SCHEDULE COMPRESSION OF AN URBAN HIGHWAY PROJECT USING THE LINEAR SCHEDULING METHOD

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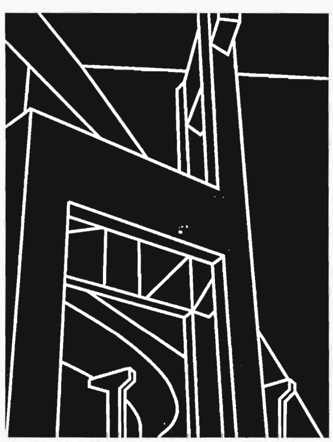

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by

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ABSTRACT

Traditional network scheduling methods such as Critical Path Method (CPM), Program Evaluation and Review Techniques (PERT), and bar charting are generally considered to be less effective for the planning of linear projects due to the cumbersome way in which they model repetitive activities. The literature indicates that linear scheduling techniques are more suitable to manage linear projects such as highways and tunnels. Linear scheduling is a practical tool that can be utilized for developing and maintaining the construction schedule as well as for seeking alternative schedules to the existing schedule. Coupling the strong visual advantage(s) and flexibility of this technique with a systematic approach, the construction schedule may be compressed without major cost impacts.

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CHAPTER 1.
INTRODUCTION

BACKGROUND

The term "schedule" is defined as "the plan for completion of a project based on a logical arrangement of activities" (Popescu and Charoenngam, 1994). Basically, a schedule consists of activities or tasks that will be performed during a project. The number of activities in a schedule usually depends on the size of the project as well as the selected level of detail. One should expect a schedule to become more complicated as the number of activities increase. A schedule is used as a means to:

a. communicate a project plan to various project participants,
b. control and project, and
c. provide management with project information for decision-making (Popescu and Charoenngam, 1994).

Several different scheduling methods, such as color graphs, percentage of completion, line of balance, linear scheduling, bar charts, and Program Evaluation and Review Techniques (PERT) have been implemented on different types of projects. Today, Critical Path Method (CPM), developed in the early 1960s, is the most widely used project method (Popescu and Charoenngam, 1994). The CPM schedule method involves a network diagram to portray the interrelationships among activities. The CPM method uses a mathematical procedure to calculate the project schedule based on the estimated duration of each activity and the assumed dependencies among the activities (Parvin and Vorster, 1993). This procedure is referred to as "network calculation."

Selecting the appropriate scheduling method is essential to achieving the aforementioned objectives of scheduling. The specific type of schedule to be used should be commensurate with the needs of the project. The question of whether CPM is the answer for linear projects such as pipelines, tunneling, and highway construction still remains unanswered. This report presents an application of an alternative scheduling method, the

Linear Scheduling Method (LSM), on an urban highway project for the specific task of construction schedule compression. The advantages that this method offers for linear type projects are discussed, along with other findings.

RESEARCH OBJECTIVES

The objectives of this research are to:

a. understand the principles of the LSM,
b. implement the method on an urban highway project as a schedule compression technique, and
c. analyze the effectiveness and appropriateness of the method for this purpose on this type of project.

RESEARCH MOTIVE

Today's urban highway construction projects are more complicated than those of the past. Projects are often constructed in close proximity to traffic and the public, increasing the importance of time for constructing a project. In many building projects, cost is the main driver behind the execution of the project. In contrast, urban highway projects typically emphasize time over cost in order to mitigate the risks associated with this public-endangering type of construction. The factors that motivated this schedule compression study and the selection of the method can be summarized under two major headings: generic factors and project-specific factors.

Generic Factors

The use of the LSM has been recommended to highway contractors for greater management and control of the work and to prove or disprove delay claims and extension requests (Parvin, 1990). It allows for a better understanding of the linear project than any other scheduling technique, primarily because the scheduler has access to activities' rates of production as well as the location (Arditi and Albulak, 1986). These attributes made application of the LSM well suited to the North Central Expressway (NCE) project.

The CPM is a useful tool for projects where there are strict dependencies and constraints between project activities, such as the construction of a building. For example, it is impossible to form the first floor deck of a building before foundation slab is poured and columns and beams are formed. However, there are fewer such clear dependencies in repetitive projects such as highway construction. The contractor has more options, such as constructing a bridge before constructing the main lanes underneath, or vice versa. Therefore, the project management team often has greater latitude to deviate from the initial construction schedule during the course of the project. The purpose of the deviation may either be schedule compression, as in this study, or achieving better constructability. The LSM was selected for its flexibility, which was needed to seek the alternative schedules.

Project-Specific Factors

The NCE has been a key link in Dallas' transportation network for over 45 years. At the start of the reconstruction project, traffic volumes on the NCE averaged 150,000 vehicles per day (Tyer and Krammes, 1993). Due to this heavy traffic load, early project completion was desired.

The reconstruction of the NCE started in 1990 with the northern section, termed North 1 (N1). Since that time, the public has been impacted by various stages of construction. In order to mitigate these adverse impacts, two decisions were made by the project stakeholders. First, a strong relationship was forged between contractors for various project segments and the Texas Department of Transportation (TxDOT) to address mitigation needs. Second, a North Central Mobility Task Force (NCMTF) was formed to address issues of mobility planning, traffic management, public information, and community outreach. Of course, early completion of the project would provide the ultimate relief to the public.

The contract between TxDOT and the contractor stipulated the use of Primavera Project Planner as the scheduling software. That decision established CPM as the scheduling method. The baseline schedule that was submitted to TxDOT consisted of more than 3,000 activities and even more activity relationships. Due to the complexity of the project, the updated CPM schedule did not reflect the current status of the project with enough precision to conduct a schedule compression study. This situation indicated that the schedule compression study might benefit from an alternative technique.

SCOPE LIMITATIONS

The scope of the study was limited to the analysis of the construction schedule compression of a selected project from TxDOT using the LSM. The following list elaborates on the scope definition of the selected project.

a. The selected construction project had only one and one-half years remaining out of an estimated five-year construction schedule when this study was initiated. There were three areas (segments) available to choose for this study. The 1,400-foot segment between station markers 71 and 85 was selected because it was the last area to be constructed. Thus, schedule compression would affect the project completion date.

b. A schedule that reflected the project team's plan was developed for the selected segment using the LSM. Schedule compression techniques were applied to the developed schedule to achieve the proposed schedule changes. For the same reason, engineering phase methods, procurement phase methods, and contractual methods used for schedule compression were not addressed this study.

c. Project management staffing methods, which deal with the way the employees are managed, were not included in the study scope to prevent interference with the internal procedures of the owner and/or contractor.

d. Economic impacts of proposed changes were not assessed in this study. Nevertheless, some suggestions were eliminated during the refinement process due to their obvious cost impacts.

REPORT STRUCTURE

The research methodology is explained in Chapter 2 and details the approach taken to solve the specific problem of schedule compression. The overall methodology that was followed is provided in the first section. Then each step is expanded, displaying the activities involved and the outcomes from the related major steps.

Chapter 3 includes the literature review and project description. Past research efforts relevant to this study are summarized in the literature review section. A detailed definition and the principles of the LSM are also presented in that section for readers who are not familiar with the method. A detailed description of the selected project for the study is provided in the second part of the chapter. The report is organized so that readers will be familiar with the selected project and the utilized method prior to Chapter 4.

Chapter 4 details the schedule compression analysis and techniques utilized throughout the study. Collected data and analysis results are presented in the chapter, as well as the contractor's recommended compression tactics. Construction Schedule Compression Analysis Method, which is reflective of lessons learned, is presented for consideration on future projects.

Finally, Chapter 5 summarizes research conclusions and provides recommendations.

CHAPTER 2.
STUDY METHODOLOGY

OVERVIEW

The methodology that was followed to complete this study is presented in this chapter. After providing a brief overview of the methodology, each major step is expanded to display the activities performed and the resulting output that becomes the input for the next step.

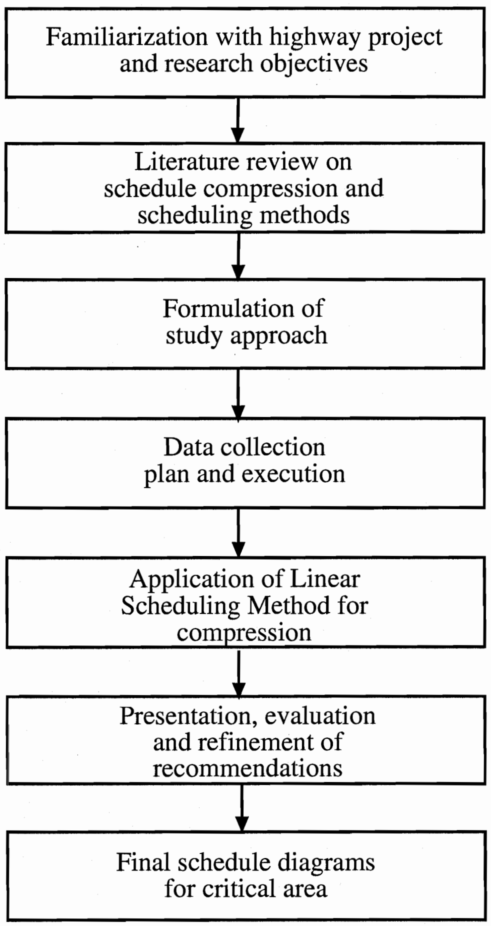

Figure 2.1. Study Methodology

Figure 2.1 illustrates the approach taken in this study. The specific steps followed included: familiarization with the highway project and research objectives; literature review; formulation of study approach; data collection; application of the LSM; presentation, evaluation and refinement of the recommendations; and presentation of proposed schedule diagrams for the critical area.

FAMILIARIZATION WITH THE HIGHWAY PROJECT AND RESEARCH OBJECTIVES

An understanding of the objectives was essential to the success of the study. Several meetings were conducted with the project team to ensure that study objectives were aligned with their expectations. These meetings were also useful in obtaining the stakeholders' approval and in creating the team environment for the study.

Due to the complexity of the project, becoming familiar with the highway project took longer than expected. Suggesting valuable alternatives to the existing schedule required that the construction logic in place be thoroughly understood. Analyzing the construction plans was the first activity undertaken. Slight differences between the plans and the actual field progress were clarified through meetings with TxDOT's project manager. Several site visits were conducted with the guidance of TxDOT inspectors. The next step was to analyze the baseline CPM schedule to better understand the construction sequence that was initially planned for the project as a whole.

As a result of these activities, study scope and objectives were documented. Figure 2.2 summarizes the activities and the outcome for this step.

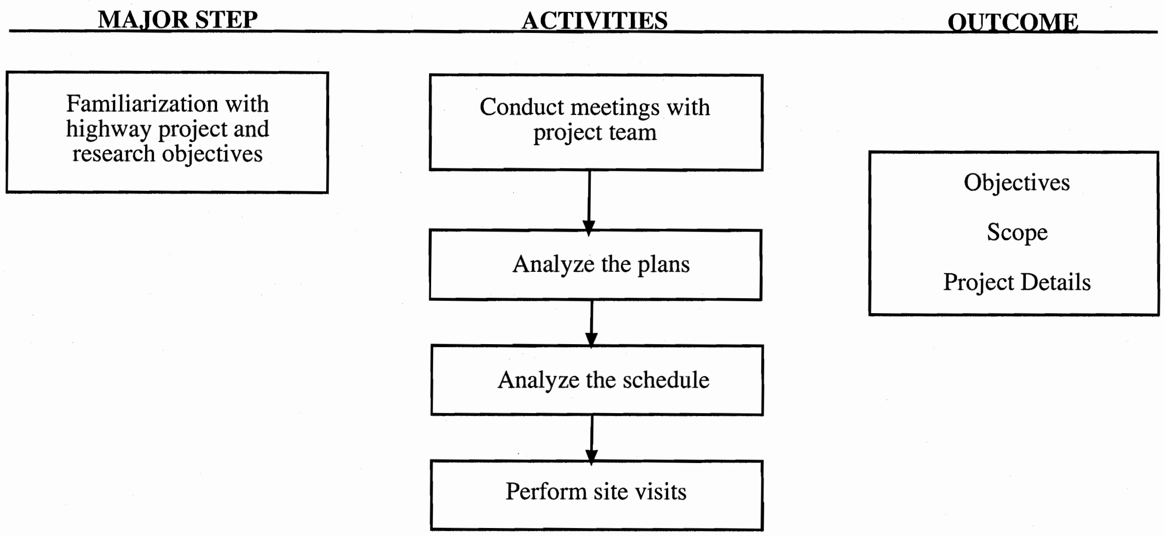

Figure 2.2. Familiarization Activities and Outcome

LITERATURE REVIEW FOR THE STUDY

A review of published literature provided background on the LSM and schedule compression strategies through a number of articles, books, journal papers, and Web pages, which were useful and informative. Lack of awareness of the LSM within the construction industry is reflected in the small number of studies that have been conducted in that field. After completing analysis of related previous studies, compression strategies were identified along with the scheduling technique to be utilized for the study. Figure 2.3 summarizes the activities and outcome for this step.

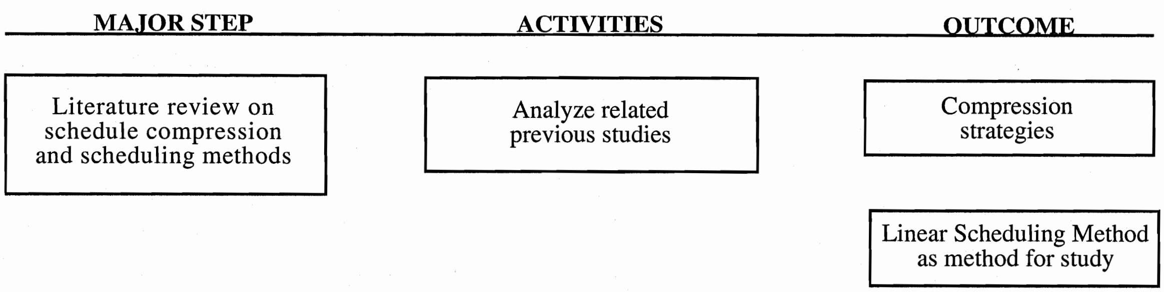

Figure 2.3. Literature Review for the Study

FORMULATING STUDY APPROACH

A linear schedule consists of diagrams showing both the time and location at which a certain crew will be working on a given operation (Parvin and Vorster, 1993). It is necessary to cover all areas of a project when the LSM is utilized as the primary method of schedule maintenance. However, for schedule compression, only critical areas that impact the overall duration of the project need to be analyzed. In the NCE project, the selected critical area was the last area to be constructed, which was independent from other areas and relatively easy to isolate.

After the selection of the critical area, required data were identified to develop the linear schedule for that area, resulting in the development of the execution plan for the study. Figure 2.4 summarizes the activities and the outcome for this step.

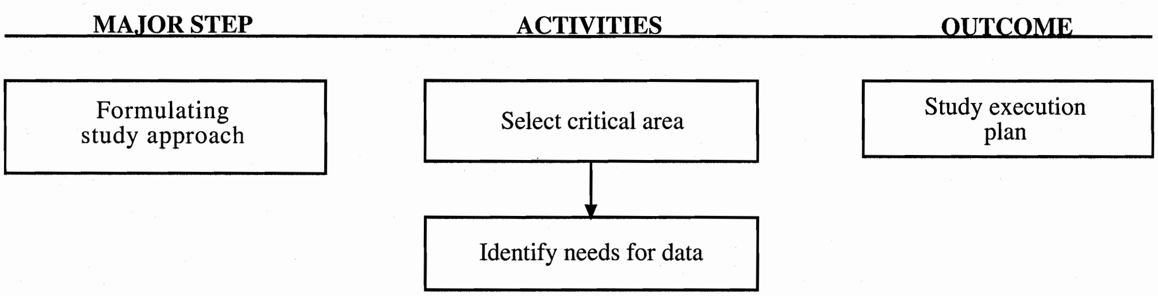

Figure 2.4. Formulating Study Approach

DATA COLLECTION PLAN AND EXECUTION

Many changes had occurred following the approval of the baseline schedule; therefore it was necessary to develop a new schedule containing the planned activities for the selected critical area. First, a Work Breakdown Structure (WBS)—a task-oriented family tree of work activities to be accomplished—was developed with the help of the contractor. The next step was to create an activity list along with work quantities and anticipated production rates of the crews. The activity list was derived from the work items of the WBS. Meetings were held with the contractor's project engineer to assure that the developed activity list matched the project team's plan. Anticipated crew production rates were either obtained from past records or through interviews with the contractor's foremen. Upon completion of the activity list, needed resources by activity were identified through meetings with the contractor's field engineers and superintendents. The accumulated data were organized and a Linear Schedule Diagram (as planned) for the critical area was drawn. Figure 2.5 summarizes the activities and the outcome for this step.

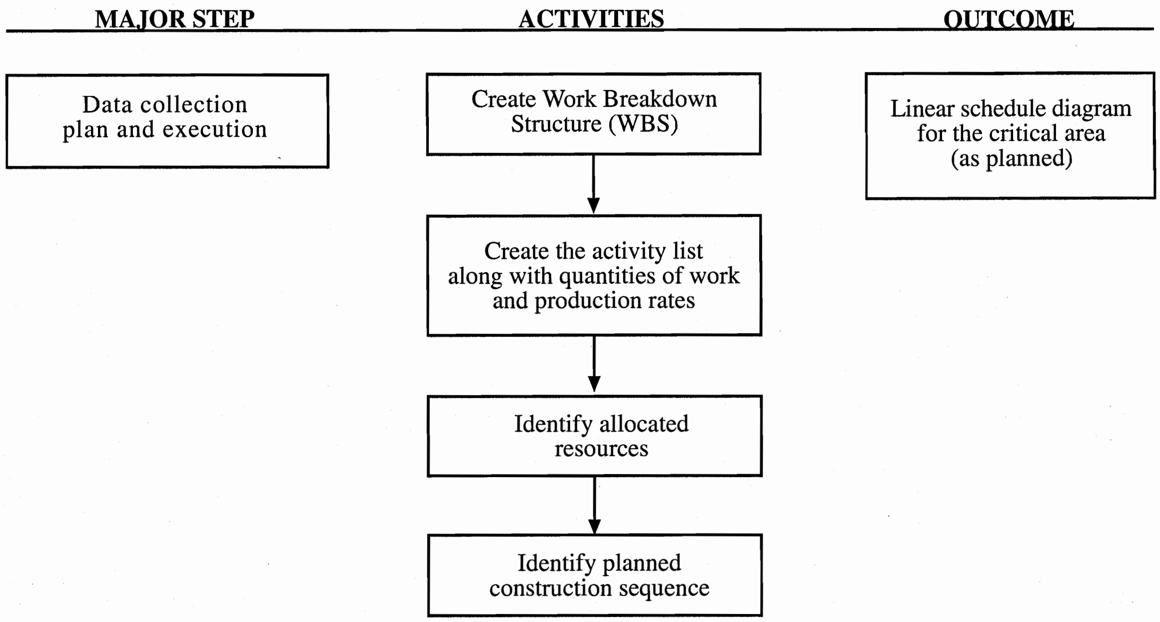

Figure 2.5. Data Collection Plan and Execution

APPLICATION OF THE LSM FOR SCHEDULE COMPRESSION

Schedule compression strategies identified in earlier steps were applied to the activities of the as-planned linear schedule, and proposed changes were developed accordingly. The activities and the outcome of this step are shown in Figure 2.6.

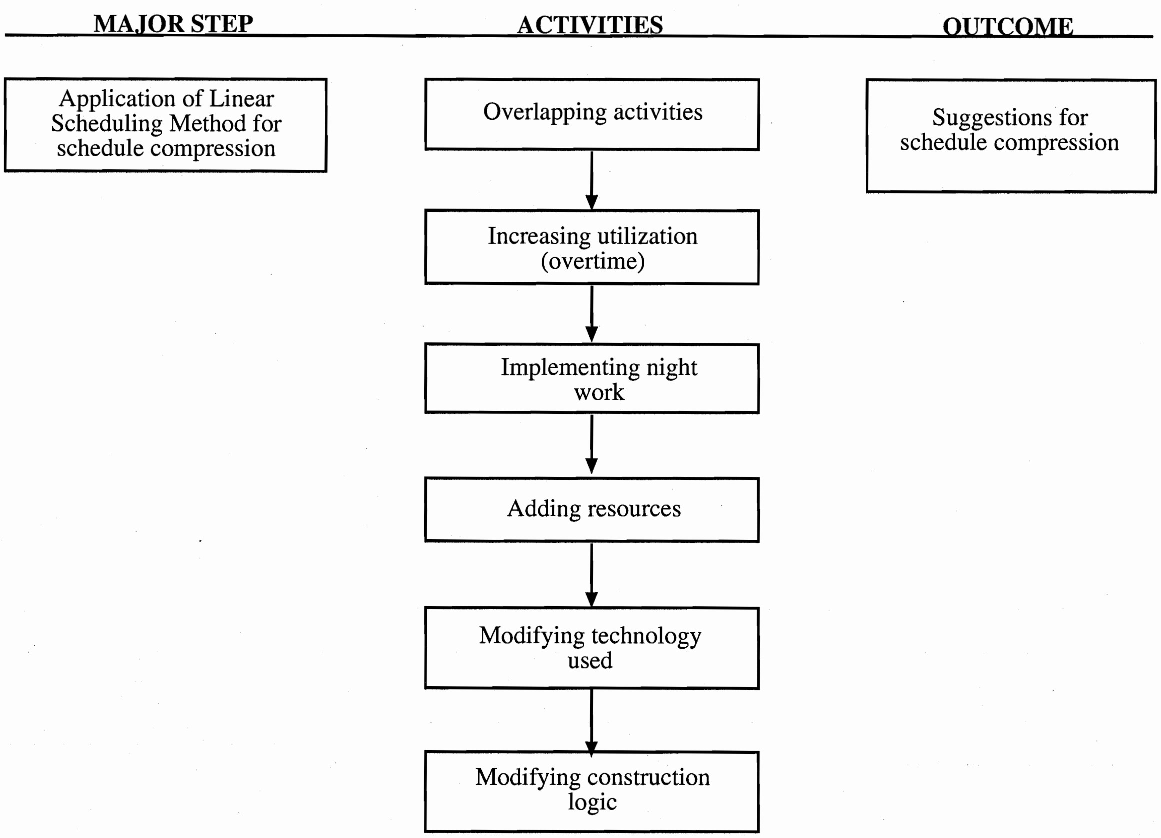

Figure 2.6. Application of the LSM for Schedule Compression

PRESENTATION, EVALUATION, AND REFINEMENT OF RECOMMENDATIONS

A final meeting was scheduled with TxDOT's project manager and the contractor's project engineer to refine the proposed changes and to select those with the greatest potential for implementation. Some of the proposed changes were eliminated due to issues such as safety concerns (for example, TxDOT did not allow the contractor to work at night) and lack of additional resources (cost impact). The activities and the outcome of this step are shown in Figure 2.7.

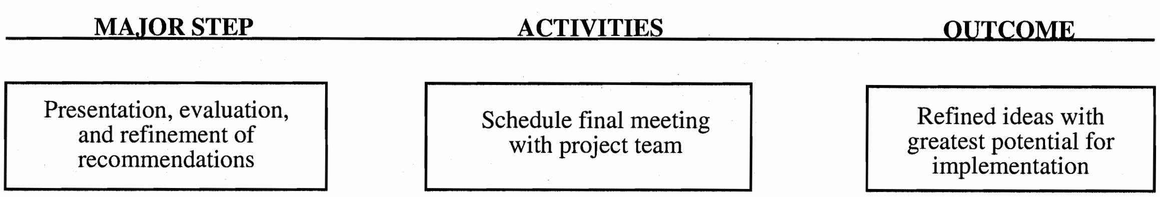

Figure 2.7. Presentation, Evaluation, and Refinement of Recommendations

PROPOSED SCHEDULE FOR THE CRITICAL AREA

Refined proposed changes formed the basis for the final step of the study. The anticipated impact of the proposed changes was characterized by comparing the as-planned linear schedule to the modified suggested linear schedule, which was impacted by the particular proposed change.

After characterizing the anticipated impact of each proposed change, the proposed schedule for the critical area was developed by utilizing those proposed changes that would give the best schedule compression solution. Comparison and elimination of proposed changes were performed in cases where the impact of one proposed change could make another proposed change less effective if applied together. More details are provided in Chapter 4.

After submitting the final report to the project team, a concluding questionnaire was developed to obtain contractor feedback on the actual application of the proposed changes. Figure 2.8 summarizes the activities and the outcome of this step.

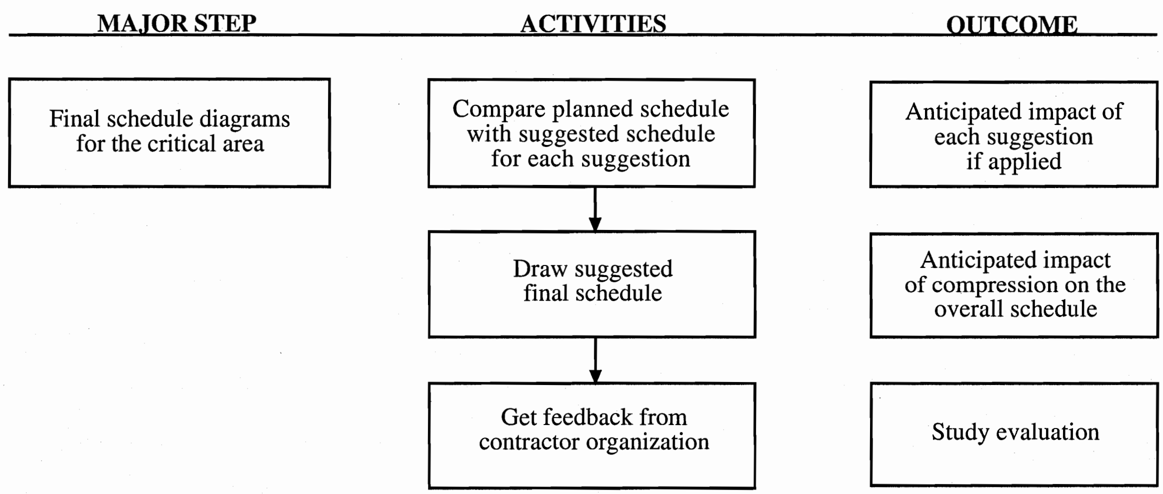

Figure 2.8. Proposed Schedule for the Critical Area

CHAPTER 3.
PROJECT DESCRIPTION AND LITERATURE REVIEW

PROJECT DESCRIPTION

The NCE lies in the heart of Dallas, linking Dallas' central business district (CBD) with the major urban and suburban areas of North Dallas. Almost 25 percent of the office space in Dallas lies in the CBD and the NCE business district.

Originally designed in the late 1940's and built in the early 1950's as one of the most extravagant public infrastructure development projects of its time, it became synonymous with the economic growth of the City of Dallas. It was designed to cater to the traveling needs of 75,000 vehicles per day, and reached its capacity in the early 1970's. For the next decade or so, it went through a period of reconstruction design development. The final design included depressing the main lanes by almost 25 feet in tight right-of-way (ROW) areas, with cantilevered frontage roads overhanging the main lanes. The circumstances associated with this plan presented challenges to project designers and constructors. The three major highlights of this reconstruction project were:

a. construction of user-friendly, extra wide bridges,
b. construction of cantilevered frontage roads, and
c. traffic control during the ten-year reconstruction process.

The nine-mile stretch of the NCE was divided into five individual projects to improve manageability, with each project being less than two miles in length. From LBJ Freeway (at the northern end) to Woodall Rodgers (at the southern end), the reconstructed freeway would have four lanes (increased from two) in both directions with continuous frontage roads and cross-street bridges above the main lanes. The five individual projects were named North 1 (N1), North 2 (N2), Middle (M), South 2 (S2), and South 1 (S1). The scope of this study was limited to a segment of the S1 project that connects Woodall Rodgers and IH-45 at the south end with the S2 project limits at the north end (see Figure 3.1). At an estimated cost of $110 million, reconstruction of the NCE is one of the largest projects in TxDOT's history.

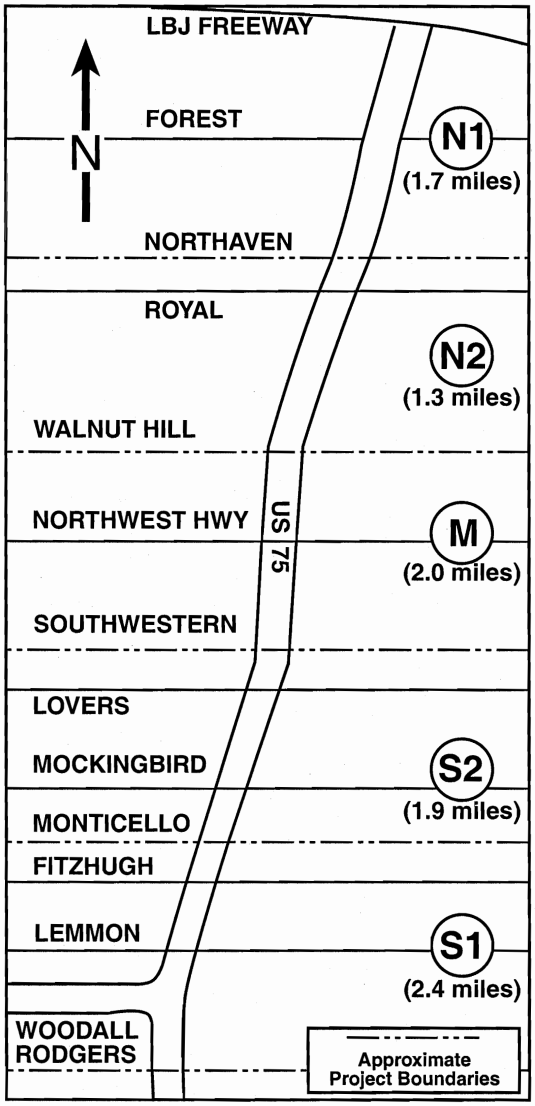

Figure 3.1. NCE Project Sections

LITERATURE REVIEW ON SCHEDULE COMPRESSION

In their 1989 review, Antill and Woodhead described network compression as the expediting of an activity or a group of activities by utilizing additional resources. They stated that this expediting is dependent only on the availability of resources, the form of utility data curves, and the desire to speed up project completion. They defined the utility data curve as the curve showing the relationship between direct cost and time of completion for each of the construction operations. Sample utility data curves of two activities are shown in Figure 3.2.

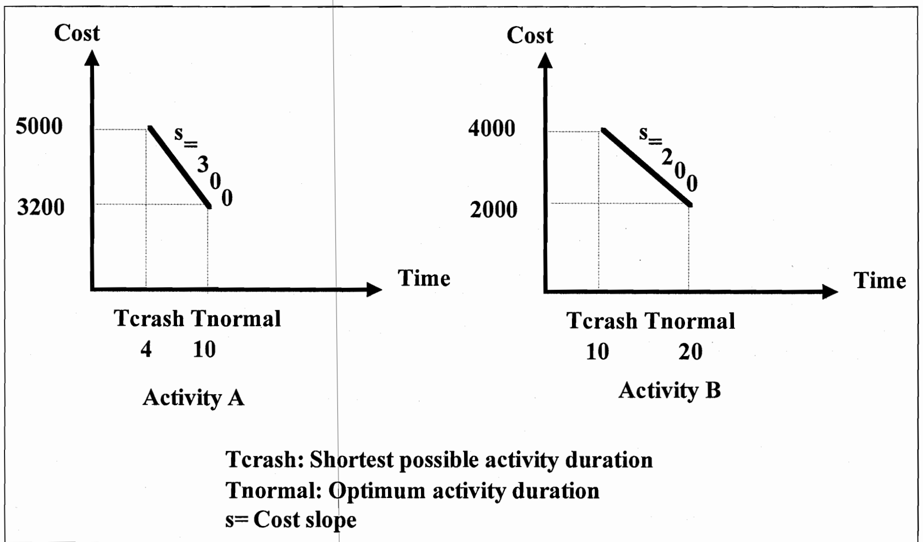

Figure 3.2. Sample Utility Data Curves

Figure 3.2 implies that for activity A (cost slope = 300), the schedule can be crashed by six days with an additional cost of $1,800. On the other hand, activity B (cost slope = 200) can be crashed by ten days with an additional cost of $2,000. The optimum solution would be compressing activity B (with its flatter cost slope). This approach is useful when the utility data curves for all activities are available.

Behrig et al. (1990) provided a detailed study on concepts and methods of schedule compression. They identified schedule compression techniques that can be used in one or more of the engineering, procurement, and construction phases of the project and evaluated each technique's impact on the project cost and duration when applied to the three phases of the project. Accordingly, they addressed 94 concepts and methods of schedule compression, which were grouped under eight major headings, and are as follows.

a. Ideas applicable to all phases of a project: These methods can be applied to any phase of the project. A few examples are "avoidance of interruption," "efficient staffing," and "incorporation of incentives."

b. Engineering phase: These methods are recommended for use in the engineering phase of the project. A few examples are "change management system during engineering," "constructability analysis during engineering," and "freezing of project scope."
c. Contractual approach: These methods are recommended for use prior to the issuance of contracts and/or subcontracts. A few examples are "fast-track scheduling," "fair risk assignment," and "minimizing owner involvement."
d. Scheduling: These methods relate to the scheduling phase of the project. A few examples are "realistic scheduling," "start-up driven scheduling," and "use of float flexibility."
e. Materials management: These methods address the schedule compression opportunities that come from better materials management. A few examples are "just-in-time material deliveries," "dedicated truck shipments," and "product identification."
f. Construction work management: These methods address the construction management issues in the field. A few examples are "advanced construction equipment," "critical equipment contingency planning," and "making site a good place to work."
g. Field labor management: These methods address the compression opportunities that come from better field labor management. A few examples are "pre-work briefings," "crew training and rehearsals," and "labor minimization."
h. Start-up phase: These methods are recommended for use in the start-up phase. A few examples are "minimizing scope of start-up," "temporary start-up systems," and "start-up planning."

Popescu[1] presented the following techniques to reduce activity duration:

[1] C. M. Popescu, Ph.D., Professor of Civil Engineering at The University of Texas at Austin, course notes from 1998 time management course.

a. select an alternate technology or production process,

b. allocate more resources if possible,

c. implement overtime schedule, and

e. eliminate/reduce imposed delay(s).

The literature indicates that there are several methods and techniques for schedule compression. However, the selection of a method requires careful consideration of many variables. Most importantly, management must consider all the project activities that will be impacted when the method is applied and predict the possible outcome of the action.

LITERATURE REVIEW ON THE LSM

Origins of the LSM

The exact origins of the LSM are not clear, and indeed there may have been multiple origins. There is no definitive information as to when linear scheduling techniques were first used to develop production schedules. Reviewing the available literature, it is apparent that interpretation and application of the method by researchers followed slightly different paths, and yet were based on common features: repetitive units of work and known or estimated rates at which these units are produced.

The LSM has some relationship to the line of balance (LOB) technique, a scheduling method developed by the U.S. Navy in the early 1950s for industrial manufacturing and production control. The objective of the LOB technique is to ensure that components or subassemblies are available at the time they are required to meet the production schedule of the final assembly. O'Brien (1969) summarized the technique in relation to the scheduling of manufacturing processes. Three diagrams are used in the LOB technique, as shown in Figure 3.3. A production diagram (Figure 3.3.a) shows the relationship of the assembly operations for a single unit. An objective diagram (Figure 3.3.b) is used to plot the planned or actual (or both) number of units produced versus time. A progress diagram (Figure 3.3.c) is prepared for any particular date of interest during the production process. The progress diagram shows the number of units for which each of the subassembly operations has been completed.

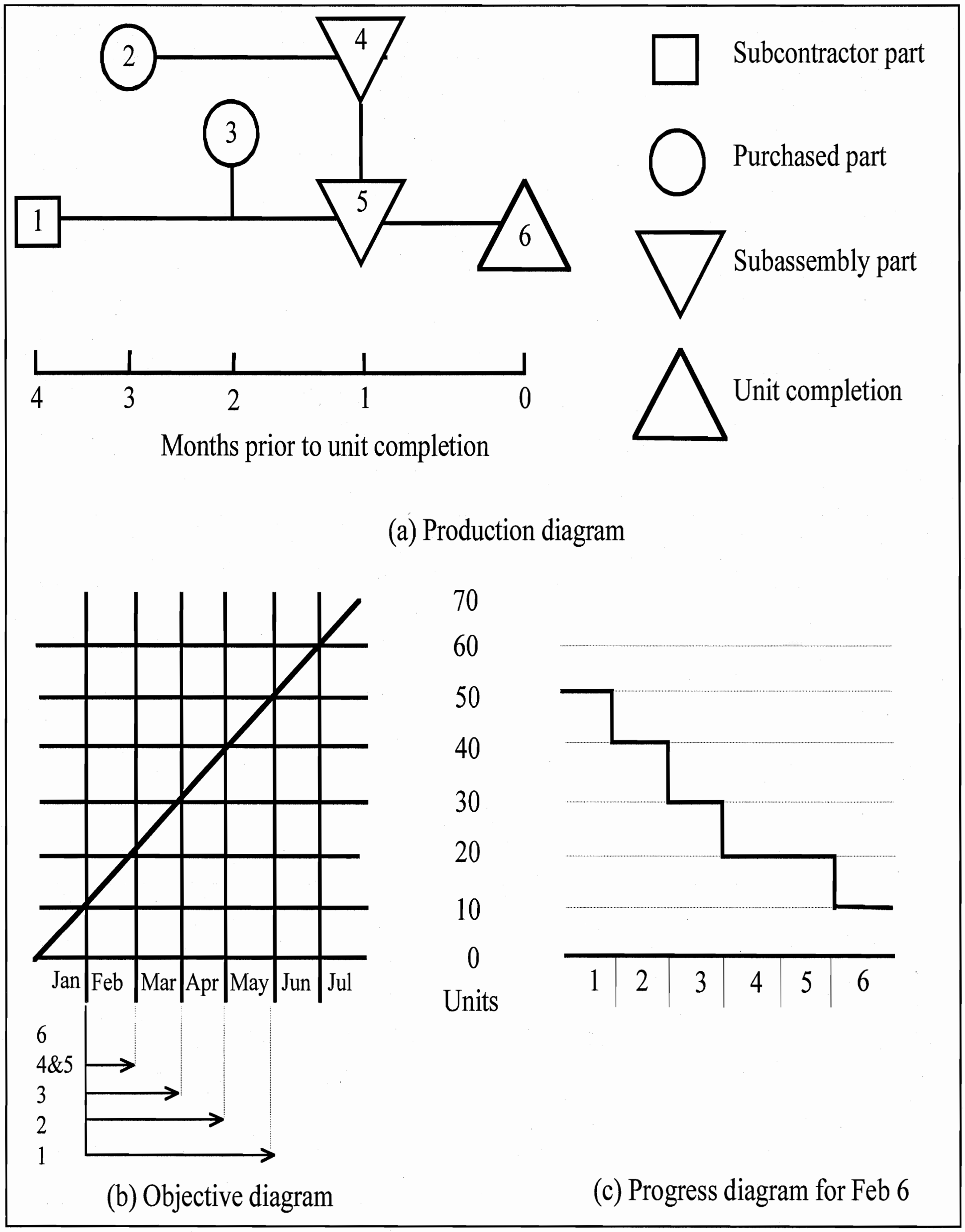

Figure 3.3. Line of Balance Technique Example

O'Brien mentioned that the production diagram of LOB is similar to an activity-on-arrow network, except that it is a network showing assembly operations for only one unit of many produced. The production diagram places primary emphasis on the event ending each assembly task.

O'Brien compared the progress diagram with the bar chart in his analysis. Prepared for a particular date, the progress diagram graphs, as a vertical bar for each task, the actual number of unit tasks completed. Actual progress is compared to the "line of balance," a level of progress needed on each task at the particular date to achieve the objective. He stated that the bar chart is different in the sense that it graphs tasks on the vertical axis versus the time period of activity on the horizontal axis. In his analysis, O'Brien mentioned that the LSM diagram resembles the objective diagram of the LOB technique in that they both use time as one axis and some measure of production as the perpendicular axis. However, the objective diagram, as seen in Figure 3.1.b, is used to schedule or record the cumulative events of unit completion, whereas the LSM diagram is used to plan or record progress of multiple activities that are moving continuously in sequence along the length of a single project. In conclusion, he stated that any differentiation between the LSM and the LOB techniques might only be a question of emphasis. LSM emphasizes a diagram similar to the objective diagram for planning purposes, while LOB puts more emphasis on the balance line of the progress diagram.

Carr and Meyer (1974) applied the LOB technique to construction planning of repetitive building units. Details of the methods were presented, as well as an examination of the method in relation to complementary CPM and bar chart methods. Popescu of the University of Texas at Austin presented a simplified example of the application of the LOB technique to repetitive building units in his graduate course, Time Management (Figure 3.4).

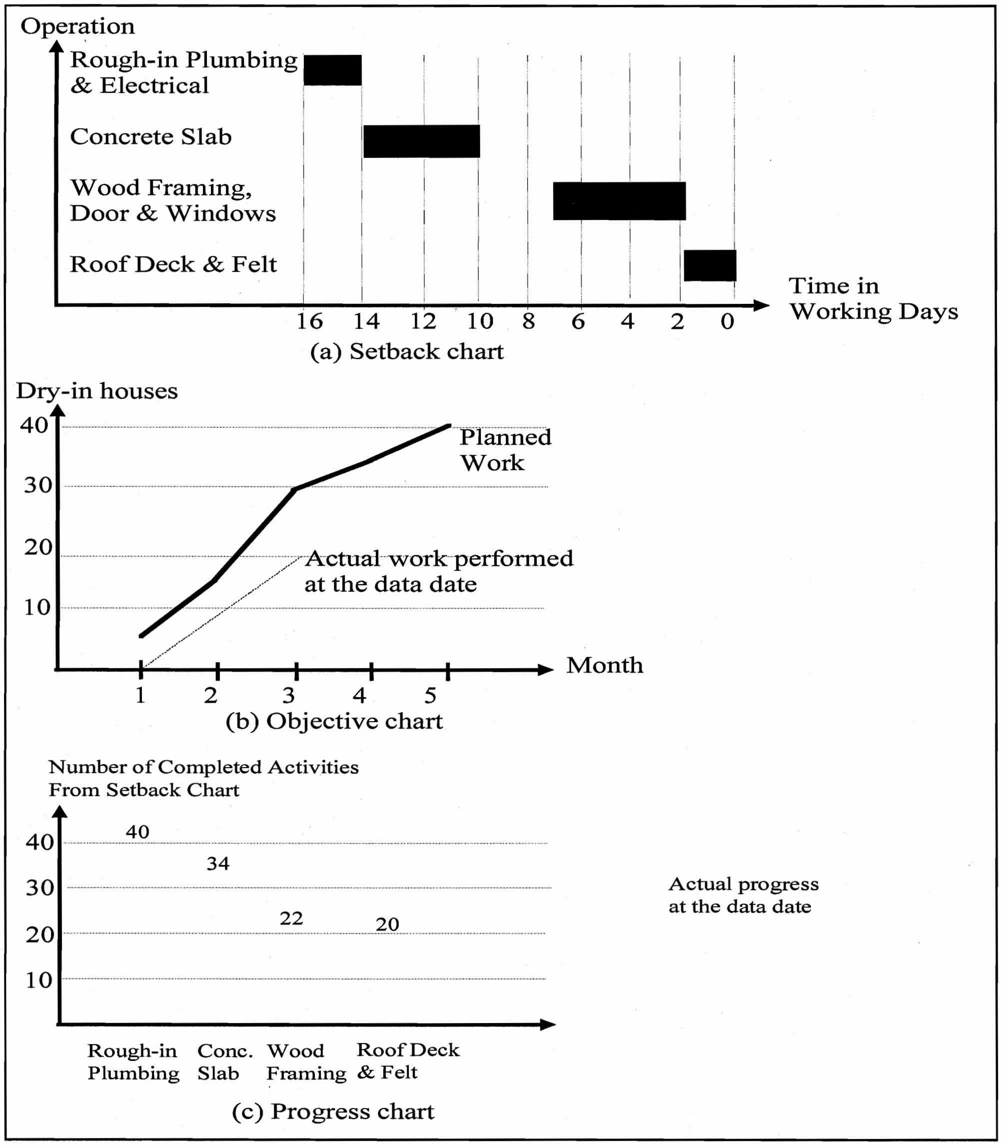

Figure 3.4. Example of LOB Technique for Construction

The sample project presented in Figure 3.4 encompasses the construction of small, wood-framed house dry-in operations. The setback chart (Figure 3.4.a) shows the operations involved in a repetitive project in their proper order. The objective chart (Figure 3.4.b) is used to schedule the work. It displays the planned number versus completed number of houses plotted on a time line. The third diagram, the progress chart, shows the number of repetitive activities completed at a specific date (data date). Arditi and Albulak (1986) addressed the flaws of this method. Specifically, they stated that the method is extremely sensitive to errors in the activity duration estimates. This attribute dictates that the estimation of the production rates should be performed with the highest possible precision.

Publications relating the LSM to highway and other transportation projects are more limited. Spang and Zimmerman (1967) described the construction of a tunnel by using a Linear Schedule Diagram showing time versus distance along the tunnel for the major activities. They found that this method improved the communication of schedule information through visual impact. In his 1981 review, Johnston described a graphical method that was particularly applicable to linear projects. He foresaw the use of the method in U. S. highway construction and maintenance projects, adding that the method was increasingly being used in the Middle East. Recently, several books on construction management have included brief sections about LSM. However, the reviewed books do not give many details about the method, and seemingly only intended to inform readers of the existence of the method.

Principles of the LSM

The LSM can be applied in different forms pursuing different objectives, as discussed in the previous section. Accordingly, researchers have discussed different sets of principles in their studies. Parvin and Vorster (1993) presented the principles of the LSM that they recommend to highway contractors. Those principles will be discussed in this section with a minor change in the axes selection. Parvin and Vorster represented location with the horizontal axis and time with the vertical axis. To facilitate the understanding of the method, the axes will be reversed. In other words, location will be plotted on the vertical axis and time will be plotted on the horizontal axis, matching the application on the NCE project.

Components of a Linear Schedule

Axes. The x-axis, or the horizontal dimension, is used to measure time. The starting date of the schedule is located at the leftmost point of the horizontal axis. The time scale is chosen to fit the scope of a particular project. Possible units for measuring time on the x-axis are working days, calendar days, or weeks. The y-axis, or the vertical dimension, is used to measure location and distance. Highway projects are linear by nature, allowing locations along the highway to be visualized as points along the vertical axis of the schedule. Possible units for measuring distance are feet, stations, miles, meters, or kilometers.

Sight Lines. After defining axes for the linear schedule, additional horizontal and vertical lines should be drawn to make the diagram easier to read. These sight lines provide visual guidance between the axes and the area used for drawing the schedule. Vertical lines correspond to dates in time, whereas horizontal lines correspond to locations. Figure 3.5 is an example of a linear schedule showing the axes and the sight lines before activities are plotted.

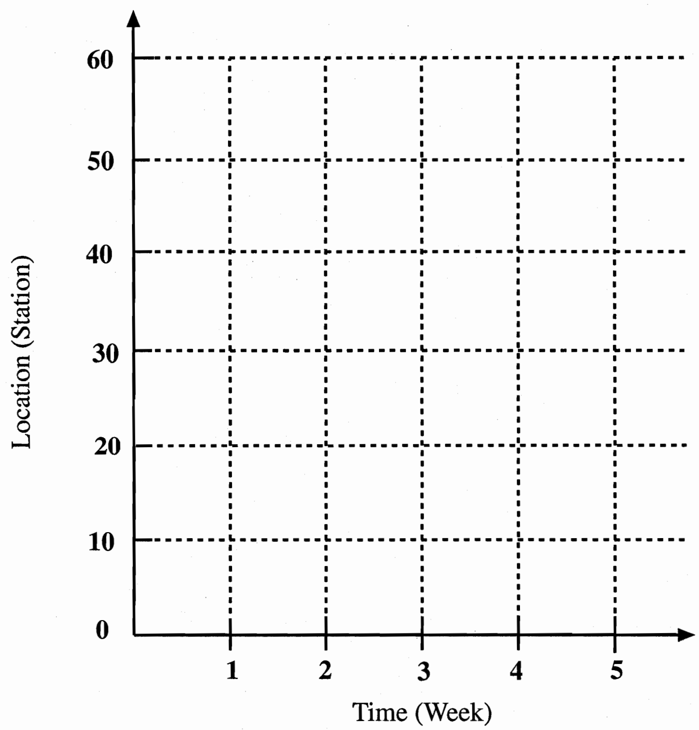

Figure 3.5. Axes and Sight Lines of a Linear Schedule

Location Details. Representation of important physical features of the project on the y-axis is a helpful visual aid in the planning process. A simple plan or profile view of the project can be drawn. Locations of features, such as bridges, culverts, or retaining walls may be placed on the plan view of the schedule. A project plan is shown along the y-axis in Figure 3.5. A bridge and a manhole are graphically represented on the plan view. This illustration strengthens the visual connection achieved between the plan view and the linear schedule, improving comprehension of the schedule.

Indication of constraints. Conditions may exist on a project that prohibit work from taking place in certain locations at certain times. Linear scheduling techniques can display access restrictions on the schedule to provide a visual reminder that an area is unavailable. Examples of access constraints are shown in Figure 3.6. The section between stations 0 and 60 is marked as "Weather Constraint" for the month of December. Similarly, the section between stations ten and 30 is marked as "Access not available" for the first two weeks of February.

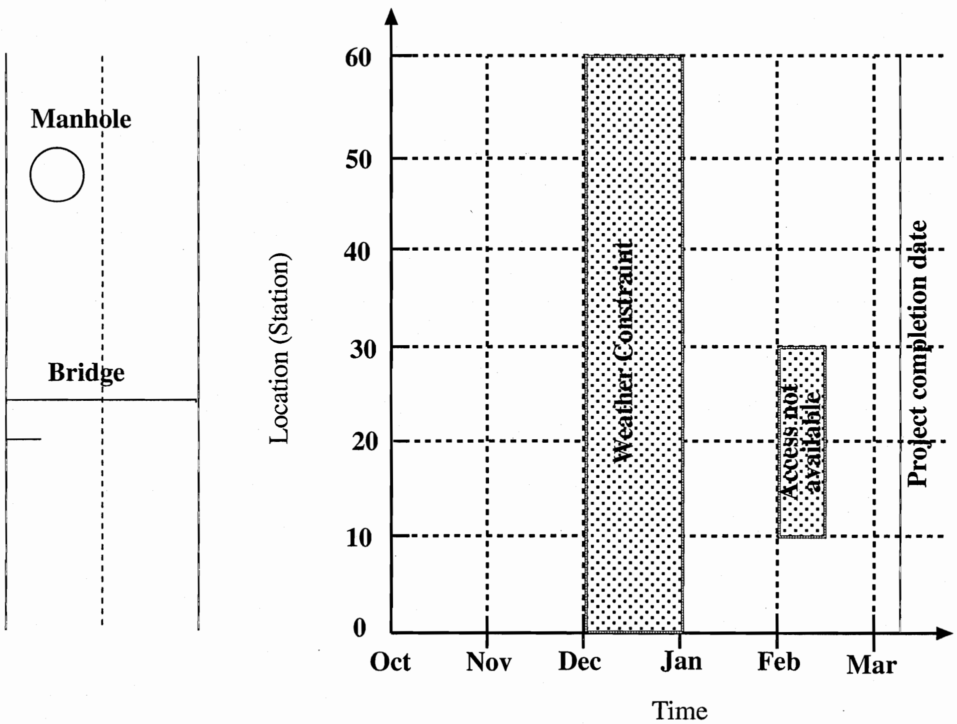

Figure 3.6. Addition of Plan View and Access Profile to Linear Schedule

Activity and crew tracking. Axes, sight lines, and other information drawn on the linear schedule provide the background for planning and scheduling. Once the axes and sight lines are plotted, the planning process can begin. This process involves tracking the construction crews and the work they perform. Three symbols—bars, lines, and blocks—are used when drawing the linear schedule to represent crews and their work. A *bar* is a horizontal line used to represent a crew working in one place for a long period of time, and is defined by its given location and the time needed to complete the work period. A *line* represents work activities with continuous movement, and is drawn to track the movement of a crew through the project as time progresses. The slope of the line represents the rate of progress or productivity of the crew. A *block* is a rectangle denoting the time and space occupied by a crew as it performs an operation in part of the work area. Certain activities, such as grading, require work to be performed over a given section of the project for an extended period. Time and space are needed to perform the work, and the crew does not necessarily progress smoothly in one direction. Figure 3.7 shows a linear schedule with the symbols described above. The position of the bar indicates that the manhole is located at station 50. The beginning of the bar signifies that the activity starts at the beginning of Week 2 and is completed at the end of the same week. The lines in the schedule represent two activities, placing base course and paving between stations 0 and 60. It is obvious that the rate of progress of placing base course is faster than the rate of paving. A steeper line, rather than a flatter line, indicates a faster rate of progress. The block, representing the grading activity, shows that the grading operation is performed between stations 24 and 60 in Week 3 and covers the entire area between those stations.

As illustrated with the examples, linear schedules are easy to understand and reflect the characteristics of schedules more effectively than CPM schedules. Avoiding the establishment of concrete relations between project activities is the power of linear scheduling, making it a flexible tool for the use of project managers. The visual aspect of the linear schedule helps identify existing relationships and encourages the project team to try different alternatives. On the contrary, a CPM network relies on concrete activity relationships, and the construction logic is difficult to change once the relations are established. This attribute is more evident in complex projects such as the NCE reconstruction. Any attempt to manipulate the logic would cause several "out-of-logic activities" after having the software compute the network.

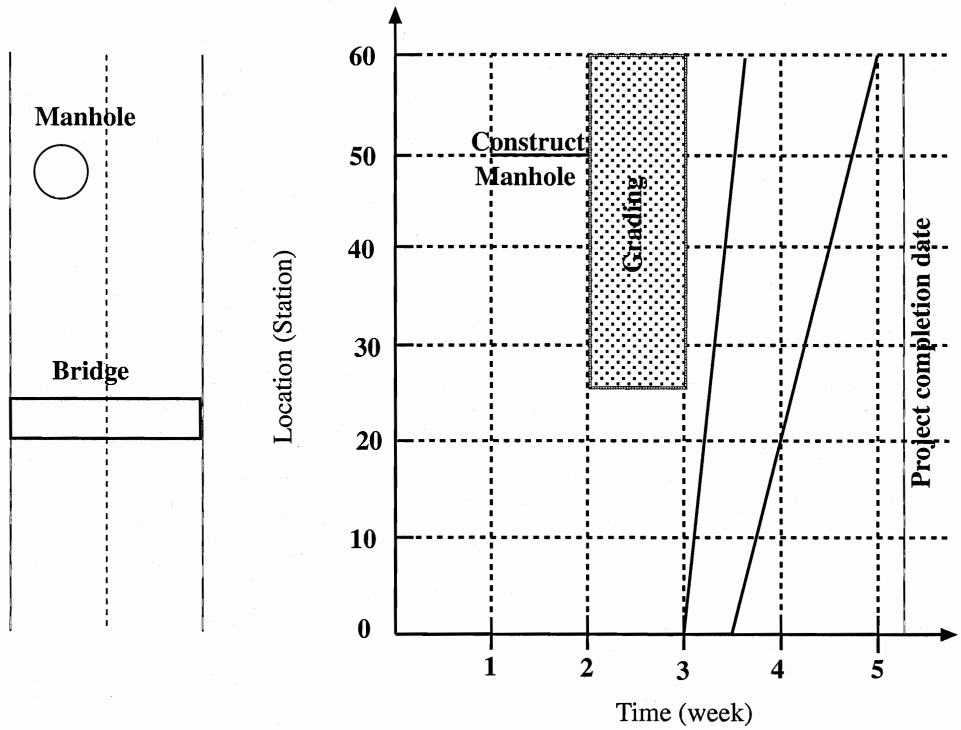

Figure 3.7. Example of Complete Linear Schedule

Need for Linear Scheduling

Parvin and Vorster (1993) compared building construction with highway construction, stating that building construction is detail oriented, demanding management's focus at the activity level of construction. They further emphasized the importance of labor and subcontractors in building projects. Another important attribute of building projects is that they are confined within a relatively small region. According to the authors, CPM schedules were developed for use in building construction where the relationships between activities are critical; however, many alternatives exist in highway construction. While certain operations must follow other operations, it is possible to pursue the work by beginning at, or changing to, different locations. In their analysis, Parvin and Vorster emphasized the importance of equipment in highway construction, whereas building construction requires the coordination of subcontractors and labor is a more important aspect. They concluded that because of the differences, it is not surprising that techniques developed for scheduling buildings, such as CPM, may not fulfill the needs of highway construction.

Johnston (1981) discussed the need for a new scheduling method to provide better management of linear projects. He analyzed CPM and PERT, and found that both approaches represented individual project activities as being discrete with the next activity starting when the previous activity is completed. He stated that this approach might not suit the needs of projects where the activities progress continuously in sequence throughout their length. Transportation projects exhibit this characteristic. He mentioned that the effort required to develop and update complex networks had discouraged many contractors. In response, contractors often preferred the simplicity of the bar charts. However, Johnston does not recommend the use of bar charts due to their weakness in indicating activity interdependence. In conclusion, he stated that an alternate approach was needed for linear construction projects and recommended the use of linear scheduling.

Use of the LSM in the Industry

In his 1981 review, Johnston assessed the possibilities for use of the LSM, conducting a limited survey to determine if the method was recognized or known to have been used in the U.S. Another survey objective was to obtain responses concerning potential for use and apparent advantages and disadvantages. In conclusion, he found that the respondents were not familiar with the method, nor had they seen it used on any project in the U.S. This does not mean that it has not been used at all in the U.S., however it does indicate that the method has not had much exposure. When the respondents were asked to assess the method's potential, they cited various advantages and disadvantages. One of the disadvantages raised was that highway construction projects are not as linear as they appear. Projects involving large cuts and fills were viewed as being more difficult to schedule with LSM than those in largely flat or gently rolling terrain. Respondents pointed out that maintenance projects such as resurfacing, shoulder improvement, and efforts to cold plane and hot plane would be good types of projects for the LSM.

A more recent study was conducted by Dr. Zohar Herbsman of the University of Florida (Simms 1998) through surveys sent to each of the state departments of transportation. Survey results seemed to indicate a definite interest in the use of LSM in the highway construction industry, but there existed a lack of familiarity and no apparent driving force for more widespread use. The survey results are presented in Table 3.1

Six generic schedule compression strategies are applicable to linear scheduling, and are now defined. (These strategies are treated in more detail in Chapter 4.)

a. Overlapping activities. Performing two or more activities at the same time instead of in sequence can shorten the overall schedule.
b. Additional resources allocation. Increasing the equipment and/or crew for an activity can shorten the overall schedule.
c. Changing the technology used. The equipment and construction materials that are utilized on the project are analyzed. Alternative technologies may enable schedule compression.
d. Changing construction logic. The technique involves changing the sequence of two or more activities; i.e., switching the predecessor and successor activities or modifying a finish-to-start relationship.
e. Implementing shift work. Any additional work shift will increase output and shorten the schedule.
f. Increasing utilization (overtime). Extended work hours will increase output and shorten the schedule.

Table 3.1. Survey on the Use of LSM

State Dept. Of Transportation[1]	Reports using Linear Scheduling Method		Reports Familiarity with Linear Scheduling Method		
	Yes	No	Very	Somewhat	None
Alabama		X			X
Arizona		X			X
Arkansas		X			X
California		X			X
Colorado		X		X	
Connecticut	X[2]		X		
Delaware		X		X	
Florida		X[5]		X	
Georgia		X[6]		X	
Idaho		X			X
Indiana		X			X
Iowa		X[7]		X	
Kansas		X			X
Kentucky		X		X	
Louisiana		X			X
Maryland		X			X
Mississippi		X			X
Missouri		X			X
Montana		X			X
Nebraska		X[3]			X
New Jersey		X		X	
New York		X		X	
Nevada		X		X	
North Carolina		X			X
North Dakota		X			X
Oregon		X[3]			X
Pennsylvania		X[3]			X
South Carolina		X			X
South Dakota		X			X
Texas	X[2]		X		

Utah		X[4]			X
Vermont		X			X
Virginia	At contractors' option[8]		X		
Washington		X			X
West Virginia		X			X
Wisconsin	Not Required[8]			X	

Notes:
[1] Only 36 states, as listed, responded to the survey.
[2] Reports using in claim analysis.
[3] Reports using LSM; actually using Bar Charts/CPM.
[4] Reports using LSM; actually using SureTrak.
[5] Interested, but wants better software.
[6] Considering trial use with some projects.
[7] Has funded research to develop specifications & software.
[8] Used by several contractors.

CHAPTER 4.
SCHEDULE COMPRESSION ANALYSIS FOR NORTH CENTRAL EXPRESSWAY (NCE)

OVERVIEW

The methodology for the study was presented in Chapter 2. This chapter describes the application of the methodology on the NCE S1 project, and includes the WBS for the critical area and the activity list, along with pertinent information such as quantity of work and allocated resources. The As-Planned linear schedule, which was developed using the collected data, is presented. The schedule compression techniques that were applied to the As-Planned schedule are described, and the proposed changes based on these techniques are listed. A proposed schedule is also presented for review. The anticipated impacts of proposed changes on labor, material, and equipment costs are evaluated, and a brief analysis of the project engineer's response to the proposed changes is performed. The schedule compression analysis method that the author recommends for future projects is presented at the end of the chapter.

WBS FOR THE CRITICAL AREA

Before developing the As-Planned schedule for the critical area, a WBS was developed to ensure that the scope of work was adequately defined. The WBS segmented the project through successive levels of details to the lowest level of detail required to identify the activities associated with the WBS work packages. The WBS provided an easy-to-follow numbering system to allow for a hierarchical tracking of levels. The first level of the WBS, given the work item code "1.0," represented the project. Level 2, given the work item code "1.1," stood for the selected critical area. Level 3 was characterized with "1.1.X," with "X" being the identifier for that level. The lowest level of the WBS, referred to as work packages, was characterized with "1.1.X.n," with "n" being the identifier. WBS for the selected area is presented in Figure 4.1.

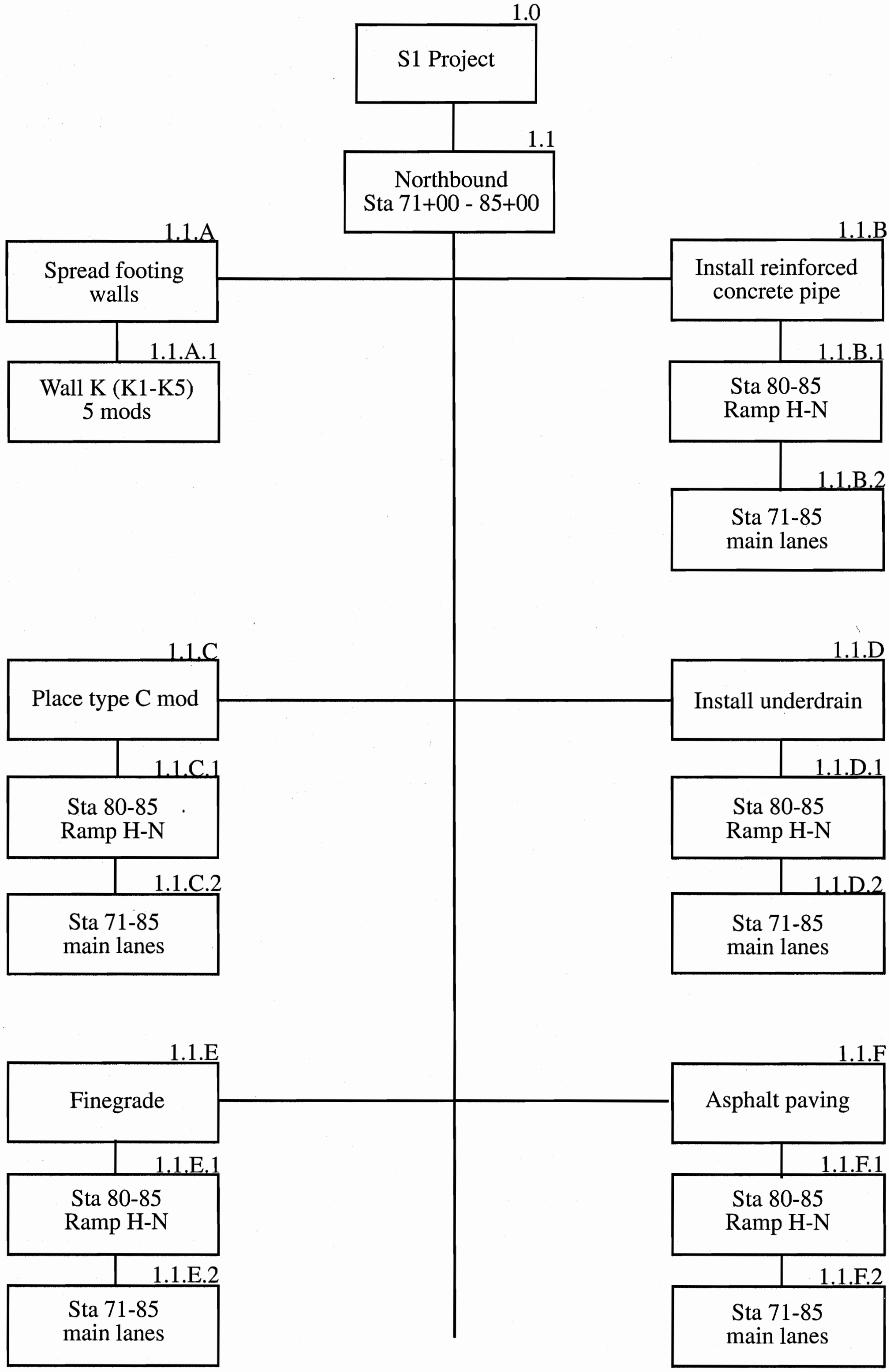

Figure 4.1. WBS for the Critical Area

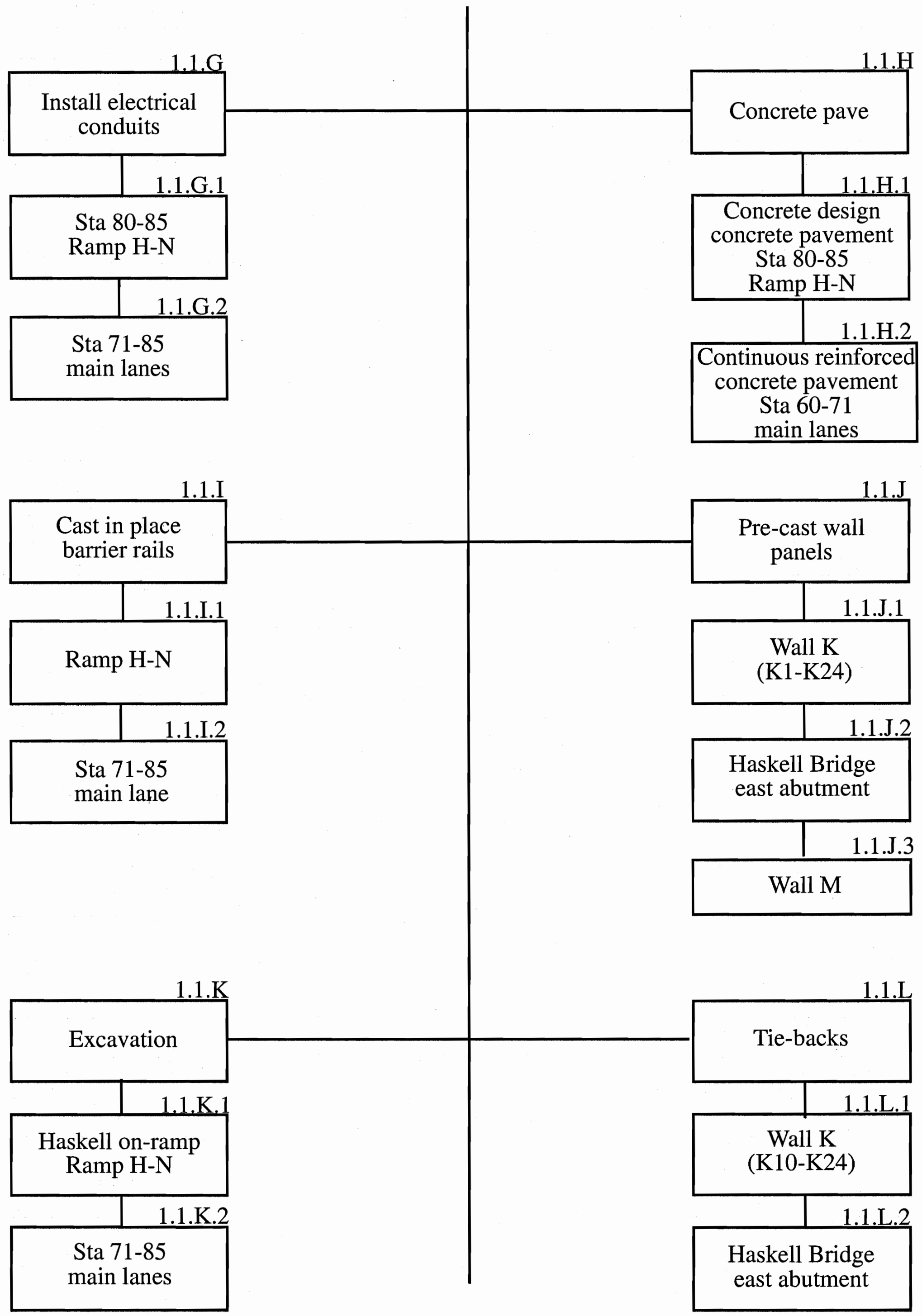

Figure 4.1. WBS for the Critical Area (cont'd)

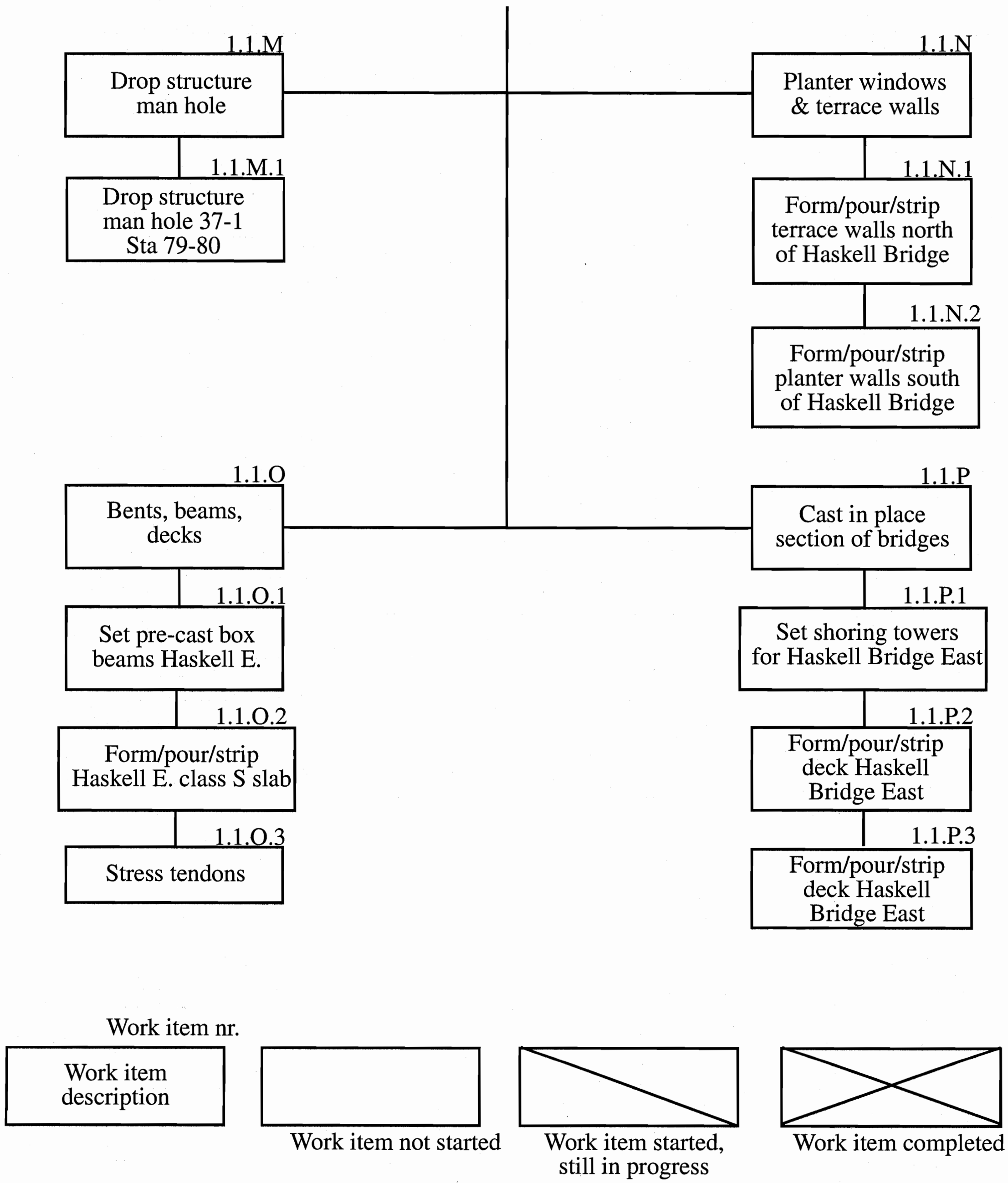

Figure 4.1. WBS for the Critical Area (cont'd)

THE AS-PLANNED LINEAR SCHEDULE

The WBS was presented to the project team to ensure that every major item in the work scope was taken into consideration. Upon completion of the WBS, the activity list for the critical area was developed. Generally, four different relationships between WBS structure and activity list may exist.

1. Each work package corresponds to an activity.
2. A work package corresponds to more than one activity.
3. An activity corresponds to more than one work package
4. More than one activity corresponds to more than one work package.

The first two approaches are most common, with the first option being preferred in this study. Some work packages were split further while developing the schedule.

After identifying all activities along with the associated WBS code, quantity take-off was performed to estimate the quantities of work. The production rate for each activity was estimated based on the historical company data and the personal experience of the contractor's project engineer. Estimated duration for each activity was then calculated by dividing estimated quantity into estimated production rate for the related activity. Each activity was assigned a crew code to represent the crew that would perform the activity. The activity list containing the above mentioned data is presented in Table 4.1.

Crew compositions and allocated equipment are presented in Table 4.2. The crew codes correspond to those presented in Table 4.1. The data displayed in Tables 4.1 and 4.2 were adequate to develop the As-Planned linear schedule for the critical area.

Based on the principles of the LSM that were discussed in Chapter 3, the As-Planned linear schedule was developed, and is presented in Appendix A. The approximate completion date was found to be the end of December 1999, which was in compliance with the project team's anticipated timeline.

Table 4.1. Planned Activities for the Critical Area

Activity Description	WBS Code	Unit	Quantity	Production Rate	Duration (Working Days)	Crew Code
North Bound Sta. 71+00 – 85+00						
Construct spread footing wall Wall K	1.1.A.1	modules	5 modules*	1 module/5 day	25	SF-1
Install reinforced concrete pipeline Ramp H-N	1.1.B.1	ft	250	100 ft/day	3	P-1
Place type C mod/Ramp H-N	1.1.C.1	cy	1,000	1,200 cy/day	1	MD-1
Install underdrain/Ramp H-N	1.1.D.1	ft	500	200 ft/day	3	U-1
Finegrade/Ramp H-N	1.1.E.1	sy	2,000	225 cy/day	8	F-1
Asphalt pave/Ramp H-N	1.1.F.1	lifts	2	2 lifts/3 days	3	AC-1
Install electrical conduits/Ramp H-N	1.1.G.1	ft	500	750 ft/day	1	EC-1
Contract design concrete pavement Ramp H-N	1.1.H.1	cy	722	60 cy/day	12	CP-1
Cast in place barrier rails Ramp H-N	1.1.I.1	ft	480	96 ft/day	5	BR-1
Set pre-cast wall panels Wall M	1.1.J.3	pcs	72	9 pcs/day	8	WP-1
Excavate mainline Sta. 71-85	1.1.K.2	cy	34,000	2,000 cy/day	17	E-1
Drill t-backs Haskell east abutment Row #1	1.1.L.2	ea	4	12-15 ea/day	1	T-1
Drill t-backs Haskell east abutment Row #2	1.1.L.2	ea	18	12-15 ea/day	2	T-1
Drill t-backs Haskell east abutment Row #3	1.1.L.2	ea	39	12-15 ea/day	4	T-1
Drill t-backs–Wall K15-K10 Row #1	1.1.L.1	ea	41	12-15 ea/day	3	T-1
Drill t-backs–Wall K16-K10 Row #2	1.1.L.1	ea	48	12-15 ea/day	4	T-1
Drill t-backs–Wall K24-K12 Row #3	1.1.L.1	ea	96	12-15 ea/day	8	T-1
Stress t-backs Haskell east abutment Row #1	1.1.L.2	ea	4	60 ea/day	1	S-1
Stress t-backs Haskell east abutment Row #2	1.1.L.2	ea	18	60 ea/day	1	S-1
Stress t-backs Haskell east abutment Row #3	1.1.L.2	ea	39	60 ea/day	1	S-1

* Module: Each module is 48 ft. long

Table 4.1. Planned Activities for the Critical Area (cont'd)

Activity Description	**WBS Code**	**Unit**	**Quantity**	**Production Rate**	**Duration (Working Days)**	**Crew Code**
Stress t-backs–Wall K15-K10 Row#1	1.1.L.1	ea	41	60 ea/day	1	S-1
Stress t-backs–Wall K15-K10 Row#2	1.1.L.1	ea	48	60 ea/day	1	S-1
Stress t-backs–Wall K24-K12 Row#3	1.1.L.1	ea	96	60 ea/day	2	S-1
Construct drop structure man hole 37-1	1.1.M.1	ea.	1	9 days/ea	9	MH-1
Install reinforced concrete pipeline–Sta 71-85	1.1.B.2	ft	1,500	100 ft/day	15	P-1
Place type C mod/main lane/Sta 71-85	1.1.C.2	cy	7,200	1,200 cy/day	6	MD-1
Install underdrain/main lane/Sta 71-85	1.1.D.2	ft	2,800	200 ft/day	14	U-1
Finegrade/main lane/Sta 71-85	1.1.E.2	ft	12,000	1,500 ft/day	8	F-1
Asphalt pave/main lane/Sta 71-85	1.1.F.2	lifts	2	2 lifts/3 days	3	AC-1
Continuous reinforced concrete pave main lane/Sta 71-85	1.1.H.2	cy	4,450	130 cy/day	36	CR-1
Cast-in-place barrier rails–Sta 71-85	1.1.I.2	ft	1,400	96 ft/day	15	BR-1
Set pre-cast wall panels–Wall K	1.1.J.1	pcs	84	9 pcs/day	10	WP-1
Se pre-cast wall panels–Haskell Bridge abutment	1.1.J.2	pcs	57	9 pcs/day	7	WP-2
Complete planter windows south of Haskell Bridge	1.1.N.2	modules	2 modules*	1 module/3 day	6	PW-1

Each module is 48 ft. long

Table 4.2. Allocated Resources

Activity	Crew Code	Labor Composition	Equipment Involved
Excavation	E-1	1 operator, 1 ticket signer, 1 flagger, variable number of trucks and drivers, 1 foreman	Excavator (CAT 375 or 350)
Drilling tiebacks	T-1	1 operator, 2 laborers, 1 driver, 1 foreman	Drill w/rig, grouting truck
Stressing tiebacks	S-1	2 laborers, 1 foreman	Hydraulic jack
Construction of mechanically stabilized earth wall	MS-1	1 structures crew (10 men), 3 carpenters, 2 laborers, truck drivers, 1 foreman	Concrete trucks
Installing reinforced concrete pipeline	P-1	1 operator, 1 grade checker, 1 laborer, 1 loader operator, 1 foreman	Excavator (CAT 235)
Placing mod	MD-1	2 operators, 2 grade checkers, 1 foreman	Compactor (CAT 815) Motor grader
Installing underdrain	U-1	2 operators, 2 laborers, 1 foreman	Trencher Backhoe (CAT 446)
Finegrading	F-1	3 operators, 2 grade checkers, 1 foreman	Motor grader, mixer Compactor (CAT 815)
Asphalt paving	AC-1	3 operators, 2 laborers, 1 foreman	Paving machine, 2 rollers
Installing conduits	EC-1	1 operator, 2 laborers, 1 foreman	Trencher
Continuous reinforced concrete pave main lane	CR-1	10-man structure crew, truck drivers,1 foreman	Concrete trucks
Contract design concrete pavement main lane	CR-1	10-man structure crew, truck drivers, 1 foreman	Concrete trucks
Cast-in-place barrier rails	BR-1	1 operator, 4 carpenters, 2 finishers, 1 foreman	Crane
Setting pre-cast wall panels	WP-1, 2	1 operator, 4 laborers, 1 foreman	Crane
Constructing spread footing wall	SF-1	10-man structure crew, 3 carpenters, 2 laborers, truck drivers, 1 foreman	Concrete trucks
Constructing drop structure man hole	MH-1	2 operators, 3 laborers, 1 foreman	Drill, crane
Completing planter windows and terrace walls	PW-1	5-man structure crew, 2 carpenters, 1 laborer, 1 foreman	No major equipment
Setting pre-cast box beams	BB-1	1 operator, 2 riggers, 4 beam setters, 1 foreman	Crane
Form/pour/strip class S slab	ST-1	10-man structure crew, truck drivers, 1 foreman	Concrete trucks

PROPOSED SCHEDULE COMPRESSION CHANGES

The linear schedule displayed in Appendix A reflected the plan that would be followed by the project team to construct the critical area. The next step was to apply the schedule compression techniques to the activities in the developed schedule. The following sections elaborate on the applied techniques and characterize the anticipated results. The brief descriptions of the techniques that were provided in Chapter 3 are repeated in this section.

Overlapping Activities (Proposed Changes #1-3)

Description of the technique. Performing two or more activities at the same time instead of sequentially can shorten the overall schedule.

<u>Proposed Change #1</u>

Subject activities: "Complete planter terraces" and "complete planter windows."

Current application: The activities are scheduled sequentially because the same crew (PW-1) is allocated to both activities.

Proposed Change: Two activities may be overlapped if another crew is allocated for one of the activities.

Anticipated Result: One week of compression. The anticipated result is graphically displayed in Appendix B.

<u>Proposed Change #2</u>

Subject activities: "Concrete pave (CRCP) between Sta. 71 and Sta. 85" and "construct cast-in-place barrier rails."

Current Application: The activities are scheduled sequentially. In other words, forming the rails does not start before concrete paving is completed.

Proposed Change: Forming the barrier rails can start after two pours (36 ft.) are accomplished. That makes it possible for the forming crew to start the activity two weeks after paving activity starts.

Anticipated result: 25 days of compression. The anticipated result is graphically displayed in Appendix C.

Proposed Change #3

Subject activities: "Construct the barrier rails" and "install pre-cast wall panels."

Current application: The activities are scheduled sequentially.

Proposed Change: It is mandatory to allow six days for the curing period of concrete after each pour. Therefore, the curing period is the driving factor while overlapping the activities. The activities can be scheduled with a finish-to-finish relationship with six days lag time. Since the "installing wall panels" activity has a steeper line due to the high production rate of pre-casting, the two lines do not intersect each other.

Anticipated result: Four days of compression. The anticipated result is graphically displayed in Appendix D.

Additional Resource Allocation (Proposed Changes #4-6)

Description of the technique. Increasing the equipment and/or crew for an activity can shorten the overall schedule.

Proposed Change #4

Subject activity: "Install underdrain between Sta. 71 and Sta. 85."

Allocated Resources: One trencher, one backhoe, two operators, two laborers, and one foreman.

Proposed Change: An additional trencher and backhoe with operating crew will help accelerate the activity.

Anticipated result: The limited workspace is likely to cause some productivity loss. Assuming the average loss is ten percent, total production rate will increase from 200 to 360 ft/day. Accordingly, the activity duration will be reduced from 17 to ten days, which warrants seven days of compression.

Proposed Change #5

Subject activity: "Construct cast-in-place barrier rails."

Allocated resources: One crane, one operator, four carpenters, two finishers, and one foreman.

Proposed Change: Allocating another crew and crane will increase the production rate. More forms will be needed accordingly.

Anticipated result: Taking the ten percent productivity loss into consideration, average production rate for the activity will increase from 96 to 172 ft/day. Accordingly, the activity duration will decrease from 20 to 11 days, which translates to nine days of compression.

Proposed Change #6

Subject activity: "Set pre-cast wall panels and do the closures between panels."

Allocated resources: One crane, one operator, four laborers, and one foreman. The same crew installs the wall panels and spends the remainder of the day on the panel closures.

Proposed Change: Allocating another crew solely for the closure will double the productivity. In that way, the crew that installs the panels will work continuously, followed by the closure crew.

Anticipated result: The activity will be completed in nine days instead of 18. No productivity loss is expected because the crews will not be sharing the same space.

Changing the Technology Used (Proposed Change #7)

Description of the technology. The equipment and construction materials that are utilized on the project are analyzed. Alternative technologies may enable schedule compression.

Subject activity: "Concrete pave (continuous reinforced concrete pavement) between Sta. 71 and Sta. 85."

Current application: The concrete type used in concrete paving is "Class A," requiring that the crew wait four days for curing and a minimum of two days before drilling.

Proposed Change: Class K concrete, which is an early strength concrete type, can be used for paving. In that way, it will be possible to drill the concrete the day after it is poured.

Anticipated result: Eight pours are planned for the concrete paving of the main lanes between Sta. 71 and Sta. 85. The crew has to wait a total of 14 days between the pours. Using early strength concrete will reduce that duration to seven days. The effect on the overall duration depends on the implementation of the other proposed changes. For example, if construction of barrier rails is performed after the completion of the eight pours, then the gain will be seven days, as previously mentioned. However, the gain will be less if two activities are overlapped.

Changing Construction Logic (Proposed Change #8)

Description of the technique. The technique involves changing the sequence of two or more activities, such as switching the predecessor and successor activities or modifying a finish-to-start relationship.

Subject activities: "Drill tiebacks," "stress tiebacks," and "excavate for the next row of tiebacks."

Current sequence: The stressing begins six days after drilling. Excavation for the next row does not start until tiebacks are stressed and grouted.

Proposed Change: Starting excavation right after drilling the tiebacks will eliminate the six-day waiting period. Man lifts will be needed to stress the tiebacks after excavation.

Anticipated result: 17 days of compression. The anticipated result is graphically displayed in Appendix E.

Finally, all proposed changes and their anticipated results are summarized in Table 4.3.

Table 4.3. Proposed Changes and Anticipated Results

Proposed Change	Activities Involved	Utilized Technique	Anticipated Result
1	Planter terraces and planter windows	Overlapping	6 days
2	Continuous reinforced concrete pavement and cast-in-place barrier rails	Overlapping	25 days
3	Barrier rails and pre-cast wall panels	Overlapping	4 days
4	Underdraining	Additional resource allocation	7 days
5	Cast-in-place barrier rails	Additional resource allocation	9 days
6	Setting pre-cast wall panels	Additional resource allocation	9 days
7	Continuous reinforced concrete pavement	Changing technology	6 days
8	Drilling and stressing tiebacks	Changing construction logic	17 days

ANTICIPATED COST IMPACT OF PROPOSED CHANGES

Schedule compression is generally subject to an increase in cost. As discussed in Chapter 3, the activities that can be compressed with the least cost impact should have priority in the compression process. The anticipated cost impact of the proposed changes is displayed in Table 4.4 in terms of the impact on labor and equipment cost. The monetary estimate was not performed due to the scope definition. The table was presented to TxDOT and the contractor as a complementary tool to proposed changes, since they had full access to the cost data.

Table 4.4. Anticipated Labor, Material, and Equipment Cost Impacts from Proposed Changes

Proposed Change	Description of Proposed Change	Impact on Labor Cost	Impact on Material Cost	Impact on Equipment Cost
1	Overlapping construction of planter terraces and windows	Cost of an additional crew	Cost of additional forms and construction tools	No impact
2	Overlapping concrete paving and barrier rails	No impact	No impact	No impact
3	Overlapping barrier rails and pre-cast wall panels	No impact	No impact	No impact
4	Allocating more resources for underdraining	Cost of an additional crew	No impact	Cost of additional trencher and a backhoe
5	Allocating more resources for cast-in-place barrier rails	Cost of an additional crew	No impact	Cost of additional crane
6	Allocating more resources for pre-cast wall panels	Cost of additional crew for closures	No impact	No impact
7	Changing concrete type used	No impact	Extra cost of early strength concrete	No impact
8	Changing logic–excavating before stressing tiebacks	Extra payment to subcontractor for productivity loss		

PROPOSED SCHEDULE

Eight distinct changes were proposed to the project team for consideration. It is essential to consider the impact of one proposed change on others because one change might offset the effect of another change, or it may technically not be possible to implement two proposed changes at the same time. For the sake of argument, proposed change #2 (overlapping concrete paving with the construction of cast-in-place barrier rails) and proposed change #3 (overlapping construction of barrier rails with setting wall panels) cannot be implemented together due to inadequate working space for the three crews. The combination of the proposed changes deemed to be the most efficient was presented to the project team for review, and is given in Appendix F. The substantial completion date of the project was found to be mid-October, 1999 as opposed to the end of December 1999, which was the completion date for the As-Planned schedule.

RESPONSES TO PROPOSED CHANGES

A questionnaire was developed as a follow-up to the report in order to determine the status of the proposed changes. The purpose of the questionnaire was to determine whether the proposed changes were incorporated into the construction schedule and to document the final responses of the project team to the proposed changes. This questionnaire was mailed to the general contractor two months after submission of the report, and is presented in Appendix G.

ANALYSIS OF RESPONSES

The responses can be analyzed based on the schedule compression techniques: overlapping, increasing utilization, changing the technology used, and changing the construction sequence.

The given responses showed that the contractor favored the proposed changes that were developed by overlapping activities. This technique is advantageous because it usually does not impact cost. Proposed changes #2 and #3 were already implemented and proposed change #1 will be implemented in future construction.

Proposed changes related to allocating additional resources were expected to impact at least one of the three cost categories (labor, material, and equipment). The contractor decided that the benefits of proposed changes #4 and #5 would not justify the cost impact. However, the same criterion favored the implementation of proposed change #6, which involved allocating an additional crew just for the panel closures. The cost of the additional crew was more than offset by the reduction in time required to complete the activity. On the other hand, proposed changes #4 and #5 were not incorporated into the proposed schedule either, because their impact would be offset by the implementation of proposed changes #1, #2, and #3.

The techniques of changing the technology used and the construction logic (proposed changes #7 and #8) were both found feasible by the contractor. Proposed change #7 was determined feasible because the reduction in duration justified the cost of early strength concrete. Proposed change #8 was determined to be feasible because the additional payment that would be required for the use of man lifts by the subcontractor was offset by the reduction in time required to complete the tiebacks. For these reasons, proposed change #8 was implemented and proposed change #7 would be implemented for the concrete pour. The linear schedule reflecting approved changes is presented in Appendix H. The completion date was found to be the end of October 1999, a few weeks later than the completion date on the proposed schedule.

RECOMMENDED CONSTRUCTION SCHEDULE COMPRESSION ANALYSIS METHOD

As discussed in Chapter 3, use of the LSM is not common among contractors. Figure 4.2 presents a procedural flowchart of steps for compressing construction duration using the linear scheduling. The flowchart is similar to the methodology followed for this study, but it is also reflective of lessons learned in the application.

After analyzing the current schedule and becoming familiar with the project and schedule compression objectives, an important question must be answered. The schedule should mirror the real status of the project as of the data date and it should clearly reflect the plan of the project team for the remaining activities. In other words, the schedule should contain a well-organized network, be regularly updated, and be accepted and used by the project team. If the current schedule does not comply with these qualities, then it is necessary to develop a new schedule for the remaining activities in the project. The steps that must be taken to develop a new schedule were discussed in Chapter 3.

If the current schedule is reliable, then it can be directly converted to the linear scheduling format by following the principles as discussed in Chapter 3. Once the As-Planned linear schedule is developed, the critical area must be selected. Critical area is defined as the remaining segment of the project, which drives project duration. Schedule compression techniques can then be applied to the activities to obtain the compressed linear schedule.

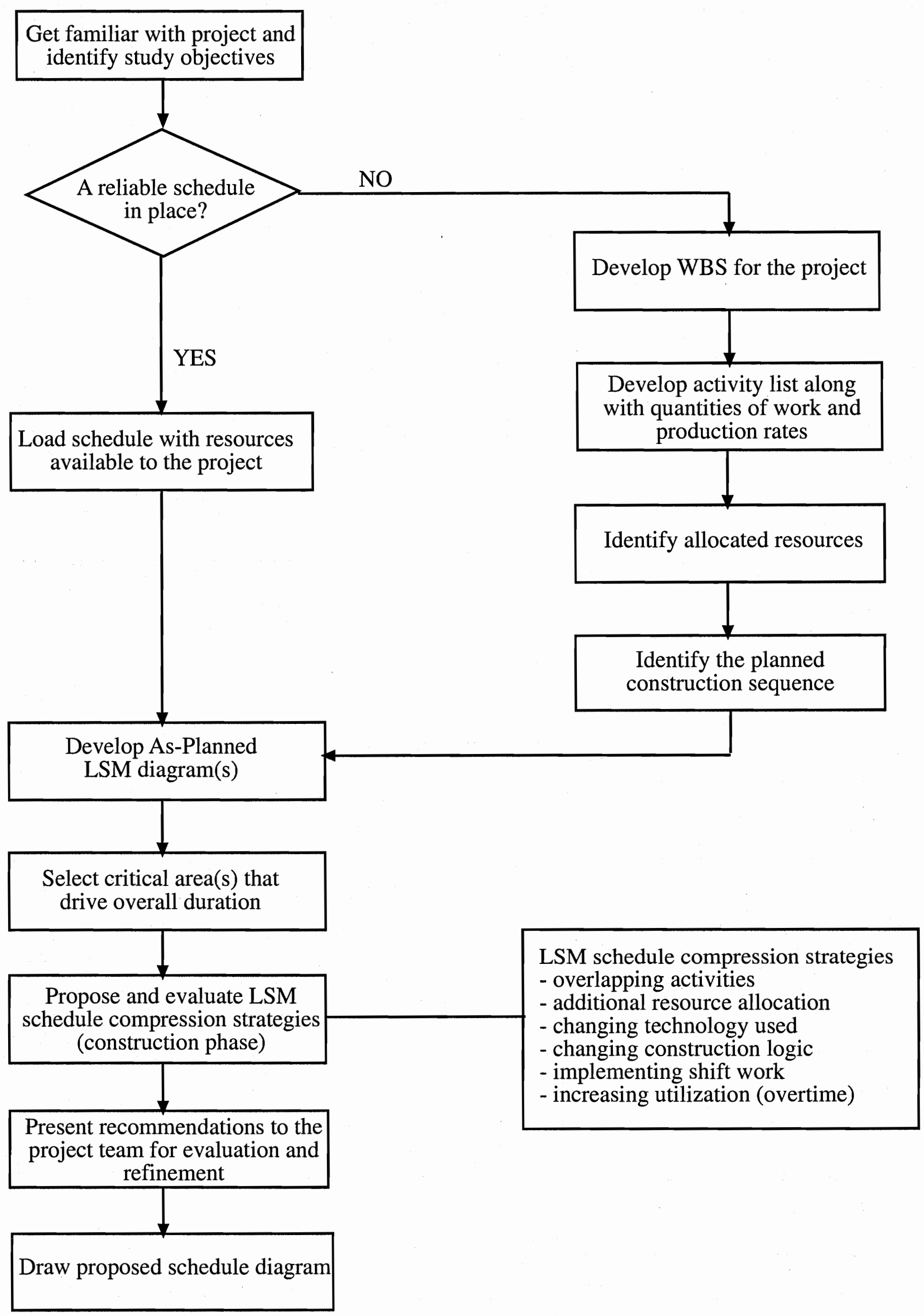

Figure 4.2. Construction Schedule Compression Analysis Method

CHAPTER 5.
CONCLUSIONS AND RECOMMENDATIONS

The objectives of this study were to understand the principles of the LSM and to implement it on an urban highway project undertaken by TxDOT. The specific objective was to detail the process that was used to compress the NCE reconstruction schedule and to characterize anticipated results. This chapter provides conclusions and recommendations that were drawn based on the research findings.

CONCLUSIONS

The LSM is an effective management tool for transportation construction projects. It facilitates the planning process by allowing visualization of the activities through time and location. The use of the method in this study relieved the complexity of the project's construction schedule.

Combining the study findings and literature review, the advantages of linear scheduling are:

1. Linear schedules can communicate even the most complex construction schedules easily. During the study, the method was explained to both TxDOT and contractor field staffs, who were receptive and found the method to be practical for field use.
2. CPM schedules rely on concrete relationships between activities to calculate the network. It is difficult to manipulate the schedule once the initial logic is established. Software based on CPM will give error messages and out-of-logic activity warnings if the schedule is not updated in compliance with the initial logic. This attribute of CPM limits its flexibility and as a result most of the schedules in the construction industry do not reflect current status of projects properly. On the contrary, linear schedules represent activity relations visually and this facilitates the exploration of alternative schedules in order to improve time and cost aspects of the project.
3. Critical path is an essential concept in CPM. The activities that have zero total float are named as critical activities and these activities together form the critical path.

However, linear scheduling makes it possible to divide the project into segments if these segments are independent from each other, as was done in this study. The method visibly points out the activities that drive the construction duration of the segment. Schedule compression strategies can then be applied to these activities.

Presently, contractors are required to comply with the scheduling specifications in the contracts. In cases where a CPM schedule is required, contractors can maintain a CPM schedule while using the more practical and advantageous linear schedule as a construction management tool either in the field or for specific tasks such as schedule compression, as discussed in this study.

RECOMMENDATIONS

The degree of detail of the linear schedule diagram must be evaluated carefully. The activities and scale of the diagrams should be selected appropriately so that the activity lines and descriptions are clearly seen on the diagram. A linear schedule that consists of oblique lines crossing each other will not be of practical use. Indicating overlapping activities with different colors may also be useful to differentiate among them.

One of the drawbacks of using the LSM is that it takes considerable time to update the schedule because of the lack of scheduling software supporting the method. Although there are some attempts in the software market to introduce this method to the construction industry, their success has been limited. The whole process should be computerized so as to encourage project managers.

The NCE project was suitable for the application of the LSM due to its one-dimensional nature. For projects that are not linear, such as interchanges, development of project-specific models is necessary. That process may consist of dividing the project into one-dimensional segments so as to plot all activities of the project that are not necessarily on the same plane.

Although the method is not new, the surveys indicate that it is not popular among transportation contractors. There is little doubt that the LSM is suitable for scheduling and controlling repetitive projects. Further research should be conducted to identify the drawbacks, eliminate implementation problems, and make these methods more attractive to the construction industry.

The schedule compression analysis method that is proposed in this study is deemed to be applicable for most linear projects. However, certain types of projects may require that the method be tailored to satisfy project requirements.

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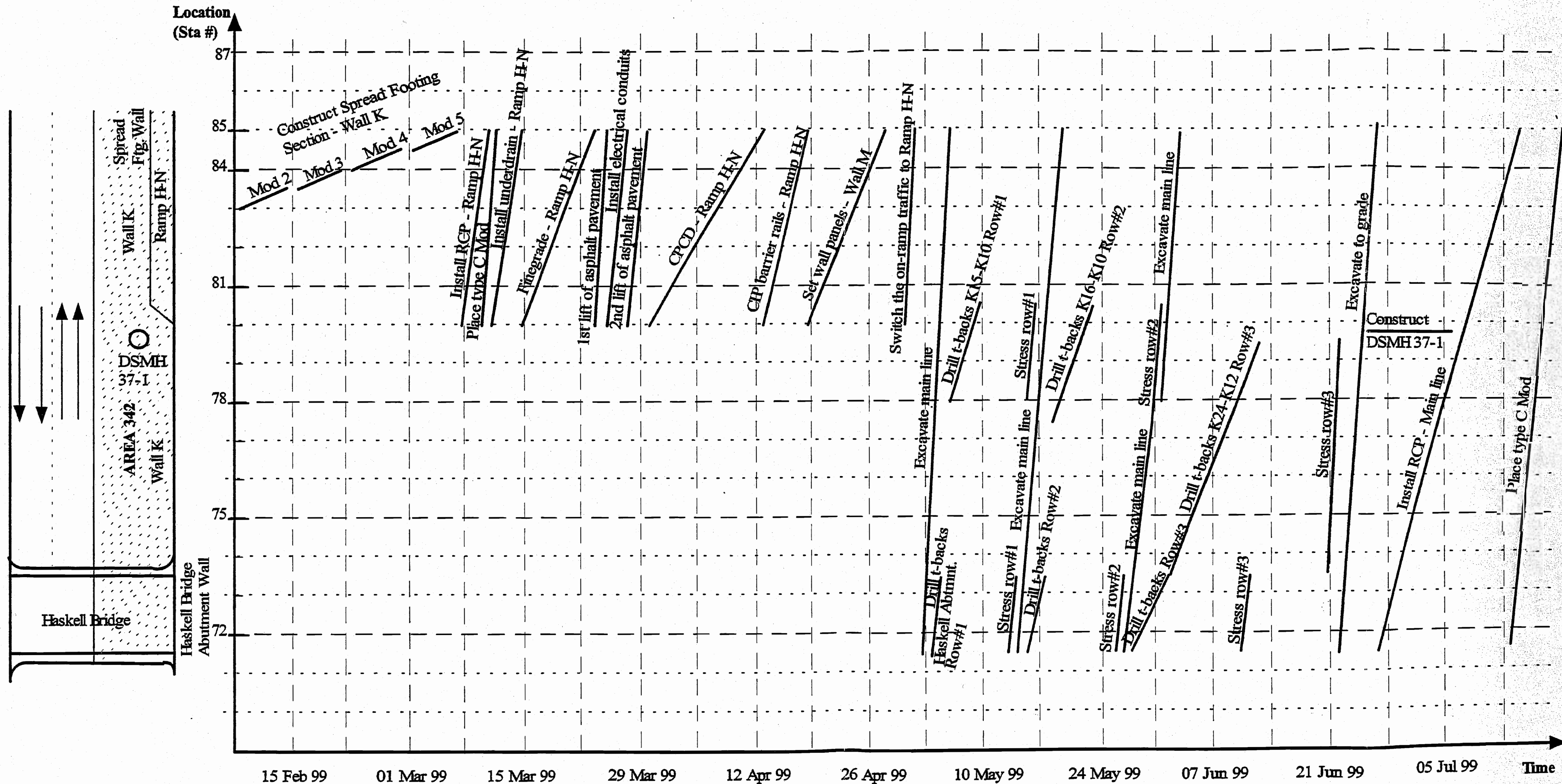
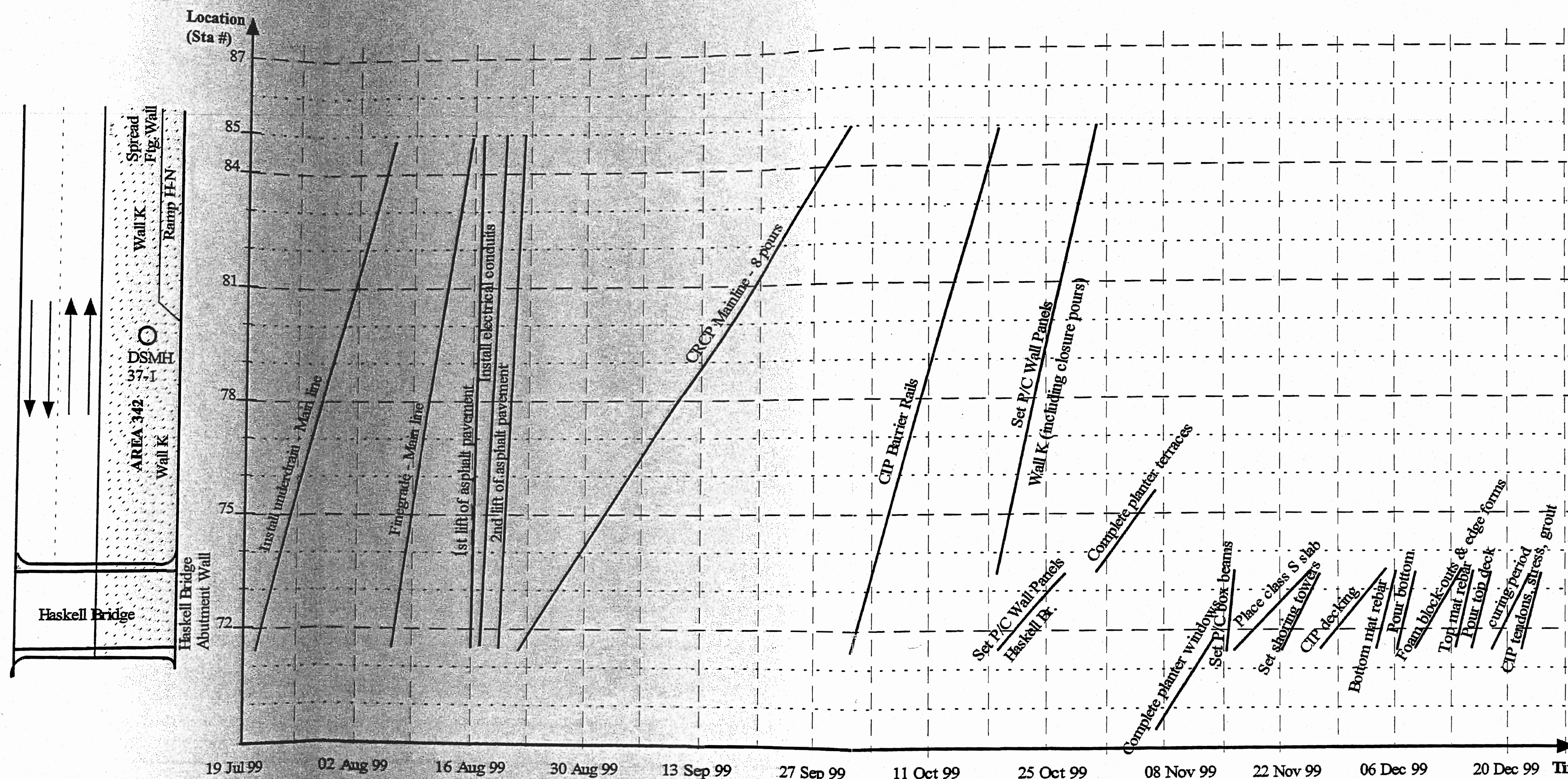
APPENDIX A

AS-PLANNED LINEAR SCHEDULE

APPENDIX A AS-PLANNED LINEAR SCHEDULE



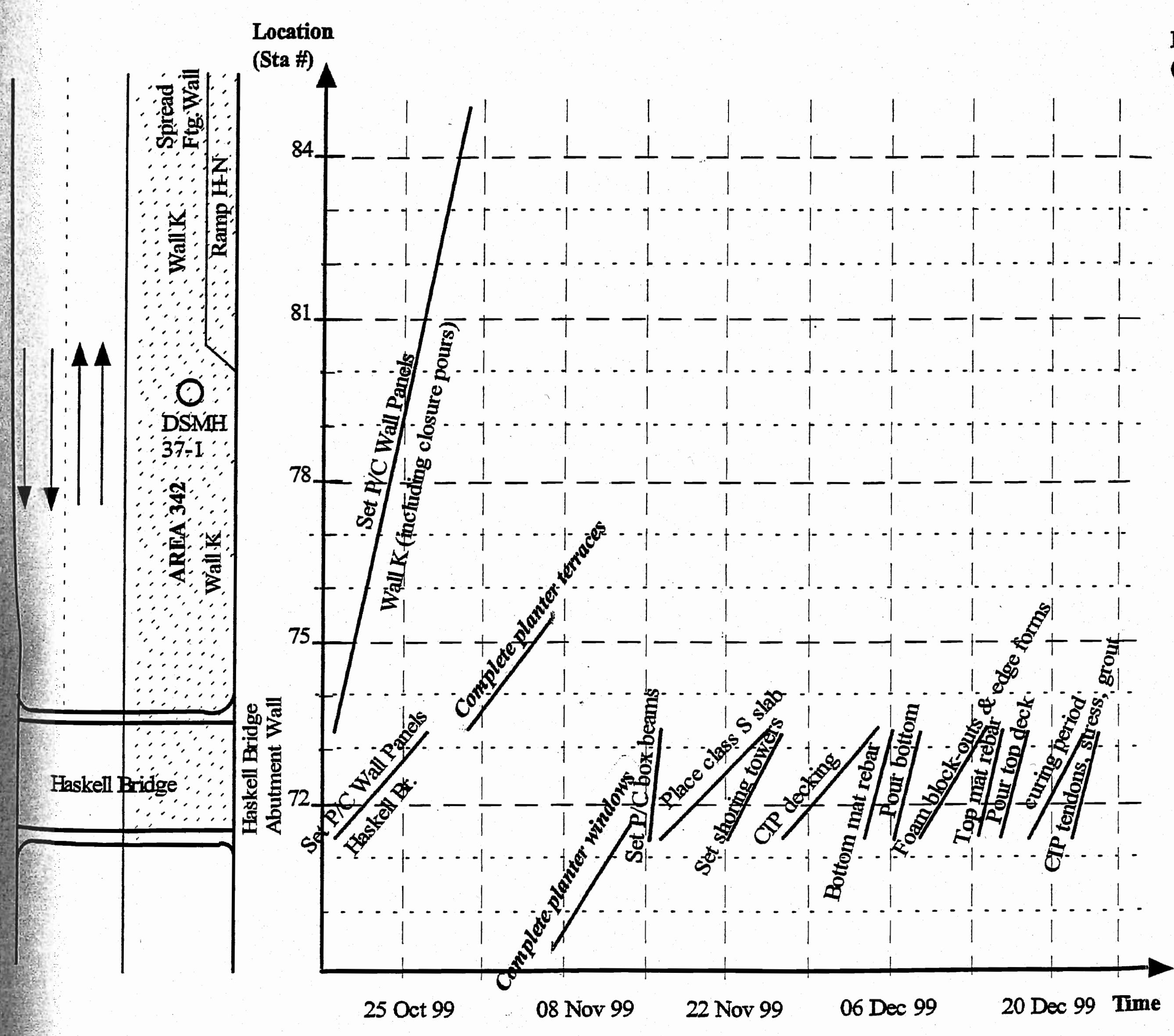
APPENDIX A AS-PLANNED LINEAR SCHEDULE (cont'd)



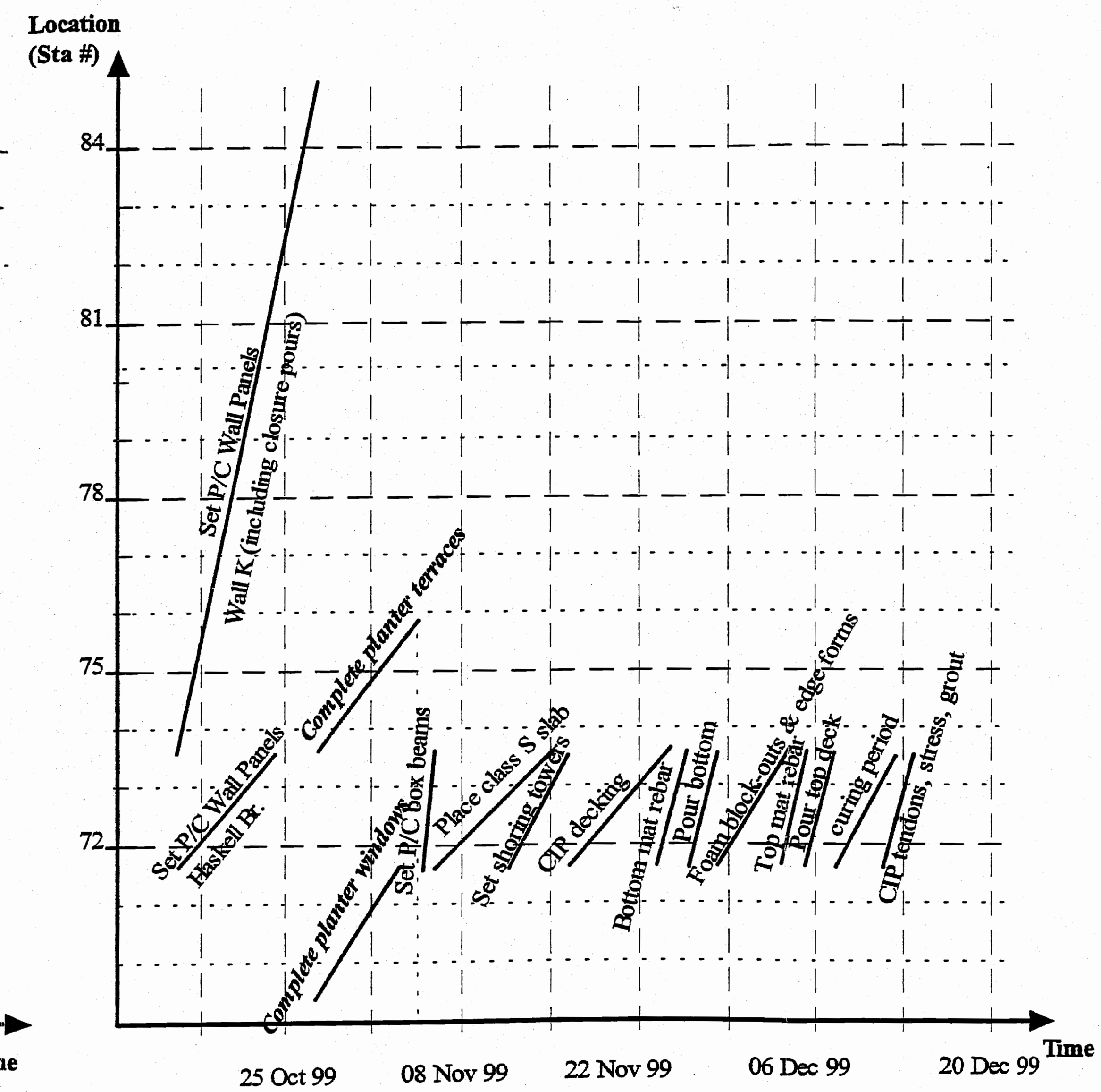
APPENDIX B

SCHEDULE WITH PROPOSED CHANGE #1

APPENDIX B SCHEDULE WITH PROPOSED CHANGE #1



Fragmented Planned Schedule

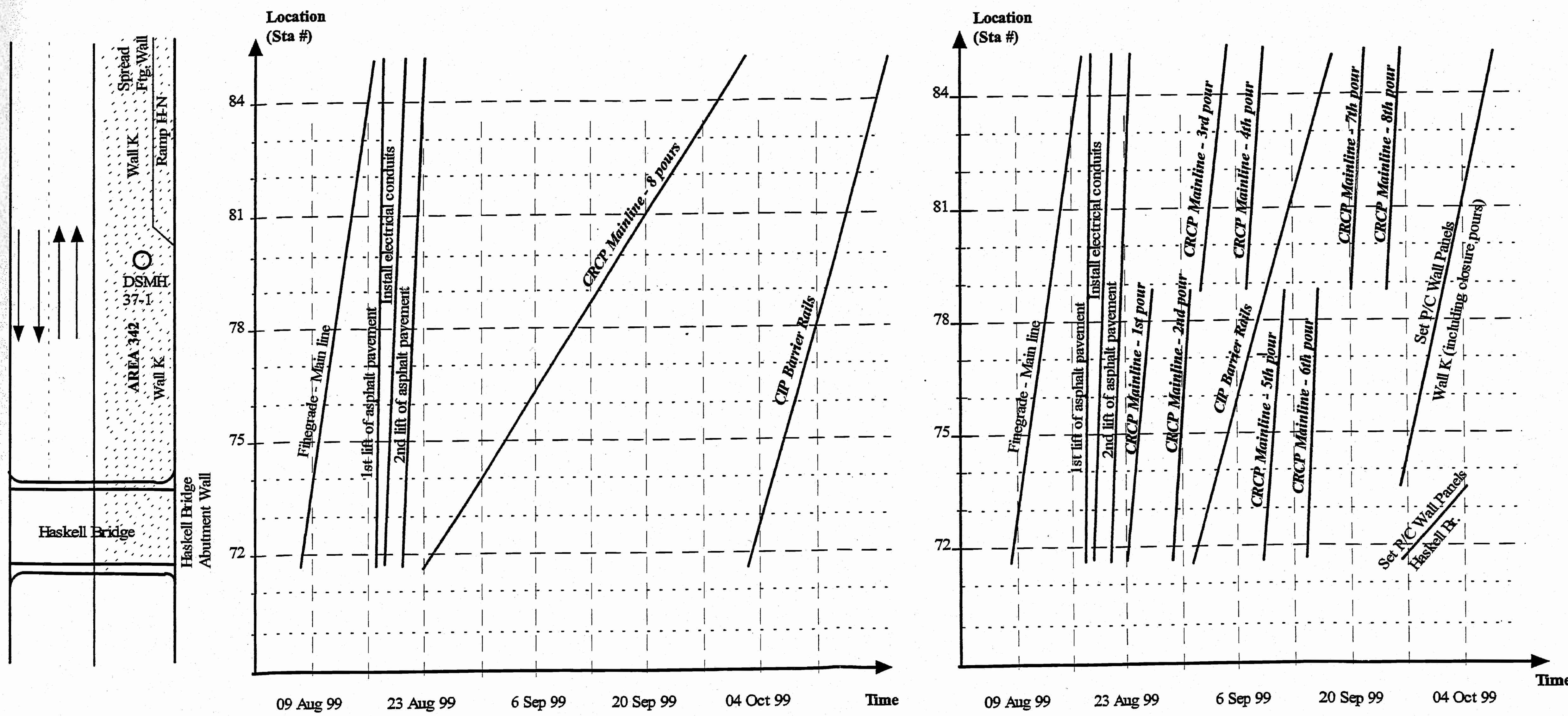


Anticipated Schedule Impact

APPENDIX C

SCHEDULE WITH PROPOSED CHANGE #2

APPENDIX C SCHEDULE WITH PROPOSED CHANGE #2



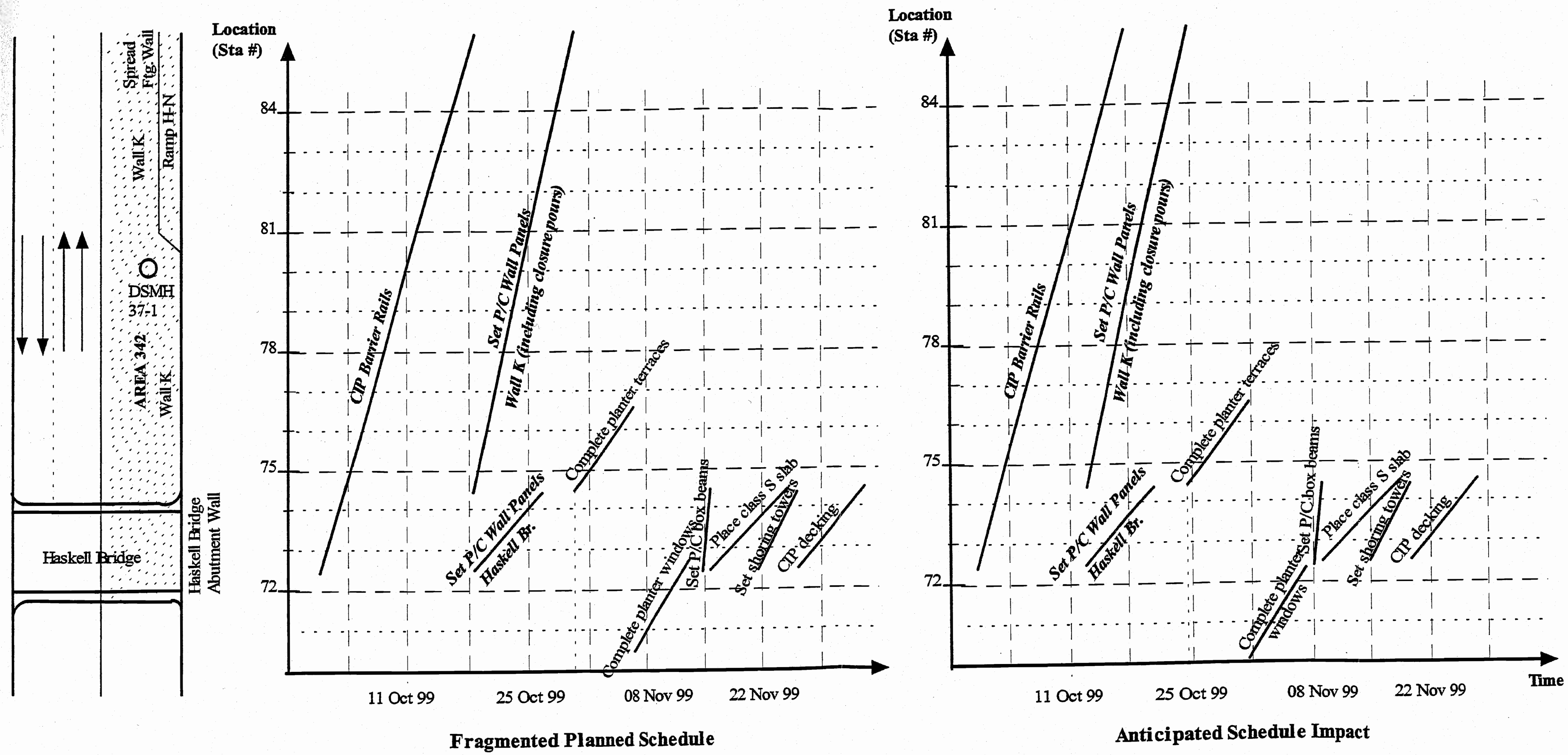
Fragmented Planned Schedule

Anticipated Schedule Impact

APPENDIX D

SCHEDULE WITH PROPOSED CHANGE #3

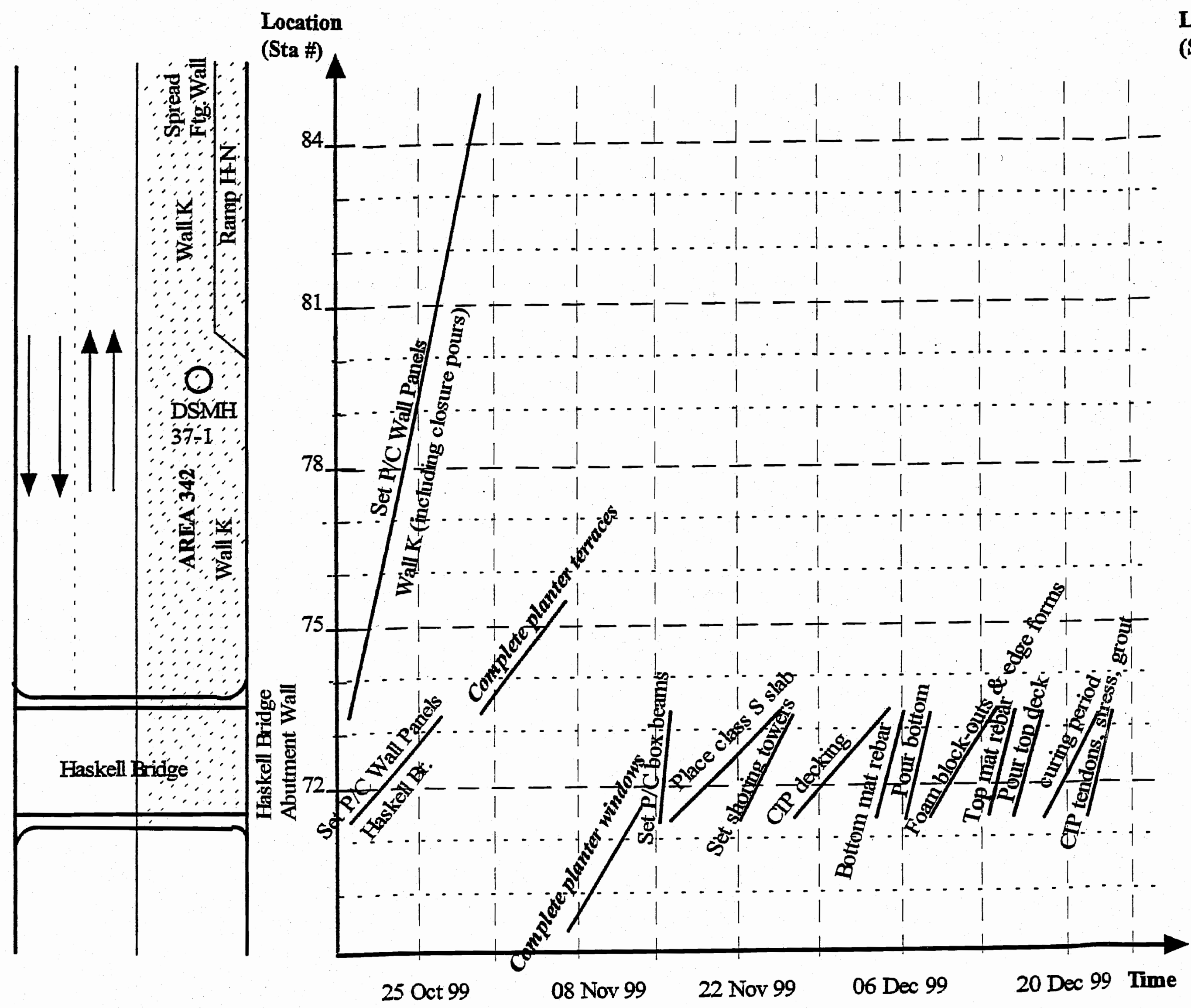
APPENDIX D SCHEDULE WITH PROPOSED CHANGE #3



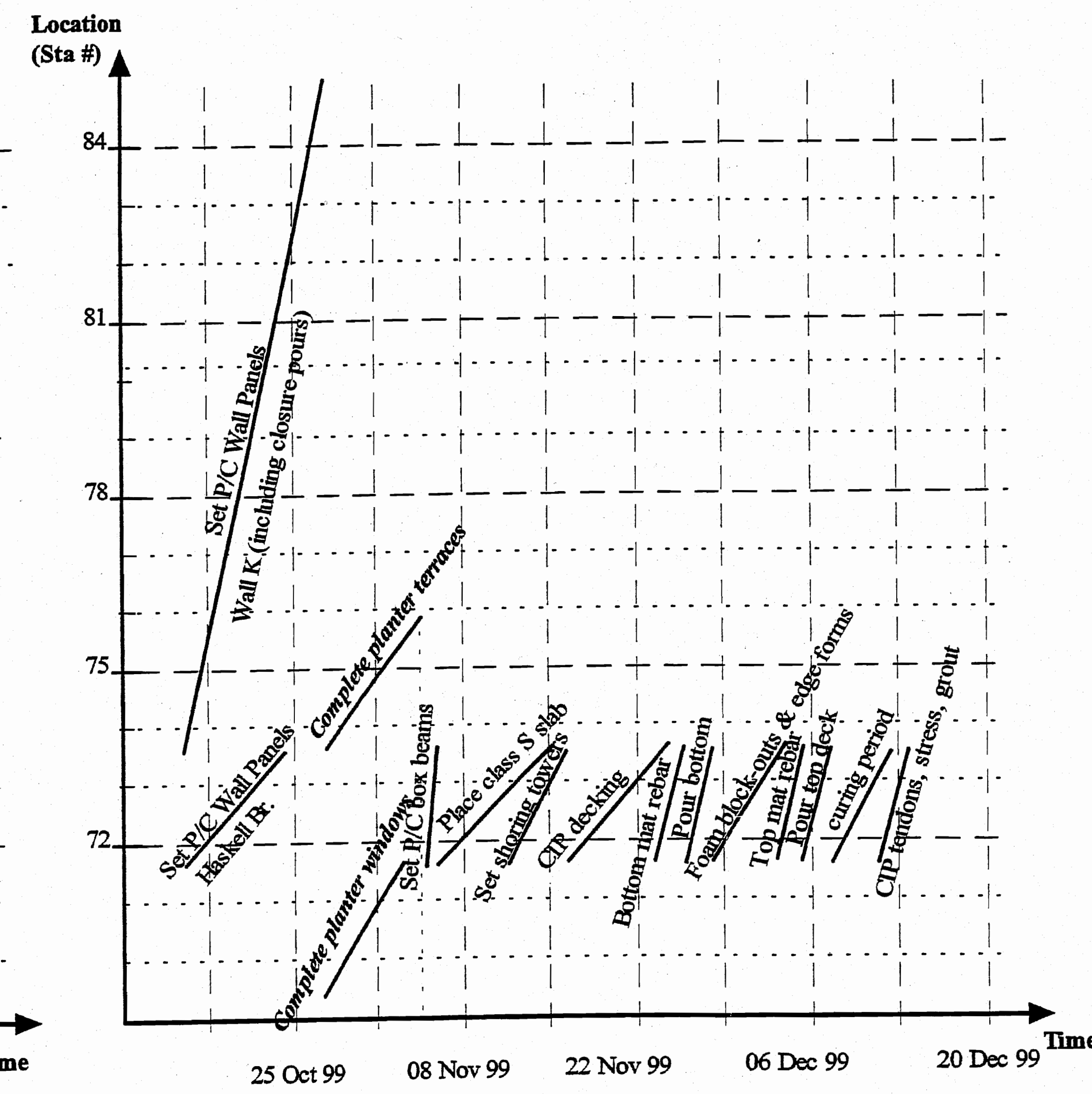
APPENDIX E

SCHEDULE WITH PROPOSED CHANGE #8

APPENDIX E SCHEDULE WITH PROPOSED CHANGE #8



Fragmented Planned Schedule

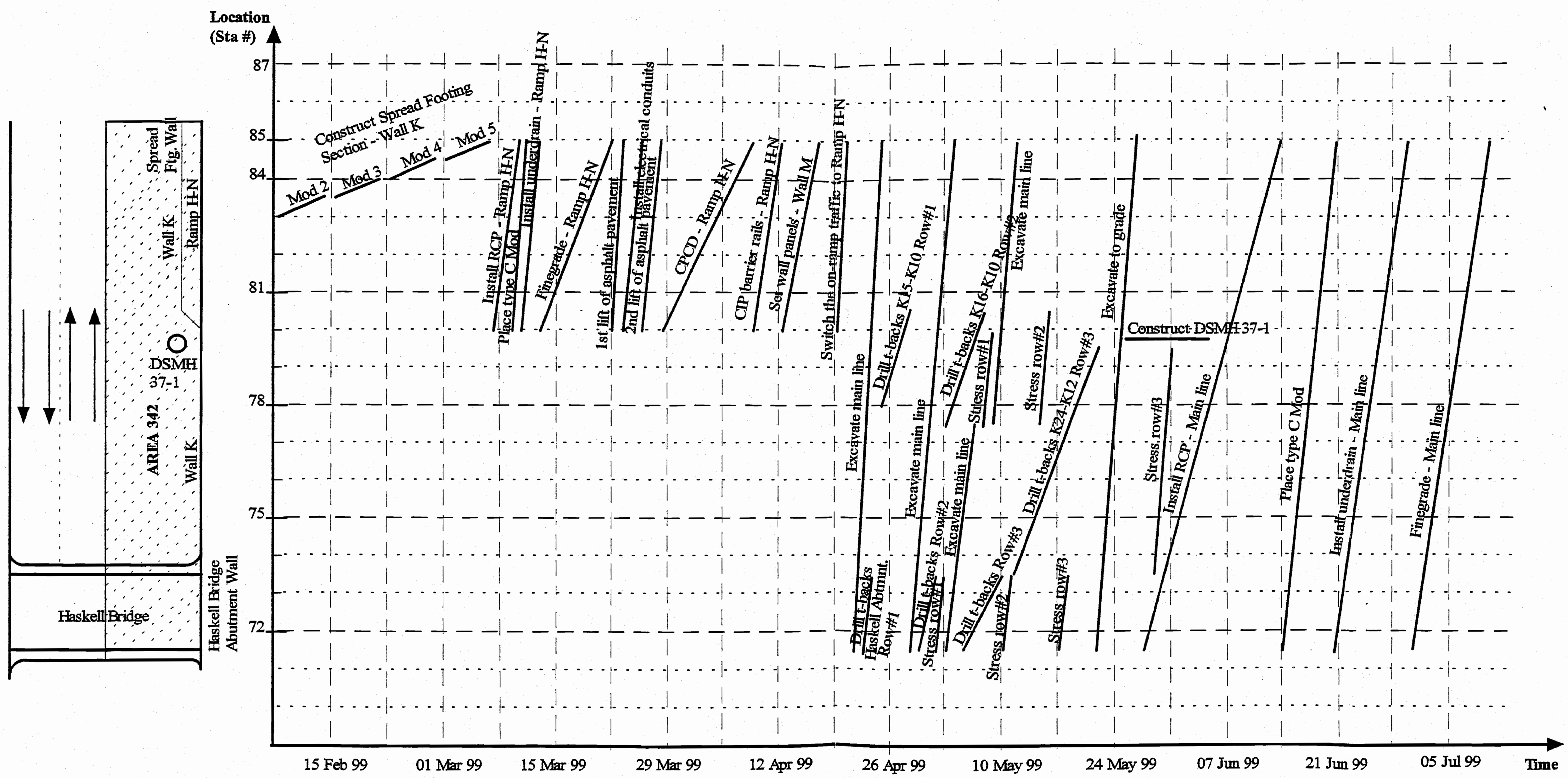


Anticipated Schedule Impact

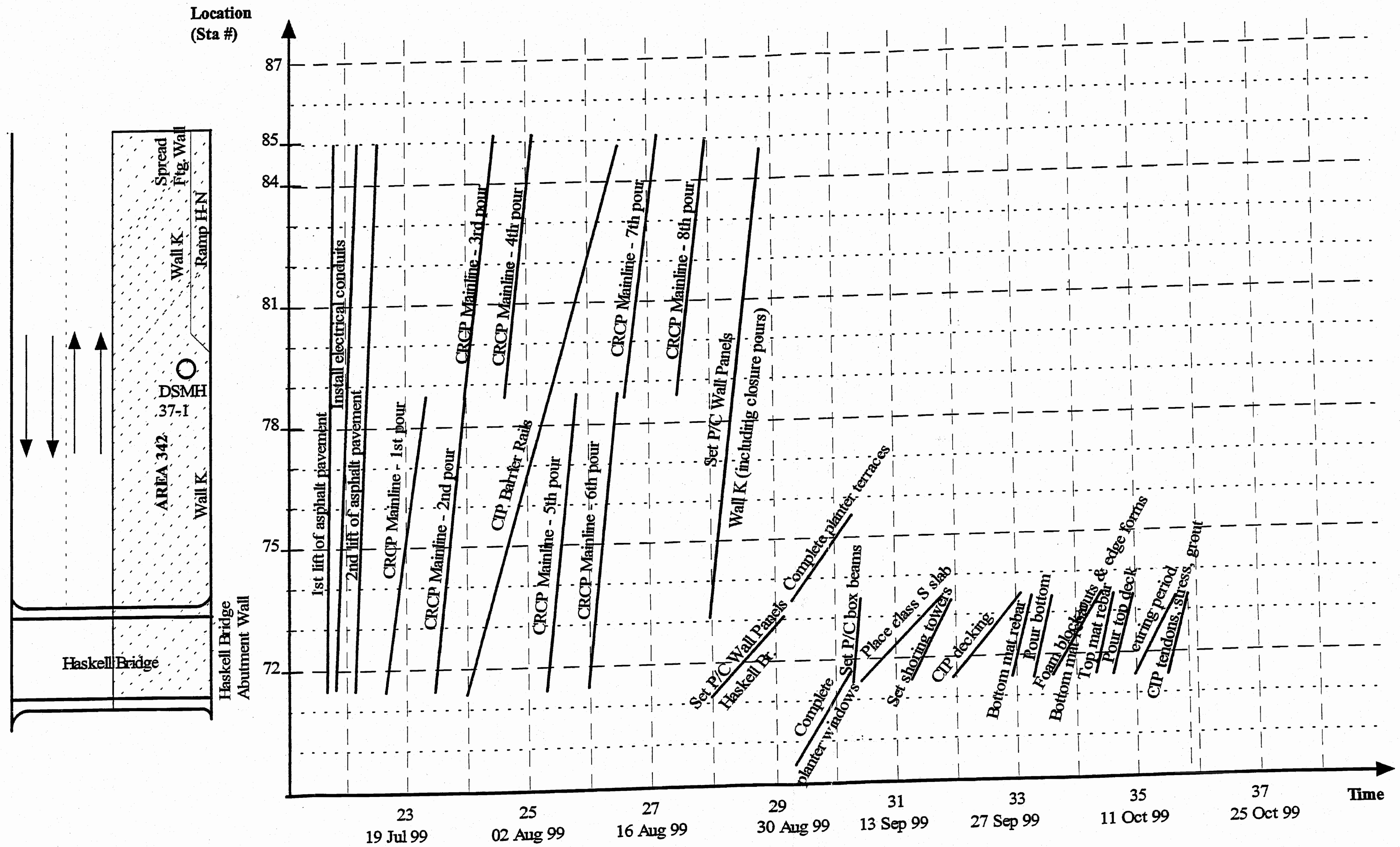
APPENDIX F

PROPOSED LINEAR SCHEDULE FOR REVIEW

APPENDIX F PROPOSED LINEAR SCHEDULE FOR REVIEW



APPENDIX F PROPOSED LINEAR SCHEDULE FOR REVIEW (cont'd)



APPENDIX G
SCHEDULE COMPRESSION QUESTIONNAIRE

APPENDIX G

SCHEDULE COMPRESSION QUESTIONNAIRE

Please respond to the following questions by choosing the most appropriate answer. Provide brief explanations pertaining to your answer.

The questionnaire is filled out by:

Lyle Clark, Project Engineer for Granite Construction Company.

Utilized Technique: Overlapping

1) *Subject Activities*: Constructing planter terraces and constructing planter windows.

Suggestion: Overlapping the activities by allocating an additional crew.

Response:

a) Can not be applied

b) Will be applied

c) Already applied

The limiting factor is the additional crew, which we do not have at this time. However, in the future we feel that we can have two crews devoted to these activities upon the completion of the waterproofing,. etc.

2) *Subject activities:* Continuous reinforced concrete pavement (CRCP) and constructing cast-in-place barrier rails.

Suggestion: Starting the construction of the barrier rails two weeks after the paving starts as opposed to a finish-to-start type of relationship.

Response:

a) Can not be applied

b) Will be applied

c) Already applied

We have the barrier crew starting after the outside shoulder and the 24' lane next to the shoulder is poured/cured. This is the minimum room required as mentioned in your suggestion.

3) *Subject activities:* Constructing the barrier rails and installing pre-cast wall panels.

   Suggestion: Overlapping the two activities with 6 days of lag between them.

   Response:

   a) Can not be applied

   b) Will be applied

   c) Already applied

   We have the panel crew starting approximately 5 days after the barrier rail crew. By this time the barrier rail crew proceeds forward. In that way, enough working space is provided for the panel crew.

Utilized Technique: Increasing Utilities

4) *Subject activity*: Installing underdrain between Sta. 71 and Sta. 85.

   Suggestion: Allocating an additional trencher and a backhoe with supporting crew.

   Response:

   a) Can not be applied

   b) Will be applied

   c) Already applied

   After analyzing the situation, we decided that a small quantity of remaining underdrain does not warrant hiring a second crew and acquiring equipment.

5) *Subject Activity:* Constructing cast-in-place barrier rails.

   Suggestion: Allocating another crew and a crane.

   Response:

   a) Can not be applied

   b) Will be applied

c) Already applied

At this point in the job, with a small quantity of barrier rail remaining and overall schedule showing that barrier rail crew is staying ahead of the panels but is not catching up with the paving crew, we do not foresee the application of the suggestion.

6) *Subject activity:* Setting pre-cast wall panels

Suggestion: Allocating another crew just for the panel closures.

Response:

a) Can not be applied

b) Will be applied

c) Already applied

Second crew is pouring the closures and the suggestion has worked well.

Utilized Technique: Changing the technology used.

7) *Subject activity:* Continuous reinforced concrete paving (CRCP)

Suggestion: Using 'class K' type of concrete as opposed to 'class A' type of concrete.

Response:

a) Can not be applied

b) Will be applied

c) Already applied

The use of early strength CRCP is to be determined by TxDOT. Extra cost associated with this would fall to TxDOT taxpayers. However, this is a very important idea to accelerate very specific pours.

8) *Subject activities:* Drilling tiebacks, stressing tiebacks and excavating for the next row of tiebacks.

Suggestion: Starting excavation right after drilling the tiebacks. Man lifts will be used to stress the tiebacks after excavation.

Response:

a) Can not be applied

b) Will be applied

c) ***Already applied***

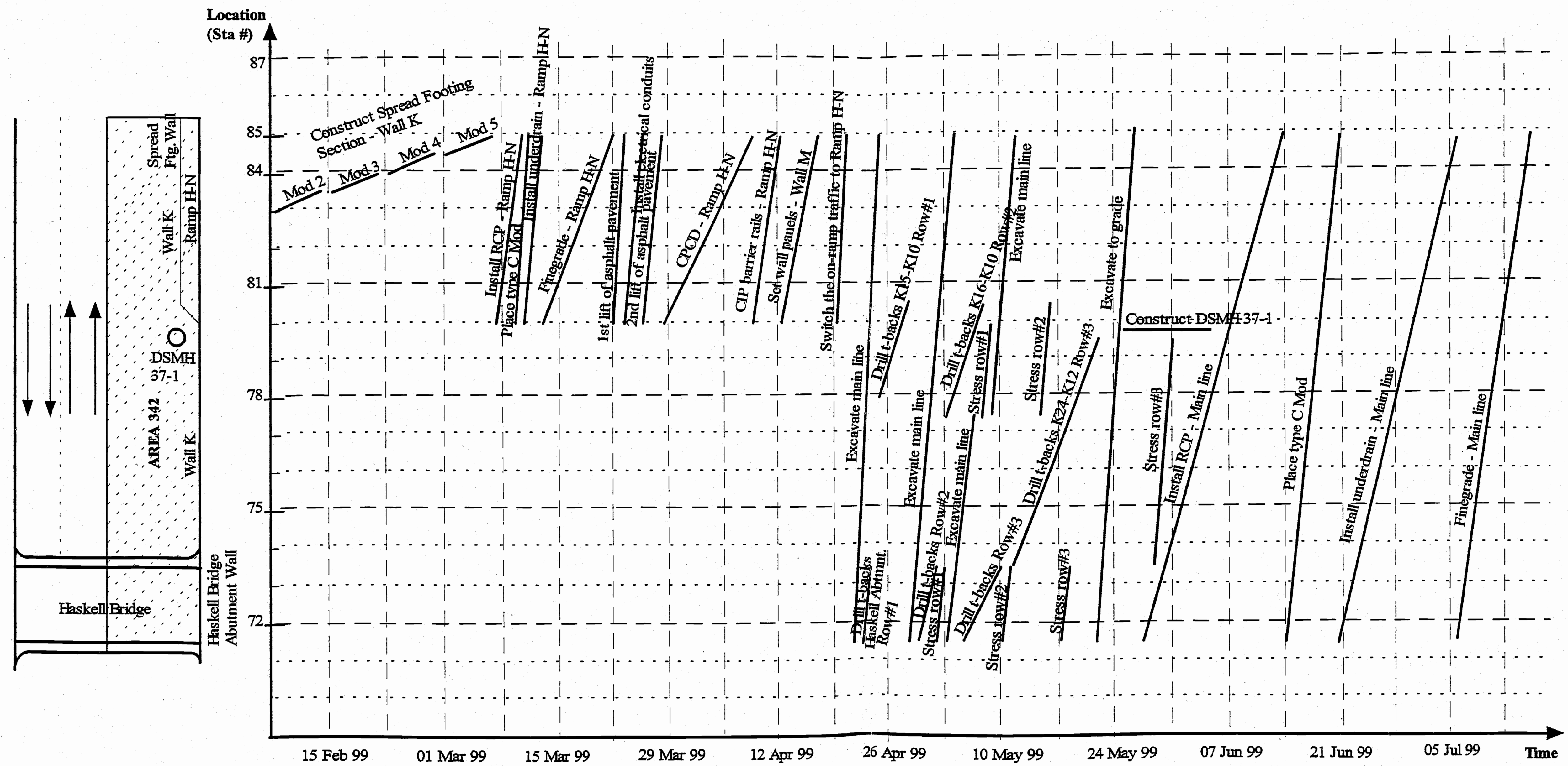
This has been applied at our last wall, Wall H, and worked very effectively. The drawback to this is in the case of Wall H; we had a minor failure in top row, which caused us to rebuild a bench to allow the tieback to be redrilled.

The application may not be cost effective if more failures are encountered.

APPENDIX H

LINEAR SCHEDULE WITH APPROVED CHANGES

APPENDIX H LINEAR SCHEDULE WITH APPROVED CHANGES



APPENDIX H LINEAR SCHEDULE WITH APPROVED CHANGES (cont'd)