Extending the Range of Linear Scheduling
in Highway Construction

by

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(ABSTRACT)

Linear Scheduling Method is a powerful graphical scheduling method which is best suited for scheduling projects involving repetitive activities. Highway construction projects are excellent examples of projects displaying repetitive characteristics. The research explores usefulness of linear scheduling in highway construction.

The Linear Scheduling Method (LSM) was implemented in the field to schedule highway projects. Problems encountered during the field experience were studied and responses to the problems were identified. The research resulted in a number of advancements to the technique. These are reported in the thesis. The advancements exploit the simplicity and graphical nature of this technique.

The research identified the true potential of a graphical technique in communicating information, and in evaluating scheduling alternatives. The importance of visualization and the role of LSM in planning, execution, and control phases of a project are discussed. The concepts of lateral float and use of LSM as a graphical simulation tool are presented.
A comprehensive description of the linear schedule's format and symbols is presented in the thesis and this will lead the technique towards a standard format. The enhancements to the format and symbols, reported in the thesis, will make the technique more robust, increase its effectiveness, and help in scheduling complex projects using the technique.

The need for representing the information contained in the linear schedules in tabular formats was identified during the field implementation of the technique. The concept of Crew Movement Chart (CMC), which shows deployment and movement of various crews in the project in a tabular format, is presented. The use of spreadsheets and databases to generate the CMC is discussed and a computer software package, LINC, which can be used to generate CMC by input through user-interface screens, is presented.

The need for an interface between the Critical Path Method (CPM) and the Linear Scheduling Method (LSM) was identified during the field experience. This thesis presents a discussion on the development of the computer interface, the Linear Scheduling Software (LSS). A combined computer scheduling system comprising of the LSS and LINC, which can be used to generate linear schedules as well as tabular reports, is presented.
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CHAPTER 1

INTRODUCTION

Many construction projects, such as highways, pipelines, and high-rise building projects, involve repetitive activities. Linear Scheduling Method (LSM) is a simple but powerful graphical scheduling method which is best suited for scheduling projects involving repetitive activities. Highway construction projects are excellent examples of projects displaying repetitive characteristics. This thesis explores use of LSM to schedule highway projects and reports on methods to extend the range of linear scheduling in highway construction.

1.1 BACKGROUND

It is generally accepted by parties involved in the construction operations that there is a need for systematic planning and scheduling. However, the demands and requirements of various parties for the level of detail, and type and amount of information, vary. This variation occurs from project to project and is generally dependant on the complexity and the type of the project. The nature and number of parties involved in construction also
influences the type and amount of information which must be produced in the process of planning and scheduling.

Most highway projects are state owned. The owners in these cases are State Departments of Transportation (DOTs). Most of the DOTs require the contractor to carry out some form of planning and scheduling. The DOTs generally require a plan of operations in order to control the work (Road 1987). The insistence on the provisions of a competent plan of operations ensures that the contractor has given thought to his works planning and scheduling. Vorster (1989) states that a plan of operations provides the owner with: (1) The information needed to fulfill its obligation to the public, (2) The information needed to coordinate the work to be done by utilities, inspectors and other parties involved in the work, and (3) A mechanism for measuring physical progress. Contractors also stand to gain from carrying out planning and scheduling. It improves their understanding of the job and may result in increased profits. This will ultimately reflect in the long-term efficiency of the industry.

The majority of the projects are governed by general specifications. The general specifications of DOTs usually do not specify a particular technique to be used for preparing the project schedule. Specifications for the Virginia Department of Transportation (Road 1987) state:

The plan of operations shall be in such form and in such detail as to show clearly the sequence of operations and the period of time required for completion of each item or group of like items in the Contract.

1. Introduction
Lately, owners of highway projects are specifying special provisions on scheduling for some projects. The thrust of these special provisions has been in the direction of requiring, or at least showing preference for, use of a given scheduling technique (Special 1990). The contractors have voiced their concern on this matter. They feel that contract provisions requiring the use of a given scheduling technique are not required (Vorster 1989).

Although the need for scheduling is accepted by members of the highway construction industry, the general feeling is that emphasis should be on carrying out scheduling to meet the needs of the project, and not to merely fulfill contractual obligations. The level of detail in a schedule and the specific type of technique to be used should thus be commensurate with needs of the project.

This thesis is an attempt to extend the range of a scheduling technique suited to highway projects. This will provide an alternative to the traditional techniques such as bar charts and network methods and will add flexibility in contractor's decision on the technique to be used. The option itself, the Linear Scheduling Method, is very effective and efficient for use in almost all types of highway projects.

1.2 OBJECTIVE OF THE RESEARCH

The need for systematic project management in construction projects cannot be over emphasized. A number of techniques are currently being used to plan and schedule construction projects. Linear projects display characteristics different from other types of projects. Although the traditional techniques have been used in the past, they appear to
have had limited success with scheduling of linear and repetitive projects. This has led to the development of special techniques to handle such jobs. Linear Scheduling Method (LSM) is one such technique and has found special use in scheduling of highway projects. LSM as a technique has been in use for a long time but its true potential has not been fully realized. The objective of this research is to rejuvenate the technique and enhance its effectiveness and usefulness for scheduling highway projects through advancements and enhancements. Most of these advancements are based on the responses to actual field problems encountered during the field implementation of the technique.

As discussed in Section 1.1, extending the range of linear scheduling method will add flexibility in contractors' decisions on the technique to be used. It will provide for a technique which is commensurate with the needs of the project. LSM is a simple, yet powerful technique which is easily understood by the majority of people involved in construction operations. It is a graphical technique which effectively handles the movement of crews through time and space and is well suited to the management of highway projects. The objective of this research is to exploit the simplicity and the graphical nature of the technique. This objective focuses on the schedule as a medium for communication. Only when a schedule: (1) Is clear enough to be understood by people at the field level of operation, who may not have sufficient technical knowledge to understand complex schedules, and (2) Is strong enough tool to effectively portray all the information needed to plan and control the operations, will it become more than another chart on the wall.

1. Introduction
1.3 SCOPE AND LIMITATIONS OF THE RESEARCH

The use of linear scheduling method, or similar techniques having different names, has been reported for high-rise buildings (O'Brien 1975), pipelines (Stradal and Cacha 1982), highways (Johnston 1981; and Chrzanowski and Johnston 1986), and such other projects involving repetitive activities. The scope of this research is limited to use of LSM in horizontal construction such as highways, railroads, and pipelines.

This thesis will explore the need for systematic planning and scheduling, and present a review of the literature available on traditional scheduling techniques used in construction such as bar charts and network techniques. However, the scope of the literature review is limited to evaluating the role of traditional techniques in scheduling linear projects which combine unique and repetitive operations.

The review and evaluation of literature of specific techniques to schedule linear projects is carried out in this thesis. However, this review, except for linear scheduling method, is carried out only to critically evaluate their role in scheduling highway projects. This thesis does not present an exhaustive review of the literature available on all the specific methods to schedule linear projects. Moreover, the review of literature on mathematical models/techniques which assist in scheduling linear projects, is done primarily to give an idea about the nature of research being carried out in the area.

A computer software package, LINC, has been developed as a part of this research to provide tabular output from the linear schedules. This package is in prototype form and

1. Introduction
has been developed in order to understand and test the concepts involved. LINC may thus require additional work prior to its full scale use in the industry.

A computer interface between the critical path method (CPM) and the linear scheduling method (LSM) was developed at Virginia Tech as a separate but parallel activity to this research. The researcher contributed to the development of the software as one of the members of the three member team that formalized the basic concept. Formatting of the screens through which the user interacts with the package, was carried out. The writing of the computer program, titled Linear Scheduling Software (LSS), was not carried out as a part of this research.

1.4 PRESENTATION OF THESIS

This thesis consists of eight chapters. Figure 1.1 presents an outline and sequencing of these chapters. The first chapter presents an introduction to the thesis and discusses the needs of various parties involved in construction regarding works planning and scheduling. The objective of the thesis, and its scope and limitations are outlined.

Chapter 2 and 3 are devoted to studying the technique through literature survey and field experience. Chapter 2 presents a critical review and evaluation of the literature on specific techniques to schedule linear projects. It also presents a limited review of the literature on need and importance of planning and scheduling, and on the traditional scheduling techniques such as bar chart and network methods. Chapter 3 describes the field implementation phase of this research when highway projects were scheduled using critical
Figure 1.1 Outline of the Thesis
path method as well as linear scheduling method. The chapter reports problems encountered during this phase and outlines the responses to the problems encountered. These responses were researched in detail and the results are reported in Chapters 4 through 7.

Chapter 4 discusses the need and importance of visualization in various phases of the construction process and describes the ways in which visualization helps in evaluating scheduling alternatives and the role of linear scheduling method in this evaluation. The concepts of soft logic and lateral float are described.

Chapter 5 discusses advancements and enhancements to the format and the symbols used to represent various activities on the linear schedule. These advancements, however simple they might be, will make linear scheduling a robust enough technique to handle complex highway projects.

A need for presenting the information portrayed on the linear schedule in tabular format was identified during the field implementation phase. This resulted in the concept of a crew movement chart (CMC) which is discussed in detail in Chapter 6. Use of spreadsheet as well as database computer packages to generate a CMC is described. Development of a computer software package, LINC, which can generate CMC based on user input, is reported. Although a database package is used for LINC, the user does not have to be proficient with the use of the package. The user interacts with the package through user-interface screens.

1. Introduction
The users of scheduling techniques are constantly faced with the dilemma of choosing between the critical path method and the linear scheduling method. Chapter 7 describes work which was done in parallel with this thesis to develop a computer interface between the two techniques, the linear scheduling software (LSS), which garners the advantages of both the techniques. The contribution of others in the development of LSS is stressed.

Chapter 8 serves as a conclusion and summary to this thesis. The chapter discusses various stages of development of linear scheduling as a technique during the course of this research. Recommendations and directives for future work are provided.

A number of appendices are also attached to this thesis. Appendices A and E contain the user-interface screens for LINC and LSS, respectively. Appendices B, C, and D contain the computer programs for LINC. Appendix F presents a case example of a highway project. A bar chart and a CPM schedule (Time Scaled Logic Diagram) for the project are provided. The project data is used to generate a linear schedule and a number of crew movement charts using the combined scheduling system, comprising of LSS and LINC, which is discussed in Chapter 7.

1. Introduction
CHAPTER 2

REVIEW AND EVALUATION OF LITERATURE

The need for systematic project management in construction projects can not be over emphasized. There has been considerable research in this field and numerous techniques are currently being used to plan and schedule construction projects. This chapter will explore the need for systematic planning and scheduling, and present a limited review of the literature available on traditional scheduling techniques used in construction. Emphasis will be placed on evaluating the role of these traditional techniques in scheduling of linear projects which combine unique and repetitive operations.

Although the traditional techniques have been used in the past, they appear to have had limited success with scheduling of linear and repetitive projects. Literature investigating the inadequacies of such techniques in linear construction will be reviewed. Numerous techniques which are specifically suited to schedule linear and repetitive construction projects have been investigated in the last 15-20 years. This chapter will review such techniques and evaluate these for use in scheduling highway construction projects.
2.1 NEED FOR SYSTEMATIC PLANNING AND SCHEDULING

Most of the construction projects are one-time and largely unique efforts of limited time duration which involve work of a non-standardized and variable nature (Clough and Sears 1979). Use of a systematic project management system in order to successfully execute such projects is important. Planning and scheduling are two vital elements of a systematic project management system. Clough and Sears (1979) define planning as "the devising of a workable scheme of operations to accomplish an established objective when put in action." The planning phase consists of defining how the work will be done, identifying various activities, establishing mutual interdependencies between these activities, and sequencing them, based on project constraints and requirements. The scheduling phase introduces time parameters for these activities to determine completion dates of individual activities and the overall completion of the project. Together, they form a system designed for maximum utilization of manpower, money, material, and time (Morad 1990).

Surveys conducted by Choromokos and McKee (1981) and Arditi (1985) among the Engineering News-Record top 400 contractors indicated that planning and scheduling are regarded by the majority of large contractors as having a high potential for productivity improvement. Based on the survey conducted in 1979, Choromokos and McKee (1981) commented that, "A prerequisite for productivity improvement is long-range and short-range planning and scheduling." There seems to be consensus among the respondents to both the surveys that there is a need for improvement in planning and scheduling.

Vorster and Parvin (1990) believe that there is an increased need to improve scheduling in the nineties. Projects in the nineties are seen as more difficult to execute because the

2. Review and Evaluation of Literature
construction site is often more closely integrated with the public than was the case in the past. Employees' attitudes towards their jobs are different and they change companies more frequently than in the past. Owners' needs are different in the nineties because the projects are more complex than they used to be. Because of these continued trends in the characteristics of the construction projects, construction companies, and attitudes of owners and employees, improved scheduling is needed so that the projects could be completed with reduced overall cost and time, and increased public safety and convenience.

The need for planning and scheduling in highway construction projects can not be over emphasized. Johnston (1981) commented that application of procedures to improve planning, scheduling, and control of highway construction and maintenance projects can provide many benefits. Improved organization of the construction process usually reduces overall cost, increases construction safety, and shortens the project duration. For new highway construction, a shorter duration increases public safety by allowing a needed highway to open earlier. For highway maintenance projects, a shorter duration also increases public safety by reducing traffic interruption (Johnston 1981).

2.2 SCHEDULING TECHNIQUES IN CONSTRUCTION

Little is known of planning and scheduling methods used in the construction of the great structures of past civilizations (McCall 1978). In fact, little has been written of formalized procedures for the management of operations prior to the early 1900s when Henry L. Gantt and Frederick W. Taylor popularized the graphical representation of work versus time that

2. Review and Evaluation of Literature
is the basis for today's bar charts. This is the first known record of scientific consideration of the problem of work scheduling (McGough 1982).

Traditional scheduling methods can be classified into two major categories: bar charts and network based systems. Bar chart is one of the simplest scheduling methods and is an excellent representation of how activities are spread over time. However, a bar chart can not clearly show complex inter-relationships between the activities. Melin and Whiteaker (1981), while discussing disadvantages of the bar chart, state that, "The bar chart does not show the interface between the activities." Network based systems have overcome that disadvantage but they have had limited success with scheduling of linear and repetitive construction projects (Arditi and Albulak 1986; and Kavanagh 1985). Chrzanowski and Johnston (1986) attribute this to the repetition of information, and state that, "Since the same activities are repeated throughout a project's duration (in a project consisting of repetitive activities), the resultant CPM schedule is cluttered with the repetition of information." To cater to the needs of linear and repetitive projects, specific techniques have been developed in the past 15-20 years to schedule such projects. These techniques have multiple origins, multitude of variations, and many different names (Arditi and Albulak 1986).

In the next two sections of this chapter a limited review of the traditional methods of scheduling, viz. bar charts and network based system is presented. Emphasis will be placed on evaluating the role of these traditional scheduling methods in scheduling of linear projects. In section 2.5 of this chapter, a review is presented of the available methods and techniques which have specific relevance to scheduling linear projects. These techniques

2. Review and Evaluation of Literature
shall be evaluated for their use in highway construction projects. The chapter ends with a discussion on the conclusions drawn from the review and evaluation of the literature.

2.3 BAR CHART

A bar chart is an excellent representation of the planning process that is easily read and understood by all levels of management and supervision. It is an acceptable means of communicating job progress information to nontechnically trained people, or even to construction experts whose need to know is limited to progress data only (McGough 1982). A bar chart graphically plots activities versus time, with the activities being listed vertically, and, when possible, in sequential order. The proposed period of execution for each activity is plotted as a bar on the time graph corresponding to the planned times of occurrence, with actual occurrences being plotted parallel to these (Chrzanowski and Johnston 1986).

The advantages of a bar chart are that it is clear, simple, and intelligible to the unskilled. Its disadvantages are that it does not show clearly the sequential relationships (Stradal and Cacha 1982) and that there is no indication of activity interdependence (Johnston 1981). However, as Stradal and Cacha (1982) comment, "It is useful as a complement of other techniques for the reason of intelligibility and as a rough preliminary plan."

A modification of the bar chart has been reported by Melin and Whiteaker (1981) and has been labeled as the "fenced bar chart." Though Melin and Whiteaker do not suggest use of fenced bar charts to schedule linear projects, it is felt that these could be used in such

2. Review and Evaluation of Literature
projects (Arditi and Albulak 1986) because of their simplicity and portrayal of interdependencies between activities.

2.3.1 Fenced Bar Chart

Melin and Whiteaker (1981) suggested a modification on the standard bar charts and labeled these as the fenced bar charts. Fenced bar charts retain the simplicity of the standard bar charts and look like a bar chart so that people quickly understand what is being shown. These also show the logic of the schedule which is normally found only in network based schedules. Activities are organized in sequential path order so that each successive path is clearly visible. The fences are added to indicate the logical constraints. A fence is an event or milestone which occurs after the activity on the left side of the fence is completed. This milestone must occur before activities to the right of the fence may start (Melin and Whiteaker 1981).

Because of the simplicity of fenced bar charts, they have become an effective scheduling tool. However, the only reference to their usefulness in scheduling linear projects is made by Arditi and Albulak (1986). Even this reference does not give any specific example of their use in such projects. One of the reasons for this could be the non-availability of commercial computer software packages that use this technique.

2. Review and Evaluation of Literature
2.4 NETWORK BASED TECHNIQUES

Network based techniques were originated during the late 1950s, when the Sperry Rand Corporation devised the Critical Path Method (CPM) technique for DuPont to schedule construction, maintenance, and shutdown of chemical process plants. At the same time, the Navy Special Projects Office developed an integrated management technique for use in the Polaris Missile Program known as Program Evaluation and Review Technique (PERT). While superficially different, both CPM and PERT use a network as a model for an actual project (McGough 1982).

The network based techniques are very useful on projects that are logically deterministic and consist of activities with assumed deterministic parameters (Chrzanowski and Johnston 1986). These techniques clearly illustrate the logical sequence of activities in a project. One-of-a-kind projects have relied heavily on the use of network based techniques for scheduling purposes.

The use of network analysis for construction planning, scheduling, and control has gradually increased, but not at the pace anticipated when it was first introduced in construction (Johnston 1981). There has been considerable research in the recent past on the perceived disadvantages of the network based techniques. John Fondahl (1990), while delivering the Fifth Annual Peurifoy Construction Research Award address, commented:

After 30 years very few practitioners or even those teaching the subject seem to be aware of some of the basic shortcomings of widely used network scheduling techniques.

2. Review and Evaluation of Literature
A number of reasons have been proposed as to why CPM/PERT is not completely fulfilling the needs of the contractor (Ashley 1980, Birrel 1980, Carr and Meyer 1974, Crandall 1976, Jaafari 1984, Johnston 1981, Kavanagh 1985, Morad and Beliveau 1991, Peer 1974, and Stradal and Cacha 1982). Morad and Beliveau (1991) state that the network techniques, despite their widespread use for the last three decades, have many limitations. This section of the thesis discusses some of the limitations of the network techniques and the reasons why they are not fulfilling the needs of the contractor. However, it is clarified here that the intention of this thesis is not to present an exhaustive critique of CPM/PERT. This research acknowledges the importance of CPM/PERT in scheduling of projects to finer details and in resource analysis.

A survey conducted by Davis (1974), indicated that 45% of the Engineering News Record top 400 construction companies seldom or never used CPM. The most frequently voiced concern in this survey was that the construction personnel who must do the work, or supervise it, are not really using it. The second most frequent concern was that implementation of a CPM system requires excessive amount of work (Davis 1974). For complex projects, a CPM schedule becomes extremely detailed. As this occurs, field personnel, who are usually not trained to understand the methodologies of the CPM, find the schedule confusing, therefore less useful (Johnston 1981).

CPM/PERT places emphasis on minimizing the total duration of a project and, in its basic form, makes the assumption that resources are unlimited and centrally controlled. Peer (1974) comments:

2. Review and Evaluation of Literature
Limitations are imposed on the use of network analysis for planning the production process by its fundamental unrealistic assumptions of unlimited resources that can be hired and fired freely, and independent activities of fixed duration that can be shifted freely between earliest start and latest finish. The need for creating working continuity and balancing the whole process into an integrated production system is completely neglected.

Some of these shortcomings have been addressed by the concept of resource leveling. In most cases, the importance of resource leveling is a matter of reducing costs by avoiding peaks and valleys in daily requirements. However, in many cases it is essential because there are availability limits that must be met (Fondahl 1990). Fondahl (1990) comments about the extent of use of resource leveling in network techniques:

While resource leveling techniques have been available since the early 1960's, for many years they were largely ignored in CPM applications. Even though resource leveling programs are more prevalent today and no longer require a mainframe computer, their usage seems to occur mostly in the claims stage after problems have occurred.

Program Evaluation and Review Technique has also been used to schedule construction projects. Moder et al. (1983) state that, "PERT is particularly appropriate for scheduling and controlling research and development type projects, or others comprised primarily of activities whose actual times are subject to considerable chance variation." Kavanagh (1985) has questioned usefulness of PERT and Graphical Evaluation and Review Technique (GERT) in construction projects. He states:

PERT, by requiring three instead of one activity duration estimates, compounds the problem, work and cost of CPM in the eyes of the user. GERT is a much more sophisticated, and therefore complex, modelling system than either CPM or PERT, which is an assurance that it will never be widely used in construction. The inverse relationship between the sophistication of a model and the extent to which the model is used is

2. Review and Evaluation of Literature
demonstrated by the fact that bar charts are still by far the most widely used method of representing a project's plan and progress.

Network based techniques have been less successful in scheduling linear projects than in traditional discrete projects. Since these projects frequently have activities which are repeated throughout the project, the CPM schedule becomes cluttered with repetition of information (Chrzanowski and Johnston 1986). The CPM network for a repetitive project, thus, generally is very clumsy and becomes intelligible only after considerable effort and training.

Carr and Meyer (1974) have investigated the inadequacies of network techniques for scheduling linear projects. They comment:

The CPM is a powerful tool for projects which meet two criteria: (1) The number of activities are commensurate with the complexity of the project; and (2) the activities have clear dependencies which define a required progress through to project completion. Repetitive construction often lacks these characteristics.

This will become clear with the following example of a highway project. A simple 5 mile long highway project may consist of, say, 30 activities. If the basic unit of scheduling is the entire highway section, then this would result in a reasonably simple CPM schedule. However, it is very likely that the project would be executed in at least 10 different sections. The resulting network will now have over 300 activities. Most of these 300 activities will be overlapping each other in the execution of the project and would be characterized by lead and lag relationships with their predecessors and successors. This proliferation of number of activities and number of relationships makes this straightforward

2. Review and Evaluation of Literature
project seem quite complex. Thus the first of the two CPM requirements, cited by Carr and Meyer (1974), often is not met in linear and repetitive projects.

There are few clear dependencies in highway projects between various sections of the project, except those within a particular section. The scheduling of activities within a section of the highway may have clear and deterministic dependencies and it may be possible to develop a network for a particular section of the project. However, the scheduling of various section may be a matter of choice and personal preference. As Vorster and Parvin (1990) state, "On highway work, the location of the work is important. The order of the work (between different sections of the project) is less important than in building construction because the work is spread out over such a large area." Thus, the dependencies between various networks for different sections of the linear project in the overall master project network is not clear and deterministic. Therefore, second of the two requirements, cited by Carr and Meyer (1974), for effective use of CPM, is also not met.

Kavanagh (1985) cites another reason, which is closely related to the one discussed in the preceding paragraph. He comments:

   The site superintendent (in linear and repetitive projects) schedules his crews to work sequentially to obtain maximum resource utilization. (CPM schedule) totally neglects the priority of creating work continuity and production balancing.

It is because of these special characteristics of the linear and repetitive projects that need for specific techniques was felt. Many such techniques have been investigated in the last 15-20 years. These techniques are discussed in detail in the following section.

2. Review and Evaluation of Literature
2.5 SPECIFIC METHODS TO SCHEDULE LINEAR PROJECTS

An awareness that the traditional network is not the most adequate tool for the planning of linear projects has led to a surge of techniques to handle such jobs in the recent past (Handa and Barcia 1986). The techniques that were developed are generally referred to as "Linear Scheduling Methods." Their origins are not clear; there may actually have been multiple origins, possibly in different countries. They have been originally devised to solve industrial production problems and their consideration for use in construction industry is rather a recent event. The techniques include a multitude of variations and are named differently (Arditi and Albulak 1986). Johnston (1981) has summarized the development of linear scheduling methods in construction industry. A detailed survey of the literature available on various techniques that have been used to schedule linear projects is presented in his 1981 paper.

Projects that are generally characterized as linear could be divided into two categories. The first category includes projects which are linear due to uniform repetition of a unit network of activities, throughout the project. A multiple housing project, involving repetitive construction of similar houses, is a good example of this category of projects. The second category includes projects which are linear essentially due to geometrical layout. Highway projects are excellent examples of this category. Highway projects are generally not characterized by uniform repetition of a unit network and they involve a number of activities that are discrete or unique in nature.

Specific techniques that are available to schedule linear projects should be categorized, based on discussion in the preceding paragraph. A review is presented of available

2. Review and Evaluation of Literature
literature on graphical techniques that are useful and effective in scheduling projects which are linear due to the repetitive use of a unit network in section 2.5.1. Techniques suited to projects that are linear due to geometrical layout are discussed in section 2.5.2. Some research has been done in the recent past to develop mathematical models/techniques to schedule linear projects. A limited review of some of these mathematical techniques is presented in section 2.5.3.

2.5.1 Techniques for Projects Characterized by the Repetitive Use of a Unit Network

A construction activity on some projects is similar to the continuous manufacture of many units on a production line. Examples of such projects are construction of repetitive buildings (Carr and Meyer 1974) and construction of successive floors in a high-rise building (O'Brien 1975). Development of a prototypical unit network is helpful in these projects. There are some techniques that use the concept of a unit network to graphically depict the project schedule. Line-of-Balance scheduling (LOB) and Vertical Production Method (VPM) are two such techniques. These are reviewed and evaluated in sections 2.5.1.1 and 2.5.1.2 respectively.

2.5.1.1 Line-of-Balance Scheduling

Line-of-Balance is a graphical method of scheduling. The technique was developed by the U. S. Navy Special Projects Office in the early 1950s (O'Brien 1969). LOB was first applied to industrial manufacturing and production control where the objective is to attain or evaluate a production line flow rate of finished products (Johnston 1981). LOB has proved
itself an effective management tool for steady-state production activities (Schoderbek and Digman 1967).

The LOB technique requires the following three inputs (Carr and Meyer 1974), which are usually represented graphically: (1) A unit network (production diagram) showing activity dependencies and time required between activity and unit completion; (2) an objective chart showing cumulative calendar schedule of unit completion; and (3) a progress chart showing the completion of the activities for each unit.

Johnston (1981), describing various diagrams of a LOB schedule, states:

The production diagram of LOB is similar to an activity-on-arrow diagram network, except that it is a network showing assembly operations for only one unit of many to be produced. Standing alone, this does not show interference which may occur between assembly operations on separate units.

The progress diagram is somewhat similar to a bar chart in that both graph individual activities, but there are clear differences. Prepared for a particular date, the progress diagram graphs, as a vertical bar for each task, the actual number of units completed (or percent completed). However, the bar chart graphs tasks on the vertical axis versus the time period of activity on the horizontal axis.

Al Sarraj (1990) "formalized" the line-of-balance method by developing its algorithms. He states that, "By adopting the method in its formalized form, there is no need for any diagrams to be drawn as a means of defining the schedules."

Although LOB has been used in some linear construction projects which are characterized by the repetitive use of a unit network (Lumsden 1968; Carr and Meyer 1974; and Arditi

2. Review and Evaluation of Literature
and Albulak 1985), its widespread use in all types of linear projects is doubtful. It is not always possible to break down the project into a set of repetitive sections. There are many factors which inhibit representation of the entire project by repetition of a unit network throughout the duration of the project. Kavanagh (1985) states that, "(LOB techniques) were designed to model simple repetitive production processes and, therefore, they do not transplant readily into the complex and capricious construction environment." Ashley (1980), commenting on the analogy between a production line and a linear construction operation, stated:

Multiple-unit, multiple-floor, linearly progressive projects resemble assembly line processes in their structure of a small set of tasks in repeating sequences. The complex and environmentally exposed nature of construction in many instances does not allow the analogy to go further. Rather deterministic task operation times for an assembly line become quite variable when weather and exogenous factors are more free to affect the process.

Ashley (1980), commenting on the usefulness of LOB in complex linear construction projects, stated that, "Learning curve effects, 'come back' delays, constraining resources, and stochastic activity durations, all important characteristics of repetitive-unit construction, cannot be modeled by the LOB technique."

2.5.1.2 Vertical Production Method

Vertical production method (VPM) was developed by O'Brien (1975) for specific use in construction of high-rise buildings. O'Brien recognized the importance of using CPM to schedule basic preparation work for a high-rise building, such as site work, foundations, and structures to the first typical floor. However, when the high-rise project reaches a
certain point, usually the construction of the first typical floor, the whole project momentum changes. The entire project from this point onwards could be represented by repetition of a unit network for a prototypical floor. At this stage in a high-rise project the arrangement of project logic into a repetitive vertical format is advantageous.

The diagram that O'Brien (1975) and O'Brien et al. (1985) used to graphically portray the Vertical Production Method is similar to the linear scheduling diagram (discussed in section 2.5.2.1). In VPM diagram, the horizontal and vertical axes are used to depict time and floors in the high-rise building, respectively. Goldhaber et al. (1977) presented a diagram for a high-rise building which they labeled as the "trade progress chart." This diagram is very similar to the one used in VPM.

2.5.2 Techniques for Scheduling Projects Characterized by Linear Geometrical Layout

Some construction projects are linear essentially due to their geometrical layout. These projects may not be characterized by uniform repetition of a unit network. These projects generally involve a number of activities that are discrete in nature, in addition to linear activities. The execution of the linear activities is often not in a uniform fashion from the start to end of the project. Examples of such projects are highways, rail lines, pipe lines, and tunnels. Some high-rise buildings and multiple housing projects, which involve considerable variations from unit to unit, will also fall under this category. Graphical techniques such as Linear Scheduling Method (LSM) and Time-Space Scheduling Method are two techniques which are useful in scheduling such projects. These techniques are discussed in sections 2.5.2.1 and 2.5.2.2 respectively.

2. Review and Evaluation of Literature
2.5.2.1 Linear Scheduling Method

The Linear Scheduling Method is a graphical method which is particularly applicable to linear projects. The term "linear scheduling method", in the context of this research, will be exclusively used for this graphical method which has two axes, viz. the time axis and the distance (or location) axis.

One of the first references to this graphical technique is found in the literature reporting research in the Middle East (Johnston 1981). Peer (1974) and Selinger (1980) developed a method, since named the construction planning technique (CPT), in the process of analyzing parameters affecting construction time in repetitive housing projects. Peer and Selinger used the x-axis to denote time and y-axis to denote number of sections. Activities were represented by straight lines. Efforts to put CPT on a mathematical basis were also included.

Further research has been carried out since CPT was first introduced, in the field of mathematical analysis using an algorithm based on linear programming, and optimal control theory. These advancements are discussed in section 2.5.3.2.

Gorman (1972) suggested the use of "time versus distance diagram", to achieve better communication of schedule information through visual impact, in rapid transit, highway, and pipeline projects. This diagram had location on the x-axis and time on y-axis. Harris and Evans (1976) used a diagram, which was essentially a linear scheduling diagram, to convey the construction schedule for a road construction simulation game example.

2. Review and Evaluation of Literature
Clough and Sears (1979) presented a "bar chart for repetitive operations" in their book. This diagram is essentially a linear scheduling diagram. The example used showed repetitive activities for a pipeline relocation drawn has straight lines on a graphical layout having location as the horizontal axis and time as the vertical axis. Barrie and Paulson (1984) presented a "linear balance chart" in their book. This diagram also is essentially a linear scheduling diagram.

Johnston (1981) first used the term "linear scheduling method" for the technique that he reviewed in his publication. He discussed the basic elements and concepts of LSM. In Johnston's publication, the horizontal axis of the scheduling diagram plots time while the perpendicular axis plots location along the length of the project. The activities are plotted as a series of diagonal lines. Activity production rates are used to define the slope of the activity lines.

In several ways, the LSM diagram resembles the objective diagram of the line-of-balance technique. Both use time as one axis and some measure of production as the other axis (Johnston 1981). Differentiation between LOB and LSM is in the matter of emphasis. LSM emphasizes a diagram similar to the objective diagram for planning purposes while LOB places more emphasis on the balance line of progress diagram.

Chrzanowski and Johnston (1986) applied the linear scheduling method to schedule a roadway project located in North Carolina. A discussion was presented of the advantages that LSM offered and the limitations encountered during field use.

2. Review and Evaluation of Literature
LSM is useful for almost all types of linear projects. Projects which are linear in geometric layout can be scheduled very effectively using LSM. Projects that are characterized by repetition of unit network can also be graphically scheduled using LSM. A complete discussion of LSM, its format and symbols, its usefulness and effectiveness, and developments and enhancements in the technique will be presented in the following chapters of this thesis.

2.5.2.2 Time Space Scheduling Method

Stradal and Cacha (1982) presented a construction scheduling technique titled "time-space scheduling method." This technique is very similar to the linear scheduling method discussed in the previous section. The technique is labeled time-space scheduling method because it shows the connection of activities, their duration times, and sections (space) where they take place in a given time. Examples of the application of this technique were given for the pump foundation in a pipeline, construction of an apartment house, a multi-storied concrete building, a road section, and a railway bridge.

2.5.3 Mathematical Approaches to Scheduling Linear Construction

A discussion on graphical techniques to schedule linear construction projects was presented in sections 2.5.1 and 2.5.2. Some research has been done in the recent past to develop mathematical models/techniques to assist in scheduling linear projects. A limited review of some such techniques is presented in the following sub-sections to give an idea about the research being carried out in these areas.

2. Review and Evaluation of Literature
2.5.3.1 Simulation Methods for Repetitive Construction

Efforts have been made to explore computer simulation modelling of repetitive construction projects. Ashley (1980) made a case for using simulation technique to enhance management intuition in repetitive-unit construction planning. He provided an example that demonstrates how crew size, equipment allocation, and learning effects can be manipulated by a manager to gain insight into construction operations. Kavanagh (1985) presented SIREN (Simulation of REpetitive Networks) which is a computer model of repetitive construction. Harris and Evans (1977) used a game to simulate road construction.

2.5.3.2 Construction Planning Technique and Optimal Control Theory

As discussed in section 2.5.2.1, Construction Planning Technique (CPT) was first developed in the Middle East by Peer and Selinger. Peer (1974) presented a discussion on the principles of CPT. He also discussed the ineffectiveness of resource allocation programs in the network analysis. Selinger (1980) presented an algorithm to determine the quantity of resources for each sequence of tasks ("production line"), and the start and finish times of each activity, with a view to minimize total construction time of the linear project. The algorithm was based on dynamic programming.

Handa and Barcia (1986) tried to overcome difficulties in computerization of the linear scheduling methods. Optimal control theory, a branch of optimization, was used to view the construction-production process as a dynamic system that evolves over time. Russell and Caselton (1988) have reported further research on the subject.

2. Review and Evaluation of Literature
2.5.3.3 Stochastic Scheduling of Linear Construction using Time Velocity Diagram

Dressler (1974) suggested development of economical construction schedules for linear construction by means of a time velocity diagram. This time velocity diagram is essentially a linear scheduling diagram, because it represents the determined route (location) on one axis and the construction time on the other. He reported that deterministic spatial condition and stochastic time and weather-dependent production conditions jointly influence the production velocity achievable through specified resources within each production zone. The mathematical model developed takes into consideration stochastic production velocities.

2.6 DISCUSSION

This chapter has laid the foundation of the thesis by reviewing and evaluating the literature available on LSM, the technique which will be studied, investigated, and researched in detail throughout the rest of the thesis. Discussion on need for systematic planning and scheduling brought out the importance of carrying out systematic project management. A review of available traditional bar chart and network based techniques for scheduling construction projects was carried out in order to evaluate their role in scheduling linear projects. It was shown that success of these traditional techniques has been limited despite the fact that they have been used in the past to schedule linear projects. This occurs because of the special characteristics of linear projects.

2. Review and Evaluation of Literature
Numerous specific techniques have been developed to schedule linear projects. These were studied and evaluated for their use in complex highway projects. Since complex highway projects are not characterized by the repetitive use of a unit network throughout the entire project length and duration, they are not well suited to techniques such as line-of-balance scheduling. LSM was shown to be suitable, simple, and powerful graphical technique. It is also easily understood by all involved in construction operations, making it amenable to actual implementation in the field.

The remainder of this thesis will be devoted to extending the range of linear scheduling in highway construction. A complete discussion on LSM, its format and symbols used to represent various operations, and its usefulness and effectiveness will be presented. LSM has been used in actual field construction to schedule two highway projects. Lessons learned from this field implementation will be presented. Many advancements and enhancements to the technique have been investigated as a part of this research effort. These will be reported.

2. Review and Evaluation of Literature
CHAPTER 3

FIELD IMPLEMENTATION OF
THE LINEAR SCHEDULING METHOD

Various traditional scheduling techniques, and specific methods which can be used to schedule linear construction projects, were discussed in the previous chapter. It was suggested that the Linear Scheduling Method (LSM) is best suited to schedule complex highway projects. Special characteristics of complex highway projects such as the mix of linear and discrete activities as well as the presence of repetitive operations in an otherwise unique project, are well modeled by the LSM. The graphical nature of the linear scheduling method is an added advantage over other techniques since a graphical schedule is easy to understand and follow by all involved in the construction operations.

A summer internship was undertaken by the author in 1990 to obtain field experience in the subject of linear scheduling. Field implementation of LSM was carried out on two highway construction projects. Information gathered on these projects in the areas of developing, updating, and modifying linear schedules will be discussed in this chapter. The chapter contributes to the thesis through a frank discussion of the problems encountered during the field implementation of LSM on these projects.
Field experience made two things possible: (1) Real problems with implementation of the technique, and areas of concern could be identified; and (2) Proper practical and effective responses to these areas could be formulated. The work done for the thesis, the enhancements to the technique and the conclusions drawn, are thus based on feedback received from the field. Figure 3.1 depicts the field implementation phase of this research and shows that this phase led to identification of problems with the technique and areas of concern with the technology.

Figure 3.1  Field Implementation of LSM

3. Field Implementation of LSM
3.1 LINEAR SCHEDULING VIDEO TAPES

Two events occurred in the Spring 1990 which were instrumental in starting this research effort. These were: (1) the production and marketing of a set of video tapes on linear scheduling in highway construction, and (2) a summer internship undertaken by the author to test the concepts set out in the tapes and obtain field experience needed to develop and improve the then current state-of-the-practice. This section discusses the set of video tapes. Field implementation of LSM is discussed in Section 3.2.

Michael C. Vorster, Professor of Civil Engineering at Virginia Tech, and Cordell M. Parvin, produced a set of three video tapes titled 'Linear Scheduling for Highway Contractors and State DOTs', in the Spring of 1990.

The tapes played an important role in describing the concept of linear scheduling and introducing the researcher to the subject. These have also helped practitioners in the highway industry to understand LSM and the ways in which LSM can be used to the benefit of all the parties involved.

The tapes address the following three issues: 1) The need and benefit of planning and scheduling; 2) The format and layout of the linear schedules; and 3) The use and application of LSM in contract administration and claims resolution. The contribution made by the tapes regarding the increased need and benefit of planning and scheduling in the nineties has already been discussed in Chapter 2, Section 2.1.

3. Field Implementation of LSM
The tapes make significant contribution towards defining a standard format for the linear schedules. They make an input to the discussion in Section 3.4 and to Chapter 5 which discusses the enhancements to the format and layout of LSM and symbols used.

The tapes discuss the use and application of LSM for management, control, contract administration, and dispute resolution. Most of these issues are not within the scope of this thesis except the discussion regarding three criteria which must be met for success in planning a linear job. These criteria are: 1) The production crews must be given time and space to do their work; 2) The work must be done in an ordered sequence; and 3) Delays and changes must be minimized.

3.2 FIELD IMPLEMENTATION OF LSM

In the summer of 1990, this researcher took up a summer internship with Moore Brothers Company, Inc. Moore Brothers (MBC) is a general contracting company and it specializes in highway construction. It has its offices in Verona, Virginia and construction sites in the Northern Virginia (suburban Washington, D. C.) area. The internship gave this researcher an opportunity to develop and implement a number of linear schedules for projects undertaken by MBC.

In preparation for the summer internship, the researcher familiarized himself with linear scheduling by reviewing the set of video tapes discussed in Section 3.1. A brief literature survey was also carried out and published work on the subject was collected.
The linear schedules produced during the internship were developed using GenericCAD, a Computer Aided Design and Drafting (CADD) package. Use of a CADD package makes the saving, storing, modifying, updating, and re-storing of linear schedule easy. The quality and clarity of output is better than manually drawn schedules. Use of CADD package led to a lot of thinking regarding visualization, and its importance. It also led to the ideas of using different colors, line types, and hatch patterns, and using LSM for scheduling non-linear sections of projects.

The field implementation brought to the fore many problems associated with scheduling of highway projects. A brief overview of the projects where field implementation took place is presented in this section to assist in understanding the scheduling related problems which are discussed in detail in Section 3.3. Efforts to address these problems led to several advancements and enhancements to the technique. These are discussed briefly in Section 3.4, and in detail in the rest of this thesis.

3.2.1 Dulles Toll Road Project

The project, labeled as 'Job 36' for the company's internal communications, entailed widening approximately 3.5 miles of the Dulles Toll Road to take it from four to six lanes. Since no equipment was allowed to cross the median, due to the layout of roads, the project was treated by the contractor as being composed of two separate sub-projects, viz. the east bound lane (EBL) and the west bound lane (WBL). It was decided to construct each of these lanes in three sections, viz. the west end section, the middle section, and the east end section. The project included widening of two bridges, constructing three retaining wall of

3. Field Implementation of LSM
varying lengths, and installing a number of box and pipe culverts, in addition to the regular works connected with widening of roadway.

3.2.2 Route 28 Project

The project under review, labeled as 'Job 50' for company's internal communications, entailed widening Rt. 28 from a four-lane highway to six-lane divided highway, with auxiliary lanes for collecting/distributing traffic from/to the ramps. It involved construction of a number of ramps at the intersection of Rt. 28 and the Dulles Toll Road. The project also involved replacing existing bridge decks and widening existing bridges. One new bridge construction was also part of the project. Special design median barriers were to be placed in position to physical divide the highway.

3.3 PROBLEMS ENCOUNTERED

Field implementation of LSM to schedule two highway construction projects, described in Section 3.2, posed many problems. These are discussed in this section. The problems encountered provided the experience needed to identify and focus the responses outlined in Section 3.4, and discussed in detail in Chapters 4 through 7.

3. Field Implementation of LSM
3.3.1 Lack of Historical Database

The lack of a data-base for scheduling was one of the first problems to surface. The company kept very little organized information about the productivity of the crews and little was known regarding the optimum work sequence logic. One of the first tasks was to interact with the field personnel, and collect basic information on these subjects so that a preliminary schedule could be developed. Securing time from the field personnel, especially when the project was in full swing, was extremely difficult.

3.3.2 Concerns About the Critical Path Method

Discussions with the field personnel revealed a serious problem concerning paradigms of the field personnel regarding scheduling. Most of them thought that the whole exercise was worthless and felt that they should be left to do their jobs the way they have been doing for years. This attitudinal problem was overcome by educating the field personnel about the need and importance of systematic planning and scheduling. Once this was accomplished, a second problem concerning the fact that most of the personnel had very little or no familiarity with the Critical Path Method (CPM) had to be addressed. There was a universal feeling among most personnel that CPM was "not for them". It was perceived to be too difficult a technique to be understood, especially when they had very little time on hand after taking care of their routine chores. Moreover, it was felt that CPM was being thrust upon them, that they really didn't need it, and that they would never have time to fully understand the complexities of issues such as 'lead' and 'lag' relationships, and 'pure-logic' diagrams.

3. Field Implementation of LSM
Another impression in the minds of the field personnel was regarding the way in which scheduling techniques perceive projects as deterministic operations. It was emphasized that construction is not a consistent, predictable operation. Availability of crews is not certain, weather conditions are not predictable, and above all, site conditions are not predictable.

Critical Path Method does not provide a graphical output which has spatial dimension to portray location information. This was a major problem since location in a highway project is of immense interest to planners and executors. Field personnel were of the opinion that techniques for use in highway construction should be able to capture the parameters of space as well as time.

3.3.3 Concerns About the Linear Scheduling Method

Linear Scheduling Method (LSM) was a new technique to most field personnel and it was soon apparent that few had ever seen a linear schedule. Basic instructions about LSM soon created an almost unanimous feeling that this was 'the' technique which would truly capture the parameters of space and time, both of which were of immense interest to them. The linear schedule was found to be easy enough to be understood by all concerned. The simplicity of the linear schedule output brought another point to the fore. LSM was viewed as too simple a technique and there was an initial feeling in the minds of some that it may be suitable for simple highway projects but scheduling complex projects like 'Job 50' would not be possible using the technique.

The concern expressed by some field personnel that LSM was too simple a technique to be able to effectively depict a complex project, seemed to be genuine. The state-of-the-practice

3. Field Implementation of LSM
at that time did present LSM as a rather simple technique. Most of the examples used in literature were of simple projects and the resultant diagrams looked innocuously simple. Most of these diagrams had a series of inclined lines, running from start to end of the project. Very few publications referred to the use of a rectangle to depict activities on a linear schedule.

Although highway projects appear perfectly linear, they frequently include ramps, loops, and side roads. Project execution seldom begins at the start of the project and finishes at the end as they are frequently executed in small, discontinuous sections. Most of the literature on linear construction, when refers to linear projects, perceives these projects to be linear from start to end. This is clear from the examples used in the literature and the way information is portrayed.

3.3.4 Format of Linear Schedule

The field experience identified a number of shortcomings with regard to the ability of LSM to effectively schedule complex projects. The linear schedule for a complex project needs to portray a large number activities. Some activities are basically similar but performed by different crews while some other activities are different but performed by the same crew. Since all the symbols, representing different operations of a similar nature, are basically the same, there appeared to be no way to distinguish between these symbols. The schedule thus would become cluttered with symbols and be very much less intelligible.

The section of the 'Job 50' consisting of the intersection between Rt. 28 and Dulles Toll Road could not be called linear in the true sense of the term. Scheduling this section thus

3. Field Implementation of LSM
required an approach which could accommodate sections of work which were not on the main line of the job.

3.3.5 Lack of Tabular Output

A linear schedule is a schematic representation of the operations. It not uncommon to prepare these schedules on large size drawing sheets in order to make the information on the schedule legible. Since there is no tabular output that is available from the linear schedule, it is difficult for the field personnel to refer to the schedule when they are out of their offices, on the job site.

3.3.6 Controversy Between CPM and LSM

Critical Path Method was found to be a powerful technique for carrying out schedule calculations during field implementation phase. It is a good tool for computing project dates and it handles relationship constraints, dates constraints, and forward and backward pass calculations and loops in the schedule very well. Use of computerized programs for generating CPM schedules has made recording, sorting, selecting, storing, modifying, and updating of the schedule information easier. Moreover, introduction of resource leveling as an additional feature of the technique has increased its effectiveness. CPM does, however, has its limitations. It lacks graphical output having spatial dimension to portray location information. It excessively relies on deterministic relationship constraints. Assumption of unlimited resource availability is not commensurate with actual practice and the concept of resource leveling is not very well defined.

3. Field Implementation of LSM
Linear Scheduling Method is a good visual technique and has a better communication potential than CPM. It is easier to identify scheduling alternatives using LSM. As discussed in Section 3.2, linear schedules were drawn during the field implementation phase using a Computer Aided Design and Drafting (CADD) package. Although the use of a CADD package results in better quality of the output, it is a complex task and requires specialized knowledge, professional training, and experience. Furthermore, LSM lacks the capability to compute project dates and there is no computerized program which carries out scheduling based on user input information.

Critical Path Method (CPM) as well as Linear Scheduling Method (LSM) were used to schedule projects during the field implementation phase. It was identified that there is a constant controversy between the two. The user is confronted with two questions when he/she has to decide about the technique for scheduling a project. The first question is which one of the two techniques should be used, and the second question is which one of the two is a better technique. Both the techniques have their advantages and disadvantages.

3.4 RESPONSES TO THE PROBLEMS ENCOUNTERED

The problems encountered during the field implementation of the Linear Scheduling Method, discussed in Section 3.3, made it possible to identify a number of specific responses. The first problem, reported in Section 3.3.1, regarding lack of historical database is outside the scope of this thesis and is not directly addressed. However, consistent use of a standard format, to be discussed in Section 3.4.2, causes the experience of the personnel using the technique to be collected in a standard way. This assists in the

3. Field Implementation of LSM
development of a database of information. Other problems encountered, discussed in Sections 3.3.2 to 3.3.6, are addressed. These are discussed under the following four headings, each of which is later expanded into a chapter.

3.4.1 Visualization in Planning, Execution, and Control

As discussed in Section 3.3.2, one of the major concerns regarding Critical Path Method as a scheduling technique for highway construction was lack of graphical output having spatial dimension to portray location information. It was identified during the field implementation phase that one of the biggest advantages of the linear scheduling method is its graphical and visual nature which provides for better communication potential than most other scheduling techniques. Visualization helps in better understanding of the project in the planning phase and helps the planner to analyze various scheduling alternatives. Field personnel find the graphical nature of the technique helpful in understanding the schedule. Visualization helps in updating, modifying, and revising the linear schedule, during the control phase. The topic of visualization, and the role of LSM in visualization, was studied in detail. A detailed discussion on visualization in project planning, execution, and control, and use of LSM to evaluate scheduling alternatives, is presented in Chapter 4.

3.4.2 Linear Schedule: Format and Symbols

Field implementation clearly showed that the state-of-the-practice was not sufficient to develop linear schedules for all sections of a complex project. As discussed in Section 3.3.3, LSM was presented as a rather simple technique. The format and the symbols used in the technique were studied in detail. A number of features such as plan, profile, sight

3. Field Implementation of LSM
lines, period numbers, access details etcetera were added to the format of the linear schedule. Symbols to depict earth movement were developed. A detailed discussion on the features and symbols used in a linear schedule is presented in Chapter 5. A standard format for the linear schedule, based on allocation of horizontal axis to distance, and vertical axis to time, is suggested. The standard format utilizes various symbols and features discussed above. The use of different line types, hatch patterns, and colors was identified to cater to the problem discussed in Section 3.3.4. Ways to schedule non-linear sections of a project and using LSM to do multi-project scheduling were identified and are discussed in Sections 5.9 and 5.10, respectively.

3.4.3 Representation of Linear Schedule in Tabular Format

As discussed in Section 3.3.5, the need for tabular format was identified during the field implementation phase. A Crew Movement Chart (CMC) was developed in response to this need and the results are presented in Chapter 6. A CMC shows deployment and movement of various crews, in a tabular format. Sorting and selecting criteria are used to generate CMC containing information about specific, crews, operations, stations, or dates. Use of spreadsheet as well as database computer packages to carry out sorting and selection of activities is also discussed in Chapter 6. A computer software program titled LINC was developed as a part of this research which is discussed in Chapter 6. LINC can be used to generate a CMC using user-interface screens to input the required data.

3. Field Implementation of LSM
3.4.4 Linear Scheduling Software

As discussed in Section 3.3.6, there is a constant controversy between Critical Path Method (CPM) and Linear Scheduling Method (LSM). The questions that the users are confronted with are: Whether to use CPM, or LSM; and Which one is better of the two techniques. The idea of developing a computer program which provides an interface between both the techniques and builds on the strength of each technique evolved in discussions during this research. Chapter 7 discusses the development of the resulting software, the Linear Scheduling Software (LSS), and the contribution made by the author to the development process. Further work to combine LSS and LINC, the computer software package to generate Crew Movement Chart, is also discussed.

3.5 DISCUSSION

The focus and content of this thesis is based on field experience. The initial phase of the research effort exposed the researcher to specific problems regarding utilization of the technique in complex highway construction projects. This phase was critical to the quality of the work done and it ensures that the developments proposed will lead to a better understanding in both planning and executing the work. Importance of on-hands field experience in this endeavor, and input from the field personnel, simply can not overemphasized.

3. Field Implementation of LSM
Real problems with implementation of the technique, and areas of concern were identified during field experience. This chapter discussed these problems and outlined proper practical and effective responses which were briefly discussed in Section 3.4. Each of these areas is expanded in a chapter and discussed in Chapters 4 through 7.

3. Field Implementation of LSM
CHAPTER 4

VISUALIZATION IN PLANNING, EXECUTION, AND CONTROL

One of the biggest advantages of the Linear Scheduling Method (LSM) is its graphical and visual nature which provides for better communication than most other scheduling techniques. This chapter discusses the role and importance of visualization in increasing the effectiveness of LSM.

Figure 4.1 shows various phases in a construction project and role of visualization in these phases. Planning phase consists of defining how the work will be done, identifying various activities, establishing mutual interdependencies between these activities, and sequencing them, based on project constraints and requirements. Scheduling phase introduces time parameters for these activities to determine completion dates of individual activities and the overall completion of the project. The project is built during the execution phase. The constructors may encounter problems related to scheduling, resources, information and site conditions. During the control phase, alternatives are analyzed and the
Figure 4.1  Phases in a Construction Project and Role of Visualization
schedule is modified and/or updated. Visualization is of help in all these phases of a construction project.

4.1 PLANNING AND SCHEDULING PHASE

Most of the construction projects are one-time and largely unique efforts of limited time duration which involve work of a non-standardized and variable nature (Clough and Sears 1979). In order to successfully execute such projects, use of a systematic project management system is important. Planning and scheduling are two vital elements of a systematic project management system. Visualization helps in better understanding of the project in the planning and scheduling phase. Use of LSM in highway construction projects will result in a better plan. It is better to do a better job with planning, and replanning, rather than produce a poor plan and experiment with this poor plan. In the construction industry, there is very little room for experimentation at the execution stage. A project can be built many times on the paper, but it is built only once in the field.

It is very seldom that the planners get a complete feel of the project during the project planning phase. Many a times, planning and execution are treated as two distinct and separate operations. The planner uses established rules, algorithms, and practices to make assumptions in the planning process. Most construction projects are complex, and thus it is physically impossible to completely visualize all the steps needed to plan and schedule the project. This thesis suggests that, in highway construction projects, use of the Linear Scheduling Method will allow the planner to produce a schematic diagram which is easy to understand and which bears a strong resemblance to the project. This schematic diagram

4. Visualization in Planning, Execution, and Control
will serve as an aid to visualization of the construction processes, sequences, and resource requirements, as planning progresses. This will occur because of the visual nature of the technique used which lets the planner understand the job as it is going to be built, and exercise judgement during planning.

4.2 EXECUTION PHASE

The relationship between the planner and the constructor does not end with the completion of the planning phase. Firstly, it is very seldom that the planning and execution occur in totally different time periods. More often than not, these two phases overlap each other. Visualization helps in the execution phase by better communication between the planner and the constructor, and better understanding of the project by the constructor.

Visualization helps in communicating planning and scheduling data to the constructor. Communication may be defined as the transfer of information that is meaningful to those involved (Ivancevich et al. 1977). It is vital that effective communication occurs between all levels of the organization so that information, on the tasks to be carried out, can be shared. In construction organizations, it is important that effective communication occurs between the planners and the constructors in all phases of a construction project. Communication in the construction organizations may occur in the following ways: Verbal, written, and graphical. It is practically impossible to verbally communicate planning data and information due to amount of information and its complexity. Written communication of information regarding planning and scheduling, may result in problems of semantics (different interpretations of the meanings of words) and differences in perception.

4. Visualization in Planning, Execution, and Control
Graphical communication is the best way to communicate planning and scheduling information in a construction organization. Linear scheduling method is a graphical method and is effective in communicating information in linear projects. Effectiveness of LSM stems out of the repetitive nature of information which makes it easier to be represented graphically.

In the execution phase, visualization also helps in better understanding of the plan and schedule. While execution of the project is going on, the constructor may be confronted with change in conditions. This may lead to reconsideration of the scheduling alternatives. Visualization helps in reconsidering and reevaluating the alternatives.

4.3 CONTROL PHASE

Constructors invariably encounter many problems related to scheduling, resources, information, and site conditions during execution. Use of a graphical tool helps in identifying these problems and their solutions. Once the problems are identified, they need to be communicated to the planners for updating and/or modifying the original schedules. The planner revises the original schedule and communicates the revised version of data and information to the constructor. Communication of information is easier with the use of a graphical tool such as LSM.

4. Visualization in Planning, Execution, and Control
4.4 EVALUATING ALTERNATIVES

It is generally not that important that the construction personnel in projects which are characterized by deterministic operating sequences and relationships become fully aware about the cause-and-effect relationship of the scheduling alternatives. However, in projects which are not characterized by deterministic sequences and relationships, and highway projects are excellent examples of such projects, there is no unique schedule. Therefore, it is important that the personnel are aware of the cause-and-effect relationships of the scheduling alternatives. There is a need for a mechanism to evaluate alternatives. It is generally not possible to analyze scheduling alternatives in a quick and easy way when the traditional techniques are used for scheduling. Use of a visual tool, such as the LSM, allows the planner to see the effect of various scheduling alternatives. This section discusses use of LSM in evaluating alternatives.

A simple case example will be used throughout this section. Figures 4.2 to 4.6 are based on this case example. The project is executed in three sections. The sections are from stations 0 to 100 (Section 1), 100 to 200 (Section 2), and 200 to 300 (Section 3). The project consists of ten activities. Grading, subbase, and base course operations are carried out in each section and in addition to these, there is a culvert at station 60. The activities and their ID numbers are listed in Table 4.1. The duration of all the activities is 2 weeks except the culvert (activity 100) which has a duration of 4 weeks.

Certain lag constraints exist between the activities, due to the nature and sequence of operations executed, that must be satisfied. There must be a 1 week lag between completion of grading and start of subbase in that section so that grading work may be

4. Visualization in Planning, Execution, and Control
Table 4.1 Activities for the Example Project

<table>
<thead>
<tr>
<th>Section</th>
<th>Sect No.</th>
<th>Culvert</th>
<th>Grading</th>
<th>Subbase</th>
<th>Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sta 0-100</td>
<td>1</td>
<td>100</td>
<td>101</td>
<td>102</td>
<td>103</td>
</tr>
<tr>
<td>Sta 100-200</td>
<td>2</td>
<td></td>
<td>201</td>
<td>202</td>
<td>203</td>
</tr>
<tr>
<td>Sta 200-300</td>
<td>3</td>
<td></td>
<td>301</td>
<td>302</td>
<td>303</td>
</tr>
</tbody>
</table>

tested prior to starting subbase. Similarly, base course can start in a section only one week after the subbase activity for that section starts and this constraint is also for testing purposes.

Each activity in the sample project uses one resource unit per week. Grading is done by grading crew. It is assumed that the three sections of the project have self contained earthwork operations which means that no earth movement between the sections will be needed. Subbase and base are done by subbase crew and base crew respectively. Culvert is constructed by the concrete crew.

4.4.1 Schedules Based on Hard Logic Alone

It is common to consider unlimited resource availability in the beginning of the scheduling phase. An unconstrained schedule has relatively fewer critical activities and considerable float is available in various activities. At this stage the relationships between the activities are defined using 'hard logic' alone. Hard logic is defined as the 'technical' relationship constraints in the schedule that must be satisfied when carrying out the operations. The relationship constraint that subbase course must be placed before laying base course in the same section of the project, is an example of a hard logic constraint.

4. Visualization in Planning, Execution, and Control
The critical path schedules generally show available float. Total float can be defined as units of time by which an activity can be delayed without directly causing any increase in the total time to complete the project (Moder et al. 1983). In the linear scheduling environment this can be termed as 'time float'. Activities not having time float are critical. These activities will be called 'Critical Path Critical' (CPC) for the purpose of discussion in this chapter. Any delay in a critical activity, in the unconstrained schedule, will result in the delay of the project duration by equal duration.

Figure 4.2 shows a CPM as well as a LSM schedule for the example project. These schedule are based on hard logic alone. It is assumed that unlimited resources are available. Therefore activities for grading, subbase, and base operations in sections 2 and 3 can be executed concurrently. However, due to the 'technical' constraint that grading in section 1 can begin only after completion of the culvert at Station 60, grading as well as subbase and base operations in this section of the project can not be executed concurrently with the other two sections. The critical path in the unconstrained schedule passes through the activities of the section 1, and all the four activities of this section are critical.

4.4.2 Effect of Resource Leveling

John Fondahl (1990) states that, "Almost all construction projects are affected by the availability and economics of usage of resources." It is important to carry out resource leveling in the scheduling operations. Fondahl (1990) further states, regarding the need for resource leveling:

4. Visualization in Planning, Execution, and Control
Figure 4.2 Schedules Based on Hard Logic Alone

Note: Activities shaded in CPM schedule are critical.
In most cases, the importance of resource leveling is a matter of reducing costs by avoiding peaks and valleys in daily requirements. However, in many cases it is essential because there are availability limits that must be met.

Resource leveling is defined in some literature as the rescheduling of activities within the limits of available float to achieve better distribution of resources and is differentiated from resource allocation which is described as fixed resource limits scheduling (Moder et al. 1983). In this thesis the term resource leveling is used to describe rescheduling to avoid peaks and valleys in resource requirement as well as to meet constrained resource availability limits.

The activities are prioritized for allocation of resources, based on heuristics, during the process of resource leveling. The first condition to be satisfied for allocation of resources is eligibility. An activity will be eligible for consideration when it is at or beyond its early start date at the time of allocation. The most commonly used heuristic for resource leveling is time to late start (remaining total float). Duration of the activity can be the next priority for eligibility. Sometimes resources are allotted to the activity having longest duration, while at other times activities having the shortest duration are given preference. Several other heuristics can also be used for successive levels of prioritization.

Location of the activity can be used as a criterion for allocation of resources. However, when resource leveling is carried out using computer software packages, a condition based on location will generally have to be introduced as a hard rule for the entire project. For example, a condition may be imposed in the example project that all the activities in section 3 be scheduled prior to section 2, all other things being equal. However, there may be

4. Visualization in Planning, Execution, and Control
times when the user wishes to have some activities of section 3 scheduled prior to section 2 while some other activities of section 2 prior to section 3. Although it is within the realm of capabilities of computer scheduling software packages to carry out resource leveling based on such conditions, it frequently becomes very complex and requires a very high level of skill and training.

Most of the time float which was available prior to resource leveling is consumed in the process and a number of activities become resource critical. A resource critical activity (RSC) can be defined as an activity which has time float available in an unconstrained schedule, however it does not have any float available after resource leveling. John Fondahl (1990) states, on the subject of resource critical activities:

> Often those activities that must release resource units may not be critical in the sense of having zero float. However, if they fail to release the resource units needed by a critical activity, they delay that activity and, hence, the project. Therefore, an activity having positive float can still be "resource-critical" since it will delay project completion if it fails to release resources on time.

A resource constraint has been put on all the resources for the example project and the maximum availability of each resource has been limited to 1. Resource leveling is carried out to satisfy resource constraints. Figure 4.3 shows CPM schedule after resource leveling. The information in the CPM schedule is converted into a linear schedule which is also shown alongside the CPM schedule in the figure. Based on set of heuristics, described earlier in this section, activities in section 2 are scheduled prior to the activities in section 3. All the six activities, belonging to sections 2 and 3 have now turned resource critical. For example, although activity 301 is not critical in the original schedule shown in

4. Visualization in Planning, Execution, and Control
Notes: Activities shaded in CPM schedule are Critical Path Critical (CPC)
Activities hatched in the CPM schedule (201, 202, 203, 301, 302, and 303) have been Resource Critical (RSC)
Resource availability for all the resources is limited to 1 per unit time

Figure 4.3  Effect of Resource Leveling
Figure 4.2, it has turned resource critical after resource leveling. A delay in this activity will delay the releasing of the resource that activity 101 needs. Since activity 101 is on critical path, this will delay the project completion.

Primavera Project Planner was used to develop schedules for the example project. It was identified from the time scaled logic diagrams for the project that although the early start and finish dates of the activities affected by resource availability constraints are adjusted to satisfy these constraints, the late start and finish dates of these activities remain unchanged. The six activities in the example project which were referred to as resource critical in the preceding paragraph were shown to be having positive theoretical float in the schedule even after resource leveling. This is not true in actual practice. Use of a visual tool like LSM brings out clearly that all the activities between Station 100 to 300 in the example project have turned resource critical, with no availability of actual time float to any of these activity.

Critical Path Method (CPM) as a technique can handle the complexities of resource leveling. It is possible to constrain the late dates by carrying out a backward pass through the schedule after doing resource leveling. However, the computer packages as well as the literature on CPM, for example the text book by Moder et al. (1983), seldom address the issues of need of constraining the late dates and non-availability of positive float in resource critical activities. The complexity of the resource leveling process is beyond the skill level of all but the most advanced users. This leads to imperfect understanding of the technique and users frequently introduce soft logic constraints to the schedule. The concept of soft logic is discussed in the following section.

4. Visualization in Planning, Execution, and Control
4.4.3 Effect of Soft Logic Constraints

The task of scheduling such that both precedence relationships as well as resource constraints are satisfied is complex. Heuristic based approaches are resorted to for carrying out resource leveling. Moder et al. (1983) define heuristic as "a rule of thumb-a simple, easy to use guide or aid used in problem solving situations, to reduce the amount of effort required in coming up with a solution." They go on to state that "Heuristics may not always produce the best solution in every case." Heuristic based resource leveling can result in schedules which show a sequence of operation very different from that envisaged by field personnel to be most effective. Heuristics can also cause the sequence of operations to change for reasons not apparent to the user or field personnel. In order to get a resource constrained schedule which matches the sequence of operations that is otherwise found to be practical and effective, the schedulers generally resort to constraining of the schedule with soft logic.

Soft logic constraints, in the context of this thesis, are defined as sequence logic constraints over and above those mandated by firm technical requirements. These constraints are introduced in the schedule so that practical considerations are satisfied. It is not necessary that constraints based on soft logic must be satisfied in order to complete the project. However, these are 'practically desirable' constraints which will lend the schedule effectiveness and will make them satisfy practical considerations. Total number of critical activities in a schedule based on soft logic is generally much more than in a schedule based on hard logic alone.

4. Visualization in Planning, Execution, and Control
Soft logic constraints can be based on resources, sequence, safety, space etcetera. Resource based soft logic constraints force the Critical Path Method to show execution of an activity before another activity which also use the same resource. For example, a resource based soft logic constraint between activity 301 and 201 of the example project will force the CPM to show execution of activity 301 before 201 even when it is technically possible to build them in parallel.

The schedule for the example project after resource leveling scheduled activities in section 2 prior to activities in section 3, based on heuristics. However, practical consideration of access limitation dictates that activities in section 3 be executed prior to activities section 2. This is desirable as the access to the job is available from station 300 only, at the time of scheduling. To satisfy this practical consideration, soft logic constraints are introduced between the grading, subbase and base operations of sections 3 and 2 which dictate that the activities of section 2 be started only after the completion of corresponding activity of section 3. The schedules after constraining with soft logic are shown in Figure 4.4. Activities for sections 2 and 3 which were not critical in the original unconstrained schedule have turned critical. These activities will be referred to as Soft Logic Critical Activities (SLC) in this chapter for the purpose of discussion.

As discussed in section 4.4.2, some scheduling software packages using CPM show availability of theoretical float after resource leveling, even when it can be inferred from the LSM that the activities have become resource critical and therefore do not contain actual float. This is another reason why it is desirable to resort to introduction of soft logic constraints in a schedule, rather than depend on resource leveling to produce a realistic schedule.

4. Visualization in Planning, Execution, and Control
Time Scaled Logic Diagram (CPM)

Linear Schedule (LSM)

Notes: Activities shaded in CPM schedule are critical
Resource availability for all the resources is limited to 1 per unit time
Soft logic constraints have been introduced between the activities of section 3 and 2
Activities hatched in CPM schedules have turned critical (SLC) after introduction of soft logic constraints

Figure 4.4 Effect of Soft Logic Constraints
The sequence of operations is quite flexible in highway projects due to availability of large area to work on. Projects such as highway projects in which relationships based on soft logic exist, have very dynamic schedules. The final as-built schedule has few similarities to the original as-planned schedule. This occurs because of lack of deterministic relationships in the project and to the fact that any number of impacts can cause changes to the preferred or soft logic constraints. It is quite possible to lose sight of some of the alternatives while carrying out changes in the schedule to satisfy changed conditions and constraints. LSM is of immense help in such schedules which are constrained with soft logic. Availability of spatial dimension helps in visualization of scheduling alternatives. The graphical nature of the technique helps in deciding the change in sequence to accommodate differing conditions.

4.4.4 Lateral Float

The critical path method schedules generally show available float which can be defined as units of time by which an activity could be delayed without directly causing any increase in the total time to complete the project (Moder et al. 1983). In the linear scheduling environment, this can be termed as 'time float.' There is another type of float which is available in linear projects and which can be very clearly brought out using a linear schedule. This is termed as the 'lateral float' and can be defined as the float available in an activity which lets the operation be moved laterally without an immediate increase in the project duration, if a change in conditions warrants delaying of this activity.

Whenever an activity is advanced or delayed in a construction project due to change in conditions, some resource allocation adjustments take place. Lateral float in the activity...
allows exercising of options as to where an activity can be performed if there is a change in conditions. When the resource adjustments are carried out using the lateral float, it may solve this problem arising out of the changes in the schedule, but may create future problems which may need to be addressed later. Thus, exercising the option of lateral float in many cases will provide a quick fix compromise which would maintain continuity of work but which may create downstream problems. However, in some cases exercising options using the lateral float may solve the problem without any downstream effects.

In a linear project, due to availability of large area to work on, the sequence of operations is quite flexible. Availability of lateral float, therefore, provides the user with latitude to move laterally to another section of the project if the conditions prevent execution of the activity in the originally scheduled section.

If a Critical Path Critical (CPC) activity is delayed while exercising the option provided by lateral float, it would provide an immediate solution to the problem but will create a future problem or require some changes on a later date. If either a Resource Critical (RSC) activity or a Soft Logic Critical (SLC) activity is delayed by use of lateral float, it may or may not create future problems. Use of LSM helps to identify lateral float. Availability of a spatial dimension helps in identifying options and analyzing the subsequent impact of each option. This occurs due to the graphical nature of the technique which makes it easier and more effective to judge various scheduling alternatives. The effect of exercising lateral float options and use of LSM to identify the impact is discussed for two cases based on the example project in Sections 4.4.4.1 and 4.4.4.2. In the first case there are downstream problems whereas use of lateral float solves the problem in the second case and lets a project be completed on time even when a soft logic critical (SLC) activity is delayed.

4. Visualization in Planning, Execution, and Control
4.4.4.1 Effect of Lateral Float - Downstream Problems

Schedules for the example project after introduction of soft logic constraints are shown in Figure 4.4. It is assumed that the work begins according to the schedule in this figure. However, after 1 week of project start a problem is encountered in section 3 and it is not possible to continue operations in the area. The lateral float available in the project lets the crews move laterally and start activity 201 in section 2. At this instance lateral float seemed to have provided a solution for the problem. However, as can be seen from Figure 4.5, exercising of this lateral option results in the subbase and base operation for the entire project being delayed by 1 week since activities 102 and 103 which were Critical Path Critical (CPC) are delayed by 1 week.

![Graph showing effect of lateral float on project schedule]

Figure 4.5  Effect of Using Lateral Float - Downstream Problems

4. Visualization in Planning, Execution, and Control
Linear schedule shown in Figure 4.5 helps in identifying the alternatives. Once the lateral float option has been exercised, LSM helps in visualizing future problems and their possible solutions. Compressing the testing time between grading and subbase, and subbase and base, from 1 week in each case to half a week is a good example of the solution to the problem. Another solution to the problem may be overlapping of grading and subbase operations. Overlapping of activities is discussed in Section 5.7.2.

4.4.4.2 Using Lateral Float - Delaying a Soft Logic Critical Activity

As discussed in Section 4.4.3, introduction of soft logic constraints makes a number of activities critical. As shown in Figure 4.4, activities between sections 2 and 3, which were not critical in the original schedule, became critical (SLC) when the schedule was constrained with soft logic. It is assumed that the base example is for a very complex project, and communication between the planning team and construction team is poor.

The construction team learns just prior to the beginning of the project that it is not possible to start work on the section 3. This information is transmitted to the planner. In absence of a graphical tool like LSM, it is very likely that the planner introduces a start date constraint on the activity 301 and therefore the CPM schedule in Figure 4.6 shows project delay of two months. However, if a graphical scheduling technique such as LSM is used, it is possible to visualize the available lateral float in the schedule. As shown in Figure 4.6, with availability of space, some resource adjustments will let the project be completed on time, by advancing the activities in the section 2 and delaying the activities in section 3. The project completion date will not be delayed in this case even when a SLC activity is delayed.

4. Visualization in Planning, Execution, and Control
Notes: Activities shaded in CPM schedule are critical
Resource availability for all the resources is limited to 1 per unit time
Soft logic constraints have been introduced between the activities of section 3 and 2
Activities hatched in CPM schedules have turned critical (SLC) after introduction of soft logic constraints
The start date for activity 301 is constrained by 2 weeks in CPM schedule

Figure 4.6 Using Lateral Float - Delaying a Soft Logic Critical Activity
4.5 LSM AS A GRAPHICAL SIMULATION TOOL

LSM can be called a graphical simulation tool as alternate scheduling options can be simulated by generating a number of linear schedules for various alternatives. Once the alternatives are on paper in a graphical form, a decision can then be taken based on the effectiveness of these simulated options, keeping in mind various advantages and disadvantages, resource and space constraints etcetera.

Figure 4.7 shows four different scheduling alternatives for the base example that was developed in Section 4.4 to discuss the concepts of soft logic and lateral float. It is assumed that the resources for all the activities are limited to one. The first option, option (A), has the activities being executed from the end station of the project to the beginning of the project. The subbase and base activities are carried out from the right to the left without any interruption. In option (B) activities between Station 100 and 300 are executed away from station 100 as would be the case if the only access to the job was at station 100. Option (C) has grading operations being executed in the same sequence as in option (A) but subbase and base activities are executed from left to right. In the last option, although the grading operations are executed same as in option (B), the subbase and base activities are executed from right to the left. Use of a visual technique allows the user to consider these four possible scheduling alternatives and chose the one that best suits prevailing conditions.

The alternatives suggested in this section are four of the many possible. This thesis acknowledges that whenever a decision is to be taken on a course of action, many options are available. These option may be based on compressing activity time, utilizing lateral float, overlapping activities, or increasing resources.

4. Visualization in Planning, Execution, and Control
Figure 4.7  LSM as a Graphical Simulation Tool
4.6 DISCUSSION

The importance of visualization in project construction was discussed in this chapter. Role of visualization in planning, execution, and control phases was discussed. Use of a visual tool such as LSM helps in evaluating alternatives. LSM also can be used as a graphical simulation tool.

The concept of lateral float was discussed and it was established that availability of lateral float will let the user exercise options as to where the activity can be performed if their is a change in conditions. Moving laterally to cater to changed conditions may solve the immediate problem but may create downstream problems in many cases which will need to be addressed later in the project. In some cases, it may be possible to delay a resource critical activity or an activity which turned critical after introduction of soft logic constraints in a schedule and even then not delay the project by using lateral float. Use of LSM helps in identifying lateral float, visualize possible downstream problems, and evaluate alternatives to avoid project delay.

The set of video tapes, discussed in Section 3.1, provided a discussion regarding three criteria which must be met for success in planning a linear job. The discussion presented in this chapter helps linear scheduling in meeting these criteria. Visualization helps in ascertaining that the crews are given time and space to work. Use of a visual technique also helps in conducting the work in an ordered sequence and minimizing delays and changes. Availability of lateral float can be identified using a graphical and visual technique such as LSM and this helps in minimizing delays and changes.

4. Visualization in Planning, Execution, and Control
CHAPTER 5

LINEAR SCHEDULE: FORMAT AND SYMBOLS

Linear Scheduling Method is a graphical technique and thus relies heavily on its format to communicate information to the user. This chapter presents numerous ways in which the format of the linear schedule can be modified to give it better communication and visualization potential. A linear schedule is a schematic representation of the construction operation and uses a set of symbols to represent various operations. Significant enhancements to the symbols which will increase the visualization potential of the technique are reported.

A comprehensive description of linear schedule's format and symbols is presented in the chapter and this will lead the technique towards a standard format. The enhancements reported will make the technique more robust, increase the effectiveness of the technique, and help in scheduling complex projects using the technique. These enhancements might be simple, however, they help in better understanding of the project through every stage of planning and construction process.
The discussion presented in this chapter is based on the linear scheduling video tapes (Vorster and Parvin 1990), with significant enhancements arising from the problems encountered during field experience and responses to those problems.

A case example will be developed from Section 5.1 through 5.4 to describe the concepts discussed in each section. The example project starts at station number 0 and goes through to station number 100. The start and completion dates for the project are August 1, 1991 and April 1, 1992. The project involves construction of a bridge at station 65 in addition to the regular pavement works. A retaining wall is also to be constructed between stations 15 and 25.

5.1 ALLOCATION OF AXES

Time is plotted to the horizontal axis and location to the vertical axis in majority of the literature on linear scheduling. However, in this thesis the horizontal axis is used for distance, and vertical axis for time. This reflects the fact that in highway construction projects, location is perceived has having horizontal dimension (unlike high-rise buildings in which the location has vertical dimension). Horizontal axis is therefore used for depicting location in order to create a strong visual link between the work itself and the schematic diagram which portrays the schedule.

Time is allotted to the vertical axis, with the earliest dates being at the bottom of the vertical axis. This results in the activities which are executed later being represented above the ones that were executed earlier. This results in a good graphical representation of the way

5. Linear Schedule: Format and Symbols
highways are built. Figure 5.1 shows the profile of a simplified highway project together with a linear schedule. It can be seen that the grading operations which are performed first are below the paving operations which appear in their proper layered sequence. Thus, plotting location to the horizontal axis, and time to the vertical axis results in a linear schedule which has a very strong visual resemblance to the finished product and the way it is actually built.

Figure 5.1 Representation of Time on Vertical Axis

5. Linear Schedule: Format and Symbols
5.1.1 Axis Parameters

The selection of axis parameters depends on the level of detail desired in the schedule. While the parameters for distance can be in feet or miles, division by stations (100 ft) is the commonly used unit for highway projects. The parameters for time can be in terms of hours, days, weeks or months as is appropriate to the overall project duration.

Major and minor labels are added to both the axes. Major labels are for distance and time. Minor labels mark the parameters of space and time and are attached as station numbers on the horizontal axis and the dates on the vertical axis. Figure 5.2 shows axes, major labels and minor labels for the case example described in the introductory section. Spacing between the minor labels for the distance axis is 25 stations and for the time axis is 2 month.

Figure 5.2 Allocation of Axes and Axis Parameters

5. Linear Schedule: Format and Symbols
5.2 GRAPHICAL DETAILS

Details regarding location and time aspects can be added to the linear schedule. These details are in the form of a number of graphical prompts which enhance the effectiveness of the linear schedule. Addition of these details provides background to the planning operation. Allocation of axes and addition of graphical details provides the user with a 'playing field' on which he/she is going to play.

5.2.1 Location Details

Addition of location details enhances the visualization impact of the linear schedule and integrates it with project information. Since the field personnel constantly use project information such as plans, profiles etcetera, integration of these with the linear schedules helps them in appreciating and understanding the schedule.

5.2.1.1 Plans

At times it will be advantageous to add project plan to the top of the linear schedule. Plans contain information regarding the location of ground features such as intersections, crossovers, bridges, culverts etcetera. The plan should be drawn to the same scale as the horizontal axis uses and be approximately aligned with it. Addition of project plan makes keeping track of the location of major elements of a project such as culverts, bridges, retaining walls etcetera easier. Figure 5.3 shows addition of project plan to the top of the schedule being developed for the example project. The plan clearly shows the location of the retaining wall which spans from station 15 to 25, and the bridge which is at station 65.

5. Linear Schedule: Format and Symbols
5.2.1.2 Profiles

It is advantageous to add a profile of the project at the top of the scheduling diagram. This profile should be drawn with the same horizontal scale as used for the distance axis, and should be aligned with it. Profile should have such features as representation of cut and fill areas, location of major structures such as bridges, culverts etcetera. The profile helps in

5. Linear Schedule: Format and Symbols
visualizing the earth work operations as the approximate cut and fill locations are clear from the profile. A profile is added to the example project and is shown in Figure 5.4. The profile shows cut between stations 0 and 50, and 80 and 100. The fill section is from stations 50 to 80. Addition of arrows helps in identifying cut and fill areas.

![Profile Diagram]

Figure 5.4 Addition of Profile to the Linear Schedule

5.2.2 Time Details

Details regarding time aspects may be added to the linear schedule in addition to the location details. Graphical depiction of these details helps in understanding the time constraints due to unfavorable seasons and access limitations.

5. Linear Schedule: Format and Symbols
5.2.2.1 **Season Constraints**

Highway projects are dependent on seasons to a great extent since almost all the construction work is executed outdoors. Many highway operations such as laying of asphalt etcetera, are not permitted under extremely low temperatures. It is advantageous to mark the time periods when the work cannot be carried out due to bad weather on the linear schedule. Figure 5.5 shows marking of extreme cold weather period from December 15, 1990 to January 15, 1992, which suggests that this period is not available for scheduling activities.

![Season Constraints Diagram](image)

Figure 5.5  **Season Constraints**

5. **Linear Schedule: Format and Symbols**
5.2.2.2 Access Constraints

There are situations in the field when access to the entire project is not simultaneously available to the contractor. Marking the access profile on the linear schedule will serve as a constant reminder of the unavailability of sections of project for execution of work and will help the contractor plan his operations accordingly. Figure 5.6 shows that the section between stations 75 and 100 of the example project will not be available for 2 months from the project start date.

Figure 5.6 Access Constraints

5. Linear Schedule: Format and Symbols
5.3 SIGHT LINES

Addition of vertical and horizontal sight lines to the scheduling diagram makes determining the start and end dates, and start and end station of an activity easier. Sight lines can be conveniently spaced on both the axes according to the required level of detail. Figure 5.7 shows addition of sight lines to the case example. Horizontal sight lines are placed at every second month and vertical after every 25 stations.

Additional sight lines may be added at dates or sections of special significance. A horizontal line may be added for the date on which the project is handed over by the owner to the contractor. Similarly, vertical lines may be added at each end of a significant section of the project. Figure 5.7 shows a vertical line drawn at stations 15, in addition to the regular sight line at station 25, to mark the start and end stations of the retaining wall.

![Diagram showing sight lines and scheduling](image)

Figure 5.7 Sight Lines

5. Linear Schedule: Format and Symbols
5.4 PERIOD NUMBERS

Period numbers can be added to the time axis in addition to the dates. Period numbers are given in ascending order, considering the start of the project to be number 1. Addition of period numbers is helpful in referencing to the specific time periods since it is easier than referencing to the actual dates. Addition of period numbers is of special significance for cross-referencing between the linear schedule and the Crew Movement Chart (CMC). The concept of CMC is discussed in detail in Chapter 6. Figure 5.8 shows the linear schedule for the example project after addition of period numbers.

![Figure 5.8 Period Numbers]

5. Linear Schedule: Format and Symbols
5.5 STANDARD SYMBOLS

A linear schedule is a schematic representation of the construction process. Like all other schematics, linear schedules use a set of standard symbols to represent activities. A discussion on these symbols is presented in this section.

5.5.1 Bars

A bar is a vertical line to show a crew working in one place for a long period of time. There are some operations in highway construction which occur at one location for a long duration of time. These operations are best represented by bars. A bar is defined by its given location and the time needed to complete all the work at the given location. Figure 5.9 depicts bar as a symbol to represent operations on a linear schedule. Bridges and culverts are excellent examples of operations which can be best represented using bars.

Figure 5.9 Bars

5. Linear Schedule: Format and Symbols
5.5.2 Lines

Lines are drawn to track movement of a crew through the job as time progresses. The activities represented by lines occur at one place for relatively smaller time duration and are characterized by continuous movement of operations, and the resources required to carry out the operations. The slope of the line represents the rate of progress of the crew through the job. If the line is flat, it indicates that the crew is moving very fast. If the line is very steep, it indicates that the crew is moving very slow. Figure 5.10 shows line as a symbol to represent operations on a linear schedule. The line from location A to B has a steeper slope than the line from location B to C. This represents that the rate of progress between locations B to C is faster than between A to B.

Figure 5.10 Lines

5. Linear Schedule: Format and Symbols
5.5.3 Blocks

A block is a rectangle to show time and space taken up by a crew as it performs an operation in the work area. Activities which require that work be done over a given section of the project for a relatively long period are best represented by blocks. Representation of some operations by using blocks is necessitated because not all operations move smoothly from section to section and pinpointing exact location of the work is generally not possible. Blocks are a good way of representing such operations. A block shows that the activity is to be carried out between the locations depicted by the left and right vertical sides, and between the time instants depicted by the top and bottom horizontal sides of the rectangle. Block as a symbol to represent operations on a linear schedule is depicted in Figure 5.11.

Figure 5.11 Blocks
5.5.4 Flags

Another symbol, in addition to the bars, lines, and blocks, can be used to depict project milestones and to mark significant events in the development of a project. This symbol is called the 'flag'. A flag represents only a point in location and time. Flags are particularly helpful in keeping track of contract administration dates. Different flag types can be used to note the various dates related to the administration of the contract and related to potential claims. Examples of such situations are date of detecting the differing site condition, date of stop-order, dates of communication sent, dates of communication received, date of issuance of change-order etcetera. Figure 5.12 depicts the use of flags to track contract administration dates. Flags can be of different types. Examples of different flag types are square, circular, diamond etc. Figure 5.12 portrays the use of flags.

Figure 5.12 Flags

5. Linear Schedule: Format and Symbols
5.6 GRAPHICAL DEPICTION OF EARTH MOVEMENT

Most highway projects involve substantial earth-moving and grading operations. Construction companies generally prepare a grading diagram for estimating, bidding, and execution purposes. It is suggested that earth-moving operations be depicted graphically on the LSM itself. This will tantamount to superimposing the grading diagram on the LSM and, thus, will lead to better integration of project information.

Arrows of different types can be used to graphically depict movement of earth in a project. Use of straight arrows to show earth movement between cut and fill areas was suggested by Chrzanowski and Johnston (1986). They stated that, "The blocks with arrows emanating from them represent cut areas. The arrows lead to corresponding fill regions, and the adjacent numbers represent the quantities of material to be hauled in cu yd." This thesis acknowledges that complex highway projects may involve operations other than cut and fill activities. Different types of arrows are suggested for depicting different types of earthwork activities.

5.6.1 Earth Movement Between Adjoining Sections

There are sections of highway projects where earth movement between two adjoining sections of the project is possible. In addition of movement of earth from one section to the adjoining section, which generally will be a motor scraper operation, surplus earth (either suitable or unsuitable for pavement construction) may need to be transported to the surplus earth dump site. Alternatively the section may be a borrow area and earth may need to be transported from a borrow area. Surplus and borrow operations are generally load-haul-
dump operations. Earth movement may also take place within a particular section itself. This would generally be a motor scraper operation. Figure 5.13 presents different possibilities of earth movement activities and corresponding arrow types suggested for use.

![Diagram showing earth movement between adjoining sections]

**Legend for Symbols**
- Movement of earth from one section to the adjoining section
- Movement of earth within a particular section
- Surplus earth - Transported to surplus dump site
- Borrow earth - Transported from borrow area

**Figure 5.13** Earth Movement Between Adjoining Sections

A case example is used to illustrate the functional use of different arrow types when movement of earth between the adjoining areas is possible. The total cut and fill volumes for a section are shown at the bottom of the block representing that section on the linear schedule in Figure 5.14. While the section on the left side of the figure is a borrow section, the section on the right is a surplus section. Out of the 33,200 cy of cut in the section on the right side, 2,200 cy are going to be used in that section itself. This therefore

5. Linear Schedule: Format and Symbols
is shown by the circular arrow. Out of the remaining 31,000 cy, only 27,000 cy is suitable earth and thus can be moved to the adjoining section which is in deficit. Remaining 4,000 cy is unsuitable earth and therefore needs to be transported to the surplus earth dump site.

Figure 5.14  Case Example for Earth Movement Between Adjoining Sections

5. Linear Schedule: Format and Symbols
5.6.2 Earth Movement Between Distant Sections

There are some sections of a project where earth movement is not possible between adjoining areas. Any surplus earth that such sections may have, needs to be either transported to surplus dump site, or moved to other areas where there is requirement. It is felt that depiction of earth movement in the later case by using straight arrows from the section of origin to the section of disposal may either not be possible, or, if possible, may result in complicating the linear scheduling diagram. Therefore, earth movement may be depicted by a small arrow, with details of the sections lettered adjacent to arrow head. Figure 5.15 is a graphical representation of this situation.

Figure 5.15  Earth Movement Between Distant Sections

5. Linear Schedule: Format and Symbols
Figure 5.16 is for an example illustrating the case when movement of earth between adjoining sections is either not possible or not required. In this section the cut volume is 30,000 cy and the fill volume is 10,000. Out of the surplus of 20,000 cy, 5,000 cy is to be transported to the section between Stations 284 to 313 of NBL, and thus is represented on the figure accordingly. Out of the remaining 15,000 cy, 10,000 goes to the B463 bridge embankment, and rest to the dump site.

Figure 5.16 Case Example for Earth Movement Between Distant Sections

5. Linear Schedule: Format and Symbols
5.7 COMBINATION OF SYMBOLS TO REPRESENT OPERATIONS

The linear schedules use a set of symbols to represent various operations. It was mentioned in Section 5.5 that the symbols to be used are lines, blocks, bars, and flags. There are many cases in actual field work where it is not possible to realistically portray operations using just one type of symbol. There are also cases when more than one operation occur in a particular section of the project. Such cases will be best represented by using a combination of appropriate symbols.

5.7.1 Combining Symbols

Certain operations in highway construction projects will be best represented by a combination of a block and a number of lines. Figure 5.17 is a case example of a retaining wall. Specific operations such as excavation, foundation work, and superstructure work, which are constituent operations of the overall retaining wall construction operation, can be best represented by straight lines. However, it will be desirable to enclose all these lines in a block. This block suggests that the entire section where the retaining wall is being constructed, is blocked in such a way that no other operation, different from the constituent operations of the retaining wall, can take place in this section during the time duration represented by the block.

There are other cases in actual field work where it is not possible to depict operations using just one symbol. A combination of bar and a number of lines, or block and a number of lines and bars may be used in such cases.

5. Linear Schedule: Format and Symbols
5.7.2 Overlapping Symbols

There may be more than one operation occurring in the same section in some cases. Some of these cases may be best represented by overlapping of more than one symbol. Figure 5.18 shows two such cases. In one case a bar overlaps a block. The culvert operation represented by the bar starts before the completion of rough grading operation in that area. In the other case, a line crosses over a bar. In this case fine grading operations are carried out in the same area in which a culvert is being constructed. There are other cases in the actual field work, which will be best represented by overlapping of bar and a number of lines, a block and a number of lines, and a block and a number of bars.

5. Linear Schedule: Format and Symbols
It appears quite improbable that two operations could occur in the same area, during the same time duration. However, this is well within the realm of construction reality. One of the reasons that this may occur is because LSM is a two-dimensional scheduling technique. Highways, however, have three dimensions: longitudinal (length), lateral (width), and vertical (thickness). Time axis of the linear schedule, in a way, graphs the vertical dimension of the project. Activities at the bottom of the highway cross-section are carried out earlier in time, and therefore, are represented on the bottom of the time axis. Distance axis is able to graph only one of the two horizontal dimensions, the longitudinal dimension. Since linear schedule is not able to graph the variations on the lateral dimension of the highway, overlapping of symbols may occur. When two or more operations are carried out on the same longitudinal section of the project but at different locations on the lateral axis of the project during the same time period, the result is overlapping of symbols on the linear schedule.
5.8 DIFFERENT COLORS, LINE TYPES, AND HATCH PATTERNS

It was discussed in Section 5.5 that operations are depicted on the linear schedules using a set of standard symbols. The linear schedule for a complex project needs to portray a large number of activities. Some activities are basically similar but performed by different crews while some other activities are different but performed by the same crew. Use of different colors and different line types and hatch patterns helps in differentiating between various activities drawn on the linear schedule.

Highway construction work is crew oriented. Most of the activities can be classified on the basis of the crews which execute these activities in the field. Different colors may be used for the symbols representing activities carried out by different crews. Crew foremen would find this of particular interest as they can follow the activities of their crews on a linear schedule simply by concentrating on a particular color.

Communication potential of lines can be increased manifold by using different line types. It is felt that complex highway construction projects may have large number of activities which can be represented by lines. Some of these activities may be very closely spaced. Linear schedule for such complex project may contain a large number of lines. Since the same line type (usually solid) is generally used for all the activities, there is no way to distinguish between these symbols. It results in a complex and unintelligible linear schedule which is cluttered with lines of the same type. This thesis suggests use of different line types for different activities. The clarity and legibility of the schedule increases manifold by using different line types. Using different line types alleviates need of writing the name of activity on the line. This also helps in improving the clarity of the
schedule. A legend can be presented for different line types. Examples of different line types are solid, dashed, solid-and-dash, dash-and-dot etcetera.

In a complex project, there may be a number of activities represented by blocks and bars. Since the same symbol (usually a blank rectangle) is generally used to represent numerous operations on the linear schedule, there is no way to distinguish between them. Thus, the schedule becomes cluttered with these symbols and therefore, less intelligible. Using different hatch patterns for blocks and bars will enhance the clarity of the scheduling diagram, and therefore will result in better communication of ideas between the planner and the field personnel. Different fill types can also be used for bars, in addition of using different hatch patterns.

The field personnel find use of different line types and hatch patterns of special interest to them. It makes following the progress of a particular operation easier for them as they just have to concentrate on a particular line type or hatch pattern.

A case example is presented in Figure 5.19 which depicts use of different line types and hatch patterns. The diagram on the left uses solid line types, and blank blocks and bars. The diagram on the right uses different line types and hatch/fill types to represent different operations. The difference in clarity and intelligibility between the two diagrams is clear from the figure.

5. Linear Schedule: Format and Symbols
5.9 NON-LINEAR SECTIONS OF A HIGHWAY PROJECT

It is generally believed that LSM is useful solely for repetitive and linear activities. However, there may be some sections in the projects which may not be linear, in the true sense of the term. Arranging of the diagram in such a way that it best represents the operations as they are done in the field, is the best way of representing such sections of the project.

Examples of non-linear sections in a highway project are interchanges, cross-overs, T-junctions, culverts etc. It has been identified that such sections can be best scheduled by representing the operations belonging to the non-linear sections on separate schedules. These several linear schedules can then either be arranged on the sheet of paper in a layout similar to the ground layout of the sections, or placed side by side. The schedules can then be integrated by using arrows with notations at the stations which are common between two sections.

Interchanges are the most common type of non-linear sections encountered in highway projects. A complete interchange consists of the two main highways, which are crossing each other, and a number of on and off-ramps. In actual practice, generally the main project spans along one of the main highways. Some sections of the other highway, which is generally perpendicular to the main project, may also be a part of the construction project. Depending upon the extent of the project, some or all sections of the ramps may be part of the project. For an interchange, a number of linear schedules could be generated, one each for main highways as well as ramps. These could be arranged in the same geometrical layout as the layout of the sections themselves.

5. Linear Schedule: Format and Symbols
Figure 5.20 shows the layout of linear schedules for an example project where LSM is used to schedule a highway project involving a T-junction. Rt. 126 is the main highway and it also involves construction/modification of a portion of the Seneca Drive. Since the portion of the Seneca Drive is not on the main highway, it can not be shown on the schedule for Rt. 126. As shown in the figure, two separate schedules can be generated for Rt. 126 and the Seneca Drive. These two schedules can be placed side by side. The crew dependency between the operations carried out on both the sections of the project can be shown by dotted lines.

In the case example discussed in the preceding paragraph, it was advantageous to place the schedules side by side. However, in some other cases of use of LSM for non-linear sections of a highway project, such as an interchange, it will be advantageous to arrange schedules for different sections in a layout similar to the ground layout.

5.10 MULTI-PROJECT SCHEDULING

Linear Scheduling Method can be used for multi-project planning and scheduling. There are many times that a highway construction company's resources are shared by a number of projects. A master schedule can be prepared using the LSM which can show all the activities on these various projects. The most effective way to carry out multi-project planning and scheduling is by displaying a number of linear schedules, one for each project, parallel to one another. All these schedules share a common time axis. This facilitates referencing between various projects.

5. Linear Schedule: Format and Symbols
SAMPLE PROJECT

Figure 5.20  Non-Linear Sections of a Highway Project

5. Linear Schedule: Format and Symbols
A good example of sharing of a company's resources by a number of projects is the operations of a paving company. Paving companies generally work as sub-contractors to general contractors. Their operations in a project usually last for a couple of weeks. Thus, they tend to carry out a large number of projects, in quick succession. Figure 5.21 is a case example of multi-project scheduling using LSM and it uses the operations of a paving contractor which has four projects on hand at this stage. The schedule shows the activities which this company has to carry out at all the four projects between May and July, 1991. For scheduling the operations of such companies, a master schedule is prepared using the LSM which shows all the activities on these various projects. The master schedule is shown in Figure 5.21.

![Sample Paving Corporation Schedule]

**Figure 5.21** Multi-Project Scheduling

5. **Linear Schedule: Format and Symbols**
5.11 DISCUSSION

Linear scheduling as a technique for scheduling linear projects has been in use for a long time. However, its true potential for scheduling highway projects has not been fully explored. This chapter reported advancements and enhancements in the technique that will help in improving its format and symbols. The use of LSM in scheduling non-linear sections of the project as well as for multi-project scheduling is also discussed. All these advancements and enhancements make LSM a more robust technique, which can be used to schedule almost all types of highway projects, with ease and effectiveness. A comprehensive discussion on the format also leads the technique towards a standard format.

Most of the visualization tools discussed in this chapter can be very effectively, efficiently, and easily used with the help of Computer Aided Design and Drafting (CADD) packages. CADD packages have given a distinct advantage to users in portrayal and dissemination of information. With the use of CADD packages, it is much easier to save the originally drawn linear schedule, and store it on the computers as well as on diskettes making it easier to transport the schedule from one place to another. Moreover, use of CADD packages makes it easier for the user to modify and update the schedule. A manually drawn linear schedule is very difficult to change and would require many number of manhours. However, with a computer saved schedule, it is very easy to recall the drawing, modify/update it, and then restore it. CADD functions such as use of layers in a drawings, zoom, snap, different hatch/fill patterns, different line types, different colors etcetera have been of tremendous help in generating a linear schedule.

5. Linear Schedule: Format and Symbols
CHAPTER 6

REPRESENTATION OF LINEAR SCHEDULE IN TABULAR FORMAT

Linear Scheduling Method is a graphical scheduling technique. However, there are times when representation of project information in tabular format is desirable. This chapter first discusses the need for tabular formats. It then presents the concept of Crew Movement Chart (CMC), and discusses the basic format of a CMC. Sorting and selection criteria are used to generate different Crew Movement Charts which contain information about specific crews, operations, or dates. Spreadsheet as well as database computer packages can be used to carry out sorting and selection of activities. Use of spreadsheets and databases to generate CMC is discussed in Sections 6.3 and 6.4 respectively. A computer software package, titled 'LINC', has been developed as a part of this research which can be used to generate CMC. LINC is discussed in Section 6.5.
6.1 THE NEED FOR TABULAR FORMATS

One of the biggest advantages of the Linear Scheduling Method is its graphical nature. However, the linear schedule alone is not able to fulfill the needs of the user. In complex highway project some type of tabular output in addition to the linear schedule is desirable.

6.1.1 Planning and Scheduling Phase

Use of tabular format allows the planner to allocate the crews in such a manner that there is no duplication. Duplication may occur in a linear schedule when one crew is shown as working at two different sections at a given time.

The planner assumes availability of certain resources, mainly crews in the case of highway projects, while planning. The linear schedule alone is not able to fully communicate the allocation and movement of crews in a project. The tabular output helps in communicating crew allocation and movement information from planner to the executor.

6.1.2 Execution Phase

A linear schedule is a schematic representation of the operations. Generally the schedules are prepared on large size drawing sheets. Since no tabular output is available from the linear schedule, it is difficult for the field personnel to refer to the schedule when they are on the job site, out of their offices. There is a need for converting graphical data into a tabular format. The tabular version of a linear schedule will be handier and thus, the job foremen can carry these with them at all times.

6. Representation of Linear Schedule in Tabular Format
6.1.3 Control Phase

In the process of execution, field personnel come across a number of errors, omissions, and mistakes in the schedule. Moreover, there are changes in the site conditions, weather conditions, planning assumptions, and contract conditions. These changes warrant changes to the schedule as well. Use of tabular format allows field personnel to mark the changes and communicate these back to the planner for updating and/or modification.

6.2 CREW MOVEMENT CHART (CMC)

As discussed in the preceding section, there is a need for representation of the linear schedule in tabular format. This thesis contributes to the technique by presenting the concept of Crew Movement Chart (CMC). CMC shows deployment and movement of various crews in a project in a tabular format.

In any construction project, those who plan, schedule, and supervise field work need to constantly ask themselves six questions (Oglesby et al. 1989). These key questions to ask were colorfully expressed years ago by Rudyard Kipling (1913), as follows:

I keep six honest serving men;  
They taught me all I knew.  
Their names are What and Why and When  
And How and Where and Who.

6. Representation of Linear Schedule in Tabular Format
The Crew Movement Chart answers four of these six questions. These four are connected to the scheduling phase of the project management system. Two of the questions that are not answered by the CMC are 'How' and 'Why'. These two are planning phase issues and thus need not be addressed in the scheduling phase.

The questions answered by the CMC are:

What (activity) needs to be done?
When does the activity take place?
Where does the activity take place?
Who (which crew) will do the job?

A Crew Movement Chart can be generated either concurrently with the development of the linear schedule, or after the development of the linear schedule. When generated concurrently with the development of linear schedule, CMC can be used to allocate crews to various sections and check that there is no duplication. When generated after the development of the linear schedule, the CMC provides a tabular output of the schedule which is a handier version of the linear schedule.

Work on a complex highway project is generally carried out in different sections. Division of a project into sections is carried out keeping in mind various features of the roadway. Traffic cross-overs, bridges, culverts, retaining walls, and differing typical sections of the roadway are some of the features that affect the decision to divide the project into suitable sections. Crews generally move from section to section. The basic format of a CMC is based on arranging the activities according to the sections of the project.

6. Representation of Linear Schedule in Tabular Format
A case example for the basic format of the CMC is shown in Chart 6.1. This chart shows how crews move through the project over time for the example. This can serve as the master control chart to plan and track movement of various crews on the project. Secondary sorting of the activities within a section is carried out on the project dates in this chart. This CMC helps in planning for deployment of crews. Any duplication of allocation of crews will become very clear with a chart of this sort.

As discussed in Chapter 5, Section 5.4, period numbers can be added to the time axis of the linear schedule as well as to the CMC. Period numbers are given in ascending order, considering the start of the project to be number 1. Addition of period numbers helps in cross-referencing between linear schedule and CMC.

The first two columns in the CMC are for period numbers and dates. Remaining columns of the chart are for the various sections of the project. Total number of columns in a chart of this type will be governed by number of sections in the project. Activities and crews may be represented by acronyms because of the narrow width of the columns and, in such cases, a complete legend is given at the bottom of the chart.

6.2.1 CMC - Activities Selected for Specific Dates

Selection of activities can be carried out to generate CMC which contain activities occurring between two specific dates. This selection is of much practical significance because it gives the field personnel 'look-ahead' scheduling information of a specific period. The current practice of the construction industry is to prepare schedules which contain information of a limited time duration. This presents the field personnel with the information about areas

6. Representation of Linear Schedule in Tabular Format
### Chart 6.1  Crew Movement Chart - The Basic Format
Activities Arranged According to the Sections of the Project

<table>
<thead>
<tr>
<th>Pd Nos.</th>
<th>Date</th>
<th>Sections of the Project</th>
<th>Crew</th>
<th>Work</th>
<th>Crew</th>
<th>Work</th>
<th>Crew</th>
<th>Work</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Middle Section - Sta 35-75</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>4/1/91</td>
<td>CG</td>
<td>Clearing &amp; Grubbing</td>
<td></td>
<td></td>
<td>CG</td>
<td>Clearing &amp; Grubbing</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>4/8/91</td>
<td>RG</td>
<td>Rough grading</td>
<td>CG</td>
<td>Clearing &amp; Grubbing</td>
<td>CON</td>
<td>Culvert</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>4/15/91</td>
<td>RG</td>
<td>Rough grading</td>
<td>CON</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4/22/91</td>
<td>FG</td>
<td>Demolition</td>
<td>CON</td>
<td>Retaining wall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>4/29/91</td>
<td>FG</td>
<td>Fine Grading</td>
<td>CON</td>
<td>Retaining wall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>5/6/91</td>
<td>FG</td>
<td>Fine Grading</td>
<td>CON</td>
<td>Retaining wall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>5/13/91</td>
<td>SCA</td>
<td>CS Subgrade</td>
<td>RG</td>
<td>Rough grading</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>5/20/91</td>
<td>SCA</td>
<td>CS Subgrade</td>
<td>FG</td>
<td>Demolition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>5/27/91</td>
<td>FG</td>
<td>CTA Subbase</td>
<td>FG</td>
<td>Fine Grading</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>6/3/91</td>
<td>FG</td>
<td>Fine Grading</td>
<td>SCA</td>
<td>CS Subgrade</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>6/10/91</td>
<td>SCA</td>
<td>CS Subgrade</td>
<td>FG</td>
<td>Demolition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>6/17/91</td>
<td>FG</td>
<td>CTA Subbase</td>
<td>FG</td>
<td>Fine Grading</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>6/24/91</td>
<td>FG</td>
<td>Fine Grading</td>
<td>SCA</td>
<td>CS Subgrade</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>7/1/91</td>
<td>FG</td>
<td>Fine Grading</td>
<td>SCA</td>
<td>CS Subgrade</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
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<td>SCA</td>
<td>CS Subgrade</td>
<td>SCA</td>
<td>CS Subgrade</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>7/15/91</td>
<td>SCB</td>
<td>B3 Base</td>
<td>SCB</td>
<td>B3 Base</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>7/22/91</td>
<td>SCB</td>
<td>B3 Base</td>
<td>FG</td>
<td>CTA Subbase</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
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<td>SCB</td>
<td>B3 Base</td>
<td>SCC</td>
<td>S5 Surfacing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>8/5/91</td>
<td>SCC</td>
<td>S5 Surfacing</td>
<td>SCC</td>
<td>S5 Surfacing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>8/12/91</td>
<td>SCD</td>
<td>Permanent Striping</td>
<td>SCD</td>
<td>Permanent Striping</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Legend for the Crews:

- RG - Rough Grading
- CG - Clearing & Grubbing
- FG - Fine Grading
- CON - Concrete Crew
- SCA - Sub Contractor "A"
- SCB - Sub Contractor "B"
- SCC - Sub Contractor "C"
- SCD - Sub Contractor "D"
and activities which require their immediate attention. Schedules of such nature have been labeled as 'the look-ahead schedule', 'the 3-week schedule', 'the 100 day schedule' etc. CMC generated by selecting activities between two specific dates utilize the concept of a 'look-ahead' schedule.

Chart 6.2 presents a case example of CMC which contains activities between specific dates. It uses the CMC given in Chart 6.1, using the basic format, as the base project. Information is presented for a 3-week period, from 04/29/91 to 05/19/91.

6.3 GENERATING CMC USING A SPREADSHEET PACKAGE

There are two ways in which a CMC can be generated. The first method uses a tabular format. If access to computer is available, CMC can be generated using a standard spreadsheet package. As noted earlier, CMC is a tabular version of the linear schedule. Spreadsheet packages are best suited for working with data which can be represented in tabular format. This method of CMC generation is discussed in this section.

The second method uses a database format. Access to a computer is mandatory in this case and the CMC can be generated using a database package. A discussion of this method of CMC generation is presented in section 6.4.

One of the big advantages of the computerized Critical Path Method (CPM) techniques is their sorting and selection capabilities. Using multi-level sorting and selections, customized reports can be generated which contain specific and precise information needed.

6. Representation of Linear Schedule in Tabular Format
Chart 6.2  Crew Movement Chart - The Basic Format  
Activities Arranged According to the Sections of the Project  
Activities Selected for Specific Period - 04/29/91 to 05/19/91

<table>
<thead>
<tr>
<th>Pd Nos.</th>
<th>Date</th>
<th>Sections of the Project</th>
<th>Crew</th>
<th>Work</th>
<th>Crew</th>
<th>Work</th>
<th>Crew</th>
<th>Work</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Middle Section - Sta 35-75</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>East End - Sta 75-100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>West End - Sta 0-35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>4/29/91</td>
<td>FG</td>
<td>CON</td>
<td>Retaining wall</td>
<td>RG</td>
<td>Rough grading</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>5/6/91</td>
<td>FG</td>
<td>CON</td>
<td>Retaining wall</td>
<td>RG</td>
<td>Rough grading</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>5/13/91</td>
<td>SCA</td>
<td>CS Subgrade</td>
<td>RG</td>
<td></td>
<td>Rough grading</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Legend for the Crews:

FG - Fine Grading  
CON - Concrete Crew  
RG - Rough Grading  
SCA - Sub Contractor "A"
The concept of Crew Movement Chart is LSM's equivalent to CPM sorting and selection capability. The starting point in this endeavor is generation of a master control chart, which generally contains information about all the activities to be carried out in all the sections of the project. This type of chart was discussed in the preceding section and a case example was presented in Chart 6.1. Once this data is available, several sorting criteria may be used to generate CMC which contain information about specific crews, operation, section, or dates. A number of cases for different sorting criteria are discussed in the following sections.

The format of the basic CMC needs to be altered in order to allow sorting using a spreadsheet package. Instead of arranging the activities according to sections of the project, activities are arranged in separate rows. In the altered format of the CMC, there are four columns, one each for: When, Where, Who, and What. The first column is for dates (when). Rest of the columns are for stations (where), crew (who), and work (what), respectively. The rows of the spreadsheet are assigned to time. Appropriate time units such as days, weeks, or months are used. Chart 6.3 shows an empty spreadsheet template which can be used to generate CMC using spreadsheet packages.

The charts presented in Sections 6.2 and 6.3 have been generated using a computer spreadsheet package. The package used is Microsoft Excel for Apple Macintosh, Version 2.2. Microsoft is a registered trademark of Microsoft Corporation, and Apple and Macintosh are registered trademarks of Apple Computer, Inc. Microsoft Excel is copyrighted by Microsoft Corporation.

6. Representation of Linear Schedule in Tabular Format
Chart 6.3  
Crew Movement Chart  
Empty Spreadsheet Template

<table>
<thead>
<tr>
<th>Date</th>
<th>Stations</th>
<th>Crew</th>
<th>Work</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Activity data is input in the four columns shown above. Activities are arranged in separate rows.

6.3.1 Sorted by Crews

A CMC can be sorted on the crews carrying out the jobs. This will provide a tabular output which lists all the activities of the project and groups them according to the crew carrying it out. Secondary and tertiary sorting can be carried out on operations, sections, or dates.

Chart 6.4 is for a CMC which is sorted by the crews. The case example is for the project used in Chart 6.1. Activities carried out by each crew are grouped. The crews are listed in alphabetical order. Secondary sorting within a crew is carried out on project dates for this chart but it can be carried out on any other of the remaining two columns as well.

6.3.1.1 Activities Selected for a Specific Crew

Activities can be selected out of a CMC sorted on crews to show only those which are carried out by a specific crew. A chart of this nature is a very useful tool for the crew foreman as it provides a tabular listing of the work on the linear schedule that is of direct concern for him.

6. Representation of Linear Schedule in Tabular Format
### Chart 6.4
Crew Movement Chart
Activities Sorted by Crews

<table>
<thead>
<tr>
<th>Date</th>
<th>Stations</th>
<th>Crew</th>
<th>Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/1/91</td>
<td>Sta 0-35</td>
<td>Clear &amp; Grub</td>
<td>Clearing &amp; Grubbing</td>
</tr>
<tr>
<td>4/1/91</td>
<td>Sta 35-75</td>
<td>Clear &amp; Grub</td>
<td>Clearing &amp; Grubbing</td>
</tr>
<tr>
<td>4/8/91</td>
<td>Sta 75-100</td>
<td>Clear &amp; Grub</td>
<td>Clearing &amp; Grubbing</td>
</tr>
<tr>
<td>4/8/91</td>
<td>Sta 0-35</td>
<td>Concrete</td>
<td>Culvert</td>
</tr>
<tr>
<td>4/15/91</td>
<td>Sta 0-35</td>
<td>Concrete</td>
<td>Culvert</td>
</tr>
<tr>
<td>4/22/91</td>
<td>Sta 75-100</td>
<td>Concrete</td>
<td>Retaining Wall</td>
</tr>
<tr>
<td>4/29/91</td>
<td>Sta 75-100</td>
<td>Concrete</td>
<td>Retaining Wall</td>
</tr>
<tr>
<td>5/6/91</td>
<td>Sta 75-100</td>
<td>Concrete</td>
<td>Retaining Wall</td>
</tr>
<tr>
<td>4/22/91</td>
<td>Sta 35-75</td>
<td>Fine Grad</td>
<td>Demolition</td>
</tr>
<tr>
<td>4/29/91</td>
<td>Sta 35-75</td>
<td>Fine Grad</td>
<td>Fine Grading</td>
</tr>
<tr>
<td>5/6/91</td>
<td>Sta 35-75</td>
<td>Fine Grad</td>
<td>Fine Grading</td>
</tr>
<tr>
<td>5/20/91</td>
<td>Sta 75-100</td>
<td>Fine Grad</td>
<td>Demolition</td>
</tr>
<tr>
<td>5/27/91</td>
<td>Sta 35-75</td>
<td>Fine Grad</td>
<td>CTA Subbase</td>
</tr>
<tr>
<td>6/3/91</td>
<td>Sta 75-100</td>
<td>Fine Grad</td>
<td>Fine Grading</td>
</tr>
<tr>
<td>6/10/91</td>
<td>Sta 0-35</td>
<td>Fine Grad</td>
<td>Demolition</td>
</tr>
<tr>
<td>6/17/91</td>
<td>Sta 75-100</td>
<td>Fine Grad</td>
<td>CTA Subbase</td>
</tr>
<tr>
<td>6/24/91</td>
<td>Sta 0-35</td>
<td>Fine Grad</td>
<td>Fine Grading</td>
</tr>
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<td>7/1/91</td>
<td>Sta 0-35</td>
<td>Fine Grad</td>
<td>Fine Grading</td>
</tr>
<tr>
<td>7/22/91</td>
<td>Sta 0-35</td>
<td>Fine Grad</td>
<td>CTA Subbase</td>
</tr>
<tr>
<td>4/8/91</td>
<td>Sta 35-75</td>
<td>Rough Grad</td>
<td>Rough Grading</td>
</tr>
<tr>
<td>4/15/91</td>
<td>Sta 35-75</td>
<td>Rough Grad</td>
<td>Rough Grading</td>
</tr>
<tr>
<td>4/22/91</td>
<td>Sta 0-35</td>
<td>Rough Grad</td>
<td>Rough Grading</td>
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<td>Sta 0-35</td>
<td>Rough Grad</td>
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<td>Sta 0-35</td>
<td>Rough Grad</td>
<td>Rough Grading</td>
</tr>
<tr>
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<td>Sta 75-100</td>
<td>Rough Grad</td>
<td>Rough Grading</td>
</tr>
<tr>
<td>5/13/91</td>
<td>Sta 35-75</td>
<td>Sub Contractor &quot;A&quot;</td>
<td>Cement Stabilize Subgrade</td>
</tr>
<tr>
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<td>Sta 35-75</td>
<td>Sub Contractor &quot;A&quot;</td>
<td>Cement Stabilize Subgrade</td>
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<tr>
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<td>Sub Contractor &quot;A&quot;</td>
<td>Cement Stabilize Subgrade</td>
</tr>
<tr>
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<td>Sta 0-35</td>
<td>Sub Contractor &quot;A&quot;</td>
<td>Cement Stabilize Subgrade</td>
</tr>
<tr>
<td>7/15/91</td>
<td>Sta 0-35</td>
<td>Sub Contractor &quot;A&quot;</td>
<td>Cement Stabilize Subgrade</td>
</tr>
<tr>
<td>7/15/91</td>
<td>Sta 35-75</td>
<td>Sub Contractor &quot;B&quot;</td>
<td>B3 Base</td>
</tr>
<tr>
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<td>Sub Contractor &quot;B&quot;</td>
<td>B3 Base</td>
</tr>
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<td>B3 Base</td>
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<tr>
<td>8/5/91</td>
<td>Sta 75-100</td>
<td>Sub Contractor &quot;C&quot;</td>
<td>S5 Surfacing</td>
</tr>
<tr>
<td>8/12/91</td>
<td>Sta 0-35</td>
<td>Sub Contractor &quot;D&quot;</td>
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</tr>
<tr>
<td>8/12/91</td>
<td>Sta 35-75</td>
<td>Sub Contractor &quot;D&quot;</td>
<td>Permanent Striping</td>
</tr>
<tr>
<td>8/12/91</td>
<td>Sta 75-100</td>
<td>Sub Contractor &quot;D&quot;</td>
<td>Permanent Striping</td>
</tr>
</tbody>
</table>

6. Representation of Linear Schedule in Tabular Format
Chart 6.5 is a case example of a CMC which lists activities selected for a specific crew. The crew used in this case is the "Fine Grading Crew." The chart lists the description of the work, stations where the work is to be carried out, and dates on which the work is carried out.

<table>
<thead>
<tr>
<th>Date</th>
<th>Stations</th>
<th>Crew</th>
<th>Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/22/91</td>
<td>Sta 35-75</td>
<td>Fine Grad</td>
<td>Demolition</td>
</tr>
<tr>
<td>4/29/91</td>
<td>Sta 35-75</td>
<td>Fine Grad</td>
<td>Fine Grading</td>
</tr>
<tr>
<td>5/6/91</td>
<td>Sta 35-75</td>
<td>Fine Grad</td>
<td>Fine Grading</td>
</tr>
<tr>
<td>5/20/91</td>
<td>Sta 75-100</td>
<td>Fine Grad</td>
<td>Demolition</td>
</tr>
<tr>
<td>5/27/91</td>
<td>Sta 35-75</td>
<td>Fine Grad</td>
<td>CTA Subbase</td>
</tr>
<tr>
<td>6/3/91</td>
<td>Sta 75-100</td>
<td>Fine Grad</td>
<td>Fine Grading</td>
</tr>
<tr>
<td>6/10/91</td>
<td>Sta 0-35</td>
<td>Fine Grad</td>
<td>Demolition</td>
</tr>
<tr>
<td>6/17/91</td>
<td>Sta 75-100</td>
<td>Fine Grad</td>
<td>CTA Subbase</td>
</tr>
<tr>
<td>6/24/91</td>
<td>Sta 0-35</td>
<td>Fine Grad</td>
<td>Fine Grading</td>
</tr>
<tr>
<td>7/1/91</td>
<td>Sta 0-35</td>
<td>Fine Grad</td>
<td>Fine Grading</td>
</tr>
<tr>
<td>7/22/91</td>
<td>Sta 0-35</td>
<td>Fine Grad</td>
<td>CTA Subbase</td>
</tr>
</tbody>
</table>

6.3.2 Sorted by Operations

A CMC can be sorted on the operations. A CMC of this type lists all the activities of the project, grouping them according to the operations. A case example is presented in Chart 6.6. This example uses the project data given in Chart 6.1, and presents the activities after sorting them on the operations. Secondary and tertiary sorting can be carried out on dates, stations, or crews. Secondary sorting was carried out by dates for Chart 6.6.

6. Representation of Linear Schedule in Tabular Format
Chart 6.6  Crew Movement Chart
Activities Sorted by Operations

<table>
<thead>
<tr>
<th>Date</th>
<th>Stations</th>
<th>Crew</th>
<th>Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/15/91</td>
<td>Sta 35-75</td>
<td>Sub Contractor &quot;B&quot;</td>
<td>B3 Base</td>
</tr>
<tr>
<td>7/22/91</td>
<td>Sta 75-100</td>
<td>Sub Contractor &quot;B&quot;</td>
<td>B3 Base</td>
</tr>
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<td>Sta 0-35</td>
<td>Sub Contractor &quot;B&quot;</td>
<td>B3 Base</td>
</tr>
<tr>
<td>5/13/91</td>
<td>Sta 35-75</td>
<td>Sub Contractor &quot;A&quot;</td>
<td>Cement Stabilize Subgrade</td>
</tr>
<tr>
<td>5/20/91</td>
<td>Sta 35-75</td>
<td>Sub Contractor &quot;A&quot;</td>
<td>Cement Stabilize Subgrade</td>
</tr>
<tr>
<td>6/10/91</td>
<td>Sta 75-100</td>
<td>Sub Contractor &quot;A&quot;</td>
<td>Cement Stabilize Subgrade</td>
</tr>
<tr>
<td>7/8/91</td>
<td>Sta 0-35</td>
<td>Sub Contractor &quot;A&quot;</td>
<td>Cement Stabilize Subgrade</td>
</tr>
<tr>
<td>7/15/91</td>
<td>Sta 0-35</td>
<td>Sub Contractor &quot;A&quot;</td>
<td>Cement Stabilize Subgrade</td>
</tr>
<tr>
<td>4/1/91</td>
<td>Sta 0-35</td>
<td>Clear &amp; Grub</td>
<td>Clearing &amp; Grubbing</td>
</tr>
<tr>
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<td>Sta 35-75</td>
<td>Clear &amp; Grub</td>
<td>Clearing &amp; Grubbing</td>
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<td>Sta 75-100</td>
<td>Clear &amp; Grub</td>
<td>Clearing &amp; Grubbing</td>
</tr>
<tr>
<td>5/27/91</td>
<td>Sta 35-75</td>
<td>Fine Grad</td>
<td>CTA Subbase</td>
</tr>
<tr>
<td>6/17/91</td>
<td>Sta 75-100</td>
<td>Fine Grad</td>
<td>CTA Subbase</td>
</tr>
<tr>
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<td>Sta 0-35</td>
<td>Fine Grad</td>
<td>CTA Subbase</td>
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<tr>
<td>4/8/91</td>
<td>Sta 0-35</td>
<td>Concrete</td>
<td>Culvert</td>
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<td>Sta 0-35</td>
<td>Concrete</td>
<td>Culvert</td>
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<td>Fine Grad</td>
<td>Demolition</td>
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<tr>
<td>5/20/91</td>
<td>Sta 75-100</td>
<td>Fine Grad</td>
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<td>Fine Grad</td>
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<td>Fine Grad</td>
<td>Fine Grading</td>
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<tr>
<td>5/6/91</td>
<td>Sta 35-75</td>
<td>Fine Grad</td>
<td>Fine Grading</td>
</tr>
<tr>
<td>6/3/91</td>
<td>Sta 75-100</td>
<td>Fine Grad</td>
<td>Fine Grading</td>
</tr>
<tr>
<td>6/24/91</td>
<td>Sta 0-35</td>
<td>Fine Grad</td>
<td>Fine Grading</td>
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<tr>
<td>7/1/91</td>
<td>Sta 0-35</td>
<td>Fine Grad</td>
<td>Fine Grading</td>
</tr>
<tr>
<td>8/12/91</td>
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</tr>
<tr>
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<td>Sta 35-75</td>
<td>Sub Contractor &quot;D&quot;</td>
<td>Permanent Striping</td>
</tr>
<tr>
<td>8/12/91</td>
<td>Sta 75-100</td>
<td>Sub Contractor &quot;D&quot;</td>
<td>Permanent Striping</td>
</tr>
<tr>
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<td>Sta 75-100</td>
<td>Concrete</td>
<td>Retaining Wall</td>
</tr>
<tr>
<td>4/29/91</td>
<td>Sta 75-100</td>
<td>Concrete</td>
<td>Retaining Wall</td>
</tr>
<tr>
<td>5/6/91</td>
<td>Sta 75-100</td>
<td>Concrete</td>
<td>Retaining Wall</td>
</tr>
<tr>
<td>4/8/91</td>
<td>Sta 35-75</td>
<td>Rough Grad</td>
<td>Rough Grading</td>
</tr>
<tr>
<td>4/15/91</td>
<td>Sta 35-75</td>
<td>Rough Grad</td>
<td>Rough Grading</td>
</tr>
<tr>
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<td>Rough Grad</td>
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</tr>
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</tr>
<tr>
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</tr>
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<tr>
<td>8/5/91</td>
<td>Sta 75-100</td>
<td>Sub Contractor &quot;C&quot;</td>
<td>S5 Surfacing</td>
</tr>
</tbody>
</table>

6. Representation of Linear Schedule in Tabular Format
6.3.2.1 Activities selected for a Specific Operation

A chart of this nature reports all the activities of a particular type which are carried out throughout the project. A case example is presented in Chart 6.7. The case example uses the project presented in Chart 6.1 as the base project and lists all the activities for the operation "CS Subgrade." These activities are selected out of the CMC sorted on operations given in Chart 6.6.

<table>
<thead>
<tr>
<th>Date</th>
<th>Stations</th>
<th>Crew</th>
<th>Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/27/91</td>
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<td>CTA Subbase</td>
</tr>
<tr>
<td>6/17/91</td>
<td>Sta 75-100</td>
<td>Fine Grad</td>
<td>CTA Subbase</td>
</tr>
<tr>
<td>7/22/91</td>
<td>Sta 0-35</td>
<td>Fine Grad</td>
<td>CTA Subbase</td>
</tr>
</tbody>
</table>

6.3.3 Sorted by Sections

A CMC can be sorted on the sections of the project. The information portrayed in this chart is similar to the basic format of CMC, which was discussed in Section 6.2. The difference between the two charts is in the format. A CMC sorted by sections contains activity information for each activity in a separate row. Activities are grouped according to the sections of the project. As discussed in Sections 6.3.1 and 6.3.2, secondary and tertiary sorting can also be carried out. Chart 6.8 presents a case example of CMC with primary sorting by sections and secondary sorting by dates.

6. Representation of Linear Schedule in Tabular Format
<table>
<thead>
<tr>
<th>Date</th>
<th>Stations</th>
<th>Crew</th>
<th>Work</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
<tr>
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<td>Sta 0-35</td>
<td>Concrete</td>
<td>Culvert</td>
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<tr>
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<td>Sta 0-35</td>
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<td>Culvert</td>
</tr>
<tr>
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<td>Rough Grad</td>
<td>Rough Grading</td>
</tr>
<tr>
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<td>Sta 0-35</td>
<td>Rough Grad</td>
<td>Rough Grading</td>
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<tr>
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<td>Rough Grading</td>
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<td>Demolition</td>
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<td>Fine Grad</td>
<td>Fine Grading</td>
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<td>Fine Grad</td>
<td>Fine Grading</td>
</tr>
<tr>
<td>7/8/91</td>
<td>Sta 0-35</td>
<td>Sub Contractor &quot;A&quot;</td>
<td>Cement Stabilize Subgrade</td>
</tr>
<tr>
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<td>Sta 0-35</td>
<td>Sub Contractor &quot;A&quot;</td>
<td>Cement Stabilize Subgrade</td>
</tr>
<tr>
<td>7/22/91</td>
<td>Sta 0-35</td>
<td>Fine Grad</td>
<td>CTA Subbase</td>
</tr>
<tr>
<td>7/29/91</td>
<td>Sta 0-35</td>
<td>Sub Contractor &quot;B&quot;</td>
<td>B3 Base</td>
</tr>
<tr>
<td>8/5/91</td>
<td>Sta 0-35</td>
<td>Sub Contractor &quot;C&quot;</td>
<td>S5 Surfacing</td>
</tr>
<tr>
<td>8/12/91</td>
<td>Sta 0-35</td>
<td>Sub Contractor &quot;D&quot;</td>
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</tr>
<tr>
<td>4/1/91</td>
<td>Sta 35-75</td>
<td>Clear &amp; Grub</td>
<td>Clearing &amp; Grubbing</td>
</tr>
<tr>
<td>4/8/91</td>
<td>Sta 35-75</td>
<td>Rough Grad</td>
<td>Rough Grading</td>
</tr>
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<td>4/15/91</td>
<td>Sta 35-75</td>
<td>Rough Grad</td>
<td>Rough Grading</td>
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<td>Fine Grad</td>
<td>Fine Grading</td>
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<td>Sta 35-75</td>
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<td>Cement Stabilize Subgrade</td>
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<tr>
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<tr>
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<td>Fine Grad</td>
<td>CTA Subbase</td>
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<tr>
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<td>Sta 35-75</td>
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<td>B3 Base</td>
</tr>
<tr>
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<td>Sta 35-75</td>
<td>Sub Contractor &quot;C&quot;</td>
<td>S5 Surfacing</td>
</tr>
<tr>
<td>8/12/91</td>
<td>Sta 35-75</td>
<td>Sub Contractor &quot;D&quot;</td>
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<td>Sta 75-100</td>
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<td>Clearing &amp; Grubbing</td>
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<tr>
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<td>Sta 75-100</td>
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<td>Retaining Wall</td>
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<tr>
<td>4/29/91</td>
<td>Sta 75-100</td>
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<td>Retaining Wall</td>
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<tr>
<td>5/6/91</td>
<td>Sta 75-100</td>
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<td>Retaining Wall</td>
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<tr>
<td>5/13/91</td>
<td>Sta 75-100</td>
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<td>Rough Grading</td>
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<tr>
<td>5/20/91</td>
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<td>6/3/91</td>
<td>Sta 75-100</td>
<td>Fine Grad</td>
<td>Fine Grading</td>
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<tr>
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<td>Sta 75-100</td>
<td>Sub Contractor &quot;A&quot;</td>
<td>Cement Stabilize Subgrade</td>
</tr>
<tr>
<td>6/17/91</td>
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<td>Fine Grad</td>
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<tr>
<td>7/22/91</td>
<td>Sta 75-100</td>
<td>Sub Contractor &quot;B&quot;</td>
<td>B3 Base</td>
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<td>8/12/91</td>
<td>Sta 75-100</td>
<td>Sub Contractor &quot;D&quot;</td>
<td>Permanent Striping</td>
</tr>
</tbody>
</table>

6. Representation of Linear Schedule in Tabular Format
6.3.3.1 Activities Selected for a Specific Section

A CMC can be generated to report all the activities to be carried out in a specific section of the project. This type of CMC is of special interest to the area superintendents as it presents tabular output containing all the activities that concern him/her. Chart 6.9 is an example of such a CMC. It reports information relating to the activities for the section between stations 35 and 75 of the project.

Chart 6.9
Crew Movement Chart
Activities Selected for a Specific Section - "Middle Section - Sta 35-75"

<table>
<thead>
<tr>
<th>Date</th>
<th>Stations</th>
<th>Crew</th>
<th>Work</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Clear &amp; Grub</td>
<td>Clearing &amp; Grubbing</td>
</tr>
<tr>
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<td>Sta 35-75</td>
<td>Rough Grad</td>
<td>Rough Grading</td>
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<td>Sta 35-75</td>
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<td>Sta 35-75</td>
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<td>Demolition</td>
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<td>Fine Grading</td>
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</tr>
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<td>8/5/91</td>
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<td>Sub Contractor &quot;C&quot;</td>
<td>S5 Surfacing</td>
</tr>
<tr>
<td>8/12/91</td>
<td>Sta 35-75</td>
<td>Sub Contractor &quot;D&quot;</td>
<td>Permanent Striping</td>
</tr>
</tbody>
</table>

6.3.4 Sorted by Dates

A CMC sorted on the dates lists all the activities of the project, grouping them according to the dates. Secondary and tertiary sorting may be done on crews, operations, or stations. Chart 6.10 is an example of a chart of this type.

6. Representation of Linear Schedule in Tabular Format
Chart 6.10  
Crew Movement Chart  
Activities Sorted by Dates

<table>
<thead>
<tr>
<th>Date</th>
<th>Stations</th>
<th>Crew</th>
<th>Work</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
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<td>Clearing &amp; Grubbing</td>
</tr>
<tr>
<td>4/8/91</td>
<td>Sta 0-35</td>
<td>Concrete</td>
<td>Culvert</td>
</tr>
<tr>
<td>4/8/91</td>
<td>Sta 35-75</td>
<td>Rough Grad</td>
<td>Rough Grading</td>
</tr>
<tr>
<td>4/8/91</td>
<td>Sta 75-100</td>
<td>Clear &amp; Grub</td>
<td>Clearing &amp; Grubbing</td>
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<td>Rough Grad</td>
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<tr>
<td>4/22/91</td>
<td>Sta 35-75</td>
<td>Fine Grad</td>
<td>Demolition</td>
</tr>
<tr>
<td>4/22/91</td>
<td>Sta 75-100</td>
<td>Concrete</td>
<td>Retaining Wall</td>
</tr>
<tr>
<td>4/29/91</td>
<td>Sta 0-35</td>
<td>Rough Grad</td>
<td>Rough Grading</td>
</tr>
<tr>
<td>4/29/91</td>
<td>Sta 35-75</td>
<td>Fine Grad</td>
<td>Fine Grading</td>
</tr>
<tr>
<td>4/29/91</td>
<td>Sta 75-100</td>
<td>Concrete</td>
<td>Retaining Wall</td>
</tr>
<tr>
<td>5/6/91</td>
<td>Sta 0-35</td>
<td>Rough Grad</td>
<td>Rough Grading</td>
</tr>
<tr>
<td>5/6/91</td>
<td>Sta 35-75</td>
<td>Fine Grad</td>
<td>Fine Grading</td>
</tr>
<tr>
<td>5/6/91</td>
<td>Sta 75-100</td>
<td>Concrete</td>
<td>Retaining Wall</td>
</tr>
<tr>
<td>5/13/91</td>
<td>Sta 35-75</td>
<td>Sub Contractor &quot;A&quot;</td>
<td>Cement Stabilize Subgrade</td>
</tr>
<tr>
<td>5/13/91</td>
<td>Sta 75-100</td>
<td>Rough Grad</td>
<td>Rough Grading</td>
</tr>
<tr>
<td>5/20/91</td>
<td>Sta 35-75</td>
<td>Sub Contractor &quot;A&quot;</td>
<td>Cement Stabilize Subgrade</td>
</tr>
<tr>
<td>5/20/91</td>
<td>Sta 75-100</td>
<td>Fine Grad</td>
<td>Demolition</td>
</tr>
<tr>
<td>5/27/91</td>
<td>Sta 35-75</td>
<td>Fine Grad</td>
<td>CTA Subbase</td>
</tr>
<tr>
<td>6/3/91</td>
<td>Sta 75-100</td>
<td>Fine Grad</td>
<td>Fine Grading</td>
</tr>
<tr>
<td>6/10/91</td>
<td>Sta 0-35</td>
<td>Fine Grad</td>
<td>Demolition</td>
</tr>
<tr>
<td>6/10/91</td>
<td>Sta 75-100</td>
<td>Sub Contractor &quot;A&quot;</td>
<td>Cement Stabilize Subgrade</td>
</tr>
<tr>
<td>6/17/91</td>
<td>Sta 75-100</td>
<td>Fine Grad</td>
<td>CTA Subbase</td>
</tr>
<tr>
<td>6/24/91</td>
<td>Sta 0-35</td>
<td>Fine Grad</td>
<td>Fine Grading</td>
</tr>
<tr>
<td>7/1/91</td>
<td>Sta 0-35</td>
<td>Fine Grad</td>
<td>Fine Grading</td>
</tr>
<tr>
<td>7/8/91</td>
<td>Sta 0-35</td>
<td>Sub Contractor &quot;A&quot;</td>
<td>Cement Stabilize Subgrade</td>
</tr>
<tr>
<td>7/15/91</td>
<td>Sta 0-35</td>
<td>Sub Contractor &quot;A&quot;</td>
<td>Cement Stabilize Subgrade</td>
</tr>
<tr>
<td>7/15/91</td>
<td>Sta 35-75</td>
<td>Sub Contractor &quot;B&quot;</td>
<td>B3 Base</td>
</tr>
<tr>
<td>7/22/91</td>
<td>Sta 0-35</td>
<td>Fine Grad</td>
<td>CTA Subbase</td>
</tr>
<tr>
<td>7/22/91</td>
<td>Sta 75-100</td>
<td>Sub Contractor &quot;B&quot;</td>
<td>B3 Base</td>
</tr>
<tr>
<td>7/29/91</td>
<td>Sta 0-35</td>
<td>Sub Contractor &quot;B&quot;</td>
<td>B3 Base</td>
</tr>
<tr>
<td>8/5/91</td>
<td>Sta 0-35</td>
<td>Sub Contractor &quot;C&quot;</td>
<td>S5 Surfacing</td>
</tr>
<tr>
<td>8/5/91</td>
<td>Sta 35-75</td>
<td>Sub Contractor &quot;C&quot;</td>
<td>S5 Surfacing</td>
</tr>
<tr>
<td>8/5/91</td>
<td>Sta 75-100</td>
<td>Sub Contractor &quot;C&quot;</td>
<td>S5 Surfacing</td>
</tr>
<tr>
<td>8/12/91</td>
<td>Sta 0-35</td>
<td>Sub Contractor &quot;D&quot;</td>
<td>Permanent Striping</td>
</tr>
<tr>
<td>8/12/91</td>
<td>Sta 35-75</td>
<td>Sub Contractor &quot;D&quot;</td>
<td>Permanent Striping</td>
</tr>
<tr>
<td>8/12/91</td>
<td>Sta 75-100</td>
<td>Sub Contractor &quot;D&quot;</td>
<td>Permanent Striping</td>
</tr>
</tbody>
</table>

6. Representation of Linear Schedule in Tabular Format
6.3.4.1 Activities Selected for Specific Dates

For the case when dates are used to sort the CMC, selection of activities can be carried out to generate CMC which contain activities occurring between two specific dates. As discussed in Section 6.2.1, this selection is of much practical significance because it gives the field personnel 'look-ahead' scheduling information of a specific period. Chart 6.11 contains information is presented for a 3-week period, from 04/29/91 to 05/19/91.

Chart 6.11 Crew Movement Chart
Activities Selected for Specific Dates - "From 04/29/91 to 05/19/91"

<table>
<thead>
<tr>
<th>Date</th>
<th>Stations</th>
<th>Crew</th>
<th>Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/29/91</td>
<td>Sta 0-35</td>
<td>Rough Grad</td>
<td>Rough Grading</td>
</tr>
<tr>
<td>4/29/91</td>
<td>Sta 35-75</td>
<td>Fine Grad</td>
<td>Fine Grading</td>
</tr>
<tr>
<td>4/29/91</td>
<td>Sta 75-100</td>
<td>Concrete</td>
<td>Retaining Wall</td>
</tr>
<tr>
<td>5/6/91</td>
<td>Sta 0-35</td>
<td>Rough Grad</td>
<td>Rough Grading</td>
</tr>
<tr>
<td>5/6/91</td>
<td>Sta 35-75</td>
<td>Fine Grad</td>
<td>Fine Grading</td>
</tr>
<tr>
<td>5/6/91</td>
<td>Sta 75-100</td>
<td>Concrete</td>
<td>Retaining Wall</td>
</tr>
<tr>
<td>5/13/91</td>
<td>Sta 35-75</td>
<td>Sub Contractor &quot;A&quot;</td>
<td>Cement Stabilize Subgrade</td>
</tr>
<tr>
<td>5/13/91</td>
<td>Sta 75-100</td>
<td>Rough Grad</td>
<td>Rough Grading</td>
</tr>
</tbody>
</table>

6.3.5 Sorting and Selection Criteria Tree

Numerous sorting and selection criteria have been discussed in Sections 6.3.1 to 6.3.4.2. Figure 6.1 presents a tree portraying these sorting and selection criteria when CMC is generated using spreadsheet package. As depicted in the figure, the primary, secondary and tertiary sorting criteria can be chosen from crews, operations, sections, and dates. Selection of activities can be done using the same criterion as used for primary sorting. There are a total of 48 ways in which a CMC can presented using a spreadsheet package.

6. Representation of Linear Schedule in Tabular Format
Legend for the Criteria:  
C - Crew,  O - Operation,  S - Section,  D - Date,  N - None

Note: □ denotes a CMC

Figure 6.1  Sorting and Selection Criteria Tree for
Generating CMC Using Spreadsheet Package

6. Representation of Linear Schedule in Tabular Format
6.4 GENERATING CMC USING A DATABASE PACKAGE

Information regarding various activities can be stored and organized in database format. A database is a body of information organized for ease of reference (Language 1988). A standard database package can be used to store, retrieve, and manage information. The database package used by the researcher is dBASE IV which is copyrighted by Ashton-Tate Corporation.

Various fields are created for different types of information such as activity description, crew name, start and end stations, start and end dates etc. These field in the database file define its structure which is discussed in section 6.4.1. Sorting, selecting, listing, displaying, and printing of data are discussed in Section 6.4.2 to 6.4.4.

6.4.1 Structure of the Database

The first step in order to generate CMC using database package, is to define the structure of the database. Fields are created for activity description, crew description, start station, end station, start date, and end date. Table 6.1 shows the structure of a sample database which is created for the purpose of discussion in this section. It lists the field names along with information about field types, field width, places after decimals, and whether indexed on that field or not.

The field type for activity description and crew description, in the sample database, is 'Character.' These two field, ACTDES and CREWDES, contain descriptive information about the activity and the crew, respectively, and thus, can be alphanumeric characters,

6. Representation of Linear Schedule in Tabular Format
Table 6.1  Structure of the Sample Database

<table>
<thead>
<tr>
<th>Field Name</th>
<th>Field Type</th>
<th>Width</th>
<th>Pl. after Decimal</th>
<th>Whether Indexed</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACTDES</td>
<td>Character</td>
<td>20</td>
<td></td>
<td>N</td>
</tr>
<tr>
<td>CREWDES</td>
<td>Character</td>
<td>20</td>
<td></td>
<td>N</td>
</tr>
<tr>
<td>ACTSTST</td>
<td>Numeric</td>
<td>6</td>
<td>1</td>
<td>N</td>
</tr>
<tr>
<td>ACTSTEND</td>
<td>Numeric</td>
<td>6</td>
<td>1</td>
<td>N</td>
</tr>
<tr>
<td>ACTDTST</td>
<td>Date</td>
<td>8</td>
<td></td>
<td>N</td>
</tr>
<tr>
<td>ACTDTEND</td>
<td>Date</td>
<td>8</td>
<td></td>
<td>N</td>
</tr>
</tbody>
</table>

with a maximum limit of 20 in each case. The field type for start and end stations is 'Numeric.' These two field are labeled ACTSTST and ACTSTEND respectively. The station numbers can have a maximum width of 6, out of which one space is reserved for decimal, and one for a numeral after decimal. Thus, 9999.9 is the maximum number that can be input for stations. The last two field are for start date and end date of the activity. These are labeled ACTDTST and ACTDTEND respectively. The field type is 'Date' and the information can be input in mm/dd/yy format only.

Once the basic structure of the database is ready, it can be used to generate database file for a specific project. Information regarding various activities is input. The database file is saved under an appropriate name. Sorting and selection can be carried out to generate CMC of different types.

6.4.2  Sorting Data

Data in a database file can be sorted using the SORT command. When sorting, the file is rewritten as a new database file and the information is arranged in the desired order. The

6. Representation of Linear Schedule in Tabular Format
basic command statement in dBASE IV for sorting a database file is:

```
. SORT TO <filename> ON <field>
```

<filename> is the name of the new database in which the sorted information will be stored after sorting. <field> is for the field on which the data is being sorted. The information can be sorted in ascending or descending order. The default is for ascending order. The command statement for sorting data in descending order is:

```
. SORT TO <filename> ON <field>/D
```

Multiple level sorting is possible using dBASE IV. For each level, whether ascending or descending order can be specified. A sample command for three levels of sorting, first in ascending order, and the other two in descending order is:

```
. SORT TO <filename> ON <field1>/A,<field2>/D,<field3>/D
```

6.4.2.1 Primary Sorting by Crews

As discussed in Sections 6.3.1, a CMC can be sorted on the crews carrying out the jobs. This will result in the activities in the database being grouped according to the crews. The key expression for sorting is CREWDES. Command statement to be entered is:

```
. SORT TO <filename> ON CREWDES
```

6.4.2.2 Primary Sorting by Operations

A CMC can be sorted on the operations. A CMC of this type lists all the activities of the project, grouping them according to the operations. The key expression for sorting is

6. Representation of Linear Schedule in Tabular Format
ACTDES. Command to be used for generating a CMC sorted on operations is:

```
.SORT TO <filename> ON ACTDES
```

6.4.2.3 Primary Sorting by Stations

When a database package is used to generate CMC, generally two separate fields are set up
for start and end stations. A CMC can be generated by sorting the activities either by the
start or the end station. The key expression for sorting in these two cases is ACTSTST and
ACTSTEND respectively. Command statements for both the cases are given below:

```
.SORT TO <filename> ON ACTSTST
.SORT TO <filename> ON ACTSTEND
```

6.4.2.4 Primary Sorting by Dates

As described in section 6.4.1, two separate fields are set up for the start and the end dates.
These two fields can be used to sort the database file and generate CMC in which the
activities are sorted by project dates. Command statements to be used are:

```
.SORT TO <filename> ON ACTDTST
.SORT TO <filename> ON ACTDTEND
```

6.4.2.5 Secondary and Tertiary Sorting

As discussed in Section 6.4.2, multiple level sorting can be carried out using database
packages. Secondary and tertiary sorting on crews, operations, stations, or dates can be
done for the cases described in Sections 6.4.2.1 to 6.4.2.4.

6. Representation of Linear Schedule in Tabular Format
6.4.3 Listing, Displaying, Saving, and Printing Data

Once the data is input in the database files and ordered according to the sorting criterion to generate various types of CMC, it needs to be either displayed on the screen, saved as a file and/or printed. There are two commands which can be used to view data on the screen. These are 'LIST' and 'DISPLAY.' In both the cases the CMC can be either saved as a text file or sent to the printer directly.

Once sorting commands have been executed, LIST command can be used to show all the records on the screen. DISPLAY is identical to LIST, the only difference being that it pauses after each screen's display and LIST does not. After each screen, DISPLAY prompts 'Press any key to continue.' The basic commands for various operations such as selecting, saving, printing etcetera using LIST are given in this chapter. Commands for DISPLAY are identical to those for LIST and can be written by substituting DISPLAY for LIST. The basic commands when the output is saved as a text file and printed directly are:

. LIST TO FILE <filename>

. LIST TO PRINTER

6.4.4 Selecting Data

As discussed in Section 6.2, some times it is desirable that the CMC lists activities selected only for specific dates, stations, crew, or operation. The database packages allow the user to limit the scope of the output generated using LIST or DISPLAY commands. The selection of activities can be done either without sorting of activities, or after sorting by criteria discussed in Sections 6.3.2.1 to 6.3.2.4.
The basic command statement when the scope is to be limited is as follows:

```
.LIST FOR <condition> TO PRINTER/TO FILE <filename>
```

By using 'FOR <condition>' option, a number of different CMC, whose scope has been limited by the 'condition', can be generated. Cases of CMC generated using selection criteria as 'condition', are discussed in Sections 6.4.4.1 to 6.4.4.5.

6.4.4.1 Activities Selected for a Specific Crew

As discussed in Section 6.3.1.1, a CMC which contains activities to be carried out by a specific crew is a very useful tool for the crew foremen. CMC of this type present a listing of activities which are of direct concern to them. The command for generating the CMC of this type is:

```
.LIST FOR CREWDES = "XXXXXXXXXXXXXXXXXXXXXXXX"
```

6.4.4.2 Activities Selected for a Specific Operation

The command statement for generating a CMC which contains activities for a specific operation only, is:

```
.LIST FOR ACTDES = "XXXXXXXXXXXXXXXXXXXXXXXX"
```

6.4.4.3 Activities Selected for Specific Stations

For generating a CMC which contains all the activities which take place between two specific stations, the user needs to use a command which limits the scope by two

6. Representation of Linear Schedule in Tabular Format
conditions, one each for start station and end station. The command is:

. LIST FOR ACTSTST => 9999.9 .AND. ACTSTEND <= 9999.9

The above case gives a listing of only those activities which start as well as end between the specified stations. The command for listing all the activities which occur between the specified stations, completely or partially, is:

. LIST FOR ACTSTST <= 9999.9 .AND. ACTSTEND >= 9999.9

6.4.4.4 Activities Selected for Specific Dates

There are situations when the user wishes to list information for only a limited duration of time. For generating a CMC of this type, the user needs to limit the scope of LIST or DISPLAY command by two conditions, one for start date and one for end date. The dates, which are stored in the database as character strings, are converted into date type variable using the CTOD() function. The basic command statement is:

. LIST FOR ACTDTST => CTOD("mm/dd/yy") .AND.
   ACTDTEND <= CTOD("mm/dd/yy")

The above case gives a listing of only those activities which start as well as end between the specified dates. The command statement for listing all the activities which occur between the specified dates, completely or partially, is:

. LIST FOR ACTDTST <= CTOD("mm/dd/yy") .AND.
   ACTDTEND >= CTOD("mm/dd/yy")

6.4.4.5 Combining Selection Criteria

The selection criteria discussed in Sections 6.4.4.1 to 6.4.4.4 can be combined to limit the scope of the LIST or DISPLAY command by more than one condition. It is of much

6. Representation of Linear Schedule in Tabular Format
practical significance to combine the selection criteria for specific stations, crew, or operation with specific dates. Command statements for some case examples are given below:

Specific crew, with dates:

\[ \text{LIST FOR CREWDES} = "XXXXXXX" \text{CTOD("mm/dd/yy") AND ACTDTST} \geq \text{CTOD("mm/dd/yy") AND ACTDTEND} \leq \text{CTOD("mm/dd/yy")} \]

Specific operation, with dates:

\[ \text{LIST FOR ACTDES} = "XXXXXXX" \text{CTOD("mm/dd/yy") AND ACTDTST} \geq \text{CTOD("mm/dd/yy") AND ACTDTEND} \leq \text{CTOD("mm/dd/yy")} \]

Specific stations, with dates:

\[ \text{LIST FOR ACTSTST} \geq 9999.9 \text{AND ACTSTEND} \leq 9999.9 \text{AND ACTDTST} \geq \text{CTOD("mm/dd/yy") AND ACTDTEND} \leq \text{CTOD("mm/dd/yy")} \]

6.5 'LINC' - A COMPUTER SOFTWARE PACKAGE TO GENERATE CREW MOVEMENT CHARTS

A computer package which can be used to generate Crew Movement Charts has been developed as a part of this research. The package links the concepts of Linear Schedule with Crew Movement Chart and thus is titled 'LINC.'

The package uses the database format for generating CMC and utilizes the basic concepts laid out in Section 6.4. Command statements given in Section 6.4 are used in the computer programs for LINC, and are referred to in the discussion in this section. Although a database package is used for LINC, the user does not have to be proficient with the use of the package. The user interacts with the package through user-interface screens.

6. Representation of Linear Schedule in Tabular Format
6.5.1 The Basic Concept

LINC uses database format for generating Crew Movement Chart (CMC). The information portrayed in a linear schedule is used to create a database of activities. The data is sorted and selected for user defined conditions to generate CMC containing specific information desired. The concept is graphically depicted in Figure 6.2 which shows the user-interface screens through which the user interacts with the package, and the resulting databases.

There are two database files, one each for the project data, and the activity data. The structure of these databases are discussed in Sections 6.5.4.1 and 6.5.4.3, respectively. The information pertaining to the project is gathered through project title screens and it is stored in project database. For each project there is an activity database which contains information pertaining to numerous activities. This information is gathered through a series of user-interface activity data input screens.

Once the activity database is ready, the user is questioned about various multi-level sorting and selection criteria. Sorting criteria are used to arrange the information in the activity database in the order desired by the user. However, sorting does not alter the overall constitution of the database. Selection criteria are used to limit the information to be presented in the CMC.

The user sorted and selected information is presented in custom-designed report formats. The report format is automatically chosen by the computer program depending on the nature of information desired by the user. The CMC generated can either be printed immediately or saved as a text file.

6. Representation of Linear Schedule in Tabular Format
Figure 6.2  The Basic Concept for LiNC

6. Representation of Linear Schedule in Tabular Format
6.5.2 The Structure of 'LINC'

LINC uses dBASE IV as the database package used for creating, managing, and organizing the database file. The computer programs are written using dBASE Programming Language.

The user-interface screens for the package are developed using HI-SCREEN XL, a user-interface screen generating and managing package. HI-SCREEN XL is a trademark of Softway, Inc. HI-SCREEN XL allows users to generate screens using a format and layout of their choice. A number of data fields are created in each screen. User inputs data through these fields. Nature of data for a specific field, such as numeric, alphanumeric etcetera, can be specified. The screens developed for LINC are attached to this thesis as Appendix A. The screens are referred to in the discussion in this chapter by their numbers in the appendix.

Figure 6.3 depicts the structure of LINC. LINC is basically composed of two parts. The computer program for the first part is titled CMCGET which is used to collect data from the user regarding activities. This data is stored in a database file. The second part is used to generate CMC. The user is asked for a number of sorting criteria and two selection criteria. The computer program for the second part is titled CMCGEN. Based on the user's input, generated CMC is either sent directly to the printer or saved as a text file, in one of the four custom-designed report formats. Another computer program labeled CMCA works as the controller of the two programs discussed earlier in this paragraph. CMCA can be described as the outer shell within which CMCGET and CMCGEN function. The user accesses LINC by invoking CMCA, and exits LINC through CMCA once the operations are over.

6. Representation of Linear Schedule in Tabular Format
6.5.3 Accessing and Exiting LINC

The user accesses LINC by running computer program CMCA.PRG. The user types CMCA once he/she is at the appropriate sub-directory, and a batch file loads the computer program CMCA and runs it. The first screen, which is the Options Screen, appears on the computer monitor. The user gathers data, generates CMC, and prints/saves them. Once the entire operation is over, the user exits LINC through CMCA.

6. Representation of Linear Schedule in Tabular Format
6.5.3.1 Options Screen

The first screen that appears when the program is loaded is the Options Screen. The Options Screen, which is shown in Screen A-1 of the Appendix A, provides user with three options. As shown in Figure 6.3, the first option (Option 'A') activates the computer program CMCGET.PRG which is used to gather the data about the project and the activities. Second option (Option 'B') activates the computer program CMCGEN.PRG which is used to sort, select, and print/save the information as CMC. The last option (Option 'X') lets the user exit LINC.

6.5.3.2 Computer Program CMCA

The computer program CMCA is attached to this thesis as Appendix B. It is written in dBASE Programming Language. As shown in the appendix, the first six commands of this program are used to set the parameters of dBASE and the computer monitor to desired settings. An iteration loop ('DO' loop) is used to run the program until the user decides to exit by choosing option 'X' on the Options Screen. 'DO' loop allows command statements between the 'DO WHILE' command and the 'ENDDO' command to be repeated as long as the specified condition is true. A 'USE' statement which utilizes syntax specified by HI-SCREEN to be used with dBASE IV, is used to display the Options Screen which has been described in Section 6.5.3.1. A condition statement ('DO CASE') is used to provide three alternatives to the user. 'DO CASE' statement is a command that selects only one course of action from a set of alternatives. When the user exits the program, last set of commands of CMCA.PRG resets the parameters of dBASE and the computer monitor.

6. Representation of Linear Schedule in Tabular Format
6.5.4 Collecting Data

This section discusses the part of LINC which is used to collect project and activity data. The structure of the databases storing project data and activity data are discussed. The sequencing of user-interface screens for this part of the program is shown in Figure 6.4. All these screen use two keys for the same function. Function key 'Esc' is used to return and 'F10' is used to validate the data and advance. Computer program titled CMCGET.PRG runs this part of LINC.

Figure 6.4 Screens for Gathering Project and Activity Data

6. Representation of Linear Schedule in Tabular Format
6.5.4.1 Structure of the Project Database

The information about the project such as project title, start date, and end date of the project is stored in the project database file which is labeled CMCPDB.DBF. Information regarding field name, field type, width, character type, and whether the database is indexed on the field or not, for the project database is listed in Table 6.2. The field name for the project title is NAMEPROJ and its type is 'Character.' The fields for the start and the end date of the project are labeled CMCDATEST and CMCDATEEND, respectively. The field type is 'Date' and the information can be input in mm/dd/yy format only.

<table>
<thead>
<tr>
<th>Field Name</th>
<th>Field Type</th>
<th>Width</th>
<th>Pl. after Decimal</th>
<th>Whether Indexed</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAMEPROJ</td>
<td>Character</td>
<td>8</td>
<td></td>
<td>N</td>
</tr>
<tr>
<td>CMCDATEST</td>
<td>Date</td>
<td>8</td>
<td></td>
<td>N</td>
</tr>
<tr>
<td>CMCDATEEND</td>
<td>Date</td>
<td>8</td>
<td></td>
<td>N</td>
</tr>
</tbody>
</table>

6.5.4.2 Project Title Screens

The first Project Title Screen, shown in Screen A-2, allows user to input name of the project. The project name can have a maximum of eight MS-DOS allowable characters. Function key 'F10' validates the data and superimposes Screens E-3 and E-4 on this screen. Screen E-3 presents two fields for gathering information about the start date and the end date of the project. Screen E-4 is a one line function strip and it adds function key 'F6' to the screen which is used to delete information about the project displayed on the screen. Function key 'F10' advances user to the Activity Data Input Screen, Screen A-5.

6. Representation of Linear Schedule in Tabular Format
6.5.4.3 Structure of the Activity Database

The information regarding various activities is stored in the activity database file, the structure of which is shown in Table 6.3. The database file is labeled FORMAT.DBF and is copied under the name of the project being used, before inputting activity data into it. Each activity is given a unique identification number and it is stored under the filed name of ACTID. Activity name information is collected by ACTCODE and ACTDES fields, and information about the crew carrying out the activity is collected by CREWCODE and CREWDES fields. ACTSTST and ACTSTEND are used for gathering start and end station information about the activity and the field type for these fields is 'Numeric,' with one numeral after the decimal. These fields can have 9999.9 as their maximum value. Information regarding the activity start and end dates is gathered in ACTDTST and ACTDTEND respectively. These have field type of 'Date' and the information can be input in these fields in mm/dd/yy format only.

Table 6.3 Structure of the Activity Database

<table>
<thead>
<tr>
<th>Field Name</th>
<th>Field Type</th>
<th>Width</th>
<th>Pl. after Decimal</th>
<th>Whether Indexed</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACTID</td>
<td>Character</td>
<td>10</td>
<td></td>
<td>N</td>
</tr>
<tr>
<td>ACTCODE</td>
<td>Character</td>
<td>6</td>
<td></td>
<td>N</td>
</tr>
<tr>
<td>ACTDES</td>
<td>Character</td>
<td>20</td>
<td></td>
<td>N</td>
</tr>
<tr>
<td>CREWCODE</td>
<td>Character</td>
<td>3</td>
<td></td>
<td>N</td>
</tr>
<tr>
<td>CREWDES</td>
<td>Character</td>
<td>20</td>
<td></td>
<td>N</td>
</tr>
<tr>
<td>ACTSTST</td>
<td>Numeric</td>
<td>6</td>
<td>1</td>
<td>N</td>
</tr>
<tr>
<td>ACTSTEND</td>
<td>Numeric</td>
<td>6</td>
<td>1</td>
<td>N</td>
</tr>
<tr>
<td>ACTDTST</td>
<td>Date</td>
<td>8</td>
<td></td>
<td>N</td>
</tr>
<tr>
<td>ACTDTEND</td>
<td>Date</td>
<td>8</td>
<td></td>
<td>N</td>
</tr>
</tbody>
</table>

6. Representation of Linear Schedule in Tabular Format
6.5.4.4 Activity Data Input Screen

Screen A-5 is used to gather information regarding the activities. For each activity information is gathered regarding its identification number, name details, crew details, stations, and dates. Information regarding the activity name is collected in two fields. ACTCODE is a 6 character field which is used to specify the type of the operation whereas ACTDES is a 20 character field which is used to get detailed description of the operation. The reason for setting up two different fields for similar information is based on practical considerations. Maintaining complete uniformity in spelling, style and content of the description which is 20 characters long, is difficult and if computer operation such as sorting and selection are carried out on this field, there are possibilities of error. Therefore, a separate field with a smaller width is set up for activity code and it is used primarily for sorting and selection purposes.

Information regarding crew carrying out the job is gathered in CREWCODE and CREWDES fields. The reason for setting up two separate fields is same as given for activity details in the preceding paragraph. The remaining four fields on this screen are for start and end stations, and start and end dates for the activity.

Function keys 'F3' and 'F4' are used to scroll backwards and forwards, respectively, in the activity database. Function key 'F5' is used to add a new activity. Function key 'F6' is used to delete the activity displayed on the screen. If the user wishes to go to a specific activity, its ID is entered and function key 'F7' is used to search for it.

6. Representation of Linear Schedule in Tabular Format
6.5.4.5 Computer Program CMCGET

The computer program CMCGET is used to gather project and activity data from the user and store it in respective databases. It is attached to this thesis as Appendix C. When the user selects option 'A' from the Options Screen, CMCGET is activated. A 'DO' command is used to mark the start of an iteration loop which is used to run the program until the user decides to return to the Options Screen.

The project database which contains details about project name, start date, and end date for all the projects is opened with the help of a 'USE' command. Screens are displayed with the help of a 'USE' statement. The first screen to be displayed is the Project Title Screen, Screen A-2. The user enters the name of the project and presses function key 'F10' to validate the data. The computer program uses a 'RECOVER' statement to recover the project name from the screen and through a 'SEEK' statement, checks whether details for the project with the name provided by the user, exist. Screens A-3 and A-4 are superimposed on the screen using a 'OPEN' statement, and if the details are found for the project name, the values for the start date and the end date available in the existing database are displayed on the screen using a 'DISPLAY' statement. A condition statement ('DO CASE') is used to define the three function keys.

If the project name is not in the database, details about the project are stored in the project database. The database file for the activity data, FORMAT.DBF which is described in Section 6.5.4.3, is copied under the name of the project and opened. If the project name is in the database, the details about the project are updated using the 'REPLACE' statement and the existing activity database file for the project is opened for use.

6. Representation of Linear Schedule in Tabular Format
The Activity Data Input Screen, described in Section 6.5.4.4, is displayed on the screen. A condition statement is used to define the function keys. 'DISPLAY,' 'RECOVER,' and 'REPLACE' statements are used to display existing data, recovering the data from the computer screen, and replacing existing data with the ones displayed on the screen. An ENDDO command at the end of the program marks the end of the iteration loop described in the beginning of this section.

6.5.5 Generating CMC

This section discusses the part of LINC which is used to generate CMC from the data collected in the first part of LINC, described in Section 6.5.4. Computer program titled CMCGEN runs this part of LINC. A number of computer screens are used to gather user input. The sequencing of these screens is presented in Figure 6.5. In all the screens, function keys 'Esc' and 'F10' are used to return and validate/advance, respectively.

6.5.5.1 Project Title Screen - Option 'B'

Project Title Screen - Option B is the first screen in the second part of LINC. It is shown in Screen A-6 of the Appendix A. The user is asked for the name of the project. This information is used to find the existing project and activity details about the project which were input during the data collection phase.

6. Representation of Linear Schedule in Tabular Format
Figure 6.5 Screens for Generating CMC

6. Representation of Linear Schedule in Tabular Format
6.5.5.2 Sorting Criteria Screen

The LINC uses a number of sorting criteria to arrange the information in the activity database in the order desired by the user. The Sorting Criteria Screen, shown in Screen A-7, is used to query user about three sorting criteria. The options available to the user for each level of sorting are: Activity ID, Starting Station, Starting Date, Crew and Operation. User is also asked whether the data is to be arranged in ascending or descending order for each of the sorting criterion. The sorted information is stored in a temporary database file.

The user is questioned whether he/she would like to carry out selection of activities for a specific crew, an operation, or a section of the project. If the user wishes to carry out primary selection, then 'F10' displays the Primary Selection Criterion Screen, Screen A-8. However, if the user does not wish to carry out primary selection, then Screen A-12 which is the Secondary Selection criterion Screen is displayed. Figure 6.5 clearly portrays these sequencing options.

6.5.5.3 Primary Selection Criterion Screens

As discussed earlier in this chapter, there are times when the user wishes to list only selected information in the CMC. LINC allows primary selection of activities on the basis of a crew, an operation, or a section of a project. The Primary Selection Criterion Screen, Screen A-8, provides user with three options. There are three separate computer screens, one each for the crew, operation or section as the criterion. Depending on the selection criterion chosen, one of the three screens is superimposed on Screen A-8. The screen to follow, for all the three cases, is the Secondary Selection Criterion Screen, Screen A-12.

6. Representation of Linear Schedule in Tabular Format
Screen A-9 is for crew as the primary selection criterion and it asks the user for the code of the crew for which the information is to be presented. Screen A-10 is for operation as the primary selection criterion and the user is questioned about the activity code for the selection. Screen A-11 is for the case when a section of the project is used as the primary selection criterion. The section is defined by its start and end stations. The user is also questioned whether all the activities which occur between the specified stations, completely or partially, or only those activities which start as well as end between the specified stations, are to be listed.

6.5.5.4 Secondary Selection Criterion Screens

Secondary Selection Criterion Screen provides user with the option of listing activities selected for a specified period only. Screen A-12 provided user with two options. If the user wishes to list activities for the entire project duration, Output Option Screen 1, Screen A-14, is superimposed on Screen A-12. However, if the user wishes to select activities for specific dates then the Screen for Dates as Secondary Selection Criterion, Screen A-13, is superimposed.

Screen A-13 queries user about the start and end dates of the period for which the activities are to be listed. The user is also questioned whether all the activities which occur either completely or partially between the begin and the end dates specified, or only those activities which start as well as end between the specified dates, are to be listed. The screen to follow this screen is Screen A-14 which is described in the following section.

6. Representation of Linear Schedule in Tabular Format
6.5.5.5 Output Option Screens

The Output Option Screen 1, Screen A-14, is used to ask the user whether the CMC is to be saved as a text file or printed directly. If the user chooses the print option, CMC is sent to the printer and the program returns back to the Project Title Screen - Option B. However, if the CMC is to be saved as a text file, another screen, Output Option Screen A-15, is superimposed on Screen A-14. Output Option Screen 2, Screen A-15, is used to ask the user about the name under which the file is to be saved. Once the file is saved, the program returns back to the Project Title Screen - Option B.

6.5.5.6 CMC Output Formats

Four custom-designed report formats have been developed using dBASE IV. These report formats are shown in Appendix F where they are used to present the crew movement charts for the example project. These charts are generated using the modified version of LINC which is a part of the combined scheduling system described in the following chapter, in Section 7.5.

One of the four report formats is used to present the information, depending on the primary selection criterion. If no primary selection criterion is used, report form GENCMC, whose layout is shown in Chart F-2, is used. The start date, end date, start station, end station, crew code, and act code are listed for all the selected activities. A title block is also added to the report. The structure of the report form for the case when a section of the project is used as the primary selection criterion, labeled STATCMC, is similar to GENCMC. The only difference is in the title block. Chart F-5 uses the report format STATCMC.

6. Representation of Linear Schedule in Tabular Format
If crew is used as the primary selection criterion, report form CREWCMC, which is used for Chart F-3, is used. It lists start date, end date, start station, end station, and activity description. The title block shows the code of the crew which is used as the primary selection criterion. The report form for the case of an operation, OPERCMC, is similar to CREWCMC and is used for the Chart F-4. Crew descriptions are listed instead of activity descriptions and the title block shows the code of the operation used as the criterion.

6.5.5.7 Computer Program CMCGEN

The computer program CMCGEN is used to ask user about the sorting and selection criteria and generate CMC based on the criteria. It is attached to this thesis as Appendix D. When the user selects option 'B' from the Options Screen, CMCGEN is activated. A DO command is used to mark the start of an iteration loop which is used to run the program until the user decides to return to the Options Screen.

The first screen to be displayed is the Project Title Screen - Option B, Screen A-6, which is displayed with the help of a 'USE' statement. The user enters the name of the project and presses function key 'F10' to validate the data. The computer program uses a 'RECOVER' statement to recover the project name from the screen and through a 'USE' command opens the activity database for the project. The next screen is used to ask user about three levels of sorting criteria. The database is sorted in the desired order on the basis of information, using a 'SORT' command, and is stored in a temporary database file named 'ZG959GZ.'

For the rest of the screens of this part of LINC, condition loops are used to define the function keys, 'USE,' and 'OPEN' statements are used to display or superimpose screens.

6. Representation of Linear Schedule in Tabular Format
'RECOVER' statements are used to collect information, and 'ACCEPT' commands are used to store the information in the memory. After the information regarding all the sorting criteria, selection criteria, and output options has been collected, the CMC is generated. The type of report format to be used and type of output, whether to be printed or saved, are specified using a DO CASE command. The DO CASE command is also used to specify conditions which limit the scope of the activities to be listed.

6.6 DISCUSSION

The concept of Crew Movement Chart (CMC) increases the effectiveness of the Linear Scheduling Method (LSM) by providing much needed and desired tabular output from the linear schedule. It also helps in sorting and selection of information and lets the user look at specific data regarding crews, operations, locations, and dates. This chapter presented the concept of CMC and described its basic format. Spreadsheet and database packages can be used to sort, select, and present the activity information. Their use was discussed and various types of CMC using different sorting and selection criteria were described.

In this computer age, usefulness of a technique increases manifold if it can utilize computer technology to free the user from mundane tasks. LINC is a computer software package that can be used to generate CMC. Basic concept, development, and structure of the package were discussed in this chapter. In an effort to give a computer-based approach to LSM, another computer software package was developed at Virginia Tech. The next chapter discusses the development of the software and its usefulness.

6. Representation of Linear Schedule in Tabular Format
CHAPTER 7

LINEAR SCHEDULING SOFTWARE

During the field implementation phase of this research, in Summer 1990, Critical Path Method (CPM) as well as Linear Scheduling Method (LSM) were used to prepare schedules for highway construction projects. It was identified that both these techniques have their advantages and disadvantages, and a need for combining the advantages of the two techniques was felt. This chapter first discusses the need for a computer interface between CPM and LSM, and then presents a discussion on the development of the computer interface which is titled the Linear Scheduling Software (LSS). LSS has been copyrighted by Peter Kiewit Sons', Inc. of Omaha, Nebraska.

7.1 THE NEED FOR AN INTERFACE BETWEEN CPM AND LSM

During the field implementation phase of this research, discussed in Chapter 3, a number of linear schedules were produced. These schedules were prepared on a Computer Aided Design and Drafting (CADD) package. A number of advantages and disadvantages of the CADD packages were identified which are discussed in the following two paragraphs.
With the use of CADD packages, it is possible to save the originally drawn schedule, and store it on the computer. The schedule can also be stored on diskettes which makes transporting the schedule from one place to another, convenient and easy. Moreover, the user can recall the schedule, modify/update it, and then restore it. The user has the ability to do partial plotting of the schedule, or to re-scale the schedule to control the dimensions of the output. CADD functions such as use of layers in a drawing, zoom, snap etcetera are of tremendous help in generating a linear schedule. As discussed in Chapter 5, use of different hatch/fill patterns, line types, flag types, colors etcetera, enhances the visualization impact of the linear schedules. CADD packages make use these features easier.

The biggest disadvantage of using the CADD packages is the complexity of the drawing process. Using a CADD package requires specialized knowledge, professional training, and experience. Since everybody involved in the construction operations is generally not proficient in use of such packages, this limits the drawing, updating, and modifying of the schedules to only those who are well versed with the CADD packages.

During the field implementation phase of this research, schedules based on Critical Path Method (CPM) were developed. CPM is a powerful technique for carrying out schedule calculations. It is a good tool for computing project dates and handles relationship constraints, dates constraints, forward pass, backward pass, loops in the schedule etcetera very well. Use of computerized programs for generating CPM schedules has made recording, sorting, selecting, storing, modifying, and updating of the schedule information easier. Moreover, introduction of resource leveling as an additional feature of CPM technique has increased its effectiveness. Thus, it can be stated that CPM works as a good 'engine' for recording, computing, saving, and storing project dates information.

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However, as discussed earlier in this thesis in Sections 3.4.2, 3.4.6, and 4.4, CPM has its limitations. It lacks graphical output, lacks availability of spatial dimension to portray information, and excessively relies on deterministic relationship constraints. As discussed in Chapter 4, the concept of resource leveling is yet not fully understood by all involved in construction scheduling.

In highway construction projects, Critical Path Method (CPM) as well as Linear Scheduling Method (LSM) have been used as techniques to carry out scheduling. As discussed in Chapter 3, Section 3.4.4, there is a constant controversy between CPM and LSM. The questions that confront the user are: Whether to use CPM, or LSM; and Which one of the two is a better technique. The solution of the controversy is combing the advantages of both the techniques.

On completion of the field implementation phase of this research in August, 1990, during preliminary discussions with the committee members of this research, the idea of developing a computer interface between Critical Path Method (CPM) and Linear Scheduling Method (LSM) was discussed. Basic concept for developing the software was outlined in a series of meetings and the researcher acknowledges the importance of the basic input of the committee members during this period.

7. Linear Scheduling Software
7.2 THE COMPUTER INTERFACE

The computer interface between Critical Path Method (CPM) and Linear Scheduling Method (LSM), titled as the 'Linear Scheduling Software,' is based on the idea of combining the advantages of both the techniques. The idea behind development of the computer interface is graphically depicted in Figure 7.1. CPM is a good tool for carrying out schedule computations. LSM is a good visual tool and has better communication potential. Linear Scheduling Software (LSS) combines the advantages of LSM's graphical format for output with the power of CPM to calculate dates.

THE CONTROVERSY BETWEEN CPM AND LSM

CPM
Good technique for:
- Computing Project Dates
- Storing Information
- Updating/Modifying Schedules

Which of the two is a better technique?

LSM
Good technique for:
- Visualization of the Project
- Communicating Information
- Understanding Information
- Identifying Scheduling Alternatives

THE SOLUTION
Combine the advantages of the techniques through a computer interface between the two.

COMPUTER INTERFACE
CPM

LSM

Figure 7.1 Idea Behind the Computer Interface

7. Linear Scheduling Software
7.2.1 Symbols as Geometrical Entities

As discussed earlier in this thesis, a linear schedule is drawn on two axes, viz. the distance axis and the time axis. Activities are represented by various symbols on this two-dimensional diagram. Symbols used are bars, lines, blocks, and flags. Lines and blocks are defined on the scheduling diagram by the start and end stations, and start and end dates. A bar is defined by its location, and start and end dates. A flag is defined by its location and time of occurrence.

The symbols used on the scheduling diagram are geometric entities and can be defined by a system of coordinates. In this thesis, horizontal axis is used for distance and vertical axis for time. Therefore, distance axis can be called 'X-axis' and the time axis as 'Y-axis'. Each point on the scheduling diagram can be defined by its x-coordinate (location) and y-coordinate (time). As discussed in preceding paragraph, lines and blocks are defined by their start station \( (x_s) \), end station \( (x_e) \), start date \( (y_s) \), and end date \( (y_e) \). Figure 6.2 shows representation of symbols as geometric entities by defining their coordinates. A line can be defined by the coordinates of the starting point \( (x_s,y_s) \) and the ending point \( (x_e,y_e) \). Block can be defined by the coordinates of its four corners: \( (x_s,y_s), (x_e,y_e), (x_e,y_s), \) and \( (x_s,y_e) \). A bar is defined by using the information about its location \( (x_o) \), width \( (w) \), start date \( (y_s) \), and end date \( (y_e) \). Using this information, four corners of a bar can be calculated. These are: \( ((x_o-(w/2)),y_s), ((x_o+(w/2)),y_s), ((x_o-(w/2)),y_e), \) and \( ((x_o+(w/2)),y_e) \). A flag can be defined by its location \( (x_o) \) and time of occurrence \( (y_o) \), and therefore, its coordinates will be \( (x_o,y_o) \).

7. Linear Scheduling Software
7.2.2 The Concept

The computer interface is based on the idea of using a CPM schedule to provide the activity dates (y-coordinates), and gathering information about the locations (x-coordinates) and types of symbol from the user. The basic concept is graphically depicted in Figure 6.3. The information from CPM schedule is exported in database (DBF) format. Information from the user is collected through a series of user-interface screens. The information collected is for the location (x-coordinates) of the activity, and the type of symbol to be used to depict the activity on the diagram. The user is also questioned about additional information about the line types, hatch patterns, flag types, colors etcetera for each activity. The activity information, exported from CPM, and input by the user, is collected in a database. This information is used for calculating the coordinates of the geometric entities for each activity, and drawing the entities.
Figure 7.3  The Basic Concept for the Computer Interface Between CPM and LSM

7. Linear Scheduling Software
Information about the project such as project title, starting and end stations, starting and completion dates of the project, calendar unit for the dates etcetera, is collected from the user. Additional information regarding layout and format of the linear schedule such as location of the title block, spacing of sight lines, spacing of minor labels, size and style of text etcetera is collected. The information is gathered in a database, separate from the activity database, and is used to draw the basic components of the linear schedule such as the axes, sight lines, major and minor labels, and title block.

The conversion of project and activity information into a drawing is achieved by first converting the database information into a Drawing Interchange (DXF) file, and then importing this DXF file into a CADD package.

The scope of the computer interface was later expanded to allow user input for the activity dates also. Thus a CPM schedule is not necessary for providing the dates. All the information needed to generate the linear schedules can be input solely from the user.

7.3 FORMAT OF THE USER-INTERFACE AND PROGRAM DESIGN

Identifying the format of the user-interface and designing the overall structure of the program are important phases in the development process of a computer software package. The user-interface screens for the Linear Scheduling Software (LSS) were developed using HI-SCREEN XL, a user-interface screen generating and managing package. HI-SCREEN XL, a trademark of Softway, Inc., allows user to generate screens using any chosen format and layout. A number of data fields are created in each screen. User inputs data through
these fields. The nature of the data to be entered in a specific field, such as numeric, alphabetic etcetera, must be specified. Many other features such as auto tabbing, required input, help messages etcetera can also be specified to describe various input fields and prompt the user as required.

Figure 7.4 shows the sequencing of the user-interface screens formatted for LSS. These screens are given in Appendix E and are discussed in the following sections. In the discussion in this chapter, reference to the screens is made with their number in the appendix.

Figure 7.4  Sequence of Screens for the LSS

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7.3.1 Options Screen

The first screen that appears when the program is loaded is the Options Screen which is shown in Screen E-1. It provides user with three alternatives. The first option, option 'A', activates the part of computer package which lets the user gather data about the project and various activities. Second option, option 'B', activates the second part of computer package which generates a Drawing Interchange (DXF) file for export to the CADD package. The last option, option 'X', lets the user exit the package.

7.3.2 Screens for Gathering Project Data

The screens described in this section are used to gather information about the project such as project title, axes information, and layout information. Figure 7.5 shows the structure and sequencing of these screens. Two keys are used for same functions in all the screens discussed in this section. Function key 'Esc' is used to abort and function key 'F10' is used for validating the data and advancing.

7.3.2.1 Project Title Screens

The first Project Title Screen, shown in Screen E-2, allows user to input name of the project. The project name can have a maximum of eight MS-DOS allowable characters. Function key 'F10' validates the data and superimposes Screens E-3 and E-4 on this screen.

7. Linear Scheduling Software
Figure 7.5 Screens for Gathering Project Data

7. Linear Scheduling Software
Screen E-3 presents a number of fields for input from the user. These fields gather information about the project title, name of the company/client, data date, and date of the run. All this information, except the data date, will be displayed on the title block. This screen asks the user about the type of schedule. The schedule can be either as bid, as being built, or as built. This information as well as revision number, in case of revised schedules, are displayed on the title block. There are times when a user wishes to save an updated schedule while keeping the old schedule unchanged. This screen asks user queries related to this. Screen E-4 is a one line function strip and it adds function key 'F6' to the screen which is used to delete the project.

7.3.2.3 Axes Data Input Screen

The screen to follow Project Title Screen is Screen E-5 which is the Axes Data Input Screen. First four input fields on this screen gather information about project start and end stations, and also the start and end dates. This information is used to determine the limits of the scheduling diagram. Last field on this screen is for calendar unit. Options available are days, weeks, or months. Function key 'F10' is used to validate the data and advance to the next screen, which is the Layout Information Input Screen.

7.3.2.4 Layout Information Input Screens

There are two Layout Information Input Screens in this package. These are shown in Screen E-6 and E-7. These two screens are used to gather information about the format and layout of the linear schedule. Screen E-6 is used to gather information about sheet size, axes length on the sheet, coordinates of the origin of the schedule on the sheet, and

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title block. Screen E-7 is used to gather information about axes major labels, minor labels, spacing of vertical and horizontal sight lines, and activity labels.

7.3.3 Screens for Gathering Activity Data

After the project and schedule details have been gathered from the user, a number of screens are used to gather specific activity information. Figure 7.6 shows the structure and sequencing of these screens. Screens E-8 is used to inquire the user about general information, and based on user's responses to queries in this screen, one of the eight screens, Screen E-9 to E-16, is used to get specific information about the activity.

7.3.3.1 Activity Input Screen

Screen E-8 is the first of a series of Activity Input Screens. For each activity, information is gathered about the ID and the description. As discussed in Chapter 5, activities are represented on the linear schedule by various symbols. The options available are bars, lines, blocks, and flags. The Activity Input Screen E-8 is used to ask the user about the symbol with which the activity will be represented.

As discussed earlier, LSS gathers dates information about the activities either from the data exported from a CPM file, or from user input. The Activity Input Screen E-8 is used to ask user whether the activity will be linked to an activity in the CPM transfer file. CPM transfer file is the file exported from the CPM scheduling software package containing information about activity dates.

7. Linear Scheduling Software
Figure 7.6 Screens for Gathering Activity Data

7. Linear Scheduling Software
Since there are two options available concerning the source of data, for each of the four symbols, there are a total of eight scenarios. Therefore, eight screens have been formatted, one for each scenario. By pressing function key 'F10' after inputting data in the Activity Input Screen E-8, user validates the data on the screen. This results in superimposition of one of the eight screens, on Screen E-8. The specific screen which will be superimposed on Screen E-8, is dependent on user's response to the last two fields on the Screen E-8. These screens are discussed in Sections 7.3.3.2 to 7.3.3.5.

In all the screens described in Sections 7.3.3.2 to 7.3.3.5, function keys 'F3' and 'F4' are used to scroll backwards and forwards respectively, in the activity database. Function key 'F5' is used to add an activity. Function key 'F6' is used to delete the activity displayed on the screen at the time of pressing the function key. If the user wishes to go to a specific activity, its ID is entered and function key 'F7' is used to search for it.

7.3.3.2 Screens for Lines

Screen E-9 is for the case of a CPM defined line. Information is gathered about the start and the end station. Information is then gathered about the identification numbers (ID) of the activity in the CPM transfer file which defines the start date for the line. One of the following dates in the CPM transfer file is used: Early Start, Early Finish, Late Start, or Late Finish. The user is questioned about the one to be used. Similar information is gathered about the activity in the CPM transfer file which will describe the end date for the line. Information about the color to be used and the line type is also gathered. As discussed in Chapter 5, Section 5.8, using different colors and different line types help in better visualization of the linear scheduling diagram. Function key 'F10' validates the data.

7. Linear Scheduling Software
and extracts information about the description and date for the activities in the CPM transfer file.

Screen E-10 is for the case when the activity is represented by a line and is not linked to any activity in the CPM transfer file. The input fields for start date, end date, color, and line type remain the same as were in Screen E-9. However, instead of extracting the information about the activity start and end date from the CPM transfer file, it is input by the user.

7.3.3.3 Screens for Blocks

Screens E-11 and E-12 are for the cases of CPM defined block, and user defined block, respectively. All the fields, except two, perform same functions as was in the case of Screens E-9 and E-10. The fields which are different in these screens are for color and line type. In the case of the blocks, color defines the color of the hatch pattern and the line type defines the line type for the perimeter of the block. A new field is added which gathers information about the hatch pattern with which the block will be gathered. The importance of using different hatch patterns for blocks is discussed in Chapter 5, Section 5.8.

7.3.3.4 Screens for Bars

Screens E-13 and E-14 are for the cases when the activity is represented by a CPM defined bar, or a user defined bar, respectively. Instead of start and end stations for the bar, information about its location and width is gathered. An activity which spans about 60 feet is represented by a 'narrow' bar. Similarly activities spanning around 100 feet and 200 feet

7. Linear Scheduling Software
are represented by 'medium' and 'wide' bars. All other fields are same as were for the case of blocks.

7.3.3.5 Screens for Flags

Screens E-15 and E-16 are for cases when a flag is used to depict an event or a milestone on the linear schedule. Since a flag represents an event in time and space, information is collected about the location and only one date. These screens are similar in format to the screens for the bars. However, these screens do not have the fields of pattern and line type, and instead a new field is added. The new field describes the symbol to be used for the flag. As discussed in Chapter 5, Section 5.5.4, flags can be represented by various symbols such as rectangle, circle etcetera.

7.3.4 Project Title Screen - Option 'B'

Once the data has been gathered about all the activities, the user returns back to the Options Screen, Screen E-1. By pressing 'B', the second part of the software package is activated and the Project Title Screen - Option 'B', Screen E-17, is displayed which is essentially similar to Screen E-1 in format. It asks the user for name of the project for which the drawing interchange (DXF) file is to be generated. Function key 'F10' validates the data and a DXF file is generated for the project name entered.
7.4 LINEAR SCHEDULING SOFTWARE - ALPHA VERSION

The first version of the Linear Scheduling Software (LSS) was titled the Alpha Version. It used the user-interface screens described in Section 7.3. The Alpha Version had the capabilities of generating a linear schedule either from CPM input for the dates and user input for location, symbol types, and format of the linear schedule, or solely from user input. The CPM input to LSS was allowed only from schedules using the Precedence Diagramming Method (PDM).

The writing of the computer program for the Alpha Version proceeded in parallel with this research and was not carried out by the researcher. The Alpha Version was ready by the beginning of February, 1991.

7.5 LINEAR SCHEDULING SOFTWARE - BETA VERSION

Once the Alpha Version of the LSS was ready, the need for allowing input to the LSS from CPM schedules using the Arrow Diagramming Method (ADM) was identified. The CPM transfer file, discussed in 7.3.3.1, for the schedules based on Precedence Diagramming Method (PDM) contains activity identification (ID) numbers which are used to identify an activity. However, CPM transfer file for the schedules based on ADM contains i-j node information instead of the activity ID number. The researcher formatted the user-interface screens which were additional to the Alpha Version, and assisted in modifying the computer programs of Alpha Version to incorporate the changes needed to allow input from a CPM schedule using ADM. The modified Version of the LSS is titled the Beta Version.
In the Beta Version of LSS, there are three options available regarding the source of data for the symbols. These are: CPM (PDM) input; CPM (ADM) input; and User input. The Activity Input Screen was modified to add a field which asks the user whether the CPM schedule uses PDM or ADM. The modified screen is shown in Screen E-18. By pressing function key 'F10' after inputting data in the Activity Input Screen, Screen E-18, user validates the data on the screen. Since there are four symbols, and three options are available for each symbol, a total of twelve scenario are possible. One of the twelve screens is superimposed on Screen E-18 when 'F10' is pressed. The specific screen which will be superimposed, is dependent on user's response to the last three fields on the Screen E-18. Figure 7.7 depicts the sequencing of screens for gathering activity data for the Beta Version of LSS.

There are four screens for gathering activity data which are additional to the ones described in Section 7.3. These are shown in Screen E-19 to E-22, one each for bars, lines, blocks, and flags. These are similar to the ones for the CPM defined symbols, Screens E-9 for the lines, E-11 for the blocks, E-13 for the bars, and E-15 for the flags, respectively. The only difference is that the user is asked about the i-j nodes for defining the start and the end date of the activity, instead of the activity ID.

7.5 COMBINING LSS WITH LINC

Linear Scheduling Software (LSS) has been described in this chapter. Another computer software, LINC, was described in Chapter 6 which can be used to generate Crew Movement Chart (CMC) for a highway project. Both the LSS as well as the LINC use a
SCREENS FOR GATHERING PROJECT DATA
(Refer to Figure 7.5 for Details)

ACTIVITY INPUT SCREEN
Activity ID, Activity Description, Type of Symbol (Bar, Line, Block, or Flag), and Query Regarding This Activity's Link to the CPM Transfer File
Screen E-18

SCREEN FOR CPM (PDM) DEFINED LINE
Screen E-9

SCREEN FOR CPM (ADM) DEFINED LINE
Screen E-19

SCREEN FOR USER DEFINED LINE
Screen E-10

SCREEN FOR CPM (PDM) DEFINED BLOCK
Screen E-11

SCREEN FOR CPM (ADM) DEFINED BLOCK
Screen E-20

SCREEN FOR USER DEFINED BLOCK
Screen E-12

SCREEN FOR CPM (PDM) DEFINED BAR
Screen E-13

SCREEN FOR CPM (ADM) DEFINED BAR
Screen E-21

SCREEN FOR USER DEFINED BAR
Screen E-14

SCREEN FOR CPM (PDM) DEFINED FLAG
Screen E-15

SCREEN FOR CPM (ADM) DEFINED FLAG
Screen E-22

SCREEN FOR USER DEFINED FLAG
Screen E-16

Figure 7.7 Screens for Gathering Activity Data for LSS Beta Version

7. Linear Scheduling Software
set of user-interface screens to collect information about the project and the activities, and to store this information in database files. The activity database created for LSS can be modified to allow use by LINC for generating CMC. In this way, the need for the first part of LINC which gathers the project and activity information and stores it into a database, will be obliterated. Figure 7.8 displays the structure of the combined scheduling system comprising of LSS and LINC.

Combining LSS with LINC was carried out as a part of this research. The combination of LSS and LINC has not been fully tested and although the combined system functions satisfactorily, more testing is needed prior to its full scale use in the industry. The changes made to LSS as well as to LINC for developing the combined system are described in the following sections.

### 7.5.1 Changes to LSS

This section discusses the changes made to the Linear Scheduling Software - Beta Version for developing the combined system. Changes were made to the activity database structure, ten user-interface screens, and the computer programs.

#### 7.5.1.1 Options Screen and Computer Program to Access LSS

The Options Screen for LSS, Screen E-1, was modified to add a fourth option, option 'C', which accesses LINC. The modified screen is shown in Screen E-23. The computer program MENU which accesses and runs LSS, was modified to allow for this addition and was renamed LMENU.

7. Linear Scheduling Software
Figure 7.8  Combined Scheduling System Comprising of LSS and LINC

7. Linear Scheduling Software
7.5.1.2 Activity Database Structure and Screens for Gathering Activity Data

The structure of the activity database for LSS was modified to allow for gathering of crew information. Two new fields were added, one for crew code, and another for crew description. A new field was also added for activity code. The need for these fields has been described in Section 6.5.4.4 of this thesis. Addition of these fields also required reformatting of the Activity Input Screen, Screen E-18. The modified activity input screen is shown in Screen E-24.

In LSS, information regarding the start and the end date for activities whose dates are defined by CPM input is gathered under the field names of CPMDATEST and CPMDATEEND, respectively. However, for activities whose dates are defined by user input, the same information is gathered under the field names of SDATE and ENDDATE, respectively. Therefore, the information is stored under two separate fields in the activity database for start date as well as end date, depending on its source. However, for the purpose of use by LINC, dates information for activities should be stored under one field for start as well as end date. The field names for cases whose dates are defined by CPM input, were changed to match the corresponding field names for activities whose dates are defined by the user, SDATE for the start date and ENDDATE for the end date. These changes were made in a total of eight screens, four for the precedence diagramming method (PDM) input, and four for the arrow diagramming method (ADM) input. The modified screens are shown in Screens E-25 to E-32. The structure of the activity database was also modified to incorporate the changes in the field names discussed above.

7. Linear Scheduling Software
7.5.1.3 Computer Program for Gathering Data

The computer program which is used to gather data for LSS, titled GATHER, was modified and renamed LGATHER. Additions to the program were made for the three new fields titled ACTICODE, CREWCODE, and CREWDESCR. 'DISPLAY' and 'RECOVER' statements, and 'ACCEPT' and 'REPLACE' commands were added for these fields.

Changes were also made to the program so that the start and end date information for CPM defined as well as user defined activities are stored in the same field in the activity database. This was carried out for all the eight possible cases of CPM defined activities, four cases for the precedence diagramming method (PDM) input, and four for the arrow diagramming method (ADM) input.

7.5.1.4 Computer Program for Generating DXF File

The computer program which is used to generate a drawing interchange (DXF) file, titled DXFDRAW was modified and renamed LDXFDRAW. This change was needed because of the change in the activity database structure. The original computer program had an 'IF' statement which would let CPMDATEST and CPMDATEEND be used when the activity dates were defined by CPM, and STDATE and ENDDATE be used when the activity dates were defined by the user. Since this statement was no longer needed, it was deleted and now the program uses STDATE for the start date and ENDDATE for the end date in all the cases.

7. Linear Scheduling Software
7.5.2 Changes to LINC

This section discusses changes made to LINC for developing the combined scheduling system. Changes were made to two user-interface screens, and the computer programs.

7.5.2.1 Options Screen and Computer Program to Access LINC

The Options Screen for LINC, Screen A-1, was modified to delete the first option which was used to access the computer program for gathering the data. The modified screen is shown in Screen A-16. The computer program CMCA, which has been described in Section 6.5.3.2, was modified to allow for this deletion and was renamed LCMCA.

7.5.2.2 Screens for LINC and Computer Program to Generate CMC

The field names used in the activity database of LSS are different from the field names used in LINC for similar information. The computer program which is used to generate CMC, titled CMCGEN, was modified to allow for these changes. The Project Title Screen for LINC, Screen A-6, was modified since it used a field name which was different form the one LSS uses. The modified screen is shown in Screen A-17. All the screens used for generating CMC were renamed with 'L' as a prefix to their old names.

7.5.2.3 CMC Output Formats

As discussed in Section 6.5.5.6, four report formats were developed for LINC to list the desired information. These formats were modified to allow for the change in the various

7. Linear Scheduling Software
field name and were renamed with 'L' as a prefix to their old names. These formats are shown in Appendix F where they are used to present the crew movement charts for the example project.

7.6 DISCUSSION

The Linear Scheduling Software combines the advantages of CPM as well as LSM. CPM works as a good 'engine' for recording, computing, saving, and storing project dates information. LSM is a good technique for graphically portraying scheduling information. Use of CADD packages to draw linear schedules have many advantages. LSS uses LSM as the technique to graphically present the schedule, CPM as the 'engine' for carrying out calculations for project dates, and CADD tools to enhance the communication potential of the linear schedule.

This chapter discussed the contribution made by this research to the development of the Linear Scheduling Software (LSS). The contribution was made in the form of being one of the members of the three member team that formalized the basic concept for the package. Formatting of the screens through which the user interacts with the package was carried out. The writing of the computer program proceeded in parallel with this research and was not carried out by the researcher.

The chapter also discussed a combined computer scheduling system comprising of LSS and LINC. The concepts behind this combining were presented. The changes required in both the software, for the combined system to work, were described. These changes have

7. Linear Scheduling Software
been carried out and the test version of the system has been developed. Appendix F to this thesis contains a linear schedule and a number of CMC generated using the combined scheduling system. The schedule and charts are developed for the example project which is discussed in the appendix.

7. Linear Scheduling Software
CHAPTER 8

CONCLUSION

This research focused on the specific needs of highway projects with regard to works planning and scheduling. Linear scheduling method (LSM) was researched and found to be a very suitable technique to schedule highway projects. A number of ways in which the visual and graphical nature of LSM helps in the planning and scheduling were discussed.

8.1 SUMMARY

Linear scheduling method (LSM) as a technique for scheduling linear projects has been in use for a long time. However, its true potential remained largely unexplored. This research took the technique at the existing level of knowledge and exposed it to the rigors of field implementation. The literature review and field experience brought real problems to the fore. Responses to these problems were outlined, researched in detail, and presented in this thesis. The advancements reported in this thesis will allow LSM to become a robust technique to handle the complex highway projects and fulfill the needs of highway construction.
Chapter 1 of this thesis served as an introduction to the research and provided the background for the work. The scope and limitations of the research were discussed and the structure of the thesis was outlined. Chapter 2 provided a review and critical evaluation of the literature. Various traditional techniques, and specific methods which can be used to schedule linear construction projects, were discussed. A classification of the specific methods which are used to schedule linear projects, based on the nature of projects which they can effectively schedule, was presented.

Figure 8.1 shows the various stages of development of linear scheduling as a technique during the course of this research. Prior to Spring 1990, linear schedules used a format based on two axes, mostly time as horizontal axis and distance as vertical axis. Lines were the most widely used symbol. Most of the schedules were manually drawn. LSM was not considered a robust enough technique to handle complex highway projects and its use was very limited. This research identified extension in the potential of a graphical technique in communicating information, and in evaluating scheduling alternatives. Chapter 4 discussed importance of visualization and role of LSM in planning, execution, and control phases of a project. The concepts of lateral float and use of LSM as a graphical simulation tool were presented.

The field experience and the set of video tapes discussed in Chapter 3 led to improvement to the format of the linear schedule and the symbols used. Chapter 5 described the various advancements and enhancements to the technique. If the user draws the linear schedules manually, most of the advancements reported in Chapter 5, can be used for better portrayal of information. The need for tabular output was discussed in Chapter 6 and the basic

8. Conclusion
Figure 8.1  Summarizing Model
format of a crew movement chart (CMC) was described in Section 6.2. Once again, the user can use the concept of CMC to manually generate tabular reports.

Use of computers in the construction industry has increased dramatically in the recent past. The communication potential of a linear schedule can be increased tremendously with the use of a Computer Aided Design and Drafting (CADD) package. Use of CADD packages to draw linear schedules and their advantages were reported in Chapter 5. Use of computers also gives the user access to spreadsheet and database packages. This helps in sorting and selection of information and in presenting specific and precise information in the CMC. Sections 6.3 and 6.4 addressed these advantages that the computers provide.

Chapter 6 also reported development of a computer software package which can be used to generate crew movement charts. This software, LINC, uses a database package. However, the user does not have to be proficient in the use of the database package because the his/her interaction with the package is through user-interface screens. Chapter 7 reported development of a computer interface between the critical path method and the linear scheduling method. This interface, the linear scheduling software (LSS), generates a linear schedule on a CADD package with the help of user input. However, in the cases of LINC as well as LSS, the user interacts with the software through user-interface screens. This frees the user from the routine computer chores and allows him/her to experiment with innovation and creativity.

Chapter 7 reported a combined scheduling system comprising of LINC and LSS. This will provide the user with a system with which linear schedules and CMC can be generated using one set of user input information. The interaction with the computer is through user-

8. Conclusion
interface screens and therefore, the user does not have to proficient in all the computer packages that LINC and LSS use.

8.2 RECOMMENDATIONS

The advancements reported in the thesis provide technical improvements to the Linear Scheduling Method (LSM). Technical improvements are one of the most important factors in the development of a technique. The last stage of technical change consists of the process of diffusion (Arditi 1983). The future work in the direction of making LSM a useful technique for scheduling linear project should be concentrated on disseminating the information presented in this thesis to the potential users.

One of the biggest hurdles that the diffusion of information has to overcome is the issue of acceptance by the potential users. The author feels that with the work presented in this thesis, LSM would found more acceptance in the construction industry. This will occur because most the advancements reported in the thesis are based on field experience and problems encountered in the field. The advancements have been researched with the end user of the technique in mind.

There will be a need to continually improve the technique on the basis of feedback from the field once the concepts presented in the thesis are used extensively. LSS and LINC will also need further work after their use in the field. The technique will serve the needs of the construction personnel only when improvements are made to it based on feedback from the field.

8. Conclusion
8.3 EPILOGUE

This research is an effort to increase the use of a technique which is specifically suited for highway construction. The linear schedules capture the parameters of space and time effectively and result in a good graphical representation of the way the highways are actually built. The graphical nature of LSM helps in bringing the scheduling closer to reality. The graphical nature also helps in communication. This thesis revisited the ever important role of effective communication in scheduling techniques through the topics of visualization in planning, execution, and control.

This research is also an attempt to bring back the human element in scheduling. The advent of computers has been distancing schedulers from scheduling and turning them into data entry operators. However, as manifested in the concept of lateral float, even in the most sophisticated computer age, there is, and always will be, scope for human judgement. Linear scheduling allows for human judgement. The two new computer software packages presented in this thesis emphasize the utilization of construction expertise to provide the input to generate the schedules and tabular reports.

With years of accumulated experience behind them, the construction personnel do have the expertise to plan and schedule. However, they sometimes either lack, or do not have time for, systematic planning and frequently lack expert knowledge of scheduling techniques. Techniques which could capture their knowledge and experience and convert into schedules without requiring a tremendous amount of computer knowledge and expertise are very rare. This thesis is an attempt to let the humans do what they are good at, planning, deciding,

8. Conclusion
and judging, and let the computers do what they are good at, recording, sorting, and storing the information.

This thesis emphasizes use of computers for doing what currently the computers do well. However, with the advancements in the field of artificial intelligence, computers may be used to capture the knowledge and experience of construction personnel in the future. Presently the computers are used to take advantages of the time float available in a schedule. However, use of graphical and visual technique is resorted to for utilizing available lateral float in a schedule. With the future research in the fields of computer assisted reasoning and logic, computers may be able to identify and utilize various scheduling options to arrive at a practical and useful schedule.

Although the enhancements to the technique reported in this thesis are easily understood and simple, their impact will help in providing a better understanding of the project through every stage of planning and construction process. It has been shown in the thesis that the linear schedule is a simple enough tool to be understood by people at most levels of the construction operations, some of them not having sufficient technical knowledge to understand complex scheduling techniques. It was also shown that with the advancements reported in the thesis, the linear schedule has become a strong enough tool to effectively portray most of the information needed to plan and control the operations. The future work in this area should be concentrated towards increasing the acceptance of the technique by disseminating the information presented in the thesis. With the advancements reported in the thesis, the linear schedule will become more than another chart on the wall, and that is the ultimate test of a planning tool.

8. Conclusion
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Special provision for working schedule. (1990). Amendment to road and bridge specifications, for job designation no. 187-90A. Virginia Department of Transportation, Richmond, VA.


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*Road and bridge specifications.* (1987). Virginia Department of Transportation, Richmond, VA.


*Special provision for working schedule.* (1990). Amendment to road and bridge specifications, for job designation no. 187-90A. Virginia Department of Transportation, Richmond, VA.


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APPENDIX A

COMPUTER SCREENS FOR LINC

The user-interface screens developed for LINC, the computer software package to generate CMC, are shown in this appendix. The screens originally developed for LINC and later modified to allow their use in the combined scheduling system comprising of LSS and LINC are also shown. The names under which the screens are saved, are shown in their top left corner. These names are also given within parentheses, after the title of each screen.

**Screens for LINC**

| Screen A-1 | Options Screen (MENU) | 189 |
| Screen A-2 | Project Title Screen 1 (CMCTITL1) | 190 |
| Screen A-3 | Project Title Screen 2 (CMCTITL2) | 191 |
| Screen A-4 | Project Title Screen 3 (CMCTITL3) | 192 |
| Screen A-5 | Activity Data Input Screen (CMCACT) | 193 |
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Screen A-14  Output Options Screen 1 (CMCB23) .......................... 202
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Screens for the Combined Scheduling System

Comprising of LSS and LINC

Screen A-16  Options Screen for LINC (MENU2) ........................... 204
Screen A-17  Project Title Screen for LINC (LCMCTITL) ..................... 205

Appendix A. Screens for LINC
THE COMPUTER SOFTWARE
FOR GENERATING
CREW MOVEMENT CHARTS

A COLLECT ACTIVITY DATA A
FROM
B GENERATE CMC B
X EXIT LINC X

LINEAR SCHEDULE
Type the letter corresponding to
your choice, or move the selection bar

Screen A-1 Options Screen
Screen print CMCTITL

Esc-Return   F10-Validate/Advance

LINC PROJECT TITLE SCREEN

NAME OF THE PROJECT FOR WHICH CMC IS TO BE GENERATED

<table>
<thead>
<tr>
<th>Field</th>
<th>Field Name</th>
<th>Type</th>
<th>Width</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>NAMEPROJ</td>
<td>Character</td>
<td>8</td>
</tr>
</tbody>
</table>
Screen print CMCTITL3
Esc-Return F6-Delete Project F10-Validate/Advance

Note: The screen does not contain any data fields.

Screen A-4 Project Title Screen 3
LINC ACTIVITY INPUT SCREEN

LINC ACTIVITY ID

NAME OF THE ACTIVITY (USE ABBREVIATED CODE)

DETAILED DESCRIPTION OF THE ACTIVITY

NAME OF THE CREW (USE ABBREVIATED CODE)

DETAILED DESCRIPTION OF THE CREW

STARTING STATION OF THE ACTIVITY

ENDING STATION OF THE ACTIVITY

STARTING DATE FOR THE ACTIVITY

END DATES FOR THE ACTIVITY

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</tr>
<tr>
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<td>ACTDES</td>
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<td>D</td>
<td>CREWCODE</td>
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<td>CREWDES</td>
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<td>Date</td>
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<tr>
<td>I</td>
<td>ACTDtTEND</td>
<td>Date</td>
<td>8</td>
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</table>

Screen A-5  Activity Data Input Screen
LINC PROJECT TITLE SCREEN

NAME OF THE PROJECT FOR WHICH CMC IS TO BE GENERATED

NAME OF THE PROJECT SHOULD BE EXACTLY THE SAME AS THE ONE GIVEN FOR GATHERING THE ACTIVITY DATA

<table>
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<td>A</td>
<td>NAMEPROJ</td>
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</table>
Screen print CMCPRIM

Esc-Return  F10-Validate/Advance

LINC SORTING CRITERION SCREEN

IDENTIFY THE PRIMARY CRITERION FOR SORTING OF ACTIVITIES
ACTIVITY ID/STARTING STATION/STARTING DATE/CREW/OPERATION
ASCENDING OR DESCENDING

IDENTIFY THE SECONDARY CRITERION FOR SORTING OF ACTIVITIES
ACTIVITY ID/STARTING STATION/STARTING DATE/CREW/OPERATION
ASCENDING OR DESCENDING

IDENTIFY THE TERTIARY CRITERION FOR SORTING OF ACTIVITIES
ACTIVITY ID/STARTING STATION/STARTING DATE/CREW/OPERATION
ASCENDING OR DESCENDING

WOULD YOU LIKE TO LIST ALL THE ACTIVITIES,
OR SELECT THEM FOR CREW, OPERATION, OR SECTION

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<td>AD1</td>
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<td>SECCRIT</td>
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<tr>
<td>D</td>
<td>AD2</td>
<td>Character</td>
<td>1</td>
</tr>
<tr>
<td>E</td>
<td>TERCritt</td>
<td>Character</td>
<td>1</td>
</tr>
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<td>F</td>
<td>AD3</td>
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<td>SELECT</td>
<td>Character</td>
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</table>

Screen A-7   Sorting Criteria Screen
Screen print CMCSEL

Esc-Return  F10-Validate/Advance

LINC PRIMARY SELECTION CRITERION SCREEN

IDENTIFY THE PRIMARY CRITERION FOR SELECTION OF ACTIVITIES
CREW/OPERATION/SECTION

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</thead>
<tbody>
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</table>

Screen A-8  Primary Selection Criterion Screen
Screen print CMCCREW

ABBREVIATED CODE NAME OF THE CREW FOR WHICH THIS CMC IS TO BE GENERATED

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<th>Type</th>
<th>Width</th>
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<tbody>
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<td>CREWCODE</td>
<td>Character</td>
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</table>

Screen A-9 Screen for Crew as Primary Selection Criterion
ABBREVIATED CODE NAME OF THE OPERATION FOR WHICH THIS CMC IS TO BE GENERATED

<table>
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<th>Field Name</th>
<th>Type</th>
<th>Width</th>
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<tbody>
<tr>
<td>A</td>
<td>ACTCODE</td>
<td>Character</td>
<td>1</td>
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</tbody>
</table>
Screen print CMCSTAT

INPUT FOR THE SECTION FOR WHICH CMC IS TO BE GENERATED:
STARTING STATION OF THE SECTION
END STATION OF THE SECTION

WOULD YOU LIKE TO INCLUDE IN THIS CMC:
ALL THE ACTIVITIES WHICH OCCUR COMPLETELY OR PARTIALLY BETWEEN TWO
STATIONS INPUT ABOVE, OR ONLY THOSE ACTIVITIES WHICH START AS WELL
AS END BETWEEN THO STATIONS INPUT ABOVE

<table>
<thead>
<tr>
<th>Field</th>
<th>Field Name</th>
<th>Type</th>
<th>Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>ACTISTSB</td>
<td>Numeric</td>
<td>6</td>
</tr>
<tr>
<td>B</td>
<td>ACTISTENDB</td>
<td>Numeric</td>
<td>6</td>
</tr>
<tr>
<td>C</td>
<td>SOR</td>
<td>Character</td>
<td>1</td>
</tr>
</tbody>
</table>

Screen A-11  Screen for Stations as Primary Selection Criterion
LINC SECONDARY SELECTION CRITERION SCREEN

Would you like to list activities: for the entire project duration or select them for specific dates?

<table>
<thead>
<tr>
<th>Field</th>
<th>Field Name</th>
<th>Type</th>
<th>Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>EROS</td>
<td>Character</td>
<td>4</td>
</tr>
</tbody>
</table>
IF SPECIFIC DATES ARE TO BE USED, THEN:
STARTING DATE FOR THE SORT
END DATE FOR THE SORT
WOULD YOU LIKE TO INCLUDE IN THIS CMC:
ALL THE ACTIVITIES WHICH OCCUR EITHER COMPLETELY OR
PARTIALLY BETWEEN THE TWO DATES INPUT ABOVE,
OR ONLY THOSE ACTIVITIES WHICH BEGIN AS WELL AS END
BETWEEN THE TWO DATES INPUT ABOVE

<table>
<thead>
<tr>
<th>Field</th>
<th>Field Name</th>
<th>Type</th>
<th>Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>ACTIDTSIB</td>
<td>Date</td>
<td>8</td>
</tr>
<tr>
<td>B</td>
<td>ACTIDTENDB</td>
<td>Date</td>
<td>8</td>
</tr>
<tr>
<td>C</td>
<td>DOR</td>
<td>Character</td>
<td>1</td>
</tr>
</tbody>
</table>

Screen A-13  Screen for Dates as Secondary Selection Criterion
**Screen print CMCB23**

<table>
<thead>
<tr>
<th>Field</th>
<th>Field Name</th>
<th>Type</th>
<th>Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>PORS</td>
<td>Character</td>
<td>1</td>
</tr>
</tbody>
</table>
Screen print CMCB24

IF TO BE SAVED, THE NAME OF THE TEXT FILE

<table>
<thead>
<tr>
<th>Field</th>
<th>Field Name</th>
<th>Type</th>
<th>Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>NAMEFILE</td>
<td>Character</td>
<td>8</td>
</tr>
</tbody>
</table>

Screen A-15 Output Options Screen 2
THE COMPUTER SOFTWARE
FOR GENERATING
CREW MOVEMENT CHARTS

A GENERATE CMC
FROM
X EXIT LINC - RETURN TO LSS X
LINEAR SCHEDULE
Type the letter corresponding to your choice, or move the selection bar
Screen print LCMCTTL

Esc-Return    Fl0-Validate/Advance

LINC PROJECT TITLE SCREEN

NAME OF THE PROJECT FOR WHICH CMC IS TO BE GENERATED

NAME OF THE PROJECT SHOULD BE EXACTLY THE SAME
AS THE ONE GIVEN FOR GATHERING THE ACTIVITY DATA

<table>
<thead>
<tr>
<th>Field</th>
<th>Field Name</th>
<th>Type</th>
<th>Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>PROJNAME</td>
<td>Character</td>
<td>8</td>
</tr>
</tbody>
</table>

Screen A-17  Project Title Screen for LINC
This is CMCA.PRG file.

It is part of LINC, the computer software package to generate CMC

It lets the user access LINC, run it, and exit LINC once the operations are over.

-clear all

By setting the SAFETY off, the user can overwrite files without receiving a warning.

-set safety off

STATUS is set to off so that status bar information is not displayed while LINC is being run.

-set status off

By setting EXACT on, a comparison between two character string will require them to be the same length for the comparison to be true (.T.)

-set exact on

By setting TALK off, the responses to dBASE commands would not occur on the screen.

-set talk off

Making the screen go blank

-set color to n/n, n/n

Starting the loop to run the program until the
* decides to exit it using option 'X'
* DO WHILE .T.
* Syntax for activating HI-SCREEN XL
* LOAD DSPDB
* Display LINC'S Options Screen MENU.SCR
* @0,0 SAY ""
CALL DSPDB WITH "USE, MENU.SCR"
* Recover user's response to the options
* @0,0 SAY ""
CALL DSPDB WITH "MENU"
ACCEPT TO CHOICE
* Depending on the choice either access
* CMCGET.PRG, or CMCGEN.PRG, or exit.
*
DO CASE
  CASE CHOICE = "01"
    DO CMCGET
  CASE CHOICE = "02"
    DO CMCGEN
  CASE CHOICE = "03"
    EXIT
ENDCASE
* Marking the end of the loop
*
ENDDO
* Restore dbase keyboard
* @0,0 SAY ""
CALL DSPDB WITH "KEYBOARD"
*
CLEAR ALL
* Setting the background color back to
* Cyan, and status bar color to White
*
SET COLOR TO N/BG, B/W
* Setting the STATUS on will bring the

Appendix B. Computer Program CMCA
status bar back to the screen

SET STATUS ON

Setting the TALK on, responses to dBASE commands will be displayed on the screen

SET TALK ON
APPENDIX C

COMPUTER PROGRAM CMCGET

******************************************************************************
*                                                                               *
*   This is CMCGET.PRG file                                                     *
*                                                                               *
*   It is a part of LINC, the computer software                                *
*   to generate CMC                                                            *
*                                                                               *
*   This file is used to get general information                               *
*   about the project and specific information                                *
*   activities, from the user. The information is                              *
*   then stored in respective databases.                                       *
*                                                                               *
******************************************************************************

*                                                                               *
* SET TALK OFF
LOAD DISPDB
*
  Open the database containing project details
*
SELECT 1
USE CMCPDB INDEX NAMEPROJ
*
  A 'DO' command is used to mark the start of an                             *
  iteration loop which is used to run the program                              *
*
DO WHILE .T.
SELECT 1
*
  Display the project title screen CMCTITL1.SCR                               *
*
@0,0 SAY ""
CALL DISPDB WITH "USE,CMCTITL1.SCR"
*
  Esc key is used to abort                                                     *
  F10 key is used to advance                                                   *
*
@0,0 SAY ""
CALL DISPDB WITH "EXIT,ESC=A,FK0=V"
*
@0,0 SAY ""
CALL DISPDB WITH "SCREEN"

209
ACCEPT TO HSKKEY
*
DO CASE
CASE HSKKEY = "ESC"
CLOSE DATABASES
RETURN
CASE HSKKEY = "FK0"
   @0,0 SAY ""
   CALL DISPDB WITH "RECOVER,NAMEPROJ"
   ACCEPT TO HNAMEPROJ
ENDCASE
*
* Screen CMCTITL3.SCR is a function key strip which
* makes available F6 for deleting the CMC project file
*
@0,0 SAY ""
CALL DISPDB WITH "OPEN,CMCTITL3.SCR,1,1"
*
* Open screen CMCTITL2.SCR which contains field for start
* and end date of the project.
*
@0,0 SAY ""
CALL DISPDB WITH "OPEN,CMCTITL2.SCR,10,1"
*
* If the project file already exists, display its
* data, else allow user to input.
*
SEEK HNAMEPROJ
IF FOUND()
*
* Details of the project file about the start and end date.
*
HCMCDATEST = DTOC(CMCDATEST)
HCMCDATEEND = DTOC(CMCDATEEND)
*
* Display available data
* about the start and end date.
*
@0,0 SAY ""
CALL DISPDB WITH "DISPLAY,CMCDATEST,=&HCMCDATEST"
*
@0,0 SAY ""
CALL DISPDB WITH "DISPLAY,CMCDATEEND,=&HCMCDATEEND"
*
ENDIF
*
* Esc is used to abort
* F6 is used to delete the CMC project file

Appendix C. Computer Program CMCGET
* F10 is used to validate/advance
* 
* @0,0 SAY ""
CALL DISPDB WITH "FIRST,CMCDATEST"
* 
* @0,0 SAY ""
CALL DISPDB WITH
"EXIT,ESC=A,FK0=V,FK6=I,RET=N,UPA=U,DNA=D,TAB=N,BAT=P"
* 
* @0,0 SAY ""
CALL DISPDB WITH "SCREEN"
ACCEPT TO HSKEY
*
DO CASE
CASE HSKEY = "ESC"
   @0,0 SAY ""
   CALL DISPDB WITH "CLOSE"
   LOOP
*
CASE HSKEY = "FK6"
   DELETE FOR NAMEPROJ = HNAMEPROJ
   PACK
   DELFDBF = HNAMEPROJ + ".DBF"
   DELETE FILE &DELFDBF
   @0,0 SAY ""
   CALL DISPDB WITH "CLOSE"
   DELFNDX = HNAMEPROJ + ".NDX"
   DELETE FILE &DELFNDX
   @0,0 SAY ""
   CALL DISPDB WITH "CLOSE"
   LOOP
*
CASE HSKEY = "FK0"
   @0,0 SAY ""
   CALL DISPDB WITH "RECOVER,CMCDATEST"
   ACCEPT TO HCMCDATEST
*
   @0,0 SAY ""
   CALL DISPDB WITH "RECOVER,CMCDATEEND"
   ACCEPT TO HCMCDATEEND
*
ENDCASE
*
* Saving either the newly created database or
* on old one which has been updated
*
* First case - New database
*

Appendix C. Computer Program CMCGET
IF .NOT. FOUND()
    TARGETDBF = HNAMEPROJ + ".DBF"
    COPY FILE FORMAT.DBF TO &TARGETDBF
*
    TARGETNDX = HNAMEPROJ + ".NDX"
    COPY FILE FORMAT.NDX TO &TARGETNDX
*
APPEND BLANK
*
ENDIF
*
* Second case - Updating an existing database
*
IF FOUND()
    TARGETDBF = HNAMEPROJ + ".DBF"
    TARGETNDX = HNAMEPROJ + ".NDX"
*
    DELETE FOR NAMEPROJ = HNAMEPROJ
    PACK
*
APPEND BLANK
*
ENDIF
*
* Update the project data in CMCPDB.DBF, the project
* database
*
REPLACE NAMEPROJ WITH HNAMEPROJ, CMCDATEST WITH ;
CTOD(HCMCDATEST), CMCDATEEND WITH CTOD(HCMCDATEEND)
*
*  **********************************************************************************************
*
* To get the specific data about activities that
* will be a part of the CMC.
*
SELECT 2
USE &TARGETDBF INDEX &TARGETNDX
GO TOP
*
* Display the activity screen CMCACT.SCR
*
@0,0 SAY ""
CALL DISPDB WITH "USE,CMCSTAT.SCR"
*
* Save the screen
*
@0,0 SAY "*
CALL DISPDB WITH "SAVE"

Appendix C. Computer Program CMCGET
* Input activity data
* If the database is empty, then append blank record
*
IF EOF()
  APPEND BLANK
ENDIF
*
* Loop to input activity data
*
DO WHILE .NOT. EOF()
*
* Display data already available in the database
*
  HACTID = ACTID
  HACTCODE = ACTCODE
  HACTDES = ACTDES
  HCREWCODE = CREWCODE
  HACTSTST = STR(ACTSTST,6,1)
  HACTSTEND = STR(ACTSTEND,6,1)
  HACTDTST = DTOC(ACTDTST)
  HACTDTEND = DTOC(ACTDTEND)
  HCREWDES = CREWDES
*
* Display the data on the screen
*
  @0,0 SAY ""
  CALL DISPDB WITH "DISPLAY,ACTID,=,&HACTID"
*
  @0,0 SAY ""
  CALL DISPDB WITH "DISPLAY,ACTCODE,=&HACTCODE"
*
  @0,0 SAY ""
  CALL DISPDB WITH "DISPLAY,CREWCODE,=&HCREWCODE"
*
  @0,0 SAY ""
  CALL DISPDB WITH "DISPLAY,ACTDES,=&HACTDES"
*
  @0,0 SAY ""
  CALL DISPDB WITH "DISPLAY,ACTSTST,=&HACTSTST"
*
  @0,0 SAY ""
  CALL DISPDB WITH "DISPLAY,ACTSTEND,=&HACTSTEND"
*
  @0,0 SAY ""
  CALL DISPDB WITH "DISPLAY,CREWDES,=&HCREWDES"
*
  @0,0 SAY ""

Appendix C. Computer Program CMCGET
CALL DISPDB WITH "DISPLAY,ACTDTST,=&HACTDTST"
* 
@0,0 SAY ""
CALL DISPDB WITH "DISPLAY,ACTDTEND,=&HACTDTEND"
* 
@0,0 SAY ""
CALL DISPDB WITH "DISPLAY,NAMEPROJ,=&HNAMEPROJ"
* 
* Full screen input
* Esc is used to abort
* F3 is used to scroll backwards (Previous act)
* F4 is used to scroll forward (Next act)
* F5 is used to add a new activity
* F6 is used to delete an existing activity
* F7 is used to search for an activity
* F10 is used to validate
* 
@0,0 SAY ""
CALL DISPDB WITH "FIRST,ACTID"
* 
@0,0 SAY ""
CALL DISPDB WITH "SELECT,-,NAMEPROJ"
* 
@0,0 SAY ""
CALL DISPDB WITH "EXIT,RET=N,ESC=A,FK0=V,FK3=I,FK4=I,FK5=I,FK6=I,FK7=I,UPA=U,DNA=D,
  TAB=N,BAT=P"
* 
@0,0 SAY ""
CALL DISPDB WITH "SCREEN"
ACCEPT TO HSKEY
* 
DO CASE
  CASE HSKEY = "ESC"
    EXIT
  *
  CASE HSKEY = "FK3"
    IF .NOT. BOF()
      SKIP -1
    ENDF
    @0,0 SAY ""
    CALL DISPDB WITH "RESTORE"
  LOOP
* 
  CASE HSKEY = "FK4"
    IF .NOT. EOF()
      SKIP +1
    IF EOF()
SKIP -1
ENDIF
ENDIF
@0,0 SAY ""
CALL DISPDB WITH "RESTORE"
LOOP
*
CASE HSKEY = "FK5"
APPEND BLANK
@0,0 SAY ""
CALL DISPDB WITH "RESTORE"
LOOP
*
CASE HSKEY = "FK6"
DELETE
PACK
GO TOP
@0,0 SAY ""
CALL DISPDB WITH "RESTORE"
LOOP
*
CASE HSKEY = "FK7"
REC = RECNO()
@0,0 SAY ""
CALL DISPDB WITH "RECOVER,ACTID"
ACCEPT TO CMCFINDID
SEEK CMCFINDID
IF .NOT. FOUND()
@0,0 SAY ""
CALL DISPDB WITH "ERROR,ID# WAS NOT FOUND"
GOTO REC
ENDIF
LOOP
*
CASE HSKEY = "FK0"
@0,0 SAY ""
CALL DISPDB WITH "RECOVER,ACTID"
ACCEPT TO HACTID
*
@0,0 SAY ""
CALL DISPDB WITH "RECOVER,ACTCODE"
ACCEPT TO HACTCODE
*
@0,0 SAY ""
CALL DISPDB WITH "RECOVER,ACTDES"
ACCEPT TO HACTDES
*
@0,0 SAY ""

Appendix C. Computer Program CMCGET
CALL DISPDB WITH "RECOVER,CREWCODE"
ACCEPT TO HCREWCODE
*
@0,0 SAY ""
CALL DISPDB WITH "RECOVER,CREWDES"
ACCEPT TO HCREWDES
*
@0,0 SAY ""
CALL DISPDB WITH "RECOVER,ACTSTST"
INPUT TO HACTSTST
*
@0,0 SAY ""
CALL DISPDB WITH "RECOVER,ACTSTEND"
INPUT TO HACTSTEND
*
@0,0 SAY ""
CALL DISPDB WITH "RECOVER,ACTDTST"
ACCEPT TO HACTDTST
*
@0,0 SAY ""
CALL DISPDB WITH "RECOVER,ACTDTEND"
ACCEPT TO HACTDTEND
ENDCASE
*
* Delete the old data and add the displayed
* data to the activity database.
* 
SELECT 2
DELETE FOR (ACTID = HACTID .OR. ACTID = """)
PACK
APPEND BLANK
REC = RECN0()
*
* Replace activity and crew data
*
REPLACE ACTID WITH HACTID, ACTCODE WITH HACTCODE, ;
ACTDES WITH HACTDES, ;
CREWCODE WITH HCREWCODE, CREWDES WITH HCREWDES
*
* Replace station and date details about the activity
*
REPLACE FOR (ACTID = HACTID);
ACTSTST WITH HACTSTST, ACTSTEND WITH HACTSTEND, ;
ACTDTST WITH CTOD(HACTDTST), ;
ACTDTEND WITH CTOD(HACTDTEND)
*
GO REC
*

Appendix C. Computer Program CMCGET
* Close the activity data gathering loop
  *
  ENDDO
 *
* Marking the close of the iteration loop that
* lets the program be run.
*
ENDDO
APPENDIX D

COMPUTER PROGRAM CMCGEN

*****************************************************************************
**
** This is CMCGEN.PRG file
**
** It is a part of LINC, the computer software
** to generate CMC
**
** It is used to sort the data gathered in CMCGET
** according to the sorting criteria, and generate
** CMC based on user specified selection criteria.
**
*****************************************************************************
**
SELECT 3
**
* Start of the loop used to run CMCGET
*
DO WHILE .T.
*
* Display CMCTITLB.SCR screen, which is
* the title screen
*
@0,0 SAY ""
CALL DISPDB WITH "USE,CMCTITLB.SCR"
*
* Esc is to Abort
* F10 is to validate/advance
*
@0,0 SAY ""
CALL DISPDB WITH "EXIT,ESC=A,FK0=Y"
*
@0,0 SAY ""
CALL DISPDB WITH "SCREEN"
ACCEPT TO HSKEY
*

218
DO CASE
  CASE HSKEY = "ESC"
      RETURN
  CASE HSKEY = "FK0"
      @0,0 SAY ""
      CALL DISPDB WITH "RECOVER,NAMEPROJ"
      ACCEPT TO HNAMEPROJ
      *
      ENDCASE
      *
      *   Open the database for the name of project
      *   entered by the user in the Project Title Screen
      *
      USE &HNAMEPROJ INDEX &HNAMEPROJ
      *
      *   Open the screen CMCPNRM.SCR which is the Sorting
      *   Criteria Screen. It is used to ask user about
      *   the sorting criteria and the order.
      *
      @0,0 SAY ""
      CALL DISPDB WITH "USE,CMCPNRM.SCR"
      *
      *   Display the name of project in the top right
      *   corner of the screen
      *
      @0,0 SAY ""
      CALL DISPDB WITH "DISPLAY,NAMEPROJ,=&HNAMEPROJ"
      *
      *   Go to the field PRIMCRIT first
      *
      @0,0 SAY ""
      CALL DISPDB WITH "FIRST,PRIMCRIT"
      *
      *   Do not go to NAMEPROJ field for input
      *
      @0,0 SAY ""
      CALL DISPDB WITH "SELECT,.,NAMEPROJ"
      *
      *   Esc is to abort
      *   F10 is to validate
      *
      @0,0 SAY ""
      CALL DISPDB WITH
      "EXIT,ESC=A,FK0=V,RET=N,UPA=U,DNA=D,TAB=N,BAT=P"

Appendix D. Computer Program CMCGEN
* 
@0,0 SAY ""
CALL DISPDB WITH "SCREEN"
ACCEPT TO HSKEY
*
DO CASE
  CASE HSKEY = "ESC"
    LOOP
  CASE HSKEY = "FK0"
    @0,0 SAY ""
    CALL DISPDB WITH "RECOVER,PRIMCRIT"
    ACCEPT TO HPRIMCRIT
    @0,0 SAY ""
    CALL DISPDB WITH "RECOVER,AD1"
    ACCEPT TO HAD1
    @0,0 SAY ""
    CALL DISPDB WITH "RECOVER,SECCRIT"
    ACCEPT TO HSECCRIT
    @0,0 SAY ""
    CALL DISPDB WITH "RECOVER,AD2"
    ACCEPT TO HAD2
    @0,0 SAY ""
    CALL DISPDB WITH "RECOVER,TERCRIT"
    ACCEPT TO HTERCRIT
    @0,0 SAY ""
    CALL DISPDB WITH "RECOVER,AD3"
    ACCEPT TO HAD3
    @0,0 SAY ""
    CALL DISPDB WITH "RECOVER,SELECT"
    ACCEPT TO HSELECT
ENDCASE
***************
DO CASE
*
CASE (HPRIMCRIT = "A")
FIELD1 = "ACTID"
*
CASE (HPRIMCRIT = "S")
FIELD1 = "ACTSTST"
*
CASE (HPRIMCRIT = "D")
FIELD1 = "ACTDTST"
*
CASE (HPRIMCRIT = "C")

Appendix D. Computer Program CMCGEN
FIELD1 = "CREWCODE"
*
CASE (HPRIMCRIT = "O")
FIELD1 = "ACTCODE"
*
ENDCASE
*
*******
*
DO CASE
*
CASE (HSECCRIT = "A")
FIELD2 = "ACTID"
*
CASE (HSECCRIT = "S")
FIELD2 = "ACTSTST"
*
CASE (HSECCRIT = "D")
FIELD2 = "ACTDTST"
*
CASE (HSECCRIT = "C")
FIELD2 = "CREWCODE"
*
ENDCASE
*
*******
*
DO CASE
*
CASE (HTERCRT = "A")
FIELD3 = "ACTID"
*
CASE (HTERCRT = "S")
FIELD3 = "ACTSTST"
*
CASE (HTERCRT = "D")
FIELD3 = "ACTDTST"
*
CASE (HTERCRT = "C")
FIELD3 = "CREWCODE"
*

Appendix D. Computer Program CMCGEN
CASE (HTERCRIT = "O")
FIELD3 = "ACTCODE"
*
ENDCASE
*
************************
*
* Sort the data according to the sorting criteria
* to a temporary file titled ZG959GZ
*
SORT TO ZG959GZ ON &FIELD1/&HAD1,&FIELD2/&HAD2,&FIELD3/&HAD3
*
*
DO CASE
  CASE (HSELECT = "A")
    @0,0 SAY ""
    CALL DISPDB WITH "USE,CMCB21.SCR"
*
  CASE (HSELECT = "S")
    @0,0 SAY ""
    CALL DISPDB WITH "USE,CMCSOL.SCR"
*
    @0,0 SAY ""
    CALL DISPDB WITH "FIRST,SELCRIT"
*
    @0,0 SAY ""
    CALL DISPDB WITH "DISPLAY,NAMEPROJ,=&HNAMEPROJ"
*
    CALL DISPDB WITH "SELECT,-,NAMEPROJ"
*
    Esc is used to return
    F10 is used to validate/advance
*
    @0,0 SAY ""
    CALL DISPDB WITH "EXIT,ESC=A,FK0=V"
*
    @0,0 SAY ""
    CALL DISPDB WITH "SCREEN"
ACCEPT TO HSKEY
*
DO CASE
  CASE HSKEY = "ESC"
    LOOP
  CASE HSKEY = "FK0"

Appendix D. Computer Program CMCGEN
@0,0 SAY ""
CALL DISPDB WITH "RECOVER,SELCRIT"
ACCEPT TO HSELCRIT
ENDCASE
*
* Decide on the primary sorting criterion
* and open the respective screen
*
DO CASE
*
CASE (HSELCRIT = "S")
@0,0 SAY ""
CALL DISPDB WITH "OPEN,CMCSTAT.SCR,10,1"
*
CASE (HSELCRIT = "C")
@0,0 SAY ""
CALL DISPDB WITH "OPEN,CMCCREW.SCR,10,1"
*
CASE (HSELCRIT = "O")
@0,0 SAY ""
CALL DISPDB WITH "OPEN,CMCOPER.SCR,10,1"
*
ENDCASE
*
* Input data for the primary selection criterion
*
* Esc is used to abort
* F10 is used to validate
*
@0,0 SAY ""
CALL DISPDB WITH "EXIT,ESC=A,FK0=V"
*
@0,0 SAY ""
CALL DISPDB WITH "SCREEN"
ACCEPT TO HSKEY
*
DO CASE
    CASE HSKEY = "ESC"
        @0,0 SAY ""
        CALL DISPDB WITH "CLOSE"
        LOOP
    CASE HSKEY = "FK0"
*
DOCASE

Appendix D. Computer Program CMCGEN
* Case when 'section' is the primary selection crit
*
CASE (HSELCRIT = "S")
  @0,0 SAY ""
  CALL DISPDB WITH "RECOVER,ACTSTSTDB"
  INPUT TO HACTSTSTDB
  @0,0 SAY ""
  CALL DISPDB WITH "RECOVER,ACTSTENDB"
  INPUT TO HACTSTENDB
  @0,0 SAY ""
  CALL DISPDB WITH "RECOVER,SOR"
  ACCEPT TO HSOR
*
* Case when 'crew' is the primary selection crit
*
CASE (HSELCRIT = "C")
  @0,0 SAY ""
  CALL DISPDB WITH "RECOVER,CREWCODE"
  ACCEPT TO HCREWCODE
*
* Case when 'operation' is the primary selection crit
*
CASE (HSELCRIT = "O")
  @0,0 SAY ""
  CALL DISPDB WITH "RECOVER,ACTCODE"
  ACCEPT TO HACTCODE
*
ENDCASE
*
  @0,0 SAY ""
CALL DISPDB WITH "CLOSE"
*
ENDCASE
*
* Open screen CMCB21.SCR which is the screen
* where the user decides whether he/she wants to
* use the entire project or only between specific
* dates for generating the CMC
*
  @0,0 SAY ""
CALL DISPDB WITH "USE,CMCB21.SCR"
*
ENDCASE
* 
@0,0 SAY ""
CALL DISPDB WITH "DISPLAY,NAMEPROJ,=&HNAMEPROJ"
* 
@0,0 SAY ""
CALL DISPDB WITH "FIRST,EROS"
* 
@0,0 SAY ""
CALL DISPDB WITH "SELECT,-,NAMEPROJ"
* 
   Esc key is used to abort
*   F10 key is used to validate
* 
@0,0 SAY ""
CALL DISPDB WITH "EXIT,ESC=A,FK0=V"
* 
@0,0 SAY ""
CALL DISPDB WITH "SCREEN"
ACCEPT TO HSKEY
* 
DO CASE
   CASE HSKEY = "ESC"
      LOOP
   *
   CASE HSKEY = "FK0"
      @0,0 SAY ""
      CALL DISPDB WITH "RECOVER,EROS"
      ACCEPT TO HEROS
ENDCASE
* 
DO CASE
*
CASE (HEROS = "E")
@0,0 SAY ""
CALL DISPDB WITH "OPEN,CMCB23.SCR,9,1"
* 
@0,0 SAY ""
CALL DISPDB WITH "FIRST,PORS"
* 
   Esc key is used to abort
*   F10 key is used to validate
* 
@0,0 SAY ""
CALL DISPDB WITH "EXIT,ESC=A,FK0=V"

Appendix D. Computer Program CMCGEN
* 
@0,0 SAY ""
CALL DISPDB WITH "SCREEN"
ACCEPT TO HSKEY
*
DO CASE
    CASE HSKEY = "ESC"
        LOOP
    *
    CASE HSKEY = "FK0"
        @0,0 SAY ""
        CALL DISPDB WITH "RECOVER, PORS"
        ACCEPT TO HPORS
ENDCASE
*
DO CASE
*
CASE (HPORS = "S")
    @0,0 SAY ""
    CALL DISPDB WITH "OPEN, CMCB24, SCR, 11, 1"
*
    @0,0 SAY ""
    CALL DISPDB WITH "FIRST, NAMEFILE"
*
* Esc key is used to abort
* F10 key is used to validate
*
    @0,0 SAY ""
    CALL DISPDB WITH "EXIT, ESC=A, FK0=V"
*
    @0,0 SAY ""
    CALL DISPDB WITH "SCREEN"
    ACCEPT TO HSKEY
*
DO CASE
    CASE HSKEY = "ESC"
        LOOP
    *
    CASE HSKEY = "FK0"
        @0,0 SAY ""
        CALL DISPDB WITH "RECOVER, NAMEFILE"
        ACCEPT TO HNAMEFILE
ENDCASE
*

Appendix D. Computer Program CMCGEN
ENDCASE
*  
*   Input data for the dates to be used as  
*    the secondary selection criterion  
*  
CASE (HEROS = "S")  
@0,0 SAY ""  
CALL DISPDB WITH "OPEN,CMCB22.SCR,9,1"  
*  
*  
@0,0 SAY ""  
CALL DISPDB WITH "FIRST,ACTDTSTB"  
*  
*    Esc key is used to abort  
*    F10 key is used to validate  
*  
@0,0 SAY ""  
CALL DISPDB WITH "EXIT,ESC=A,FK0=V"  
*  
@0,0 SAY ""  
CALL DISPDB WITH "SCREEN"  
ACCEPT TO HSKEY  
*  
DO CASE  
   CASE HSKEY = "ESC"  
      LOOP  
   *  
   CASE HSKEY = "FK0"  
      @0,0 SAY ""  
      CALL DISPDB WITH "RECOVER,ACTDTSTB"  
      ACCEPT TO HACTDTSTB  
      @0,0 SAY ""  
      CALL DISPDB WITH "RECOVER,ACTDTENDB"  
      ACCEPT TO HACTDTENDB  
      @0,0 SAY ""  
      CALL DISPDB WITH "RECOVER,DLR"  
      ACCEPT TO HDOR  
ENDCASE  
*  
@0,0 SAY ""  
CALL DISPDB WITH "OPEN,CMCB23.SCR,18,1"  
*  
@0,0 SAY ""  
CALL DISPDB WITH "FIRST,PORS"  

Appendix D. Computer Program CMCGEN
* Esc key is used to abort
* F10 key is used to validate
*
@0,0 SAY ""
CALL DISPDB WITH "EXIT,ESC=A,FK0=V"
*
@0,0 SAY ""
CALL DISPDB WITH "SCREEN"
ACCEPT TO HSKEY
*
DO CASE
  CASE HSKEY = "ESC"
    LOOP
  *
    CASE HSKEY = "FK0"
      @0,0 SAY ""
      CALL DISPDB WITH "RECOVER,PORS"
      ACCEPT TO HPORS
  END CASE
  *
DO CASE
*
CASE (HPORS = "S")
@0,0 SAY ""
CALL DISPDB WITH "OPEN,CMCB24.SCR,20,1"
*
@0,0 SAY ""
CALL DISPDB WITH "FIRST,NAMFILE"
*
* Esc key is used to abort
* F10 key is used to validate
*
@0,0 SAY ""
CALL DISPDB WITH "EXIT,ESC=A,FK0=V"
*
@0,0 SAY ""
CALL DISPDB WITH "SCREEN"
ACCEPT TO HSKEY
*
DO CASE
  CASE HSKEY = "ESC"
    LOOP
  *

Appendix D. Computer Program CMCGEN
CASE H$KEY = "FK0"
  @0,0 SAY ""
  CALL DISPDB WITH "RECOVER,NAMFILE"
  ACCEPT TO H$NAMEFILE
ENDCASE
*
ENDCASE
*
ENDCASE
*
  Use the data stored in the temporary file ZG959GZ
*
USE ZG959GZ
*
DO CASE
*
***********
*  Cases when only sorting is carried out.
*  Selection is allowed only for dates.
***********
CASE (H$SELECT = "A" .AND. HERO$ = "E" .AND. ;
  HPORS = "S")
  REPORT FORM GENCMC.FRQ;
  TO FILE &H$NAMEFILE
  CASE (H$SELECT = "A" .AND. HERO$ = "E" .AND. ;
    HPORS = "P")
  REPORT FORM GENCMC.FRQ;
  TO PRINTER
  CASE (H$SELECT = "A" .AND. HERO$ = "S" .AND. ;
    HDOR = "O" .AND. HPORS = "S")
  REPORT FORM GENCMC.FRQ;
  FOR ACTDTST >= CTOD(HACTDTSTB) .AND. ;
  ACTDTEND <= CTOD(HACTDTENDB) TO FILE &H$NAMEFILE
  CASE (H$SELECT = "A" .AND. HERO$ = "S" .AND. ;
    HDOR = "O" .AND. HPORS = "P")
  REPORT FORM GENCMC.FRQ;
  FOR ACTDTST >= CTOD(HACTDTSTB) .AND. ;
ACTDTEND <= CTOD(HACTDTENDB) ;
TO PRINTER
*****************************************************************************
CASE (HSELECT = "A" .AND. HERO$ = "S" .AND. ;
HDOR = "A" .AND. HPORS = "S")
*
REPORT FORM GENCMC.FR G ;
FOR ACTDTST <= CTOD(HACTDTENDB) .AND. ;
ACTDTEND => CTOD(HACTDTSTB) TO FILE &HNAMEFILE
*****************************************************************************
CASE (HSELECT = "A" .AND. HERO$ = "S" .AND. ;
HDOR = "A" .AND. HPORS = "P")
*
REPORT FORM GENCMC.FR G ;
FOR ACTDTST <= CTOD(HACTDTENDB) .AND. ;
ACTDTEND => CTOD(HACTDTSTB) ;
TO PRINTER
*
*****************************************************************************
*****************************************************************************
* Cases when primary sorting is on stations and
* only those activities which start as well as end
* between the specified stations, are to be included
*****************************************************************************
*
CASE (HSELCRT = "S" .AND. HSOR = "O" .AND. HERO$ = "E" ;
,AND. HPORS = "S")
*
REPORT FORM STATCMC.FR G ;
FOR ACTSTST => HACTSTSTB .AND. ;
ACTSTEND <= HACTSTENDB TO FILE &HNAMEFILE
*****************************************************************************
CASE (HSELCRT = "S" .AND. HSOR = "O" .AND. HERO$ = "E" ;
,AND. HPORS = "P")
*
REPORT FORM STATCMC.FR G ;
FOR ACTSTST => HACTSTSTB .AND. ;
ACTSTEND <= HACTSTENDB TO PRINTER
*****************************************************************************
CASE (HSELCRT = "S" .AND. HSOR = "O" .AND. HERO$ = "S" ;
,AND. HDOR = "O" .AND. HPORS = "S")
*
REPORT FORM STATCMC.FR G ;
FOR ACTSTST => HACTSTSTB .AND. ;

Appendix D. Computer Program CMCGEN
ACTSTEND <= HACTSTENDB .AND. ACTDTST >= CTOD(HACTDTSTDB) ;
 .AND. ACTDTEND <= CTOD(HACTDTENDB) TO FILE &HNAMEFILE

CASE (HSELCRIT = "S" .AND. HSOR = "O" .AND. HEROS = "S" ;
 .AND. HDOR = "O" .AND. HPORS = "P")
 *
REPORT FORM STATCMC.FRG ;
FOR ACTSTST >= HACTSTSTB .AND. ACTSTEND <= HACTSTENDB ;
 .AND. ACTDTST >= CTOD(HACTDTSTDB) .AND. ;
ACTDTEND <= CTOD(HACTDTENDB) TO PRINTER

CASE (HSELCRIT = "S" .AND. HSOR = "O" .AND. HEROS = "S" ;
 .AND. HDOR = "A" .AND. HPORS = "S")
 *
REPORT FORM STATCMC.FRG ;
FOR ACTSTST >= HACTSTSTB .AND. ;
ACTSTEND <= HACTSTENDB .AND. ACTDTST <= CTOD(HACTDTSTDB) ;
 .AND. ACTDTEND >= CTOD(HACTDTENDB) TO FILE &HNAMEFILE

CASE (HSELCRIT = "S" .AND. HSOR = "O" .AND. HEROS = "S" ;
 .AND. HDOR = "A" .AND. HPORS = "P")
 *
REPORT FORM STATCMC.FRG ;
FOR ACTSTST >= HACTSTSTB .AND. ACTSTEND <= HACTSTENDB ;
 .AND. ACTDTST <= CTOD(HACTDTENDB) .AND. ;
ACTDTEND >= CTOD(HACTDTSTDB) TO PRINTER
 *

Cases when primary sorting is on stations and all
activities which occur (either partially or
completely) between the specified stations, are
to be included

CASE (HSELCRIT = "S" .AND. HSOR = "A" .AND. HEROS = "E" ;
 .AND. HPORS = "S")
 *
REPORT FORM STATCMC.FRG ;
FOR ACTSTST <= HACTSTSTB .AND. ;
ACTSTEND >= HACTSTSTB TO FILE &HNAMEFILE

CASE (HSELCRIT = "S" .AND. HSOR = "A" .AND. HEROS = "E" ;
 .AND. HPORS = "P")
 *

Appendix D. Computer Program CMCGEN
REPORT FORM STATCMC.FRG;
FOR ACTSTST <= HACTSTENDB .AND. ACTSTEND >= HACTSTSTB .AND. ACTDTST <= CTOD(HACTDTSTB) .AND. ACTDTEND <= CTOD(HACTDTENDB) TO PRINTER
******************************************************************************
CASE (HSELCRIT = "S" .AND. HSOR = "A" .AND. HEROS = "S" ; .AND. HDOR = "O" .AND. HPORS = "S")
*
REPORT FORM STATCMC.FRG;
FOR ACTSTST <= HACTSTENDB .AND. ACTSTEND >= HACTSTSTB ; .AND. ACTDTST <= CTOD(HACTDTSTB) .AND. ; ACTDTEND <= CTOD(HACTDTENDB) TO FILE &HNAMEFILE
******************************************************************************
CASE (HSELCRIT = "S" .AND. HSOR = "A" .AND. HEROS = "S" ; .AND. HDOR = "O" .AND. HPORS = "P")
*
REPORT FORM STATCMC.FRG;
FOR ACTSTST <= HACTSTENDB .AND. ACTSTEND >= HACTSTSTB ; .AND. ACTDTST <= CTOD(HACTDTSTB) .AND. ; ACTDTEND <= CTOD(HACTDTENDB) TO PRINTER
******************************************************************************
CASE (HSELCRIT = "S" .AND. HSOR = "A" .AND. HEROS = "S" ; .AND. HDOR = "A" .AND. HPORS = "S")
*
REPORT FORM STATCMC.FRG;
FOR ACTSTST <= HACTSTENDB .AND. ACTSTEND >= HACTSTSTB ; .AND. ACTDTST <= CTOD(HACTDTSTB) .AND. ; ACTDTEND >= CTOD(HACTDTENDB) TO PRINTER
******************************************************************************
CASE (HSELCRIT = "S" .AND. HSOR = "A" .AND. HEROS = "S" ; .AND. HDOR = "A" .AND. HPORS = "P")
*
REPORT FORM STATCMC.FRG;
FOR ACTSTST <= HACTSTENDB .AND. ACTSTEND >= HACTSTSTB ; .AND. ACTDTST <= CTOD(HACTDTSTB) .AND. ; ACTDTEND >= CTOD(HACTDTENDB) TO PRINTER
******************************************************************************

Appendix D. Computer Program CMCGEN
CASE (HSELCRIT = "C" .AND. HEROS = "E" .AND. ; HPORS = "S")
*
REPORT FORM CREWCMC.FRG ;
FOR CREWCODE = HCREWCODE TO FILE &HNAMEFILE
******************************************************************************
CASE (HSELCRIT = "C" .AND. HEROS = "E" .AND. ; HPORS = "P")
*
REPORT FORM CREWCMC.FRG ;
FOR CREWCODE = HCREWCODE TO PRINTER
******************************************************************************
CASE (HSELCRIT = "C" .AND. HEROS = "S" .AND. HDOR = "O" ; .AND. HPORS = "S")
*
REPORT FORM CREWCMC.FRG ;
FOR CREWCODE = HCREWCODE .AND. ;
ACTDTST >= CTOD(HACTDTSTB) .AND. ;
ACTDTEND <= CTOD(HACTDTENDB) TO FILE &HNAMEFILE
******************************************************************************
CASE (HSELCRIT = "C" .AND. HEROS = "S" .AND. HDOR = "O" ; .AND. HPORS = "P")
*
REPORT FORM CREWCMC.FRG ;
FOR CREWCODE = HCREWCODE .AND. ;
ACTDTST >= CTOD(HACTDTSTB) .AND. ;
ACTDTEND <= CTOD(HACTDTENDB) TO PRINTER
******************************************************************************
CASE (HSELCRIT = "C" .AND. HEROS = "S" .AND. HDOR = "A" ; .AND. HPORS = "S")
*
REPORT FORM CREWCMC.FRG ;
FOR CREWCODE = HCREWCODE .AND. ;
ACTDTST <= CTOD(HACTDTENDB) .AND. ;
ACTDTEND => CTOD(HACTDTSTB) TO FILE &HNAMEFILE
******************************************************************************
CASE (HSELCRIT = "C" .AND. HEROS = "S" .AND. HDOR = "A" ; .AND. HPORS = "P")
*
REPORT FORM CREWCMC.FRG ;
FOR CREWCODE = HCREWCODE .AND. ;
ACTDTST <= CTOD(HACTDTENDB) .AND. ;
ACTDTEND => CTOD(HACTDTSTB) TO PRINTER
******************************************************************************

Appendix D. Computer Program CMCGEN
CASE (HSELECT = "O" .AND. HEROS = "E" .AND. HPORS = "S")

REPORT FORM OPERCMC.FRG;
FOR ACTCODE = HACTCODE TO FILE &HNAMEFILE

CASE (HSELECT = "O" .AND. HEROS = "E" .AND. HPORS = "P")

REPORT FORM OPERCMC.FRG;
FOR ACTCODE = HACTCODE TO PRINTER

CASE (HSELECT = "O" .AND. HEROS = "S" .AND. HDOR = "O" .AND. HPORS = "S")

REPORT FORM OPERCMC.FRG;
FOR ACTCODE = HACTCODE .AND. ;
ACTDTST > CTOD(HACTDTSTB) .AND. ;
ACTDTEND <= CTOD(HACTDTENDB) TO FILE &HNAMEFILE

CASE (HSELECT = "O" .AND. HEROS = "S" .AND. HDOR = "O" .AND. HPORS = "P")

REPORT FORM OPERCMC.FRG;
FOR ACTCODE = HACTCODE .AND. ;
ACTDTST > CTOD(HACTDTSTB) .AND. ;
ACTDTEND <= CTOD(HACTDTENDB) TO PRINTER

CASE (HSELECT = "O" .AND. HEROS = "S" .AND. HDOR = "A" .AND. HPORS = "S")

REPORT FORM OPERCMC.FRG;
FOR ACTCODE = HACTCODE .AND. ;
ACTDTST <= CTOD(HACTDTENDB) .AND. ;
ACTDTEND >= CTOD(HACTDTSTB) TO FILE &HNAMEFILE

---

Appendix D. Computer Program CMCGEN
CASE (HSELCRIT = "O" .AND. HEROS = "S" .AND. HDOR = "A" ;
   .AND. HPORS = "P")
*
REPORT FORM OPERCMC.FRQ ;
FOR ACTCODE = HACTCODE .AND. ;
ACTDTST <= CTOD(HACTDTENDB) .AND. ;
ACTDTTEND >= CTOD(HACTDTSTB) TO PRINTER
**************************************************************************
*
ENDCASE
*
CLOSE ALL
*
CLEAR ALL
*
ENDDO
APPENDIX E

COMPUTER SCREENS FOR LSS

The user-interface screens developed for the Linear Scheduling Software (LSS) are shown in this appendix. The screens for the Alpha Version, and additional and modified screens for the Beta Version are shown. The screens originally developed for LSS and later modified to allow their use in the combined scheduling system comprising of LSS and LINC are also shown. The names under which the screens are saved, are shown in their top left corner. These names are also given within parentheses, after the title of each screen.

Screens for LSS - Alpha Version

| Screen E-1 | Options Screen (MENU) | 239 |
| Screen E-2 | Project Title Screen 1 (LSMTIT1) | 240 |
| Screen E-3 | Project Title Screen 2 (LSMTIT2) | 241 |
| Screen E-4 | Project Title Screen 3 (LSMTIT3) | 242 |
| Screen E-5 | Axes Data Input Screen (LSMAXES) | 243 |
| Screen E-6 | Layout Information Input Screen 1 (LAYOUT1) | 244 |
| Screen E-7 | Layout Information Input Screen 2 (LAYOUT2) | 245 |
| Screen E-8 | Activity Input Screen (LSMACT) | 246 |
| Screen E-9 | Screen for CPM Defined Line (LSMACTLY) | 247 |
| Screen E-10 | Screen for User Defined Line (LSMACTLN) | 248 |
Screen E-11  Screen for CPM Defined Block (LSMACTKY) .................................. 249
Screen E-12  Screen for User Defined Block (LSMACTKN) .................................. 250
Screen E-13  Screen for CPM Defined Bar (LSMACTBY) ..................................... 251
Screen E-14  Screen for User Defined Bar (LSMACTBN) ..................................... 252
Screen E-15  Screen for CPM Defined Flag (LSMACTFY) ..................................... 253
Screen E-16  Screen for User Defined Flag (LSMACTFN) ..................................... 254
Screen E-17  Project Title Screen - Option 'B' (LSMTITLEB) ................................. 255

Screens for LSS - Beta Version

Screen E-18  Activity Input Screen (LSMACT) ..................................................... 256
Screen E-19  Screen for CPM (ADM) Defined Line (ADMLINE) ......................... 257
Screen E-20  Screen for CPM (ADM) Defined Block (ADMBLOCK) ..................... 258
Screen E-21  Screen for CPM (ADM) Defined Bar (ADMBAR) ............................. 259
Screen E-22  Screen for CPM (ADM) Defined Flag (ADMFLAG) ......................... 260

Screens for the Combined Scheduling System

Comprising of LSS and LINC

Screen E-23  Options Screen for LSS (MENU1) ................................................. 261
Screen E-24  Activity Input Screen (LINCIT) .................................................. 262
Screen E-25  Screen for CPM (PDM) Defined Line (LSMACTLY) ....................... 263
Screen E-26  Screen for CPM (ADM) Defined Line (ADMLINE) ....................... 264
Screen E-27  Screen for CPM (PDM) Defined Block (LSMACTKY) .................... 265

Appendix E. Screens for LSS
| Screen E-28 | Screen for CPM (ADM) Defined Block (ADMBLOCK) | 266 |
| Screen E-29 | Screen for CPM (PDM) Defined Bar (LSMACTBY) | 267 |
| Screen E-30 | Screen for CPM (ADM) Defined Bar (ADMBAR) | 268 |
| Screen E-31 | Screen for CPM (PDM) Defined Flag (LSMACTFY) | 269 |
| Screen E-32 | Screen for CPM (ADM) Defined Flag (ADMFLAG) | 270 |

*Appendix E. Screens for LSS*
Options Screen

A Gather LSS data
B Generate DXF file
X Exit LSS System

Move the selection bar or type the letter corresponding to your choice.
Screen print LSMTIT1  
Esc-Return  F10-Validate/Advance

LSS PROJECT TITLE SCREEN

NAME OF THE PROJECT FILE

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<th>Field Name</th>
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<td>PROJNAME</td>
<td>Character</td>
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Screen E-2  Project Title Screen 1
Screen print LSMTIT2

PROJECT TITLE
NAME OF COMPANY/CLIENT
DATA DATE
DATE OF THIS RUN
TYPE OF SCHEDULE (AS BID / AS BEING BUILT / AS BUILT)
REVISION NUMBER (IF APPLICABLE)

WOULD YOU LIKE TO SAVE THIS SCHEDULE UNDER A SEPARATE NAME  (Y/N)
IF YES, ENTER NEW NAME OF THE PROJECT FILE

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<td>C</td>
<td>DATADATE</td>
<td>Date</td>
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<td>DATEAPPEAR</td>
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<td>PROJNMENEW</td>
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</table>

Screen E-3 Project Title Screen 2
Screen print LSMAKES

Esc-Return F10-Validate/Advance

LSS AXES DATA INPUT SCREEN

STARTING STATION OF THE PROJECT

END STATION OF THE PROJECT

START DATE FOR THE PROJECT

COMPLETION DATE FOR THE PROJECT

CALENDAR UNIT (DAYS / WEEKS / MONTHS)

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Screen E-5 Axes Data Input Screen
SCREEN PRINT LAYOUT
ESC-RETURN F10-VALIDATE/ADVANCE

LSS LAYOUT INFORMATION INPUT SCREEN

SHEET SIZE INFORMATION
HORIZONTAL DIMENSION OF SHEET OF PAPER (IN INCHES)
VERTICAL DIMENSION OF SHEET OF PAPER (IN INCHES)

COORDINATES FOR THE ORIGIN OF THE SCHEDULE
X-COORDINATE FOR THE ORIGIN OF THE SCHEDULE (IN INCHES)
Y-COORDINATE FOR THE ORIGIN OF THE SCHEDULE (IN INCHES)

AXES LENGTH INFORMATION
LENGTH OF THE DISTANCE AXIS (X-AXIS) (IN INCHES)
LENGTH OF THE TIME AXIS (Y-AXIS) (IN INCHES)

TITLE BLOCK INFORMATION
X-COORDINATE FOR THE TOP LEFT CORNER OF THE TITLE BLOCK (IN INCHES)
Y-COORDINATE FOR THE TOP LEFT CORNER OF THE TITLE BLOCK (IN INCHES)
COLOR FOR THE TEXT IN THE TITLE BLOCK (1-8)
STYLE FOR THE TEXT IN THE TITLE BLOCK (1-10)
SIZE FOR THE TEXT IN THE TITLE BLOCK (IN INCHES)

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Screen E-6 Layout Information Input Screen 1
Screen print LAYOUT2

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Screen E-7 Layout Information Input Screen 2
Screen print LSMACT
Esc-Return F3-Previous F4-Next F5-Add F6-Delete F7-Search F10-Validate

LSM ACTIVITY INPUT SCREEN

LSM ACTIVITY ID
LSM ACTIVITY DESCRIPTION

WILL THIS ACTIVITY BE REPRESENTED BY A LINE, BAR, BLOCK OR FLAG
WILL THIS ACTIVITY BE LINKED TO AN ACTIVITY IN THE CPM TRANSFER FILE (Y/N)

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Screen E-8 Activity Input Screen
**Screen print LSMACTLY**

**ENTER START STATION FOR THE LINE**
**ENTER END STATION FOR THE LINE**

**WHAT CPM ACTIVITY DEFINES THE START DATE FOR THE LINE**
**ACT DESCRIPTION**
**WHAT DATE DO YOU WISH TO USE FOR THE START OF THE LINE**

**WHAT CPM ACTIVITY DEFINES THE END DATE FOR THE LINE**
**ACT DESCRIPTION**
**WHAT DATE DO YOU WISH TO USE FOR THE END OF THE LINE**

**WHAT COLOR DO YOU WISH TO USE** (1-8)
**WHAT LINE TYPE DO YOU WISH TO USE** (0-8)

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Screen E-9  Screen for CPM Defined Line
Screen print LSMACTLN

ENTER START STATION FOR THE LINE
ENTER END STATION FOR THE LINE

WHAT DATE DO YOU WISH TO USE FOR THE START OF THE LINE

WHAT DATE DO YOU WISH TO USE FOR THE END OF THE LINE

WHAT COLOR DO YOU WISH TO USE {1-8}
WHAT LINE TYPE DO YOU WISH TO USE {0-8}

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Screen E-10 Screen for User Defined Line
Screen print LSMACTKY

ENTER START STATION FOR THE BLOCK
ENTER END STATION FOR THE BLOCK

WHAT CPM ACTIVITY DEFINES THE START DATE FOR THE BLOCK
ACT DESCRIPTION
WHAT DATE DO YOU WISH TO USE FOR THE BOTTOM OF THE BLOCK

WHAT CPM ACTIVITY DEFINES THE END DATE FOR THE BLOCK
ACT DESCRIPTION
WHAT DATE DO YOU WISH TO USE FOR THE TOP OF THE BLOCK

HATCH PATTERN (1-7) COLOR (1-8) LINE TYPE OF THE BLOCK (0-8)

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Screen E-11 Screen for CPM Defined Block
Screen print LSMACTKN

ENTER START STATION FOR THE BLOCK
ENTER END STATION FOR THE BLOCK

WHAT DATE DO YOU WISH TO USE FOR THE BOTTOM OF THE BLOCK

WHAT DATE DO YOU WISH TO USE FOR THE TOP OF THE BLOCK

HATCH PATTERN (1-7) COLOR (1-8) LINE TYPE OF THE BLOCK (0-8)

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Screen E-12 Screen for User Defined Block
**Screen print LSMACTBY**

**ENTER LOCATION OF THE BAR**
HOW WIDE DO YOU WISH THE BAR TO BE (NARROW / MEDIUM / WIDE)

**WHAT CPM ACTIVITY DEFINES THE START DATE FOR THE BAR**
ACT DESCRIPTION
WHAT DATE DO YOU WISH TO USE FOR THE START OF THE BAR

**WHAT CPM ACTIVITY DEFINES THE END DATE FOR THE BAR**
ACT DESCRIPTION
WHAT DATE DO YOU WISH TO USE FOR THE END OF THE BAR

**HATCH PATTERN (1-7)**
**COLOR (1-8)**
**LINE TYPE OF THE BAR (0-8)**

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**Screen E-13** Screen for CPM Defined Bar
Screen print LSMACTBN

ENTER LOCATION OF THE BAR
HOW WIDE DO YOU WISH THE BAR TO BE (NARROW / MEDIUM / WIDE)

WHAT DATE DO YOU WISH TO USE FOR THE START OF THE BAR

WHAT DATE DO YOU WISH TO USE FOR THE END OF THE BAR

HATCH PATTERN (1-7) COLOR (1-8) LINE TYPE OF THE BAR (0-8)

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Screen E-14 Screen for User Defined Bar
Screen print LSNACTFY

ENTER LOCATION OF THE FLAG

WHAT CPM ACTIVITY DEFINES THE DATE FOR THE FLAG
ACT DESCRIPTION
WHAT DATE DO YOU WISH TO USE FOR THE FLAG

WHAT COLOR DO YOU WISH TO USE
WHAT SYMBOL DO YOU WISH TO USE FOR THIS FLAG (1-8)

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Screen E-15 Screen for CPM Defined Flag
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<tr>
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Screen for User Defined Flag

Screen E-16
Screen print LSMTITLB

Esc-Return F10-Validate/Advance

LSS PROJECT TITLE SCREEN

NAME OF THE PROJECT FILE

This project name must be the same as the one used for gathering data

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Screen print LSMACT
Esc-Return F3-Previous F4-Next F5-Add F6-Delete F7-Search F10-Validate

LSS ACTIVITY INPUT SCREEN

LSS ACTIVITY ID
LSS ACTIVITY DESCRIPTION
WILL THIS ACTIVITY BE REPRESENTED BY A LINE, BAR, BLOCK OR FLAG
WILL THIS ACTIVITY BE LINKED TO AN ACTIVITY IN THE CPM TRANSFER FILE (Y/N)
WHICH IS THE METHOD USED TO GENERATE CPM SCHEDULE (PDM/ADM)

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Screen E-18 Activity Input Screen
Screen print ADMIINE

ENTER START STATION FOR THE LINE
ENTER END STATION FOR THE LINE

WHAT CPM ACTIVITY DEFINES START DATE FOR THE LINE: I-NODE J-NODE
ACT DESCRIPTION
WHAT DATE DO YOU WISH TO USE FOR THE START OF THE LINE

WHAT CPM ACTIVITY DEFINES END DATE FOR THE LINE: I-NODE J-NODE
ACT DESCRIPTION
WHAT DATE DO YOU WISH TO USE FOR THE END OF THE LINE

WHAT COLOR DO YOU WISH TO USE (1-8)
WHAT LINE TYPE DO YOU WISH TO USE (0-8)

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| G     | CPMDATEST  | Date    | 8     |
| H     | ADMENDI    | Character | 5    |
| I     | ADMENDJ    | Character | 5    |
| J     | CPMDSEND   | Character | 55   |
| K     | DATEEND    | Character | 2    |
| L     | CPMDATEEND | Date    | 8     |

Screen E-19 Screen for CPM (ADM) Defined Line
Screen print ADMBLOCK

ENTER START STATION FOR THE BLOCK
ENTER END STATION FOR THE BLOCK

WHAT CPM ACTIVITY DEFINES START DATE FOR THE BLOCK: I-NODE    J-NODE

ACT DESCRIPTION
WHAT DATE DO YOU WISH TO USE FOR THE BOTTOM OF THE BLOCK

WHAT CPM ACTIVITY DEFINES END DATE FOR THE BLOCK: I-NODE    J-NODE

ACT DESCRIPTION
WHAT DATE DO YOU WISH TO USE FOR THE TOP OF THE BLOCK

HATCH PATTERN (1-7)       COLOR (1-8)       LINE TYPE OF THE BLOCK (0-8)

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Screen E-20 Screen for CPM (ADM) Defined Block
Screen print ADMBAR

ENTER LOCATION OF THE BAR
HOW WIDE DO YOU WISH THE BAR TO BE (NARROW / MEDIUM / WIDE)

WHAT CPM ACTIVITY DEFINES START DATE FOR THE BAR: I-NODE     J-NODE
ACT DESCRIPTION
WHAT DATE DO YOU WISH TO USE FOR THE START OF THE BAR

WHAT CPM ACTIVITY DEFINES END DATE FOR THE BAR: I-NODE     J-NODE
ACT DESCRIPTION
WHAT DATE DO YOU WISH TO USE FOR THE END OF THE BAR

HATCH PATTERN (1-7)     COLOR (1-8)     LINE TYPE OF THE BAR (0-8)

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Screen E-21         Screen for CPM (ADM) Defined Bar
**Screen print ADMFLAG**

**ENTER LOCATION OF THE FLAG**

**WHAT CPM ACTIVITY DEFINES THE DATE FOR THE FLAG: I-NODE   J-NODE**

**ACT DESCRIPTION**

**WHAT DATE DO YOU WISH TO USE FOR THE FLAG**

**WHAT COLOR DO YOU WISH TO USE**

**WHAT SYMBOL DO YOU WISH TO USE FOR THIS FLAG (1-8)**

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Screen E-22  Screen for CPM (ADM) Defined Flag
Options Screen for LSS

- A Gather LSS data
- B Generate DXF file
- C Access LINC
- X Exit LSS System

Move the selection bar or type the letter corresponding to your choice
LSS ACTIVITY INPUT SCREEN

LSS ACTIVITY ID
LSS ACTIVITY CODE
WHICH CREW WILL CARRY OUT THIS JOB
DESCRIPTION
WILL THIS ACTIVITY BE REPRESENTED BY A LINE, BAR, BLOCK OR FLAG
DESCRIPTION
WILL THIS ACTIVITY BE LINKED TO AN ACTIVITY IN THE CPM TRANSFER FILE
(Y/N)
WHICH IS THE METHOD USED TO GENERATE CPM SCHEDULE (PDM/ADM)

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Screen E-24  Activity Input Screen
ENTER START STATION FOR THE LINE
ENTER END STATION FOR THE LINE

WHAT CPM ACTIVITY DEFINES THE START DATE FOR THE LINE
ACT DESCRIPTION
WHAT DATE DO YOU WISH TO USE FOR THE START OF THE LINE

WHAT CPM ACTIVITY DEFINES THE END DATE FOR THE LINE
ACT DESCRIPTION
WHAT DATE DO YOU WISH TO USE FOR THE END OF THE LINE

WHAT COLOR DO YOU WISH TO USE
WHAT LINE TYPE DO YOU WISH TO USE {1-8}

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Screen E-25
Screen for CPM (PDM) Defined Line
Screen print ADMLINE

ENTER START STATION FOR THE LINE
ENTER END STATION FOR THE LINE

WHAT CPM ACTIVITY DEFINES START DATE FOR THE LINE: I-NODE  J-NODE
ACT DESCRIPTION
WHAT DATE DO YOU WISH TO USE FOR THE START OF THE LINE

WHAT CPM ACTIVITY DEFINES END DATE FOR THE LINE: I-NODE  J-NODE
ACT DESCRIPTION
WHAT DATE DO YOU WISH TO USE FOR THE END OF THE LINE

WHAT COLOR DO YOU WISH TO USE (1-8)
WHAT LINE TYPE DO YOU WISH TO USE (0-8)

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Screen E-26 Screen for CPM (ADM) Defined Line
Screen print LSMACTKY

ENTER START STATION FOR THE BLOCK
ENTER END STATION FOR THE BLOCK

WHAT CPM ACTIVITY DEFINES THE START DATE FOR THE BLOCK
ACT DESCRIPTION
WHAT DATE DO YOU WISH TO USE FOR THE BOTTOM OF THE BLOCK

WHAT CPM ACTIVITY DEFINES THE END DATE FOR THE BLOCK
ACT DESCRIPTION
WHAT DATE DO YOU WISH TO USE FOR THE TOP OF THE BLOCK

HATCH PATTERN (1-7) COLOR (1-8) LINE TYPE OF THE BLOCK (0-8)

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Screen E-27 Screen for CPM (PDM) Defined Block
Screen print ADMBLOCK

ENTER START STATION FOR THE BLOCK
ENTER END STATION FOR THE BLOCK

WHAT CPM ACTIVITY DEFINES START DATE FOR THE BLOCK: I-NODE J-NODE
ACT DESCRIPTION
WHAT DATE DO YOU WISH TO USE FOR THE BOTTOM OF THE BLOCK

WHAT CPM ACTIVITY DEFINES END DATE FOR THE BLOCK: I-NODE J-NODE
ACT DESCRIPTION
WHAT DATE DO YOU WISH TO USE FOR THE TOP OF THE BLOCK

HATCH PATTERN (1-7) COLOR (1-8) LINE TYPE OF THE BLOCK (0-8)

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Screen E-28 Screen for CPM (ADM) Defined Block
Screen print LSMACTBY

ENTER LOCATION OF THE BAR
HOW WIDE DO YOU WISH THE BAR TO BE (NARROW / MEDIUM / WIDE)

WHAT CPM ACTIVITY DEFINES THE START DATE FOR THE BAR
ACT DESCRIPTION
WHAT DATE DO YOU WISH TO USE FOR THE START OF THE BAR

WHAT CPM ACTIVITY DEFINES THE END DATE FOR THE BAR
ACT DESCRIPTION
WHAT DATE DO YOU WISH TO USE FOR THE END OF THE BAR

HATCH PATTERN (1-7) COLOR (1-8) LINE TYPE OF THE BAR (0-8)

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Screen E-29 Screen for CPM (PDM) Defined Bar
Screen print ADMBAR

**ENTER LOCATION OF THE BAR**
**HOW WIDE DO YOU WISH THE BAR TO BE (NARROW / MEDIUM / WIDE)**

**WHAT CPM ACTIVITY DEFINES START DATE FOR THE BAR: I-NODE**
**J-NODE**

**ACT DESCRIPTION**

**WHAT DATE DO YOU WISH TO USE FOR THE START OF THE BAR**

**WHAT CPM ACTIVITY DEFINES END DATE FOR THE BAR: I-NODE**
**J-NODE**

**ACT DESCRIPTION**

**WHAT DATE DO YOU WISH TO USE FOR THE END OF THE BAR**

**HATCH PATTERN (1-7)**

**COLOR (1-8)**

**LINE TYPE OF THE BAR (0-8)**

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Screen E-30 Screen for CPM (ADM) Defined Bar
Screen print LSMACTFY

ENTER LOCATION OF THE FLAG

WHAT CPM ACTIVITY DEFINES THE DATE FOR THE FLAG
ACT DESCRIPTION
WHAT DATE DO YOU WISH TO USE FOR THE FLAG

WHAT COLOR DO YOU WISH TO USE
WHAT SYMBOL DO YOU WISH TO USE FOR THIS FLAG \{1-8\}

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Screen E-31 Screen for CPM (PDM) Defined Flag
Screen print ADMFLAG

ENTER LOCATION OF THE FLAG

WHAT CPM ACTIVITY DEFINES THE DATE FOR THE FLAG: I-NODE J-NODE

ACT DESCRIPTION

WHAT DATE DO YOU WISH TO USE FOR THE FLAG

WHAT COLOR DO YOU WISH TO USE
WHAT SYMBOL DO YOU WISH TO USE FOR THIS FLAG (1-8)

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Screen E-32 Screen for CPM (ADM) Defined Flag
APPENDIX F

EXAMPLE PROJECT

This appendix presents a case example of a highway project. A number of schedules and reports are presented for the project.

F.1 The Project

The project entails widening of an existing highway to take it from one to two lanes. The project consists of 100 stations, numbered from station 0 to 100. The pavement consists of a cement stabilized subgrade, cement treated aggregate subbase, and asphalt base and surface courses. In addition to the regular pavement jobs, the project includes construction of a retaining wall between station 80 and 90, and a culvert at station 20.

The project is executed in three sections: The west end - sta 0-35; The middle section - sta 35-75; and The east end - sta 75-100. The rough grading operations in all the three sections are self contained, which means that no earth movement between the sections will be needed.

The contractor carrying out the job plans to use one clearing and grubbing crew, one rough grading crew, one fine grading crew, and one concrete crew. The fine grading crew will carry out the demolition of existing pavement, fine grading, and laying of the subbase course. The concrete crew will perform the retaining wall jobs and the culvert job. The
cement stabilized subgrade, base course laying, asphalt surfacing, and permanent striping will be let out to the sub contractors.

F.2 CPM Schedules

Critical Path Method (CPM) schedules for the example projects are developed using Primavera Project Planner. The activity and resource data about each activity is entered. Each activity is assigned an activity ID number which consists of three numerals. The first numeral of the activity ID indicates the section to which the activity belongs and the last two numerals indicate the type of work to be executed. For example, the ID number of activity 207 suggests that it is executed in the middle section (section code 2), and the type of work for this activity is rough grading (type code 07).

The relationship constraints between the activities are introduced. In addition to the hard logic constraints, soft logic constraints are also introduced to satisfy practical considerations. For example, soft logic constraints are introduced between the activities carried out by the fine grading crew so that work in one section is scheduled continuously, with minimum breaks possible, to minimize the renting of concrete barriers. Soft logic constraints are also introduced to ensure that the work in middle section be scheduled first, followed by the east end. The pavement jobs in the west end are to be scheduled last. This is mandated by the space congestion at the west end due to the operations of the contractor working on the adjacent project. The scheduling of pavement jobs for the west end towards the completion of the project helps this problem as the contractor working on the adjacent project is due for completion within a month after the project start date.

Appendix F. Example Project
The sub contractors carrying out surfacing and permanent striping wish to carry out their operations in all the three sections in one week each. This mandates introduction of soft logic constraints between the surfacing and permanent striping activities in the three sections.

A bar chart and a time scaled logic diagram for the project are shown in Schedules F-1 and F-2, respectively. In addition to the schedules, a report containing information about the activity ID, description, early and late dates etcetera is presented in Chart F-1.

**F.3 LSM Schedule**

The combined scheduling system which was described in Chapter 7 and which comprises of the linear scheduling software (LSS), and the LINC, the software package to generate crew movement charts (CMC), is used to generate a linear schedule and a number of tabular reports for the project. The linear schedule is shown in Schedule F-3, and the tabular reports are shown in Charts F-2 to F-5.

The CPM schedule, described in the preceding section, was used to export activity dates information in a database file. While using LSS to input the activity data, dates information for the majority of the activities was extracted from this CPM exported database file. The dates information for three activities, however, was provided by the user. These activities are the clearing and grubbing for the west end (102) and the middle section (202), and the finishing milestone (901).

*Appendix F. Example Project*
The early start and finish dates from the CPM exported file are used for most of the activities. However, late dates are used for the subbase activities 212 and 312. This is mandated by the request from the sub contractor carrying out base course operation that his/her activities for all the three sections be scheduled consequently.

The blocks are used as symbols for representing the rough grading operations. The culvert construction at station 20 is depicted by a bar. The starting and finishing milestones are represented as flags. Most of the other activities are represented on the linear schedule by lines.

As can be seen from the linear schedule shown in Schedule F-3, lines are used to represent the constituent activities of the retaining wall operation. However, these lines are enclosed in a block which suggests that this area is not available for any other operation. The start date for this block is defined by the early start of activity 304, excavation for the retaining wall, and the finishing date is defined by the late finish of activity 306, superstructure works for the retaining wall.

The three activities used in the CPM schedule for surfacing as well as permanent striping are combined to be shown as one activity in each case. These two activities are represented by lines on the linear schedules.

Different line types and hatch patterns are used to depict different types of operations. Similarly different colors are used to depict operations carried out by different crews. For example, the work done by the rough grading crew is drawn in red, and the work done by all the sub contractors is drawn in violet.

Appendix F. Example Project
Charts 6.1, 6.2, and 6.4 to 6.11, presented in Chapter 6, show CMC generated using Microsoft Excel, a computer spreadsheet package. These charts use the same set of data as used for this case example. Chart 6.1 shows the basic format of the CMC. Chart 6.2 shows activities selected for specific dates and uses the basic format. Charts 6.4 to 6.11 use different sorting and selection criteria to generate different types of CMC.

A number of crew movement charts (CMC) are generated using the modified version of LINC which is a part of the combined scheduling system. These CMC use the output formats discussed in Sections 6.5.5.6 and 7.5.2.3. The start date as the primary, the start station as the secondary, and the crew code as the tertiary sorting criteria for the chart. The first chart, Chart F-2, is a complete listing of all the activities and their dates, stations, and crew information. Charts F-3 and F-4 present information selected for a specific crew and a specific operation, respectively. The fine grading crew is the crew for Chart F-3 and rough grading is the operation for Chart F-4. Chart F-5 presents information about activities between stations 35 and 75.

F.4 Discussion

This appendix contains schedules and reports for an example project. These schedules and reports help to present different types of options available to the user. The linear schedule and the CMC also help to show the layout and the format of the output form the LSS and the LINC.

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VITA

Tarun Bafna, son of Praveen and Sarla Bafna, was born in Sirohi, a small town in the state of Rajasthan, India, on April 17, 1965. He had his early school education in Sarupganj, and at Vidya Bhawan in Udaipur. He completed his school education from Sardar Higher Secondary School, Jodhpur in 1980. He then attended M. B. M. Engineering College, University of Jodhpur, Jodhpur and graduated with the class of 1985 with a Bachelor's Degree in Civil Engineering.

In February of 1986, Tarun started his professional career with I. K. Synthetics Ltd, Kota and worked as a Site Engineer on a number projects for construction of synthetic fibre manufacturing plants. In December, 1987, he moved to the Business Development Cell of the same company. He moved to Diamond & Gem Development Corporation, Jaipur in October, 1988 and was involved with the construction of the Gemstone Industrial Park. He was soon promoted to the rank of Assistant Manager (Construction). He continued to serve there until he came to the United States for pursuing graduate studies.

Tarun came to Virginia Polytechnic Institute and State University, Blacksburg, Virginia in August, 1989 where he enrolled in the Construction Engineering & Management Program. He accomplished a Master's Degree in Civil Engineering in August, 1991. He is currently working as a Field Engineer for Cianbro Corporation, on their Calvert Street Bridge Project in Washington, D.C.