned. The roadway preparation cannot occur before the culvert is complete, (at least not right above the culvert), but it can occur on either side of the culvert. If there were a number of culverts along the roadbed a substantial number of activities and a complex set of relationships would be needed to accurately model the project.

So, what typically happens? The model gets simplified rather than try to deal with the complex relationships. This causes a dilemma. The simplified schedules do not adequately model the spacial aspects of the project and a detailed schedule is much too complex and cumbersome to be useful as a management tool. It is easy to understand why many of the relationships necessary in a CPM schedule are needed only to model the spacial relationships between activities and not necessarily the logical relationships.

The linear schedule removes many of the complexities of creating CPM schedules by the added dimension of location. This allows contractors to visually plan their projects. On a linear schedule, the contractor can graphically include all of the activities necessary to accomplish the work, position these activities to correspond with their respective locations on the project, and visually validate the portrayed production rates and work sequences. Logic errors and work position conflicts are reduced to visually verifying that not more than one activity occupies the same location at the same time.

The definition of a critical path is the sequence of activities along the longest continuous time path through the network. On projects with hundreds or even thousands of activities, identifying the longest continuous time path of activities through the project can be very important, since progress on these activities is directly linked to the duration of the project. On highway construction projects, however, there seems to be small number of activities, usually not more than fifteen to twenty. The concept of critical path, a controlling sequence of activities through the project, becomes less meaningful than it is for projects with a large number of sequential activities. Most of the major activities on highway construction projects are not sequential, they progress in unison along the roadway and are graphically represented on the linear schedule as a group of near parallel lines. And, as seen on the I-80 Inlay project there was one activity in a group of six activities that established the overall rate of production for the entire group. Not until the completion of this activity, pavement removal, did another activity in the group become critical. The next subsequent activity with a controlling production rate was the paving operation, and the question that needed to be asked, is "where and when did this activity become critical?" The question was not "what was the sequence of critical activities?" The paving activity becomes critical as soon as the pavement removal activity is complete. Whatever paving was left to be completed, was on the critical path. To minimize the impact that paving had on the project, its completion should have followed that of pavement removal as closely as possible.

The critical path for the I-80 Inlay project identified the paving operation as critical throughout the entire last phase of the project since it was unable to assign only a portion of an activity to the critical path. However, on a linear schedule, a linear activity is modeled as a line containing an infinite number of points. At any position along this line, a critical point for an activity can be defined in terms of a site specific location and a point in time.

The linear schedule has the potential to provide construction managers with a powerful new tool. Not only can this tool model the critical *logical* relationships between activities, as does CPM, it can also model the critical *spacial* relationships between activities.

Recommendations

This research strongly suggests that the linear scheduling technique has great potential as a project management tool for both contractors and IDOT personnel. However, before this technique can become a viable weapon in the project management arsenal, a software application needs to be developed. This application should bring to linear scheduling a degree of functionality as rich and as comprehensive as that found in micro computer based CPM software on the market today.

For the research project, the research team manually created and updated the schedules using CAD software. This would not represent a feasible approach to the creation of linear schedules in the future. While the research team was able to show what a linear schedule would typically look like, it was still not possible to provide examples of reports and analysis that could be generated from the linear schedule with a computer application. The research effort has provided insight into how a linear scheduling application would be developed and the functionality it would need to supply to the highway construction industry.

The application would need to provide very close ties between a graphical entity's spacial attributes in the linear schedule and a wide range of related tabular information. Two types of existing applications that provide these kinds of relationships between spacial and tabular information are Computer Aided Design (CAD) programs and Geographical Information Systems (GIS). GIS was explored as an alternative, and while it is specifically designed to provide strong relationships between spacial and tabular information, the majority of these relationships are geographically oriented. CAD applications do not provide ties between the two types of information as strong as those in GIS, but they are more than adequate for a linear scheduling application. The major advantage in using a CAD application to develop linear scheduling is that the graphical manipulation capabilities are much more mature than those found in GIS applications.

The third approach to the development of a linear scheduling application would be to build one using only standard programming applications. While this could eventually provide a very concise and efficient program, the development time and costs would increase dramatically. The most reasonable approach appears to be to develop the linear scheduling application in a suitable environment, one that already provides mature graphical and tabular data manipulation routines, and can be easily customized into a useful application.

The linear scheduling application should be very flexible in its approach to entering and manipulating data. The scheduler should be able to create and update schedules by graphically manipulating the entities on the linear schedule as well as entering information through text-based entry forms. Algorithms need to be developed that will provide the information necessary to successfully meet highway construction management needs. Some of the tasks the application will need to perform are:

1. Determine and identify the critical path based on activity logic and location.
2. Reconcile the various project calendars; planned working days, charged working days, project work days, calendar days, and closure days.
3. Provide a library of resources that can be used to determine production rates and equipment requirements to meet planned production rates.
4. Allow for input of as-built information graphically or through a spreadsheet format which imitates the inspector's progress reports (this would also provide a way to electronically store and manipulate project quantity data).
5. Track progress against the baseline schedule and display graphically and in text-based reports the schedule variance of completed and in-progress activities, and the anticipated activity dates of activities not completed.

These are the basic functions that an initial linear scheduling application needs to be able to provide. It is not an exhaustive list of capabilities Existing functions would be refined and new capabilities would be developed as the application matures.

Although a linear scheduling application has not been developed, a limited number of the functions described have been prototyped. The research team is confident that an application with the capabilities outlined above can and should be developed. The impact to the highway construction industry would be substantial.

The research team recommends that the IDOT extend this research effort to include the development of a linear scheduling application. The initial application should provide, as a minimum, the capabilities outlined above. The application should be developed utilizing a widely used and proven multiple-platform environment such as AutoCAD. An interface should be developed that is consistant with current trends in software development. The system should allow user customization and employ standard file formats and structures whenever possible. Development time requirements for the initial system (beta) is estimated at nine months.

Appendix A

Basic LSM Graphical Entities

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 the proiect. The typical orientation for highway construction projects, as shown in Figure 11, 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 12 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 the project.

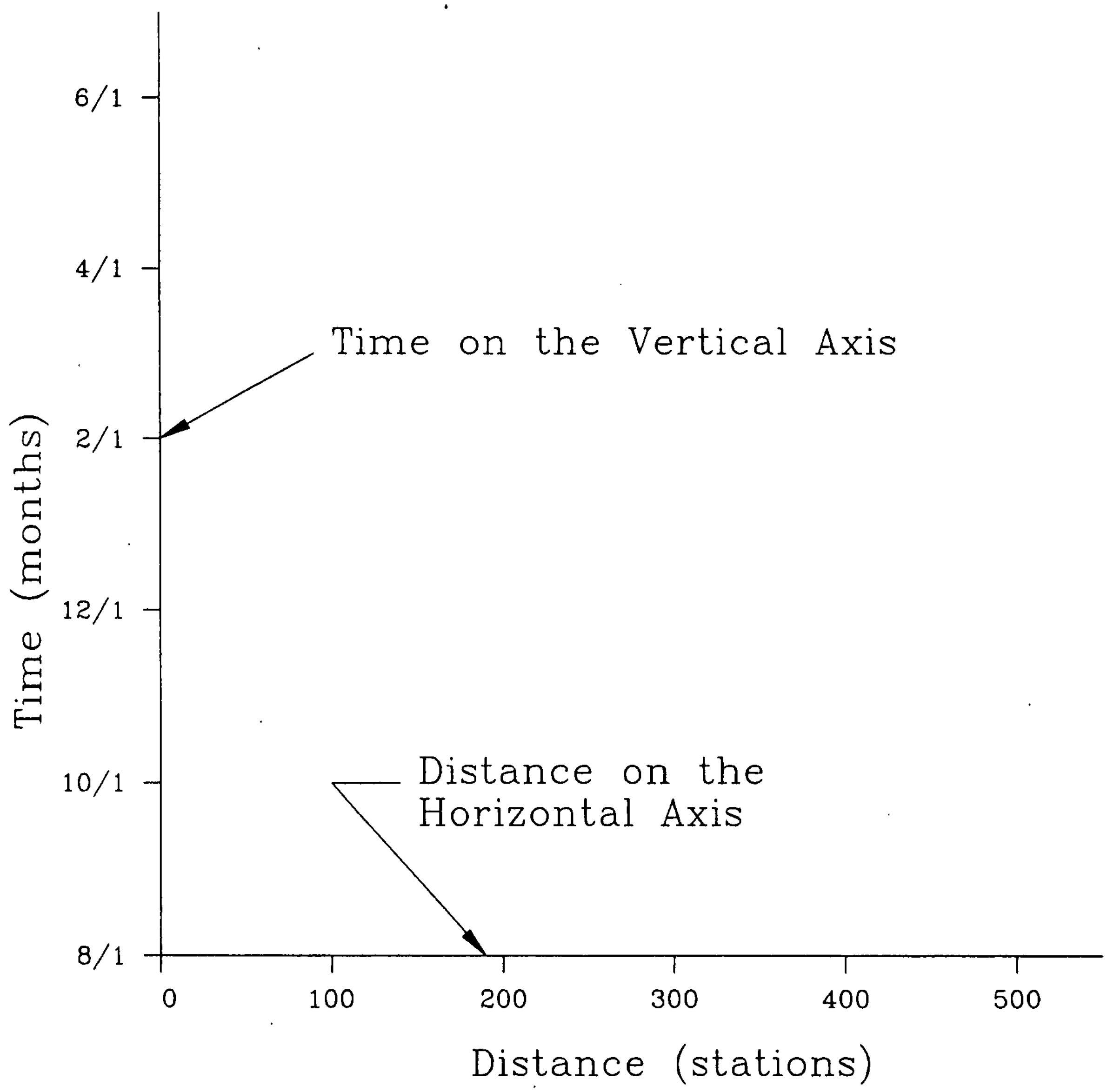

Figure 11 - Typical LSM Axes

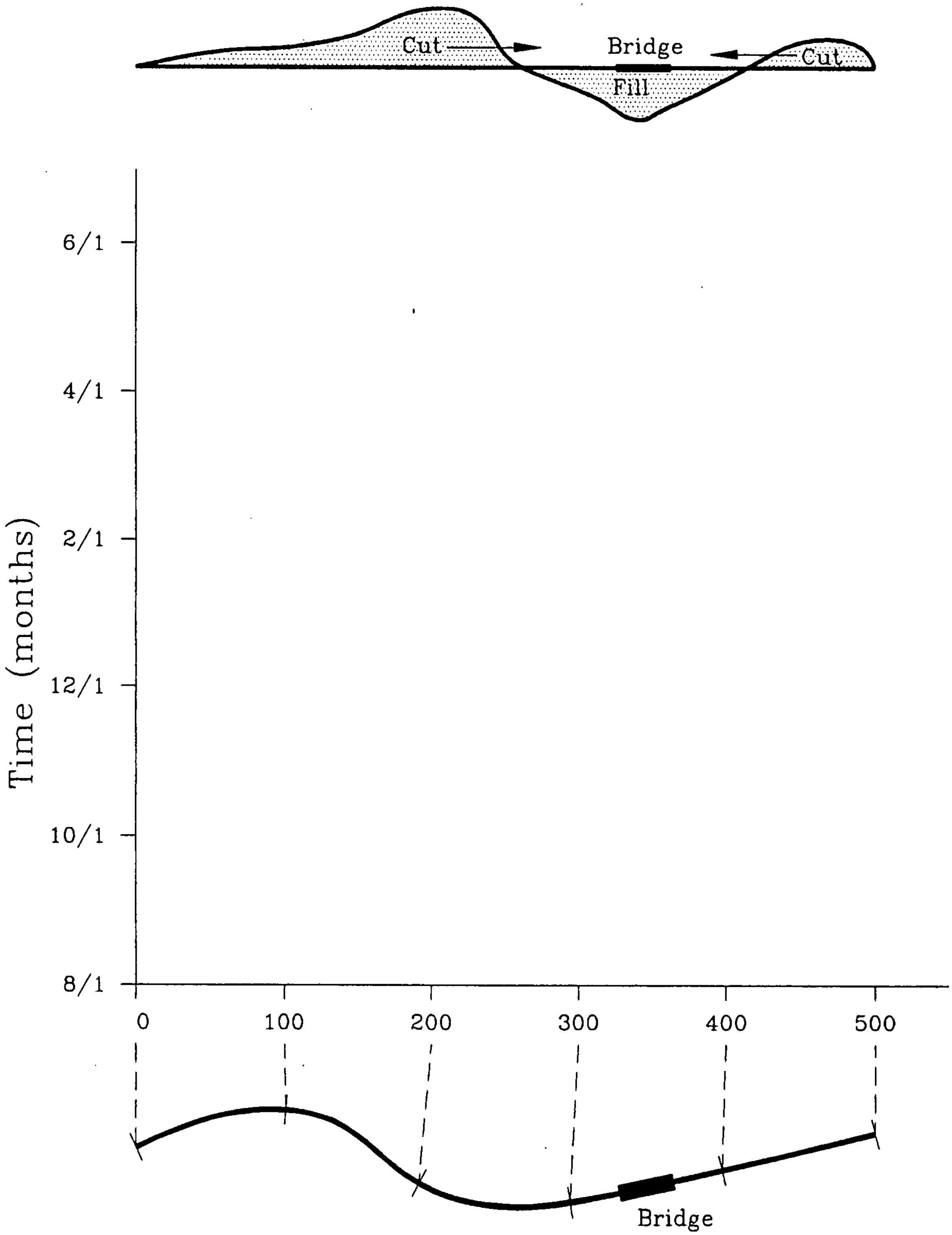

Figure 12 - LSM Plan and Profile Example

Accessibility

Areas of inaccessibilitv 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 13 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 14 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 activities necessary to complete the bridge approach are the same as the mainline paving

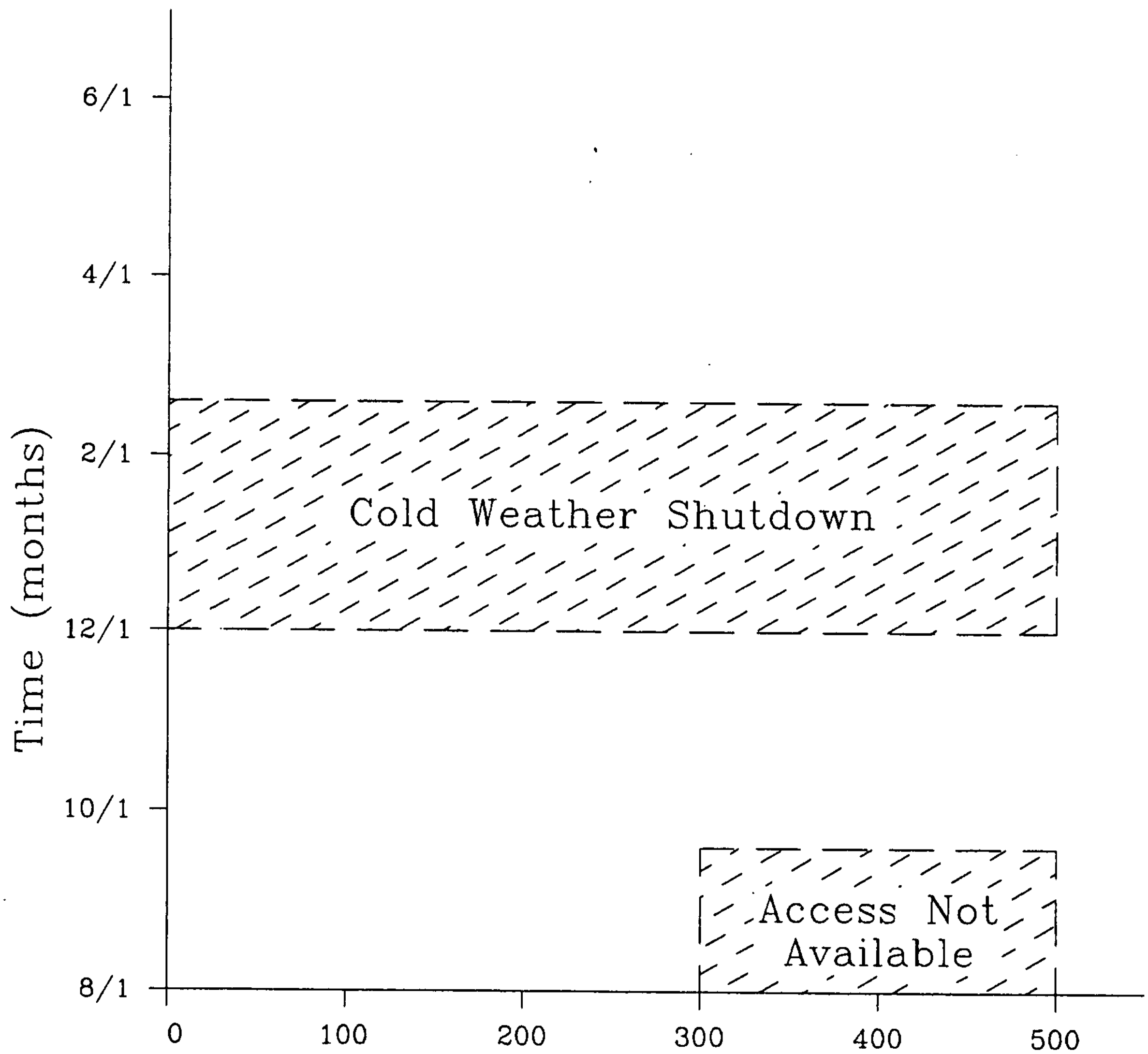

Figure 13 - LSM Accessibility Graphically Displayed

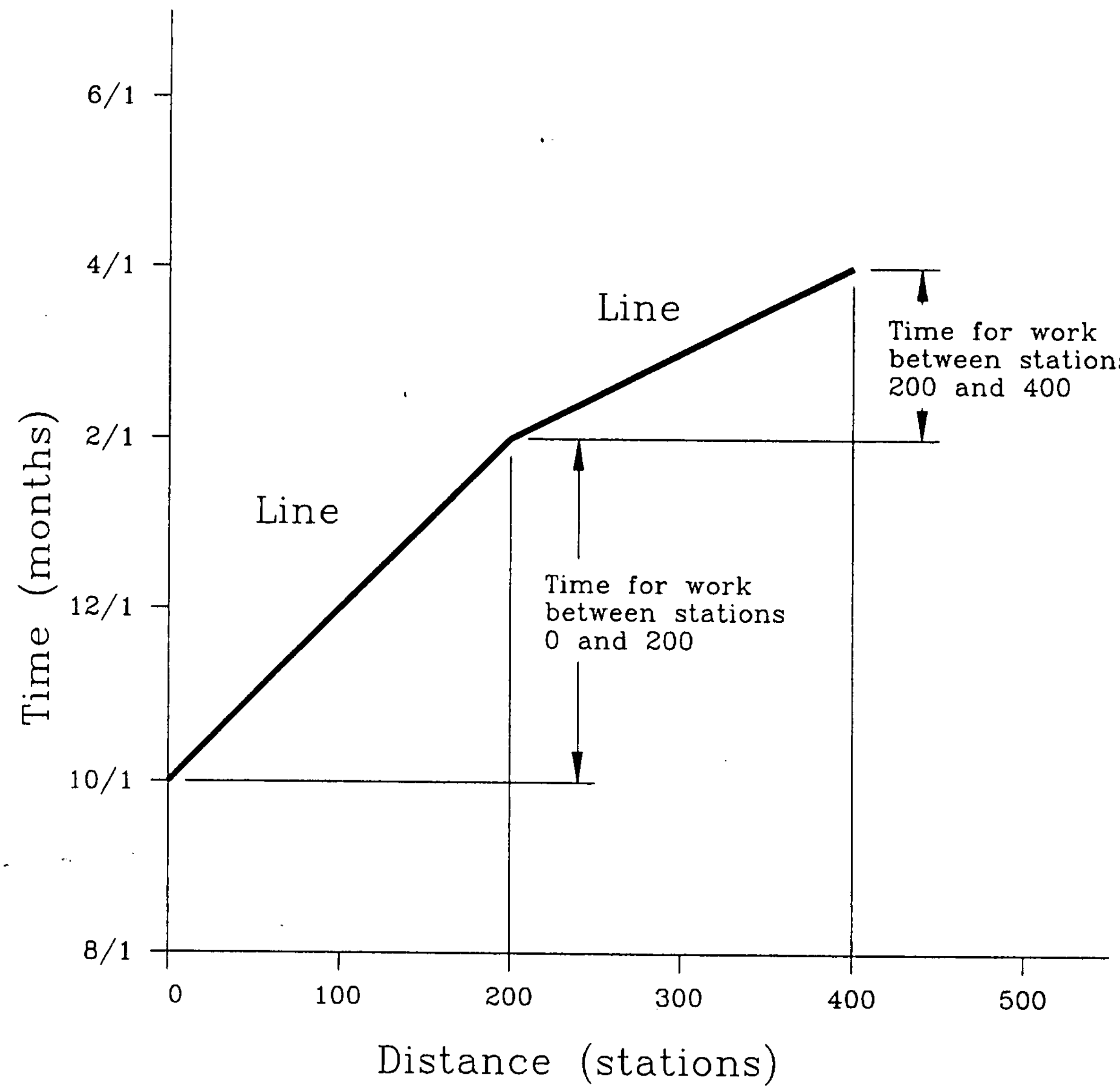

Figure 14 - LSM Line Activities

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 15.

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 16 shows.

Figure 17 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.

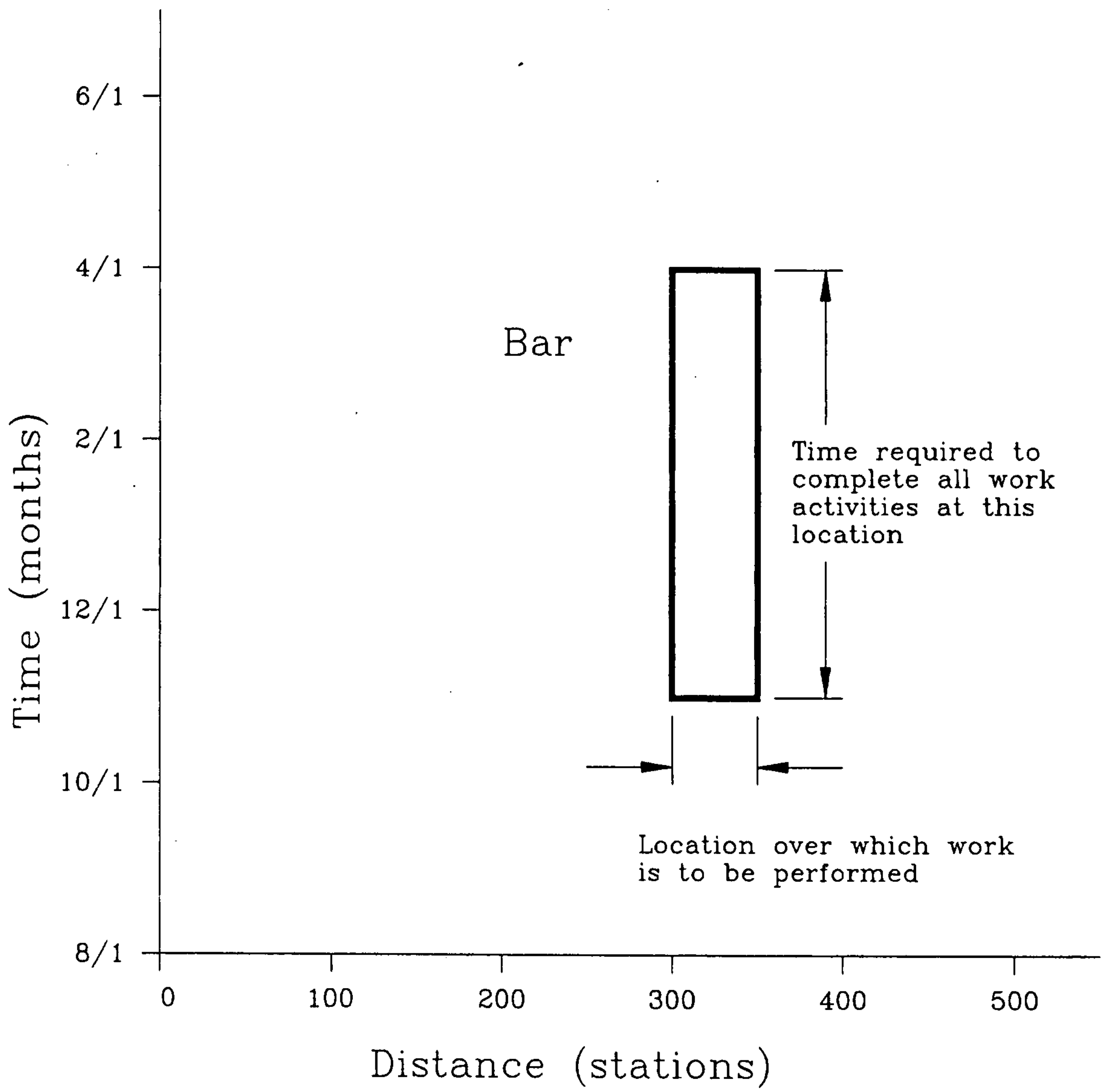

Figure 15 - LSM Bar Activities

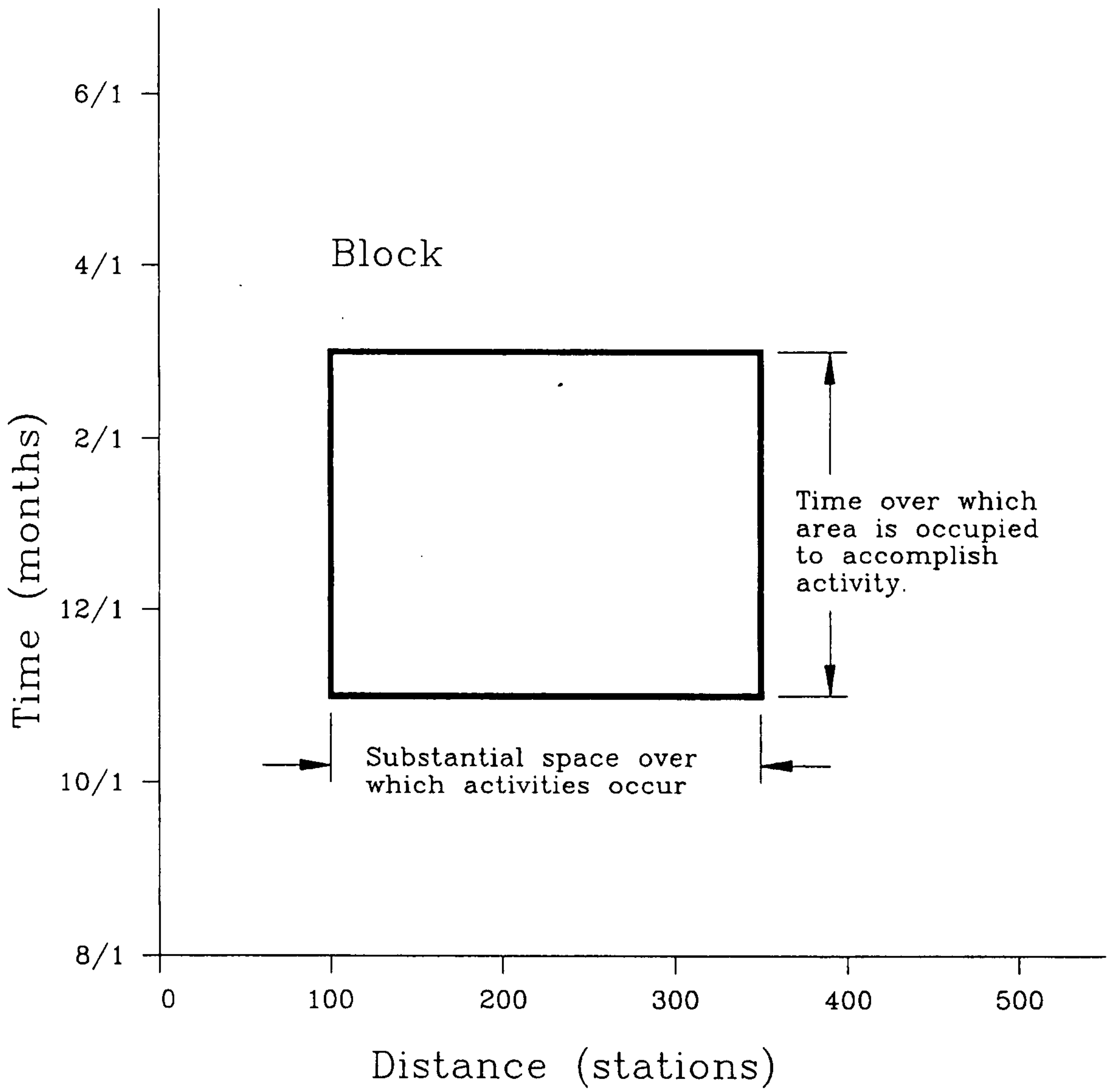

Figure 16 - LSM Block Activities

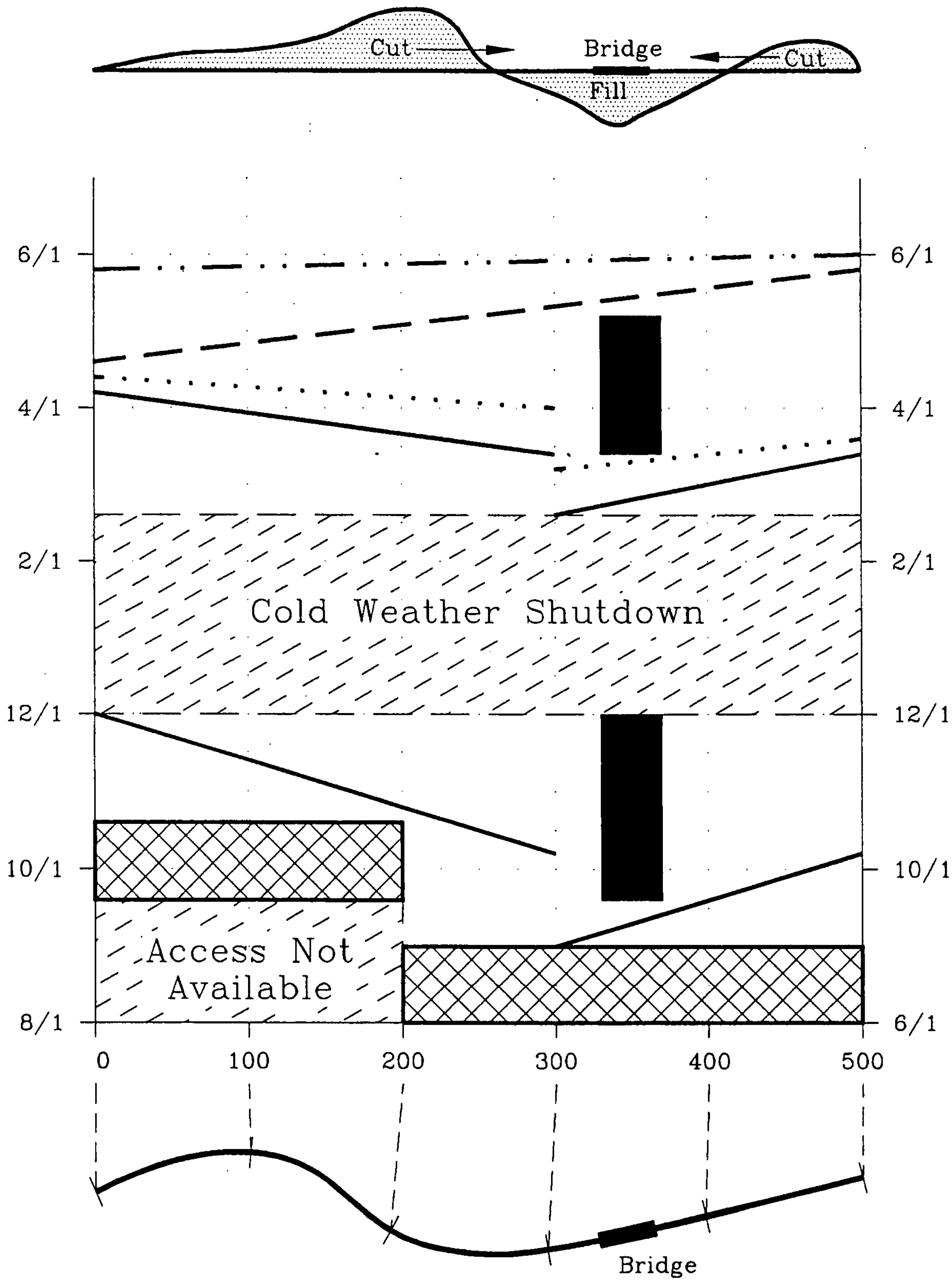

Figure 17 - A Simple Linear Schedule

Appendix B

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 andexecution 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. If no method of scheduling is identified, the choice of methods is up to the contractor. 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 and the attached requirements for schedule presentation. 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 orrevisions 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. The responsibility for providing a valid as-planned schedule is solely that of the contractor.

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 planned production rates for each major controllingitem 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. If this is not the case, the planned variability should be shown on the bar chart or included in the supporting narrative.

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. Each accepted revised schedule will represent the current "planned schedule" for purposes of measuring delay and evaluating impacts to the schedule. 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 be legible and include the following:

- ☐ activity description (sufficient to identify bid items included)
- ☐ activity duration (work days)
- ☐ planned production rates (sufficient to monitor progress on bid items)
- ☐ 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.
- ☐ all logic between activities clearly shown
- ☐ 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 planned start date (calendar date)
- ☐ Contractor's planned completion date (calendar date)
- ☐ slack or float for each activity (work days)
- ☐ quantities of bid items involved on each activity based on Contractor's intended startand 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 20work 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 on the currently approved planned schedule 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. Each accepted revised schedule will represent the current "planned schedule" for purposes of measuring delay and evaluating impacts to the schedule. 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 controllingwork items. The linear schedule 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. If this is not the case, the planned variability should be shown on the bar chart or included in the supporting narrative.

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. Each accepted revised schedule will represent the current "planned schedule" for purposes of measuring delay and evaluating impacts to the schedule. 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 linear schedule shall be included in the bid item of Mobilization. The current specification for Mobilization shall apply.