Hybrid Expert System Concept for Construction Planning and Scheduling

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ABSTRACT

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This thesis presents an integrated software approach to the development of a computerized knowledge based system for construction planning and scheduling. The concept is proposed to make available, the experiential knowledge in construction planning, and to enhance currently available project management software and other computing methods. The system, ESCHEDULER, which is developed as a proof of the concept, integrates through an expert system building tool (ESBT), a relational database, knowledge base and its control functions, a traditional network analysis software and interfacing programs written in Fortran language. The main program is written in the language provided by the ESBT, and DOS batch commands control the process of consultation and integration. This prototype system uses a micro-computer based hybrid artificial intelligence (AI) environment and has some interesting features: the determination of job logic for the activities entered through an end-user interface and a set of stand alone nested expert system modules to modify activity duration with respect to different site conditions. At the end of the consultation, ESCHEDULER prepares a realistic 'as possible' schedule. This system can successfully be applied to other domains in construction management and its modular architecture allows further enhancement and expansion.

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CHAPTER 1

INTRODUCTION

1.1 History Of Scheduling

No one really knows for sure when the concept of planning and scheduling activities began. Prehistoric man would have used sunset as the appropriate target for returning to his cave, thus setting a schedule for himself. Earliest civilizations of the east were known to have used the movement of planets to schedule their work. Today we are forced by the complexity of modern living to draw up elaborate schedules and communicate them to others in order to carry out several functions and to accomplish pre-set goals.

It was not until the turn of the century that some fundamentals were developed to systemize scheduling techniques. During World War I, Henry L. Gantt developed a display for production control which is commonly known as bar chart, upon which time points were indicated. This device has continued to be one of the most direct and easily understood methods for expressing project schedules. The demand created by the advances in mechanical and electrical systems of the building urged construction industry to use new materials and equipment produced by other industries. Since then, it became extremely difficult to maintain the schedule and to coordinate activities. Schemes were deviced to show more of the interaction between different elements of the work and their dependencies.

The evolution of project scheduling tools, involving dependency among activities, had their origin in two parallel problems of project control. In one case the U.S. Navy was instrumental in developing a method referred to as 'Program Evaluation and Review Technique' (PERT) to help them coordinate and control their contracts on the Polaris Missile Program. This method, developed as an event-oriented system, considers work tasks as definitive statements that must be completed in a step-by-step procedure. PERT involves a probability approach to time, and is used most often where no history concerning the scope of work exists. The other method to handle the problem of project control was born out of construction industry.

By 1956, complexities of construction work for chemical plants led to the research for improving, planning and scheduling of construction. This research, by Morgan Walker of du Pont and James E. Kelly of Remington Rand Corp., presented the concept of network planning and the initial mathematical theory upon which the Critical Path Method (CPM) was based (Harris, 1978). Since then, there have been many variations to this method. It soon became apparent that these network-based systems would require a greatly increased capacity for computation. In 1967, Dr. John W. Mauchly, a director of UNIVAC at that time, joined with Kelly and Walker to adapt the technique to digital computers. This resulted in completion of a project well ahead of the schedule (Bent, 1989).

1.2 Use of Computers

An opportunity unparalleled in the short history of construction management concept began three decades ago with the above introduction of digital computers to perform network solutions for planning and scheduling of construction projects. In the 60's, when computer costs were very high, most computer vendors provided some form of network-based scheduling software with their systems. While these systems did perform an otherwise impossible task, they were often controlled by data processing departments and were almost mainframe and batch-oriented, leaving project managers both physically and organizationally isolated from their use. Furthermore, these computers were large and expensive and demanded environmental conditions of their own.

Now, the advances in computer hardware, computer software, and engineering methodologies have led to an increased use of computers by construction personnel. Complex project efforts can now be planned, monitored and controlled more productively than ever before without a large data processing budget and expensive computers. The current micro-processor technology has effectively placed a mainframe on a micro chip. The introduction of the 16-bit machines along with the decreasing price of micro-processors have enabled small construction companies to enter the computer age (Moselhi, 1988). Today's personal computers (PC) and their associated peripherals no longer require an air-conditioned environment; they are small, rugged devices that can easily be accomodated in a normal site trailer.

However, in the realm of construction management, the use of computers has been limited almost exclusively to algorithmic solutions such as time analysis routines for CPM networks, critical path identification and float calculation methods, resource levelling and time-cost trade-off techniques. These applications are limited by deterministic rather than stochastic process and by precisely and quantitatively represented information, whether input or output.

1.3 Planning in Practice

Construction planning and scheduling is a very important task in the management of construction projects. Current construction planning relies upon manual formulation of plans and is usually performed in an intuitive and unstructured fashion with considerable reliance on engineering judgement. The need for engineering judgement is necessitated by the uncertain but predictable variables which dynamically affect the work tasks. Assessment of their impact is a complex problem, since they are dynamic in nature and dependent on the project conditions, location and the calendar dates when the activity will be worked on. Hence many problems in construction planning and scheduling are not amenable to purely mathematical or algorithmic solutions provided by CPM in traditional computerized systems. But if planning is carried out with reasonable care in a realistic manner, the resulting CPM schedule can be used both as a communication and control tool and as a legal document for assessment of delays and change orders (Galloway and Nielsen, 1981). The method which uses experiential knowledge and judgement to schedule a project is simple, strong, realistic, optimally cheap to use, but unfortunately not written down (Birrel, 1980). In order to manage the non-deterministic character of construction, there is a need to develop a programming environment that can incorporate engineering judgement and experience along with the algorithmic methodology used in CPM.

Hence, attention is now being focussed on the logic based computer systems as a means of deriving the human expertise and judgement. A shift is also deemed important from "black box" methods which work to some extent but are not fully understood by the end user (Beeston, 1983) to methods which are more explanatory and logically transparent. The emerging field of Artificial Intelligence (AI) provides such a programming methodology.

1.4 Computer - An Emulator

"A human investigator is placed in an isolated room. A teletype exists in the room, and by using it, he can communicate with a computer and with another human, both located in the next room. The interogator asks them each some questions, and then must guess which is the human and which is the machine. If we can program a machine in such a way that it fools the interogator into making the wrong identification at least 50 percent of the time then we shall say that the machine (as programmed) is "intelligent".

(Lenat, 1978)

Emulation of human thought process in computers, referred to as Expert Systems (ES) in Computer Science terminology, belongs to the field of AI, whose beginning as an academic discipline can be traced back to the late 50's. Most of the AI research since then has been focussed on duplication of human thought processes. Now they have emerged as practical problem solving tools that can reach a level of performance comparable to that of a human expert in some specialized problem domain. They are called Knowledge-Based Expert Systems (KBES) because their performance depends critically on the knowledge of experts stored in the system in the form of facts and heuristics. For the purpose of this work both KBES and ES are used in the same sense.

KBES provides a means to solve ill-defined problems where stringent mathematical relationship can be hard to arrive at and that demand considerable expertise. Since KBES provides a flexible software development methodology by separating knowledge from inference, considerable interest is being shown by both academic and engineering communities. KBES was categorized as one of the crucial research needs and the most promising direction for computerized construction applications in a research workshop jointly sponsored by the University of Illinois and the U.S. National Science Foundation in 1985 (Ibbs, 1986). During the last few years several KBES in the area of construction engineering and management have been developed or are being under development (Levitt, 1987). There are few notable systems for construction planning and scheduling, reported in various literature.

1.5 Scope and Objectives

The objective of the thesis is to utilize the emerging field of expert system technology to solve a number of problems in planning and scheduling construction projects and to develop a prototype expert system in the above field of application. The system will provide an efficient and economical architecture which will be easy to implement and be able to incorporate available and widely used computing methods. This flexible architecture will strike a balance in the integration of expert system technology with software systems currently available in the construction industry. A natural evolution of the system into an overall construction management tool will also be possible by enhancing and adding new knowledge bases to it and integrating more traditional computing methods.

The primary objectives of this study are to:

1. identify the inadequacy, generally associated with currently available computerized scheduling systems.
2. present the concept and discuss the structure and organization of KBES for construction planning and scheduling.
3. develop a prototype KBES as a proof of the above concept.

The scope of this study is limited only to method-related time analysis of construction planning and scheduling of building projects, albeit the concept presented can be expanded and applied to cover other areas in the management of construction projects. The system developed can be utilized to set the precedence among common activities encountered in a building project and to modify the unimpacted duration of activities with respect to expected conditions at construction site. It can be further enhanced and expanded to contain more of the valuable industrial heuristics which could be elicited from expert construction personnel.

1.6 Methodology

Upon an in depth review of literature on planning and scheduling tools, including text books (Barrie and Paulson, 1984; O'Brien, 1978; Willis, 1986) and articles, their advantages and the inadequacies in their applications to projects were noted. Hands-on experience was gained with currently available software for project scheduling (Primavera™, Promis™, Timeline™ and Workbench™) which were made available at the Centre for Building Studies, Concordia University.

Concerning the AI preparation, it was felt important to understand the basic principles and the jargon of application (Harmon and King, 1985; Waterman, 1985) before embarking on the proposal of a feasible concept. Evolution of the concept was strictly based on enhancing the existing project scheduling systems. Many expert system development environments were evaluated to identify the most appropriate tool, for the concept proposed.

First pass at the knowledge base was made by studying a number of text books on planning and scheduling at various levels of the construction process. Schedules prepared by contractors were critically analyzed to build up the knowledge base. Later literature on productivity at job site were perused to identify the major factors that affect productivity levels, and to extract the necessary knowledge. As the development of the prototype is basically a 'proof of concept' and the study is of academic nature efforts were concentrated on developing the basic system architecture which is easy to expand, rather than on increasing the size of the knowledge base, incorporating industrial heuristics. Attempts were also made to validate the prototype and to explore the applicability of the system in other problem domains.

1.7 Organization of the Thesis

Several topics in construction planning and scheduling are discussed and the need for a programming environment, to supplement current algorithmic solutions, is emphasized in Chapter 2. A review of several KBES under development for construction planning and scheduling is also included in this chapter.

A conceptual model of an integrated software approach for planning and scheduling is presented in Chapter 3. This chapter also deals with Expert System Building Tools and the criteria for the selection of an appropriate environment to implement systems for construction scheduling.

In Chapter 4, the prototype KBES, ESCHEDULER is described and the structure and contents of the knowledge bases are presented.

An example application to illustrate the essential features and capabilities of ESCHEDULER is presented in Chapter 5. Efforts made to validate the system and its applicability in other problem domains are also discussed.

Conclusions and recommendations for future work are included in Chapter 6.

CHAPTER 2

CONSTRUCTION PLANNING AND SCHEDULING

2.1 Introduction

Planning and scheduling occupies a central position in the function of any project manager. Planning which is to be useful for a project in the future has to be a forecast of the best way to successfully complete the project. What the term planning connotes has been the subject of lively debates. It is basically a decision making process performed in advance of action which endeavours to design a desired future and effective ways of bringing it about (Laufer and Tucker, 1987). A good planning and scheduling effort primarily answers the following questions: what? (tasks), how? (methods), who? (resources), and when? (sequence and timing). It should provide easy to understand and clear methods of communication.

In construction, planning and scheduling process involves the definition of tasks, the choice of construction technologies, the estimation of duration, resources and cost for individual tasks, and the preparation of project schedule. It is both crucial and challenging in the management of construction projects (Zozaya et al, 1988). It is crucial to the eventual success of a project because control and monitoring are based on a particular project schedule. Poor schedules can easily result in large construction delays and cost increase. Similar effects may be obtained because of inappropriate or inconsistent decisions concerning the method and technologies to be used when performing the tasks. It is a challenging process because planning is concerned not only with the generation of a feasible schedule, but with the formulation of a good one. There may be numerous constraints that complicate the planning process such as those related with completion time of the tasks, availability of resources or limitation on project budget.

The purpose of this chapter is to analyze the construction planning environment and the role of computers in preparing a project schedule. This chapter also identifies the inadequacy generally associated with current computerized scheduling systems. The application of ES, the new methodology developed to take care of the inadequacies, and the advantages in its application to construction industry are briefly discussed in this chapter. The computerized systems developed by various researchers, making use of this emerging technology, are also reviewed.

2.2 Planning Tools

It is reported that planning has been rated as the most important factor for productivity improvement, in a study conducted at the Illinois Institute of Technology (Arditi, 1985). Time planning is the primary focus in most construction companies as to a great extent, cost of a construction project depends on project duration (Ahuja and Nandakumar, 1985). Normally, planning and scheduling of construction projects are being performed using network techniques. Over the last three decades, network planning has evolved as a modelling tool of construction activities. There have been various presentations of networks for various uses, and the construction industry has tried to use CPM and its variations in scheduling activities.

Even though CPM has been used for over three decades, its progress in the method of application and its success has been limited. One survey involving large construction companies has shown that only 15% of the users of network techniques deem them very successful (Davis,1974). Another similar study found that only 43% used CPM effectively (BRT,1983). In small construction companies the situation is even less encouraging, as one study indicates, that only 10% attempt to use CPM (Waddill and Meyes, 1986). Failure of the majority of construction contractors to fully use CPM exposes that there is some fundamental failure in the method of application of CPM network technique. The reasons for the limited effectiveness of CPM have been discussed extensively in the literature (Birrel,1980; Erskin-Murray,1972; Fondahl, 1982; Jaafari,1984; Mason,1982; Mason, 1984; Parsons, 1983; White,1985). The following section will discuss the inadequacies of CPM which are relevant to the thesis.

In order to prepare a CPM network, it requires activity identification, duration of individual activities and their logical relationships. Knowledge, both of construction methods or constructibility and of project management is required to prepare the above. In preparing a list of activities to accomplish a project, and in deciding on the duration and the logical constraints for each activity, a scheduler, who is generally assisted by a team of experienced construction personnel, draws on knowledge of the resources that will be consumed by each activity in the project, such as time, cost and revenue availabilty and other physical constraints which might influence the timing or the duration of activities. And finally, he draws knowledge on the potential effects, both favourable and unfavourable, that numerous internal and external risk factors could have on the duration or resource consumption of the activities to be performed.

Once prepared, a CPM network will include all the above mentioned knowledge implicitly. However, only the end results of the initial schedule analysis - the activities, their durations, logical dependencies, and resource requirements - are prepared and captured explicitly in the CPM network (Levitt and Kunz, 1985). The expert's knowledge about the task domain that was employed during schedule creation is unavailable subsequently for use by other members of the project team in interpreting interim project performance or in updating the project schedule. The inability to represent or explicitly incorporate and later use the construction task knowledge is one of the major reasons why the CPM technique is considered as a deficient planning tool (Birrel, 1980).

2.3 Computerized Scheduling

Network-based project planning techniques have become indispensable as aids in planning and scheduling projects, especially after being computerized (Levitt et al, 1988). In U.S., engineering consultants and construction companies are required to demonstrate the ability to use computerized CPM scheduling to qualify for jobs (ENR, 1988). Today there are a plethora of project scheduling software systems, and according to a survey reported in 1986, over 200 of them are available in the market (Stepman, 1986). These systems perform network analyses and incorporate sophisticated techniques such as resource levelling, time-cost trade-off and multi-project scheduling. These software use database management systems for reporting. Though these software are extensively used, they are, generally, given lukewarm welcome by the construction industry.

The intrinsic domain knowledge is not captured by any traditional computer software that support project management, such as software using CPM technique. They merely carry out computation on the data provided by the human expert. As mentioned before, limited ability to represent and use construction task knowledge which has been acquired over years of experience, is the major reason why traditional computer programs are deficient and inadequate as real planning aids. They have no capability to plan, and to generate project schedules. These software request the same data that are required by the CPM network and process scheduling data that have been fed to them. These data have to be prepared by human experts and hence, are the product of experience, engineering judgement and rules of thumb, which are so prevalent in the construction industry. These limitations in traditional software result in the need for repeated input of high-level expertise to adapt and modify plans as project conditions change. No matter how pure the theory of scheduling is, construction planning must always rely on the people portion of the equation (Ashley and Levitt, 1987). The experience of the "old hands", plays an essential role in successful construction planning.

Even though there are formal techniques available from operations research or other disciplines which could potentially help in solving many of the types of problems outlined above, acquisition of meaningful data to use in such formal models is extremely difficult. It was identified that heuristic methods and not integer programming tend to show some promise in giving good results (Crowston and Thompson, 1967). Heuristic methods are procedures that are very valuable but incapable of proof. Furthermore, many of the decisions in planning and scheduling have to be made fast and involve managerial input which may not be available on time. All these factors tend to promote the value of knowledge, based on experience which can be used to select valid analogies from prior experience and to recommend suitable action plans. Hence, computerized systems should incorporate the experiential knowledge referred to as 'heuristics' to become successful planning aids. The costs of inaccurate construction schedules provide the necessary motivation among the construction community to develop such intelligent computer systems.

2.4 Knowledge Based Expert Systems

In recent years, knowledge-based expert systems have received considerable attention among professional and academic groups. The attention can be attributed to the advertisement of a few relatively successful expert systems and the great potential for the development of more successful applications (Maher, 1987). All this attention did not delineate the definition of an expert system.

"Expert systems are interactive computer programs incorporating judgement, experience, rules of thumb, intuition and other expertise to provide knowledgeable advice about a variety of tasks ".

(Gashnig et al, 1981)

The most descriptive term would be knowledge based expert systems. The term "expert system" was coined by AI researchers and refers to a system which seeks to emulate the reasoning capacity of an expert in a particular field of expertise. This definition is most popular and well accepted. These programs can be used to advise, analyze, categorize, communicate,consult, design, diagnose, explain, explore, forecast, form concepts, identify, interpret, justify, learn, manage, monitor,plan, present, retrieve, schedule, test and tutor (Michaelson et al, 1985).

Expert system technology comes from a branch of computer science that is referred to as Artificial Intelligence (AI). AI is concerned with a broad range of topics that are related to simulating human intelligence in a computing machine. Expert Systems are a result of many years of attempts to simulate or reproduce intelligent problem sol.ing behaviour in a computer program. The basic components of an expert system (Fig. 2.1) are knowledge base which may be regarded as a repositary for expert knowledge and inference mechanism, a dynamic decision making function of the system. Other components include an input/output facility which allows the user to communicate with the system and a knowledge acquisition facility which allows the system to acquire further knowledge from domain experts.

The early expert systems were developed using conventional programming techniques, such as sequential execution of program statements, because those techniques were available at that time (Maher, 1987). Other programming techniques have since been developed, largely due to the experience gained in developing MYCIN (Buchanan and Shortliffe, 1984) and similar expert systems. These other programming techniques, usually referred to as expert system techniques, include relaxing the sequential nature of the computer program which use mathematical algorithms, and providing facilities for separating the problem solving strategy from the knowledge about the problem itself. It can handle incomplete data by making inferences from programmed rules in their knowledge base. The separation of knowledge from the inferencing process may be considered as a major break through, which brought in attention from professional groups who were otherwise depending on the traditional, sequential programming techniques. Table 2.1 (Maher, 1987; Wolfgram et al, 1987) lists some of the distinguishing characteristics of conventional programs and expert systems. Even though some of the characteristics, such as interaction, and containing rules of thumb may be found in conventional programs, they do not make them expert systems as the inferencing process is intertwined with the knowledge or the data required in traditional programming.

Experience combined with subjective and qualitative judgement provides the essential starting point for a successful project scheduling engineer. Hence it is no surprise that attempts are being made to show the applicability of ES technology in this field. AI techniques provide new means to represent, and reason with, knowledge about project planning. These techniques permit computers to generate project schedules, not merely to perform numerical computations associated with network solutions. AI planning systems can handle the uncertainty involved in the content of the project. AI techniques offer the potential to create rich and easily understood representation of important knowledge involved in the project planning process, and are capable of reasoning about actions to generate schedules. They enable AI developers to capture, build and enhance on the experience gained in construction which could otherwise be lost in time due to the cyclical nature of the construction industry.

ES provides many advantages to construction firms (Finn and Reinschmidt, 1986). A statement has been made by some observers that an ES could increase a person's productivity ten times (Seaman, 1984). These systems allow for distribution of expertise such as the knowledge and logical processes that are known to experts. Hence, one can profit from the knowledge base gained through expert understanding of the field and be capable of using this systematically to provide practical and logically coherent solutions. Through the distribution of these programs, a greater degree of consistency can be achieved and maintained. Higher accuracy and performance levels can be attained due to a continuous availability of high level knowledge. This high level knowledge can be made available on a twenty-four hour a day, seven day a week basis. It reduces overall cost and eliminates time-delays incurred as a result of the expert's prior or alternate commitments. Immediate access to expert knowledge can reduce down-times for machinery and non-productive time for labour. Incremental growth and improvement of the system can be achieved through the experience of multiple users. The capability to incorporate feedback from the users can be used to improve the performance of the ES.

2.5 KBES for Construction Scheduling

Knowledge based expert systems for scheduling have been the subject of considerable research at many universities and research organizations. In the past two years, the level of interest expressed towards this topic has been on a steeply rising curve. Planning has been a part of AI research since the early 1960s. However, work directed at construction project scheduling is fairly recent.

In the literature of AI, numerous papers have addressed the general problem of planning, relevant to project management, although not necessarily in construction. The most common application has been to the achievement of desired goal state given initial conditions. Input to the planning system consists of an initial situation, a goal situation and a series of potential actions defined with preconditions. The preconditions for each action must be true before executing the action and the effects of the action on the global state are also stated in this system. In the final plan that is generated, the input and the output situations of the operations are compatible, and the operations represent a transformation from the initial situation to the goal situation. The most common application area of this means-ends approach has been in the realm of planning movements of blocks (e.g.,single robot stacking blocks on a table or moving objects through a series of rooms connected with doors) to achieve desired goals (Levitt et al, 1988).

While the AI based classic planning systems such as NOAH (Sacerdoti, 1975), NONLIN (Tate, 1977), DEVISER (Vere, 1983), and CALLISTO (Sathi et al, 1986) offer some useful conceptual tools, they have significant limitations for construction planning. These systems generally incorporate only a relatively small number of well-defined, repetitive tasks whereas construction requires numerous distinct tasks for completion. Further, construction projects have relatively small number of repetitive tasks and encounter many constraints such as the impact of the productivity-related factors which are not considered in these systems. Construction planning is highly knowledge intensive, so explicit use of expert knowledge is required in the planning process to determine the sequence and relationship among various tasks. Finally, the large size of construction planning problems suggests that efficient algorithmic scheduling tools may be more desirable than relying entirely on heuristic methods (Hendrickson and Rehak, 1987).

Over the past few years, interest is being shown by the civil engineering research community in the development of knowledge-based expert systems for various aspects of project management. A number of researchers have theorized how expert systems might be structured, and usefully applied in the field of construction (Avots, 1985; McGartland and Hendrickson, 1985; Rounds, 1986; Warzawski, 1985). Levitt (1987) provides a general review of the research in progress. Systems for schedule updating (Levitt and Kunz, 1985), schedule analysis and evaluation (O'Connor et al, 1986), activity duration estimation (Hendrickson et al, 1987), construction planning (Hendrickson et al, 1987a), prediction of cost and time of construction (Gray, 1986) and project network generation (Navinchandra et al, 1988) have been described in the literature. Most of these systems are experimental prototypes that have not yet been used in practice. A review of these systems is presented below.

PLATFORM: This is a "scheduling assistant" to update activity network for the construction of off-shore, concrete gravity type, oil drilling platforms (Levitt and Kunz, 1985). It includes knowledge on project management and about construction tasks. The system's main purpose is to update the network, i.e. alter either network attributes, such as durations or network topology, in response to reports of actual duration of activities accomplished. Network topology alteration is achieved by choosing among pre-defined alternate sub-networks for major activities and the revision of duration is based on prevailing conditions at the site. It is developed in a hybrid environment, integrating such AI tools as frame based representation, rule based reasoning, active images, and active values with LISP as an underlying programming language accessible for procedural attachment to rules within knowledge base. This integration is accomplished with object-oriented computing as the unifying methodology. In this method of programming, concepts and objects in an application are modelled as objects with attributes which have values. Attribute values can be data or programs, and objects pass values to each other or invoke actions. PLATFORM is developed using Intellicorp KEE™, AI programming environment. It operates on XEROX™ 1100 series, Symbolics™ 3600, and Texas Instrument Explorer™ computers.

CONSAS: This system is developed for the initial and progress analysis of construction networks from an owner's perspective (O'Connor et al, 1986). The program is able to check networks for compliance with managerial goals and constraints on time and money. The knowledge base for this program combines construction scheduling rules, construction knowledge, and general construction experience such as effects of weather, placement rates etc. This program is implemented in a hybrid micro-computer AI environment consisting of a project management system (Primavera™), a database management system (dBASE III™), and an expert system building tool (Personal Consultant Plus™). Primavera™ manages network data in the same way that it does in any scheduling environment. dBaseIII™ houses not only specific project data but also non-project information, such as hourly wages and productivity rates. PC Plus™ uses structured rules and some form of frames to represent the encoded knowledge. It is developed for use with TI and IBM personal computers.

MASON: MASON is an expert system which illustrates a hierarchical, rule-based approach and designed to make the estimating process more systematic and realistic (Hendrickson et al,1987). It provides facilities for estimating duration of masonry construction, explaining the calculations involved in the conclusions, and making recommendations for crew compositions and technologies. Once the basic duration estimate is complete, given crew sizes and quantities of materials, productivity adjustments are made to include factors at a job site. MASON neither provides facilities for giving optimistic and pessimistic duration times, nor will the program handle uncertain data. MASON is written in OPS5, an expert system programming language and uses a backward chaining technique to evaluate possible conclusions, and then tries to satisfy the supporting rules for each conclusion.

CONSTRUCTION PLANEX: CONSTRUCTION PLANEX is developed to generate construction schedules (Hendrickson et al, 1987a; Zozaya et al, 1988) for modular high-rise buildings. This frame-based system is intended to synthesize activity networks, to determine precedence relationships, recommend appropriate technologies, estimate required resources including durations and to develop a project schedule. It takes as input the specifications of the physical elements in the design, site information, and resource availability.

The knowledge base consists of a large number of knowledge sources for quantity take-off, element activity generation, choice of technology at different levels of the activity hierarchy, duration and cost estimation and precedence setting. Each knowledge source is input in the form of a decision table via frames which is later converted into a network of frames with rules for the knowledge base. CONSTRUCTION PLANEX is implemented on a Texas Instrument Explorer[tm] with Knowledgecraft[tm], AI programming environment.

TIME: The expert system TIME is developed to help designers evaluate different construction methods, designs, and processes to determine their effects on time and cost of construction during the initial design (Gray, 1986). The program takes rules from construction experts, operates on a database of common construction activities, and proceeds to model the construction site activity. It requires a great deal of inter-disciplinary knowledge of the construction industry. Incorporation of nested stand-alone expert systems is an interesting feature in this system. TIME is developed using PROLOG2, an AI language and a mainframe and is now being ported to IBM PC class computers.

GHOST: GHOST is a knowledge based network generator (Navinchandra et al, 1988). It is intended to be a part of a larger integrated knowledge-based environment for construction planning. It takes as input a set of activities and produces as output a schedule by setting up precedence among the activities. The knowledge base contains knowledge on physics, construction norms, redundancy in networks etc. It does not use the knowledge to build the network but only to criticize it. GHOST starts with a network with all activities in parallel and then modifies the network by introducing linearizations wherever activities cannot be done in parallel. Hence it is essentially a system that finds precedents among activities. The inference mechanism that is written in IMST, a KBES development environment developed at M.I.T. (Massachusetts Institute of Technology) orders the execution of various knowledge bases.

2.6 A Critical Review

The systems described above have been implemented under different expert system development environments. Though each has somewhat different focus, they generally address the process of developing and analyzing schedules. However,it should be noted that the application domain of construction scheduling consists of diverse characteristics and peculiarities which need to be considered before applying expert system approach. One important issue facing a developer of an ES is, fusing of computerized algorithmic analytical tools and electronic databases, which are already in use in construction industry, with heuristics which are so prevalent in the industry. Except O'Connor's system none of the above makes use of the widely used business computing software. These systems are being developed in total AI development environment, meaning special purpose platforms that are optimized to run AI languages, which are not familiar to the construction industry. One of the major concerns regarding the implementation of the above systems, is the elimination of project scheduling programs which are currently in use. Even though it is widely acknowledged that project scheduling software are inadequate for successful completion of projects, these programs could be effectively and efficiently used with the right input. The industrial impact of ES technology can be better realized through an evolutionary approach in which existing computer systems gradually absorb the most practical aspects of the new technology and coexist with them and supplement them.

PLATFORM is developed using object oriented programming and Interlisp-D version of the KEE™ system software on an AI workstation. LISP method is used to perform forward and backward passes through the network, whereas successful scheduling programs written in efficient languages are already available in the market. It requires three PERT durations from the user, which is very hard to derive for a time-tested construction activity. CONSTRUCTION PLANEX is also developed in a total AI environment. In preparing the project schedules it uses an activity network model that differs from the conventional activity-on-node and activity-on-arrow models. The intervening link between two nodes represent an activity, a precedence relationship or a window time constraint. It is hard to comment on this new approach at this time, whether the researcher is 'reinventing the wheel' without the feedback from practical applications. It uses successor data that are provided in advance in the system, and not deduced, in determining the precedence logic among activities. The system does not integrate with any traditional software (Hendrickson et al, 1987a). O'Connor's system makes use of the traditional computing methods and a personal computer for its developmental system for schedule analysis. The system is an add-on utility to existing project management software to analyze a user supplied initial schedule. Implementation of this system does not set the precedence logic among the activities, which, obviously, still requires the input of a human expert. However, it takes advantage of the electronic databases generated by the project management system. Now, efforts on this system have focussed upon applying a higher level programming environment, Automated Reasoning Tool (ART[tm]) which requires a special computer (O'Connor and De La Garza, 1987).

2.8 Summary

This chapter has provided insight to the lukewarm welcome given to computerized scheduling systems. Currently available commercial scheduling systems are incapable of performing the judgemental and higher level aspects of project scheduling. While it is true that computers cannot substitute for or eliminate the need for project managers, they can perform beyond their current algorithmic, accounting and data processing functions. ES based on empirical knowledge and heuristics are capable of making subjective judgements in order to perform intelligent functions. The advantages of utilizing this technology in construction industry are also presented in this chapter. Many systems reviewed in this chapter support the applicability of ES in construction. However, it should be the concern of the pioneers in the development of ES for construction planning to explore, how well the existing systems in the construction industry can be enhanced and integrated with this emerging technology without delivering a new technology or a system which will create a negative momentum in a very conservative environment such as construction. The next chapter presents an integrated software approach, in which expert system technology is combined with the traditional one, making use of the available computing methods and industry practice.

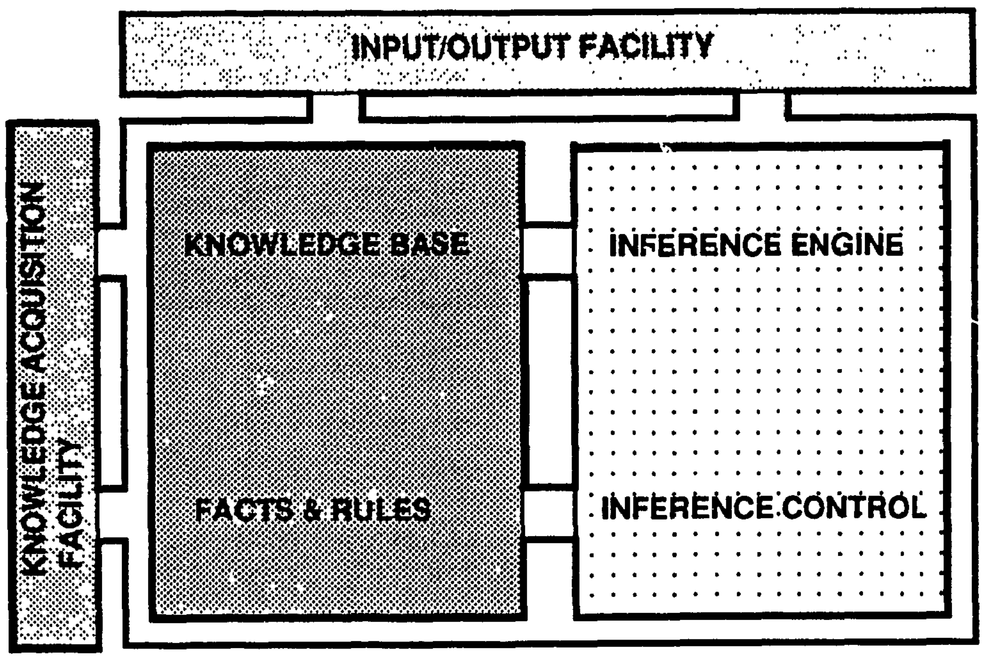


Fig. 2.1 Basic Components of an Expert System

CONVENTIONAL PROGRAMS	**EXPERT SYSTEMS**
General mechanistic areas	Specific area of expertise
Representation and use of data	Representation and use of knowledge
Knowledge and control integrated	Knowledge and control separated
Algorithmic (repetitive) process	Heuristic (inferential) process
Quantitative	Qualitative and quantitative
Effective manipulation of large data bases	Effective manipulation of large knowledge bases
Static decision process	Dynamic decision making
Programmer must ensure uniqueness and completeness	Knowledge engineer inevitably relaxes uniqueness and completeness restarints
Mid-run explanation impossible	Mid-run explanation desirable and achievable
Oriented towards numerical processing	Oriented towards symbolic processing
Programmer maintained	Expert or knowledge engineer developed

Table 2.1 Conventional Programs vs Expert Systems

CHAPTER 3

AN INTEGRATED SOFTWARE APPROACH

3.1 Introduction

While project managers have been using computerized critical path analysis tools to prepare project schedules and to archive the impact of disruptions to these schedules, AI scientists have been trying to make computers automate generation of plans and schedules. The expert systems reviewed in the preceding chapter, some of which are in the operational level (Levitt and Kunz, 1985; O'Connor et al, 1986; Gray 1986), prove that computers can emulate the human inferencing process and can be used effectively in construction planning and scheduling.

While network analysis can be automated in an algorithmic fashion, the heuristic nature of construction makes this implementation approach inadequate. An effective approach to capturing the heuristic aspects of project planning is the use of knowledge-based expert systems (O'Connor and De La Garza, 1987). However, while particularly well suited in automating heuristic or nondeterministic solution approaches, an expert system is typically not efficient in performing numerically intensive procedures (Jones and Saouma, 1988) such as critical path analysis. While there are effective methodologies available for 'number crunching' and to access databases, use of expert system technology to perform the above does not seem right in terms of making efficient use of available computer resources. A different approach from that of the systems reviewed, i.e. fusing existing software tools with heuristics is presented in this chapter, together with the problem statement. Brief descriptions about the function of these software are also stated. A set of selection criteria to choose the most appropriate expert system building tool, to help in implementing this approach is also presented.

3.2 Integration of AI technology with Traditional Computing Methods

Several important trends in the business of expert systems have (IEEE Software, 1986; IEEExpert, 1988) emerged over the past few years and the integration of expert system technology with "traditional technology" is one of them. Whether or not a system is fully embeddable in other systems, and is therefore capable of autonomous operation is becoming increasingly important, now that expert systems are moving from prototypes to being fielded (Gevarter, 1987). In construction industry, there are many traditional software already in use including software for scheduling, database management, electronic accounting, and word processing. If consideration is not given to incorporating them in any future system, the economic loss will be heavy as their past investment in automation is not put to full use. It will also be wrong to substitute available computer systems with AI methodology, which may require special retraining and equipment. It will also avoid the negative momentum generally encountered with the introduction of new technologies, particularly in a conservative industry such as construction.

A solution, then, to the problem of automating generation of schedules would be a hybrid system in which experiential knowledge and engineering judgement are represented using expert system methodology and numerically intensive procedures such as critical path analysis and data storage and retrieval, if any, using available algorithmic methodology. Such a solution would most effectively take advantage of available software tools and further build on current industry practice.

Development of expert system applications are generally aimed at bringing out mass-market oriented packages. And organizations, intending to purchase them would realize they should pay as much attention to management issues surrounding expert system adoption as they pay to technical issues (IEEExpert, 1988). Generally mass market packages gain marketabilty partially due to the integrative nature of their processing with the existing systems. 'Connectivity' referring to communication with different computer systems has become a household word through TV advertising for marketing computer systems. In the long run, organizations that consider purchasing these packages will continue to do so if they have settled matters related to adopting such new techniques. As expert systems proliferate, demand will grow for sharing and access. It is evident that future success of expert systems in the business or office market will depend on how well they can be integrated with existing systems (Richner, 1986). Also, it has become an increasingly weighted factor for equipment purchasers.

Currently, software for scheduling, database management, electronic accounting, and word processing are widely used by the construction industry. A brief description of their functions are presented in the following section.

3.3 Traditional Software

3.3.1 Project Management

Network-based project planning techniques, invented during the late fifties have become indispensable as aids in planning and scheduling after being computerized. Even though these tools may be inadequate for the successful completion of a construction project, they are very powerful and versatile and hence are being maintained by the construction industry. These application software (Fersko-Weiss, 1987; Kerzner and Thamhain, 1986) can plot planning and scheduling networks, illustrate critical path(s), identify available float for each activity, plan and control project resource and budget requirements, prepare cash flow schedules, provide cost-time trade-offs, and summarize the results in conveniently customized forms. These packages can handle any number of projects at one time, making them suitable for scheduling the construction company's total operations. The use of these software permit not only resource allocation on a single project, but also on multi-projects. Provided that the network for the projects considered have been sensibly constructed, multi-project scheduling by these software tend to produce realistic working schedules. Many of these programs have extensive editing procedures that detect loops, hanging activities or events, duplicate activities or events, out of range data, incomplete predecessors and successors etc. Some programs accept activity duration in months, weeks, days, or hours. Some even provide different calendars to be used for different activities depending on the work environment of contractors.

3.3.2 Database Management

Construction industry is in great part an information collection, information processing and information interpretation industry. Current database management packages provide direct ties between different applications, such as material procurement and tracking systems with an account payable system. This integration makes it possible to reduce duplication of items that might be needed by various departments.

There are a number of different ways by which expert system can obtain the data required to drive their inferencing process (Zobaidie and Grimson, 1987). Some expert systems simply capture all the data directly from the user as they interact with the system. Others either collect their data from real-time sensors or use data residing in online secondary storage. The latter is of great importance to the construction industry as they permit close interaction between the expert system and the database.

3.3.3 Cost Management

General ledger accounting, including payroll, account payable and receivable, is part of the construction process. There are many spreadsheet programs available in the market and used by the construction industry. Built-in spreadsheet functions provide exciting arithmetic capabilities for the users.

Cost estimating is a key factor to the success of a construction project. Project cost estimating software are being developed using spreadsheet techniques and are being used by the construction industry (Arditi and Riad, 1988). Current computer technology allows for quantity take-off using digitizer, determination of composition of various cost components of each item and the calculation of total direct cost and associated job overhead. Some come with the library of standard items and their cost database which can be modified, updated, and enhanced.

3.4 Complementing Existing Software

As mentioned in the preceding chapter, many expert system developments reported in the literature are solely developed in the AI environment. As stated earlier, the large size of construction planning problem suggests that it may be more desirable to adopt efficient algorithmic scheduling tools than rely entirely on heuristic methods, which are supported by the AI techniques. The systems reviewed in Chapter 2 take a polarized approach of only utilizing expert system technology. This polarized approach isolates many professional in the construction industry from the business computing mainstream. It often requires special computers and a mastery of exotic languages or memory management. A system which could compliment available systems without introducing construction personnel to unfamiliar AI computer and programming environment will obviously be very much welcomed. Utilizing existing tools saves effort, time, and money, provides general acceptance, and further enhances and builds on gained experience. The construction industry should be able to capitalize on such a hybrid concept that integrates currently available and widely accepted software systems and its associated industry experience and practice.

Complementing expert system technology with other technology is not a new idea. More recently there has been increasing effort in combining algorithmic and heuristic components for designs of structural elements (Jones and Saouma, 1988). This method combines expert system methodology with computational software, application databases and analysis programs.

The object of this research is to develop a prototype of a hybrid expert system to generate project schedules for building projects using commercially available software tools and inexpensive hardware affordable by the construction industry. The proposed prototype hinges on expert system methodology to represent heuristic knowledge about the construction process, currently-used computing method for data storage, commercially available application software for network analysis and programs written in algorithmic languages for interfacing and necessary management of consultation.

3.5 Architecture of the Integrated System

3.5.1 Problem Statement

A thorough plan is one among the essential requirements for a construction project to succeed. Sensitivity analysis shows that the most critical parameter affecting cost and duration of the project, is a proper schedule (Suhanic, 1980). Hence the problem of project scheduling has to be stated clearly in order to develop a feasible architecture for the computerized system that is intended to solve problems encountered and to successfully execute a project. The problem domain may be described in general as follows:

1) A set of projects is to be scheduled.

2) Each project:

    a) consists of a set of activities.

    b) has a schedule dependent duration

    c) once started, should progress at a reasonably consistent rate.

3) Within a project, each activity:

a) has a known duration

b) may not start until certain predecessor activities have finished.

c) requires a predetermined level of resources of a particular kind to be expended.

d) should be interrupted only under exceptional circumstances.

4) Limited resources are available.

Finally, durations of non-parallel critical activities are added up to forecast the project completion time. The forecast will be more reliable if the project environment that is assumed during planning is to remain static during the entire implementation period. The reliability is dependent upon the accuracy of the network logic and on the individual activity duration estimates and more importantly on the incorporation of impact of factors that affect productivity in the estimation of duration. In real life, as the project progresses, the project activities encounter many problems that may lengthen their duration. The causes of these variables are mostly uncertain but predictable which dynamically affect the activity durations (Ahuja and Nandakumar, 1985).

Currently the impact of these factors are considered intuitively to forecast activity duration, and the effectiveness depends upon the skill of the scheduling engineer. The early indication of delay through a reliable forecast allows decision to be made in a less hectic environment and an awareness of the project status helps keep the project on schedule. Any computerized system intended for construction scheduling should be able to provide a realistic forecast of the project duration.

3.5.2 System Architecture

KBES in the domain of construction planning and scheduling must be able to interact with the systems representing all types of knowledge required for this domain. Given a project, the system should help the user to breakdown the project and identify all time consuming activities and milestones and prepare a schedule based on the precedence relationships among the activities. It should analytically combine the impact of all uncertainty variables and incorporate it in the activity duration estimates. Literature survey supports the significance of these variables and many studies (Adrian, 1987; Benjamin and Greenwald, 1973; Carr, 1979) have been done to quantify the impact of these variables. Studies reported by Ahuja and Nandakumar (1985) reveal that early recognition of future events such as potential delay can be significantly helpful to the contractor and the owner in reducing their effects. Five important variables have been chosen for this study and they are discussed in the next chapter.

The architecture of the system is conceptualized, based on the recent developments and advancements made in available software and hardware tools. As stated earlier, basic consideration is given to the integration of currently used computing methods with the expert system technology to solve problems in generating construction schedules. Even though the system architecture is so conceived as to make it easily expandable to accomodate all the issues mentioned in the 'Problem Statement', this work concentrates on the function of the system, once the user has identified the activities in a project and assigned normal, unimpacted duration to each activity. This system aids in developing a realistic and accurate baseline schedule against which all progress and performance can be measured. The concept of scheduling with this system is shown in Fig. 3.1.

The initial architecture of the expert system consists of three knowledge base modules. Module 1 identifies the arbitrary assignment of activity description, input by the user, with the system compatible one. Module 2 sets the precedence relationships among the activities entered, using the knowledge on traditional construction practice. Incorporating the impact of the uncertainty variables is the function of Module 3. To achieve greater modularity, Module 3 is further sub-divided into sub-modules, each consisting of knowledge related to a particular uncertainty variable. Architecture of Module 3 allows addition of more such sub-modules if other uncertainty variables are considered more significant for a particular activity or activities. The architecture of such a comprehensive expert system is shown in Fig.3.2.

The modularization stated here, involves decomposing the problem into sub-problem modules and providing appropriate linking between these modules as required during operation. Changes can be carried out quickly and easily in one module without impacting the rest of the modules. Further modules can be added, as and when required or when knowledge base is ready. Hence modularization allows for greater flexibility and growth of the system and provides the foundation for future development and enhancement.

Apart from integrating the ES modules, the system also interacts with a project scheduling software for necessary network analysis and with a relational database for necessary data retrieval or storage (Moselhi and Nicholas, 1988). Programs written in an algorithmic language (FORTRAN) complete the necessary integration. A DOS (Disk Operating System) batch file unifies all the different software modules of the system.

The next step in the implementation of this architecture involved the selection of a suitable development environment. In some instances, traditional procedural programming languages - such as Fortran and Pascal - have been used to implement these systems (Maher, 1987). While the efficiency of such implementations is largely acknowledged, they cannot adequately satisfy many other essential requirements, especially transparency, modularity, and flexibility (Bruno et al, 1986). In procedural languages, the knowledge representation and use, turn out to be embedded in the program's control flow. Adding, deleting, or updating the knowledge base is time consuming for even a skilled programmer. During the past several years, dozens of tools providing expert system development environment have become available commercially.

3.6 Expert System Building Tool (ESBT)

First generation of ES have almost invariably been written in declarative languages like LISP and PROLOG and in AI environment (Martorelli, 1988). However, the early work on ESBT is associated with research on MYCIN, an expert system that diagnoses infectious diseases of the blood (Buchanan and Shortliffe, 1984). Part of the research effort included designing the MYCIN program in a modular fashion: the knowledge base was kept separate from the inference engine. This modularity made it possible to lift out the knowledge base used to diagnose infectious diseases. The resulting program was named EMYCIN (Empty MYCIN). It provided a shell that could house knowledge bases from other domains. Using EMYCIN, a system developer could concentrate on acquiring knowledge and putting it in programmable form, instead of spending time on developing the inferencing mechanism.

Now, commercial derivatives of these AI systems are developed by AI researchers at universities and research organizations (Gevarter, 1987) to ease the development of expert systems in various problem domains by those who are not familiar with AI technology. They provide standard ways for representing and manipulating knowledge and are designed for creating, modifying and testing expert systems and come with various support facilities. Availability of ESBT has eliminated time consuming study of special AI languages and the usage of specialized computers; thus breaking the barrier for professionals who are outside the AI research environment to develop ES in their own problem domains. Since many such tools are currently available, choosing the 'right' tool for a particular application is a very important task.

It was found difficult to choose any tool without proper consideration of that tool's intended use. A tool excellent for commercial use may be inadequate for research purposes and vice versa. In planning, there are many conflicting requirements and contingencies to consider. The knowledge and expertise required, come from several disciplines and would be descriptive and procedural. In order to communicate with different trades, knowledge dissemination by the system will have to allow for textual, numerical and graphical forms. The data required to drive the inferencing mechanism may come from users, and data residing in on-line secondary storage. The system in this problem domain may not only be used for forecasting but also for diagnosing problems. Thus the tool to build a KBES for construction planning and scheduling should be extremely versatile and flexible.

3.7 Selection Criteria

Part of this study was spent on establishing a set of selection criteria for the most appropriate tool to implement the architecture of the system (Moselhi and Nicholas, 1988a). The established criteria were then applied to many ESBT currently available in the software market. Information on specific tools was gathered from technical reports, magazine articles, user manuals and from hands-on experience. Table 3.1 shows the selection criteria established during the study. The 16-point criteria are based on knowledge of construction planning and scheduling, evaluation of traditional project management software and on a detailed review of the literature pertaining to this field. The following section explains the 16-point criteria.

Knowledge Representation: The key consideration in selecting an ESBT is how easily the knowledge can be represented in it (Gevarter,1987). Transparency of knowledge is also very important. Certain kinds of knowledge are more easily represented in one method than in another. The objective here is to select a method which embodies the real world application. In representing the knowledge about construction planning and scheduling, the descriptive knowledge about different objects, their attributes and values and the relationships among them are intertwined with the procedural knowledge, related to how the objects behave and their values change under various conditions. For example the object, duration of an activity includes labour productivity as one of its attributes. The value of productivity depends on many variable factors like weather, site geology etc. Heuristic rules have to be applied to choose a value for the productivity factor associated with different weather,site geology etc. This necessitates various forms of knowledge representation (frames, object-attribute-value (O-A-V) triplets, rules,etc.). The facility for hybrid programming incorporates the best of all methods without inherent disadvantages.

Knowledge Inference: A user of a KBES in construction planning and scheduling may want to volunteer data or expect the system to suggest one. He may use this system for forcasting as well as for diagnosing. Hence an ESBT will have to allow for various forms of inference strategies. Inference mechanism should include pure deduction, backward- and forward-chaining and class inheritance. The user may want to check the availability of material before estimating the duration of an activity or before performing cost-time trade-off analysis. This requires user controlled inferencing. Also an efficient search technique is important to account for the criticality of time and accuracy. This could include depth-first and breadth-first methods.

Handling Uncertainty: It is important to establish to what degree the knowledge and/or the data is known to be correct. There are many risk factors such as those associated with site geology, labour productivity, availability of material etc. In an effort to handle the inherent uncertainties associated with the above and others, an ESBT should be able to incorporate imprecise and incomplete data and the degree of uncertainty attached to them. This particular tool should also allow the user to select alternative parameter values and contingencies and observe the effect on the outcome viz. cost and profit.

Explanation Facility: Many of the functions in construction industry are performed at locations far from the head office, where experts may not be available at the right time. An ESBT with extensive explanation capability will not only help an inexperienced site manager to take decisions but also to train him for further assignments. An ES should be able to explain how it arrives at a specific decision or why an alternate decision is to be taken. It should also be able to explain how a piece of information is used or why a piece of information is ignored and what decisions are made for the sub-problems (McGartland and Hendrickson, 1985). The ability to answer the user's questions of 'WHY' and 'HOW' increases the user's confidence in implementing the decisions. The above is one of the characteristics which differentiates the ES from conventional programs.

Development Facility: The speed and ease with which a KBES can be developed is the primary concern of any ES builder.This can greatly enhance or impair the productivity. The features that facilitate the development of a KBES include base editors, browsers and the ability to report errors. Features can also include the ability to check the integrity of the KB to find out contradictory facts or rules, discover missing or redundant information and find syntactical errors. Spelling checkers are also important. An ESBT should also provide graphical representation of KB in order to visualize the hierarchical relationship of knowledge and a clear design of question phrasing and amplification.

Reporting Facility: As stated earlier construction planning and scheduling is performed by a multi-disciplinary team. Hence it requires an effective method of communication to deal with the various disciplines involved. There are activity network diagrams to represent the precedence relationships among activities and project duration, resource histograms for allocation of resources and cost and performance curves to represent progress at site and many other reports as media of communication. Hence the reporting facility of an ESBT is an important criterion in selecting an ESBT for planning and scheduling.

Integrating Traditional Software: A KBES should be able to utilize a conventional software (project scheduling software) as a front end and/or back end system. Hence, an

ESBT should be able to interface with them by simple calls like built-in software management functions. This will enhance the application of the conventional software. It should also be able to interface with other software like word processors, spreadsheets, relational database management systems, graphic software and communication programs.

Capacity: An ESBT usually has an upper limit on the number of rules or frames that can be stored in the system. Although many have high limits, it imposes a significant problem on the quality of the KBES. Depending on the use of the system and on the depth and breath of the problem domain, the capacity of the system required can be determined. Since the number of variables in construction planning and scheduling are less, compared to medical diagnosis etc., huge capacity is not required (Avots,1985).

Hardware Requirement: As mentioned earlier, in construction most of the functions a e carried out at a number of individual sites away from the head office and possibly in harsh environments. Hence one should look into the availability and the transportability of the hardware. Small size and robust design make micro-computers more appropriate. Faster 32- and 16 bit micro-processors and inexpensive memory enhancements make them even more attractive. Even though run time versions can be built on mainframe and then transferred and installed on micro-computers, in order to make changes in the KB quickly a micro-based expert system is favoured for construction applications. Hardware considerations should include vendor support, on-going maintenance and hardware expansion and upgradability.

Cost: Historically, construction industry is not a stable one and one has to think twice prior to making any financial commitment. ESBT has a high start-up cost. For micro-computers the low cost of ESBT has eliminated this barrier but for mainframe applications cost remains high. It should also be noted that multiple copies of the system are required to send to various sites. In purchasing an ESBT, cost of software, hardware, support and training should be considered. Some ESBT even require additional software to run. Size and financial stability of the organization and the intended use of the system should also be looked into.

Documentation and Support: Documentation should be easy to understand. Depending on the design of the system it could be a printed manual or on-line or both. An easy to understand user/reference manual with a complete tutorial to test all aspects of the tool is an important part of the system. Product support should include consulting arrangements, phone and mail assistance and optional training.

Knowledge Engineering Required: An ESBT should permit the system developer to communicate with the computer without learning complex commands or a new language. This increases the functionality of an ESBT. Communicating in natural language should be the key in designing an ESBT for construction planning and scheduling. The amount of planning effort and the expertise required to structure and encode the knowledge will prove to be impractical to a domain expert. In choosing a tool one should be certain about whether it requires a prior knowledge of programming or skill to develop an application.

Alarms to Take Measures: Construction scheduling is a combination of monitoring the progress and taking appropriate action which requires problem flagging and problem diagnosing. Hence a KBES should be able to provide timely responses and inform the user of any action to be taken for cost overrun, material shortage etc.

Execution Time: A KBES requires more machine cycles compared to conventional software to perform pattern matching, searching and researching to solve problems. During a time of crisis the project managers are frequently under pressure to produce timely updates of time and cost of revised schedules, take corrective actions and make appropriate decisions. Hence lack of processing speed would cause irritation and frustrate the user as well as the builder. An ESBT also requires an efficient memory management environment. During consultation, compiler based system which occupies less space runs faster than an interpreter based system but the development time is slowed due to compilation requirement.

User Defined Functions: Different construction companies have different management needs and operational priorities. An ESBT should allow the user to customize the system to his/her particular work environment and the problem domain, and also for augmentability, i.e. to accomodate expansion in component computational functions. An ESBT should be flexible enough to perform a variety of functions required by the user including incorporating system defaulted properties, pop-up windows to echo informations regularly required by the user and blinking important messages on the monitor when required.

Portability: The primary factors which should be considered in construction planning and scheduling are the remoteness of construction sites and dynamically changing locations.In order to distribute the application systems to various construction sites, an ESBT should provide easy methods to make run time versions of that system and be ported to variety of computers. With the proliferation of micro-computers at these locations, micro-based consultation systems are more suitable.

3.8 Evaluation of ESBT

The criteria discussed above are then applied to a number of currently available ESBT. The results are summarized in Table 3.2, outlining the facilities and the limitations of these tools in developing a KBES for planning and scheduling (Moselhi and Nicholas, 1988a).

Integration of traditional software and the hardware requirement were the most important factors considered in the selection of the ESBT, for the implementation of the concept suggested in this study. Many, if not most, ESBT permit only crude interaction between their domains and the outside automated world. Some 'shells', fully integrated within themselves, support access to built-in word processing, data communications, spreadsheets, and related utilities. Other shells allow 'breakouts' to other programs or the running of batch operating system commands. And some shells can import or export popular file formats (Lotus 1-2-3 or dBASE III). Unfortunately, these are only small steps towards integration rather than "full" integration.

When developing an engineering application system, the identification of the intended group of end-users, and their familiarity with and accessibility to different computer environments are of major considerations. The use to which a particular system can be put depends on the sophistication of the user (Bowen and Edwards, 1985). Knowledge representation technique is another important criterion. Some tools only allow for rules, and some provide multiple methods for knowledge representation such as frames, O-A-V triplets, etc. In future, it is expected that differentiating expert system tools based on knowledge representation method, or by inferencing technique will go out of fashion or at the least, a standard set of such features will become accepted without drawing too much attention. The trend in ESBT is toward less expensive, versatile, and portable tools.

Even though many of the factors mentioned in the list of criteria may be known in advance fr(developers' specifications, one can only evaluate two tools intended for the same purpose, only by building and testing the same application system using both. Although the set of criteria is established for a particular problem domain, it can be further extended and applied to other domains.

3.9 Summary

This chapter has been devoted to a discussion on the need for an integrated software approach in implementing exnert systems for construction planning and scheduling. It is very important to assume a gradual and feasible approach in introducing a new technology to a conservative industry. The selection criteria established for choosing the appropriate development environment is also dealt with in this chapter. In a rapidly expanding field, it is hard to keep up with the newest hardware and software technology. But the criteria established can act as a check list. Details about the system developed and its various components are presented in the subsequent chapter.

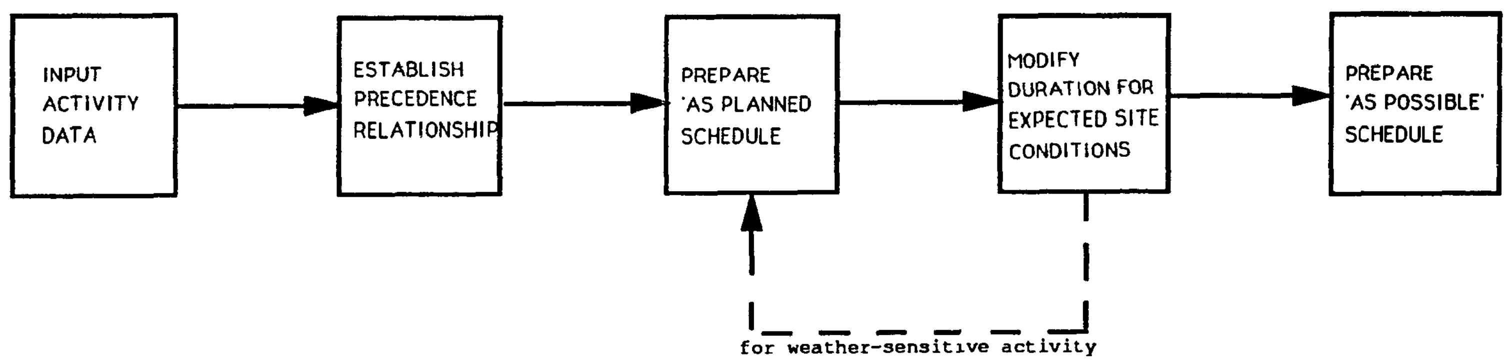


Fig. 3.1 Concept of Scheduling in the System

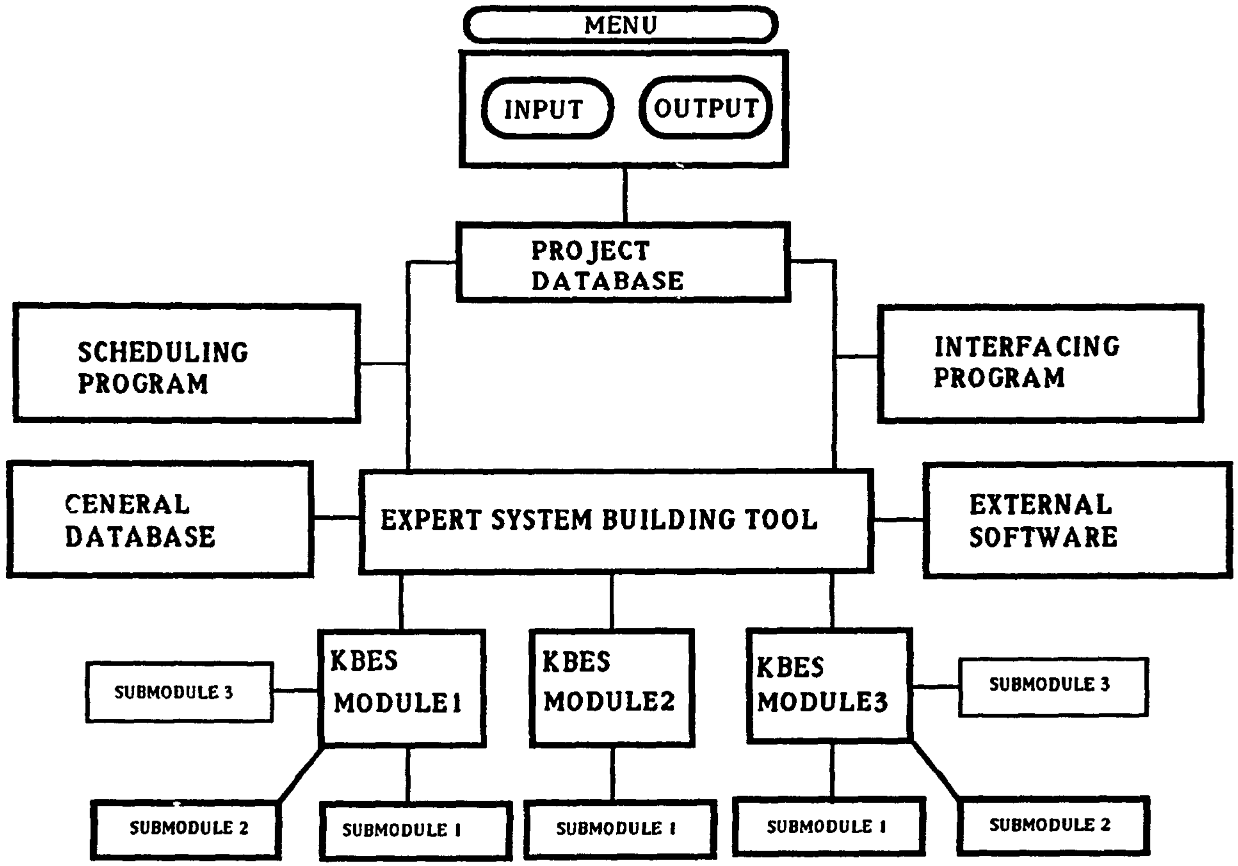


Fig. 3.2 Architecture of Integrated KBES for Construction Scheduling

1) Knowledge Representation
2) Knowledge Inference
3) Handling Uncertainty
4) Explanation Facility
5) Development Facility
6) Reporting Facility
7) Integration of Traditional Software
8) Capacity
9) Hardware Requirement
10) Cost
11) Documentation and Support
12) Knowledge Engineering Required
13) Alarm to Take Measures
14) Execution Time
15) User Defined Functions
16) Portability

Table 3.1 Selection Criteria for ESBT

NO	CRITERION	EXPERT SYSTEM BUILDING TOOL									
		GURU	PC PLUS	OBJECT NEXPERT	M1	GOLD WORKS	OPS5	ART	KEE	S1	KNOWLEDGE CRAFT
1	KNOWLEDGE REPRESENTATION	SR	SR	OB R	R	OB R, FR	R	OB R, FR	OB R, FR	SR	OB R, FR
2	KNOWLEDGE INFERENCE	BC FC	BC FC	BC FC	BC	BC FC	FC	FC	BC FC	BC	BC FC
3	HANDLING UNCERTAINTY	CF	CF	CF	CF	CF	-	CF HR	CF HR	CF	CF HR
4	EXPLANATION FACILITY	Available	Available	Available	Available	Not Available	Not Available	Available	Available	Available	Available
5	DEVELOPMENT FACILITY	Fair	Fair	Fair	Poor	Good	Poor	Good	Good	Good	Good
6	REPORTING FACILITY	Good	Fair	Fair	Poor	Good	Poor	Good	Good	Good	Good
7	INTEGRATING SOFTWARE	Available	Available	Available	Not Available	Available	Not Available	Not Available	Not Available	Not Available	Not Available
8	CAPACITY	1600 Rules	500 Rules	Limited	200 Rules	Extensive	Extensive	Extensive	Extensive	Extensive	Extensive
9	HARDWARE REQUIREMENT	Micro Computer	Micro Computer	Micro Computer	Micro Computer	Micro Computer	Main Frame	Main Frame	Main Frame	Main Frame	Main Frame
10	COST (K) US $	65	30	50-80	50	75	75	29-80	550	25-50	35-50
11	DOCUMENTATION & SUPPORT	Poor	Good	Fair	Fair	Good	Fair	Fair	Good	Fair	Good
12	KNOWLEDGE ENGINEERING REQUIRED	Limited	Limited	Extensive	Limited	Limited	Extensive	Extensive	Extensive	Limited	Limited
13	ALARMS TO TAKE MEASURES	Not Available	Not Available	Not Available	Not Available	Available	Not Available	Available	Available	Available	Available
14	EXECUTION TIME	Slow	Slow	Slow	Slow	Slow	Slow	Fast	Fast	Fast	Fast
15	USER DEFINED FUNCTIONS	Possible	Possible	Possible	Not Possible	Possible	Not Possible	Possible	Possible	Possible	Possible
16	PORTABILITY	Possible	Possible	Possible	Not Possible	Possible	Not Possible	Possible	Possible	Possible	Possible

Table 3.2 Summary of Evaluation of ESBT

__Abreviations:__

R - Rules
OB - Objects
CF - Certainty Factor
SR - Structured Rules
BC - Backward Chaining
HR - Hypothetical Reasoning
FR - Frames
FC - Forward Chaining

CHAPTER 4

EXPERT CONSTRUCTION SCHEDULER (ESCHEDULER)

4.1 Introduction

This chapter presents the development and implementation of the basic architecture that supports the concept of integration presented in the earlier chapter. Various components of the system and their function in the overall control process are described. First, an introduction is given to the KBES environment and then, the factors which influenced the selection of the ESBT to implement the architecture is discussed in detail. The contents of the knowledge bases and their importance in planning and scheduling construction projects are also discussed in this chapter.

4.2 KBES Environment

EXPERT CONSTRUCTION SCHEDULER (ESCHEDULER) is a rule-based hybrid prototype expert system for planning and scheduling of building construction projects. It receives information from the user about the description and normal, unimpacted duration of all activities to be performed in a building project. The development of the schedule is a two step process which generates an initial 'as planned' and a revised 'as possible' schedule at two different stages of consultation. The system consults three different KBES, of which one consists of five nested ES modules. It interfaces with traditional algorithmic software tools to produce the two above mentioned schedules (Moselhi and Nicholas, 1989). Fig. 4.1 provides a schematic illustration of the system environment. It integrates on-line databases provided by the ESBT to store the operational data required for consultation. An external algorithmic software is used to perform network analysis. Two interfacing programs written in FORTRAN are developed to enable the integration of the external software with the KBES. A DOS batch file controls the consultation process. A detailed description of the components of the system is given below. The following section explains why GURU™ was chosen as the appropriate ESBT of the KBES environment to implement the integrated software approach.

4.3 GURU™ - AN ESBT

The GURU™ expert system building tool was chosen after a comprehensive evaluation of a number of expert system shells (Moselhi and Nicholas, 1988) available in the market based on the facilities available for a price the users could afford and on the needs of the automated construction office environment. It is marketed by Micro Data Base Systems Inc. of Indiana, U.S.A. The specific features that influenced the choice are discussed below.

Knowledge Representation: Although there are numerous approaches to representing knowledge, most of them are highly complex and impractical for commercial application. In the industrial environment, the measure of applicability of a representation method must be its ability to accurately represent expert knowledge in the form that is clear and accessible to both the expert and the inference mechanism. It should be remembered here, that transparency of domain dependent knowledge is a distinguishing feature in KBES (Fenves, 1986). GURU[tm] allows the domain knowledge to be represented in the form of production rules which are easy to identify and understand. At this experimental stage, rule based approach is found adequate for the prototype, because scheduling problem can well be described by a set of event-driven activities operating on a database containing information on the relevant system state variables. Also, decision rules in construction management text books tend to look very much like the "IF (condition) THEN (action)" rules that are employed to represent knowledge in rule-based expert systems (Levitt, 1987). While the rule-based approach may seem simplistic, it can be a highly successful method of representing knowledge that is not algorithmic or deterministic (Finn and Reinshmidt, 1986).

Knowledge Inference: GURU[tm] is capable of using both backward- and forward chaining for inferencing values. It allows the user to assign priority and/or certainty factor to each rule to help in rule selection strategy, thus controlling the consultation process.

Explanation Facility: For any given problem GURU[tm] can explain the line of reasoning it used in reaching the solution. However explanation facility in GURU[tm] is somewhat disappointing, for it has to be written by the developer, while an automated display of the text of rules fired by the system would be preferable as made available in few other tools. It can also reason with uncertainty.

Hardware Requirement: GURU[tm] can be operated on a personal computer (IBM PC, XT, or AT, minimum RAM of 512K and hard disk storage and PCDOS or MSDOS operating system). Personal computer (PC) is the most popular machine in the construction industry of which the majority are small size contractors, who cannot afford to invest on sophisticated computers and on their related peripherals. PC are made available, even at remote sites. As the consultation systems will often be used in multiple offices, PC becomes the choice of the construction industry. The proliferation of PC in construction industry provides an existing hardware vehicle for product delivery. It should be noted that "you don't need a learning, thinking, AI-type machine to have someone at the side of a businessman who is up-to-date on all the details of his business. But you do need AI's technique to process English commands and to define this businessman's fuzzy questions." (Shank and Childers 1984). It has been found out that access to a personal computer affords an environment in which people are most willing to participate in the expert system development process (Finn and Reinschmidt, 1986). The trend toward making expert system shells, available on personal computers results in part from the increasing capabilities of these computers (Shafer, 1985). A market research company in U.S. has estimated that expenditures for PC, related primarily to the development and delivery of expert systems, were about $70 million in 1987. By 1989 it expects this figure to increase tenfold (Martorelli, 1988).

Integration of Traditional Software: GURU[tm] blends most of the familiar business computing environment into a unique AI environment for business users. It supports database management, spreadsheets, text processing, structured programming, and remote communication. Hence, it is free of the inconveniences and 'culture shock' that alien AI software deliver to business users. The inter-system communication provided by the tool allows these different systems to coexist as independent systems but provides some form of communication among them. Its complete structured programming language with major control structures helps in consulting different modules of an expert system within a procedural model as well as interactively.

Development Facility: Conventional ESBT are isolated from the business computing mainstream. They often require special computers and mastery of exotic declarative languages like LISP or PROLOG. GURU[tm] provides easy development facility to design input/output forms. The source text can be written by its text processor and/or by an external editor. It also provides a menu/template interface for easy development. GURU^tm provides different types of variables which are declared during the development stage to define the operating & consultation environment. The environment variables which describe the configuration within which GURU^tm can be made to operate and the utility variables which are used to track the effects of GURU^tm processing can be pre-defined.

In addition to rules and a goal variable, a rule set can contain an initialization sequence, a completion sequence and variable descriptions. An initialization sequence is a series of commands that will be executed as soon as a consultation is requested. This happens before any rules are considered. Similarly, a completion sequence will be executed as soon as all reasoning with the rules is completed.

Fig. 4.2 illustrates the various elements of the system and Table 4.1 provides the summary of the steps involved in developing an ES with GURU^tm. Even though GURU^tm does not allow for other knowledge representation techniques, in view of the characteristics and the architecture of ESCHEDULER, and the availability of the tool at Computer Aided Building Design (CABD) Laboratory, it was decided to use GURU^tm as the suitable tool for the development of the prototype.

4.4 Components of ESCHEDULER

ESCHEDULER contains three modules with knowledge bases one of which consists of five sub-modules. The function of these modules are described below.

4.4.1 ACTIVITY TRANSLATOR

This module initiates the consultation process, requesting the user to enter the project information, such as the name of the project and to specify the data on holidays. The primary function of this module is to check the arbitrary activity description input by the user for the compatibility with the system knowledge base (KB). This system consults the KB consisting of rules similar to the following to check whether the activity description input by the user is system compatible. The activities commonly encountered in a building project are represented in the rule base.

```
IF activity description is EXCAVATION
                     OR        DIG FOUNDATION
                     OR        EXCAVATE FOUNDATION
```

THEN replace activity description with EXCAVATION.

The system immediately advises the user of the change in activity description, if it is different from the system description. This change is deemed necessary for the ensuing operations. It also minimizes the memory requirement of the other KB modules and the processing time of the computer which are essential for a micro-based system.

Alternatively, the user has a choice of selecting activity descriptions compatible with other KB modules, directly from a menu displayed on the screen. The menu consists of a list of common activities usually encountered in building construction. This reduces the time taken for input and hence speeds up the time taken for consultation.

As the initial data on activities are input by the user, they are written on a disk for later retrieval for following operation. This module also prepares two batch files, 'prim1' and 'prim3', one to initiate the project with project information and holiday data and the other to perform network analysis by the project management software. Fig 4.3 illustrates the program flow.

4.4.2 JOBLOGIC HELPER

This determines the physical precedence relationships among the activities input by the user. It begins by creating a database of basic data on the activities by retrieving them from the disk storage mentioned in the above paragraph. Once the activity descriptions, compatible with other KB modules are transferred to the database LISTACT in GURU[tm], JOBLOGIC HELPER goes through all the activities in the above database and checks with another database LOGILIST for possible dependency between any two activities under consideration. It then consults the KB for their relationship.

The KB on physical precedences is based on necessary sequence of activities for a building project and element of work using commonly known rules of thumb based on current and established construction practice and physical laws. In scheduling activities, following principle is used. A task should generally be completed, after completing the elements which provide support to it or for which it provides enclosure. This principle is arrived at by considering the functional relationship among building components and the interaction among different trades involved in the construction process. Generation of schedules for specific activities and sequencing is done by employing the above principle and using proper representation technique. This constraint-based approach uses specific predecessor-successor relationship among activities. The following is a sample rule in the KB:

```
IF          activity A is EXCAVATION
     AND    activity B is PLACE FORMWORK
THEN        PLACE FORMWORK succedes EXCAVATION.
```

In GURU, each rule section can contain preparatory actions that will be taken once the rule has been selected for consideration, but before the rule's condition is evaluated. A procedural programming incorporated in the preparatory action can aid in differentiating multiple activities of the same type. These can also be differentiated by proper activity descriptions. The latter method is used in this study.

The system also questions the user for his/her input to determine the type of link (start-start, finish-start, finish-finish), and the lag time between two activities. These data are necessary for network analysis, performed by the external conventional project scheduling software. At the end of the consultation this module prepares an input file, 'prim2' for the scheduling software with activity descriptions and their precedence relationship. See Fig 4.4, for the flow chart.

4.4.3 DURATION MODIFIER

This module consists of five nested ES sub-modules, each containing KB pertaining to one of the following five factors which impact the productivity level of an activity at any given site: overtime, site congestion, re-assignment of labour, learning curve, and weather. Except for weather, the user is asked to describe the condition on site in a simple and direct way and/or fill in the data required by the system. The productivity levels associated with each of the five factors are obtained from available literature (Anon, 1976; Adrian, 1987; Koehn and Brown, 1985) and stored in the system. These contain the percentage of loss of productivity under a range of adverse site conditions. Except for weather, the user is asked to describe the expected adverse condition on site as one of the following: minor, average or severe. Here is a sample of the database for the impact of re-assignment of labor (Anon, 1976):

Condition :	Minor	Average	Severe
Productivity Loss :	5%	10%	15%

In the case of overtime, the user has a choice of describing the condition as above or by choosing a number pertaining to the total number of days and number of hours in a day expected to work during a week. Productivity loss related to the number of overtime hours is also stored in the system. By consulting the necessary KB the system modifies the standard durations of impacted activities to a realistic 'as possible' duration.

Duration adjustment to a weather sensitive activity is based on the early start and early finish dates of that activity. Average temperature and humidity for each calendar day of the duration is extracted from the database to assist in determining the productivity level for each day. Following two non-linear relationships showing construction productivity as a function of temperature and humidity are used for this purpose (Koehn and Brown, 1985).

$$Pc = 0.0144T - 0.00313H - 0.000107T^2 - 0.000029H^2 - 0.0000357T.H + 0.617 \quad \text{(applicable between -20 and 50F)}$$

$$Pw = 0.0517T + 0.0173H - 0.00032T^2 - 0.0000985H^2 - 0.0000911T.H - 1.459 \quad \text{(applicable between 70 and 120F)}$$

where
Pc = productivity factor for cold weather;
Pw = productivity factor for warm weather;
T = temperature in degree Fahrenheit;
H = relative humidity as a percent.

In order to obtain a smooth transition between the above two equations, they are normalized as a function of their respective maximum values and productivity at 60 F and 70 F is arbitrarily taken as unity, as explained by Koehn and

Brown. The above equations were obtained from historical data gathered from a number of sources and they agree with the findings of other researchers (Thomas and Yiakoumis, 1987). See Fig. 4.5 for program flow.

4.4.4 Databases

ESCHEDULER makes use of the relational database management system provided by the ESBT. The extended programming language of this tool gives direct access to the database. There is a dynamic link between the ES and the database. Data are retrieved from the database only when required during the operation of the ES. The developmental system at this current stage makes use of the following four databases:

a) LOGILIST contains record on description of any two activities, commonly encountered in a building project, which are dependent on each other. This database was created at the beginning of the implementation of ESCHEDULER, in order to generate rules for precedence setting for activities which are linked to each other. JOBLOGIC HELPER checks with this database whether the two activities under consideration are linked in any way, prior to consulting its KB to determine their relationship. This database not only helps in documenting the list of activities already included in the KB, but also helps in managing the rule base since it becomes tedious as its size increases. The greatest advantage of this database is experienced during the consultation with JOBLOGIC HELPER. A significant amount of time is saved as it directs the search for the relevant rule, only if it exists in KB. Hence unneccessary search in a large rule base, which may be futile for activities not linked to each other, is avoided. It allows greater memory management by leaving the random access memory (RAM) free for other operations.

b) <u>WEATHER</u> contains the predictable weather pattern for the city of Montreal based on a ten-year historical climatological data. The daily probable average temperature, humidity and windspeed for each day of the year are stored in the database.

In order to simulate the annual weather pattern for the city of Montreal, historical data on climatic conditions were used. A ten-year (1971-1980) weather data stored in a magnetic tape provided by the Atmospheric Environment Service of the Canadian Climate Centre, was accessed by Digital Equipment VAX computer, at CABD Lab of Concordia University with a program written in FORTRAN. The hourly weather data during the work hours (7 am - 5 pm) of each day of the year are averaged to derive the probable weather pattern for each day.

c) <u>CALENDAR</u> stores the work calendar of the project, including holidays. At the beginning of the consultation the user has the option of entering more holidays like Christmas and construction holidays, when applicable. As the date of a holiday is entered by the user, the system makes the necessary change in CALENDAR. The enhancement of the database system of the ESBT allows data sharing between CALENDAR and WEATHER databases by making use of its programming language. This helps in ignoring the impact of weather on an activity during a holiday period, when no work is actually performed.

d) <u>LISTACT</u> contains the list of activities along with their codes and durations. These raw data are entered by the user during the consultation with ACTIVITY TRANSLATOR. The ES, JOBLOGIC HELPER creates this database during consultation and later retrieves data on activity description from this storage for precedence setting.

e) <u>PROJREC</u> stores the project record extracted from the schedule report produced as an output by the external project scheduling software. Its fields are activity code, activity description, duration, early start and early finish dates. The ES, DURATION MODIFIER creates this database during consultation and accesses it during consultation for retrieval of project records and to make the necessary changes in duration of activities, after consultation.

Creation of the last two databases is automated. Records for these two tables exist in an ASCII text data file before being transferred to respective GURU™ databases.

4.4.5 PRIMAVERA[tm]

This is a menu driven, widely used commercial project scheduling software. Its major functions are scheduling, resource leveling and cost control. Either precedence or arrow notation may be used to schedule as many as 10,000 activities. A large variety and number of schedule, resource and cost reports and plots are available from the system.

Primavera[tm]'s batch data entry system expedites the development of project schedules. There is a batch command for each category of project data input. This requires the creation of ASCII text file containing specific network or schedule data. Primavera[tm] processes the file in its entirety through the batch routines and tests the data for the compatibility. Diagnostic messages are directed automatically to the printer or monitor, whichever the user may choose. If no errors are detected, the diagnostic report displays an audit trail of selected batch commands. Record formatting for the batch files are very important. After processing, the user can enter Primavera[tm] in the usual manner and use the interactive system to prepare reports.

4.4.6 TARGET1 and TARGET2

Two FORTRAN programs, TARGET1 and TARGET2, are developed and incorporated in ESCHEDULER to format the files to the requirements of the software tools used. One prepares input files to the project scheduling software, Primavera[tm], and the other reads the schedule report output by the same software and prepares the ASCII text file with relevant information in order to attach them to GURU(tm) database, PROJREC.

4.4.7 ESCHEDULER.BAT

Procedural language of the ESBT and its enhanced data management system are used for the flexible but tight integration of the various essential components of the prototype system. If the user wants to consult any sub-module ESCHEDULER provides the flexibility to access that particular module.

A DOS batch file was created to unify and run different software modules and their functions. It allows the user to work with the system by simply typing **escheduler.** Personalized commands are used to control the operation. Commands with replaceable parameters allow output files from the consultation with KBES to be processed by the external software, Primavera(tm). Batch files provided in this software, with commands to process ASCII files, are modified to accomplish this task.

Manipulation of various knowledge elements to arrive at a realistic duration and their importance are described in the following section.

4.5 Components of DURATION MODIFIER

Contractors, generally, are required to complete projects within a specified contractual completion date. However, circumstances that are beyond control often prevent contractors from completing their projects. Construction contracts are fraught with uncertainty (Carr, 1979; Ahuja and Nandakumar, 1985) and usually require contractors to consider normal delays in the preparation of their schedules. Delays occur when a contractor fails to forecast adequately the construction process and the resulting uncertainties associated with overtime, site congestion, re-assignment of labour, learning curve and various other delays. The module DURATION MODIFIER consults the following sub-modules to arrive at a realistic duration for the activities scheduled.

4.5.1. OVERTIME

To accelerate the construction schedule or to recover lost time, construction crews commonly work overtime during project execution. Project managers always take the first option of having their labour crews work overtime without considering the effect on overall productivity. Adrian (1987) indicates that scheduled overtime operations bring about a sharp initial drop in productivity as workers repace their output. It lowers work output and efficiency through physical fatigue and poor mental attitudes. This is usually followed by a recovery of productivity after a week or two. Productivity again drops substantially after a few more weeks. The negative effect of overtime is greatest when a crew is required to work overtime for a substantial period. OVERTIME, the KB on the impacts of overtime contains rules to utilize the information shown in Table 4.2 and also the percentage of productivity loss for different adverse site conditions.

4.5.2 CONGESTION

Site congestion may result from the physical features of the project or from the high density of tradesmen working in one area. Several concurrent activities may be scheduled within a confined area in the preparation of the initial schedule. As the project progresses, different activities are advanced or delayed to meet the schedule changes. Consequently, activities under progress in a confined area may interfere with each other for working space requirement. This results in congestion of personnel, inability to locate tools conveniently,increased loss of tools,additional safety hazards and increased visitors (Anon, 1976). Usually productivity loss due to congestion, not being part of estimating activity duration, is generally not accounted for in schedule computation (Ahuja and Nandakumar, 1985). In ESCHEDULER, expected productivity loss due to congestion which may be predictable at the inception is accounted for in the calculation of realistic activity durations. Different productivity levels are assumed depending on the expected site conditions and are incorporated in the KB, CONGESTION.

4.5.3 RE-ASSIGNMENT

Re-assignment of labour is inevitable on any project and becomes unavoidable on projects when different phases overlap (Ahuja and Nandakumar, 1985). Factors such as errors and omissions in original design and incorporation of latest improvements neccessitate changes, resulting in extended duration for certain activities. Loss of production occurs with move-on, move-off of men because of unexpected changes, excessive changes, or demand made to expedite or reschedule completion of certain work phases (Anon, 1976). Manipulation in RE-ASSIGNMENT is similar to the above KB.

4.5.4 LEARNING CURVE

It is known that productivity rate of a job increases with experience and practice. The length of time required to orientate workers is a matter of continuous study (Gates & Scarpa, 1972). Advances in product design, methods of construction, tools and equipment have resulted in changed experience curves. It is obvious that the orientation time for any worker of a particular labour category depends on the type of operation, motivation and learning environment. It is found that whenever the routine-acquiring process is interrupted for even a short time some of the experience curve effect is lost, although upon resumption of the activity, the routine-acquiring process resumes at the same decremented rate (Gates and Scarpa, 1972). The expected conditions at the site are referred in the system to extract different rates of production.

4.5.5 WEATHER

Weather is one of the most difficult and unknown factors that influence construction projects (Baldwin et al, 1971). Because of the nature of the industry, almost 50% of the activities involved are affected by weather (Benjamin and Greenwald, 1973). Although weather conditions cannot be controlled, more accurate knowledge about anticipated weather can clearly contribute to lessening the effects of weather upon construction progress. The weather, an activity faces, is dependent upon the times of the year the activity is performed. For this reason, uncertainty due to weather related to activity duration is dependent on calendar date. Modifying duration of weather sensitive activities must recognize the following relationships:

1) Weather affecting one activity duration on a site also affects concurrent activities because activities progressing simultaneously share the same weather, and

2) weather affecting one activity duration also affects durations of following activities because their start times are changed and the seasonal weather they face is also changed.

ESCHEDULER simulates the daily progress of all weather sensitive activities in a construction project. The progress of an activity is sensitive to the occurance of a weather if its progress under that weather is expected to be different from its progress under standard weather. This sensitivity of any activity to weather has been determined from empirical equations (Koehn and Brown, 1985). Based on the start and finish dates of the activity, the weather it faces, and its progress under the weather, the duration is changed to a realistic one. See Fig. 4.6 for program flow in this module.

4.5.6 Combined Effect of Site Conditions

Productivity levels associated with different conditions on site may or may not be correlated. Determination of the productivity level considering the combined impact of more than one of these factors requires careful study of whether they are mutually exclusive or not. For the purpose of this study a simple yet reasonable method is used. Incorporating the impact of the uncertainty factors is similar to the model suggested by Ahuja & Nandakumar (1985) which has also been considered by other researchers (Carr, 1979; Stevens, 1988, Stevens, 1990). The expression for combining the effect of the various factors is as follows.

Combined Productivity Level (P.L.)

= P.L. due to Variable 1 x P.L.due to variable 2 x .....

It is considered that the impact of the different uncertainty variables is independent and, hence the above multiplicative model is used to obtain their combined impact.

ESCHEDULER consults the above sub-modules to modify duration of an activity. Even though there are advantages in modularity such as ease of modification, the weakness of such approach of pure-message passing is the inability in tracing the rules fired in different modules to provide complete explanation. Automated explanation behaviour of production rules is lost in such systems. However, ESCHEDULER provides reasoning for its final calculation of the revised duration by providing the rate of productivity due to factors chosen.

4.6 Summary

This chapter presented the development environment for ESCHEDULER, including the reasons for choosing GURU as the ESBT. It should be mentioned that GURU is not an easy-to-master tool due to the complexity of its documentation and it does not use other forms of knowledge representation techniques, such as frames. The various components of ESCHEDULER and their functions are described and the manipulation of knowledge bases in developing and updating schedules is explained. The las ction briefly presents the contents of the sub-modules and their importance in determining realistic activity durations. The following chapter presents an example application to illustrate the essential features of the system and its potential application to other problem domains.

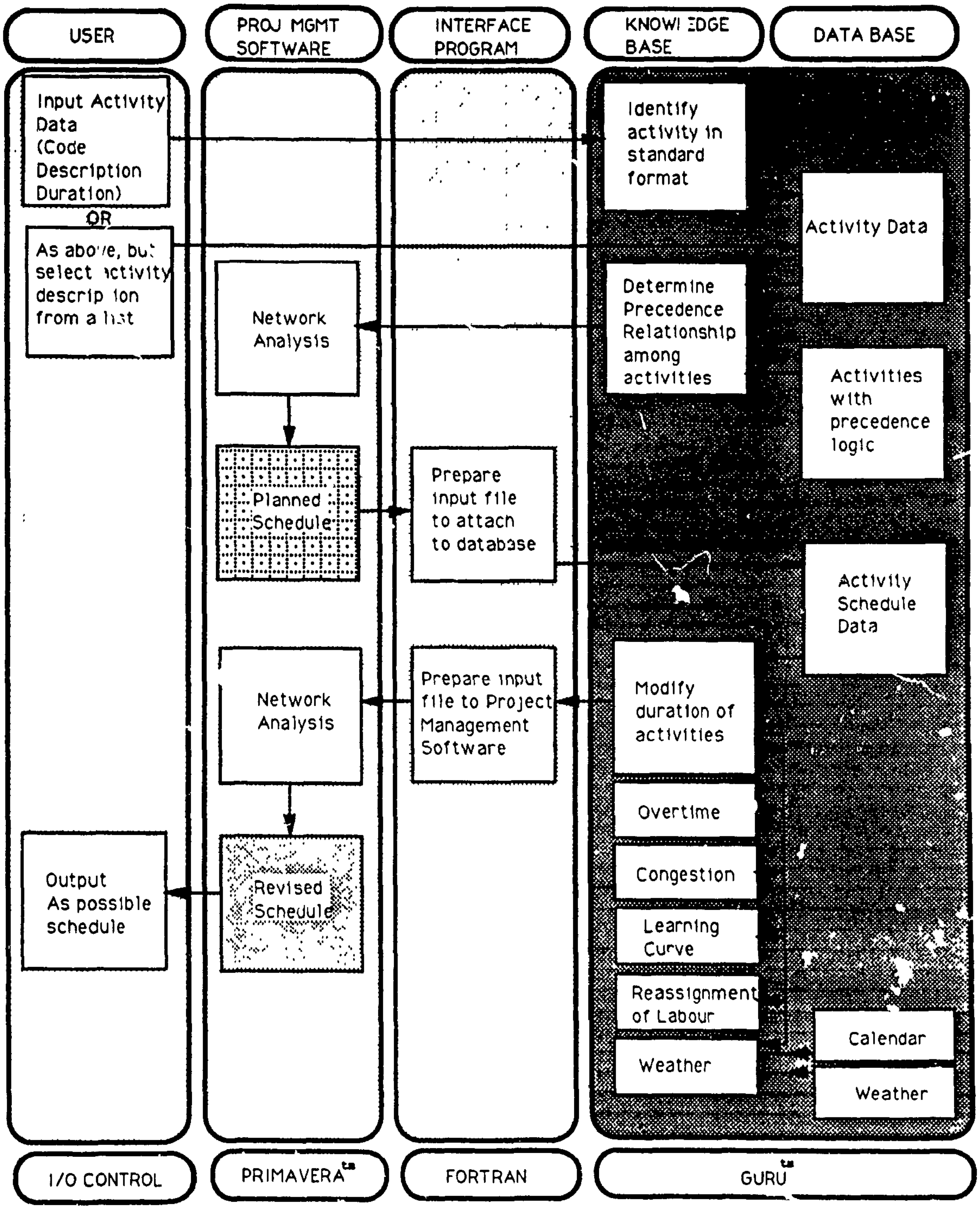


Fig 4.1 Architecture of ESCHEDULER

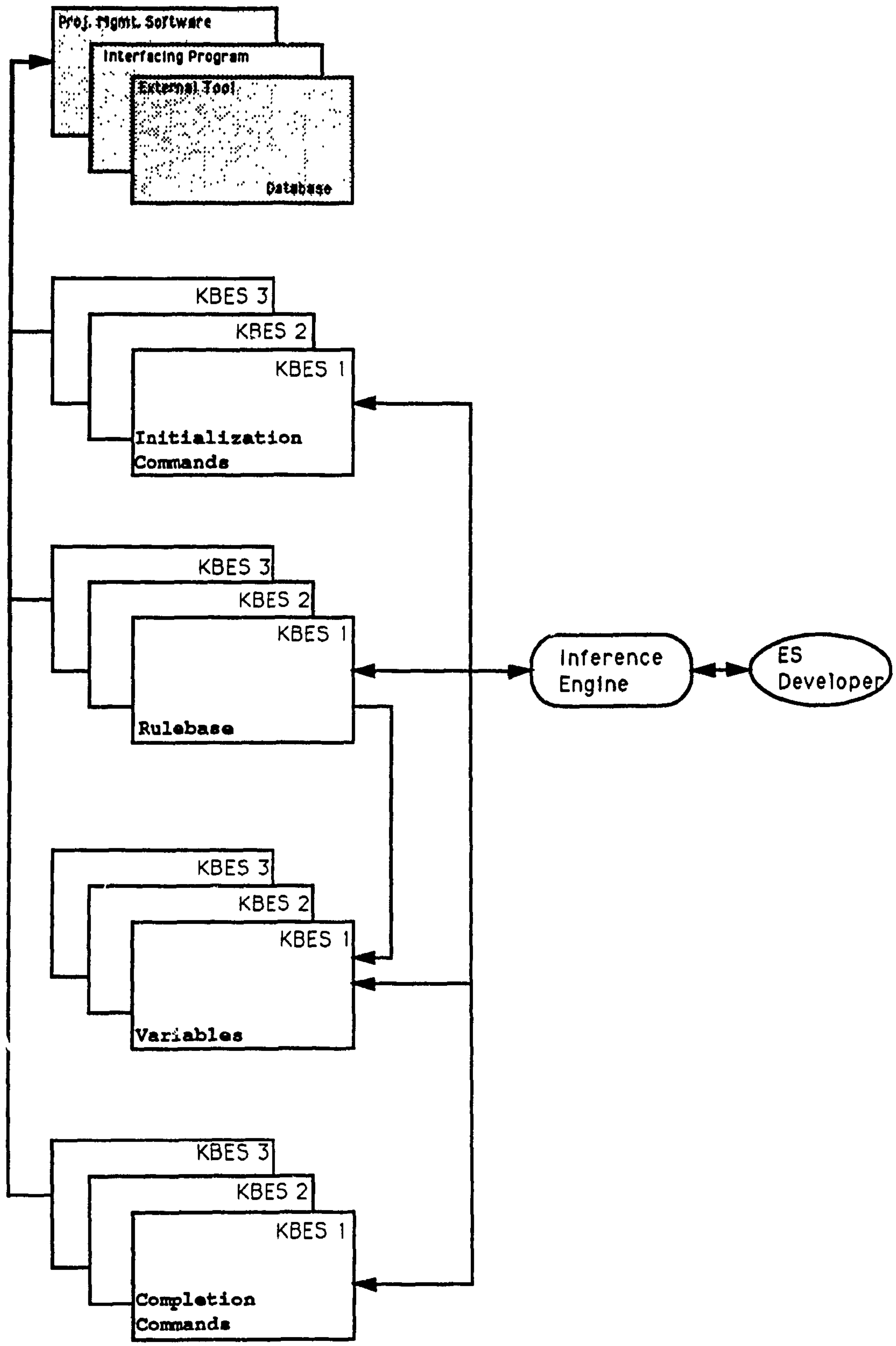


Fig. 4.2 ES Elements in GURU^{tm}

Define Goal Variable
Enter Initialization Commands
Enter Rules
Define Variables
Enter Completion Commands
Save and Compile
Review and Debug
Validate Knowledge

Table 4.1 Building ES with Guru™

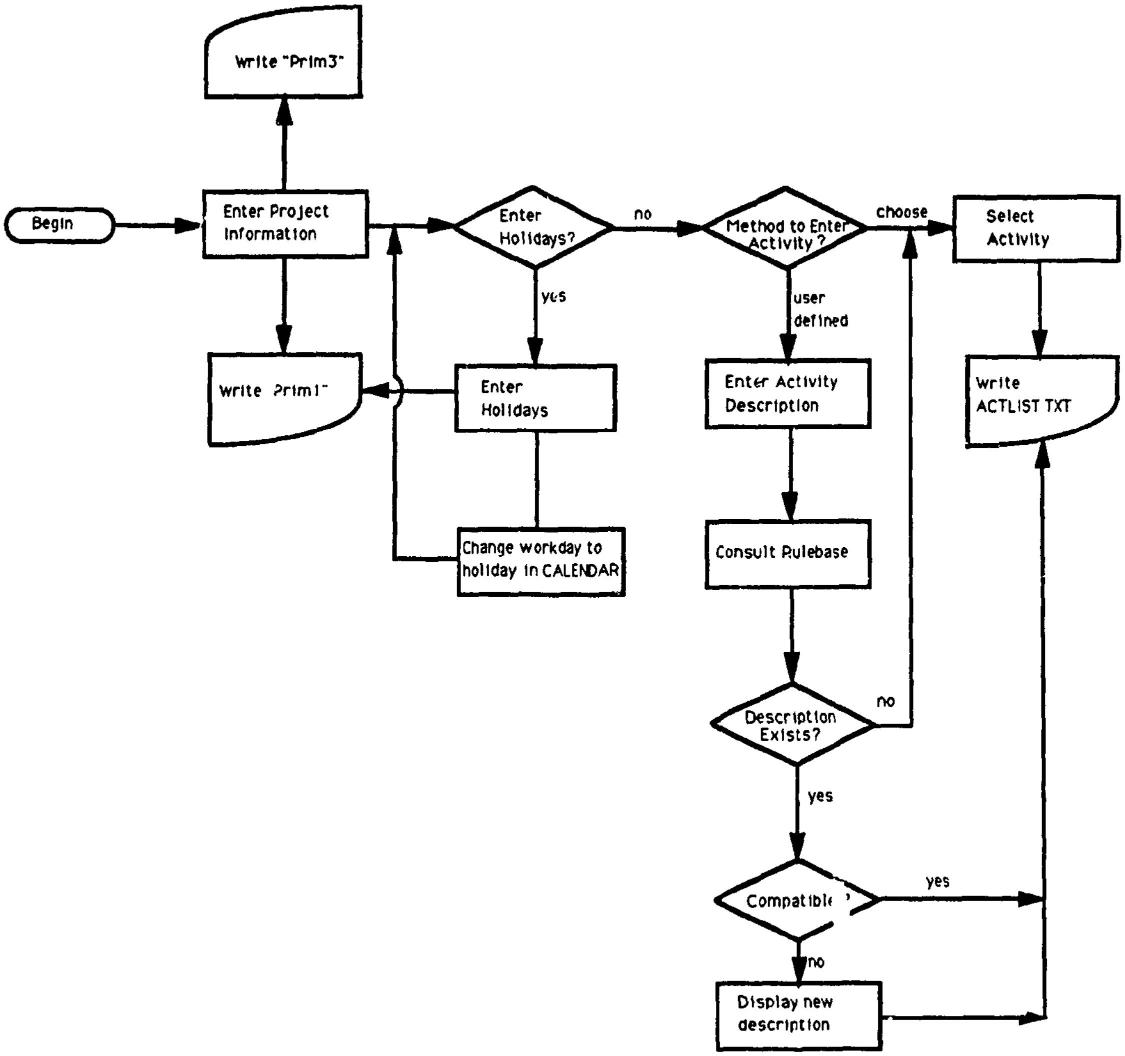


Fig. 4.3 Program Flow in ACTIVITY TRANSLATOR

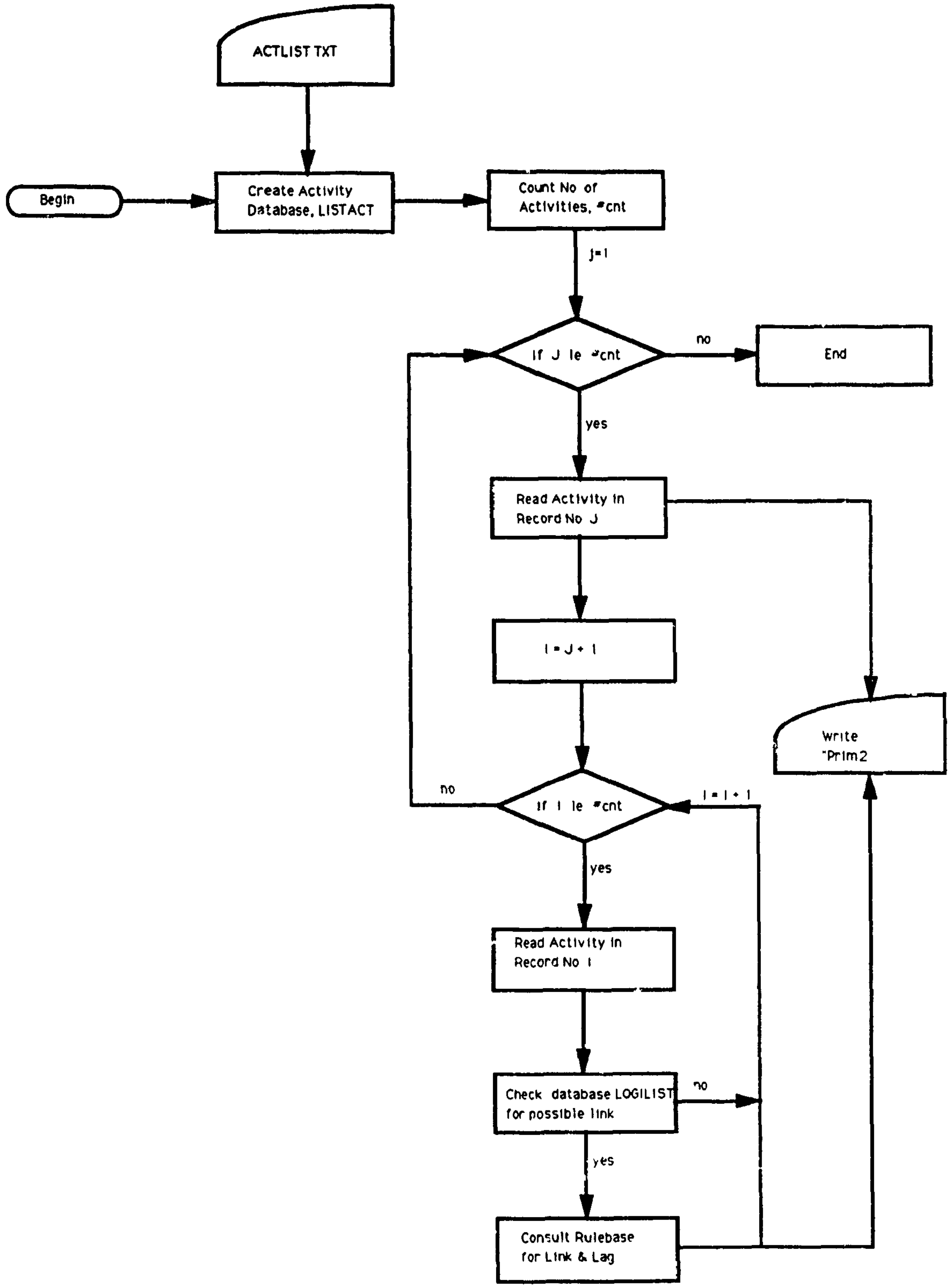


Fig. 4.4 Program Flow in JOBLOGIC HELPER

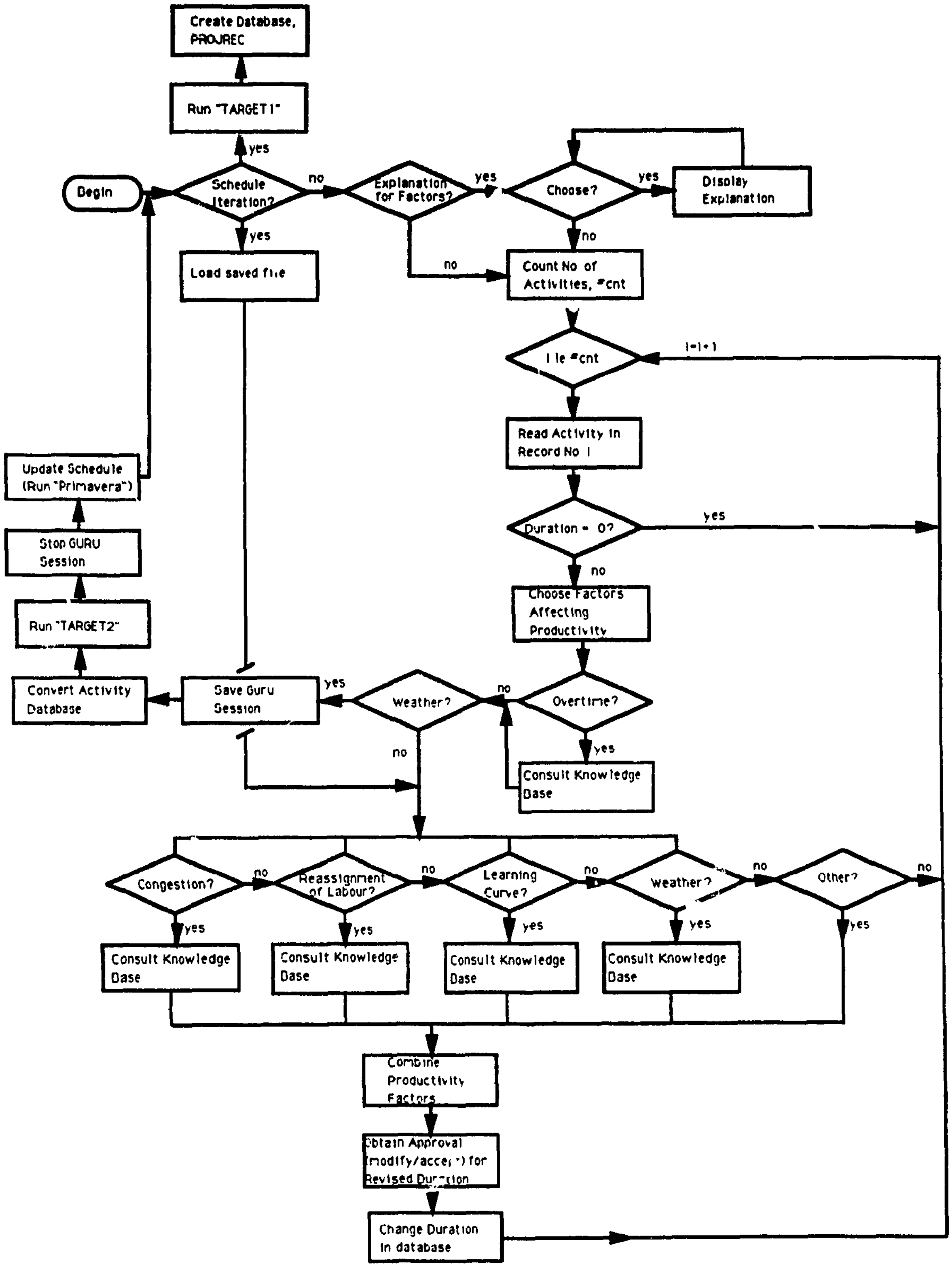


Fig. 4.5 Program Flow in DURATION MODIFIER

Days/Week	Hours/Day	Productivity (%)
5	9	95
5	10	92
5	11	89
5	12	86
6	8	97
6	9	88
6	10	82
6	11	78
6	12	75
7	8	92
7	9	83
7	10	78
7	11	75
7	12	72

Table 4.2 Productivity due to overtime

(Bureau of Labour Standards, Electrical Contractor, Jan 1970)

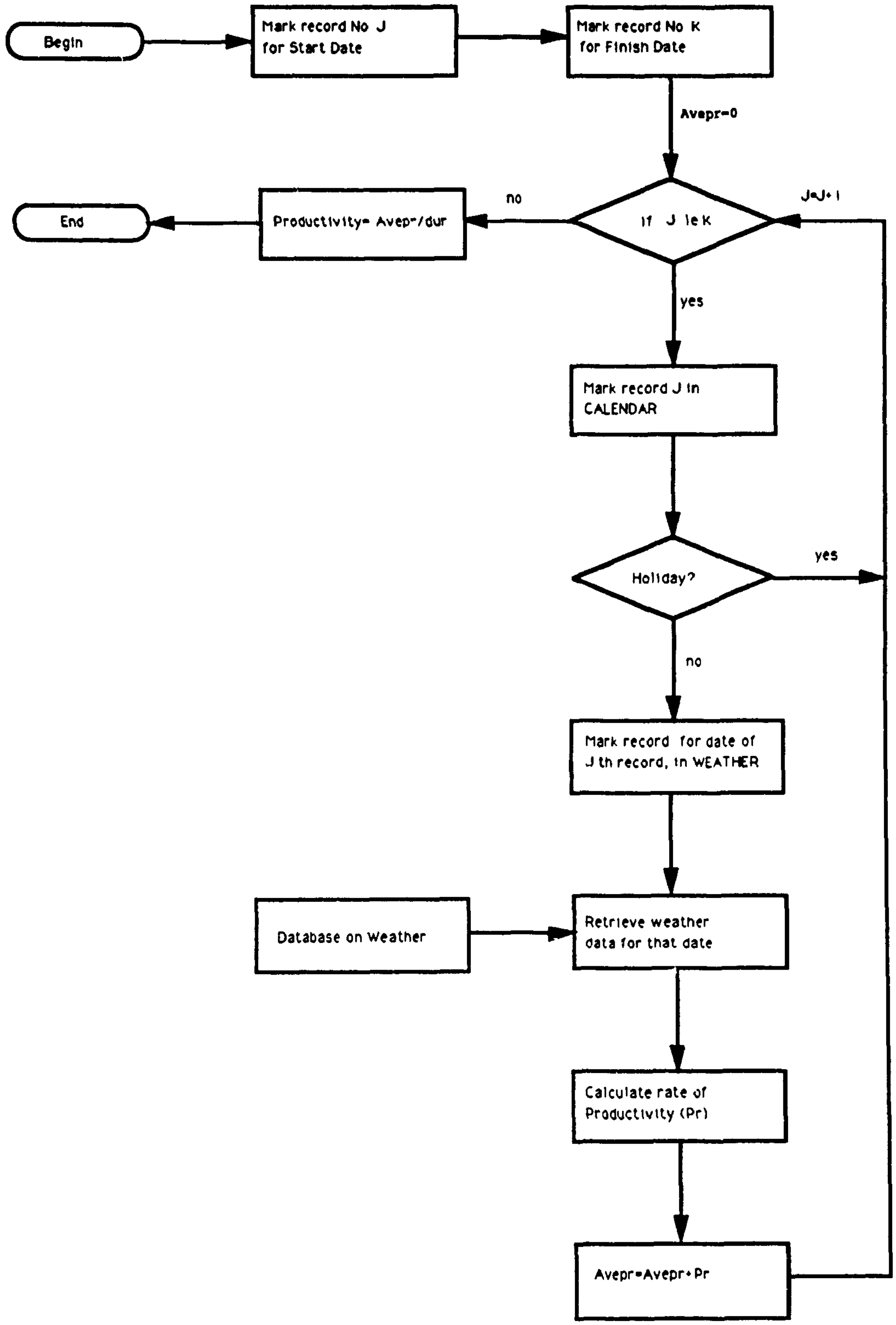


Fig 4.6 Program Flow in Sub-Module WEATHER

CHAPTER 5

APPLICATIONS

5.1 Introduction

In this chapter example applications are presented to illustrate the operation and the essential features of ESCHEDULER. System features are presented with particular emphasis on the benefits of the hybrid approach. The system's hybrid environment supports a higher level of automation. Unlike in similar developments reported in the literature where validation of the system is not addressed, efforts are made to validate ESCHEDULER. Issues in validating an expert system are briefly discussed. Use of the system in other areas of construction management are outlined.

5.2 An Example Application

In this illustration, the application of ESCHEDULER in preparing an 'as possible' schedule is described. The system progresses through consultation as the user responds to questions posed by the system. In many cases, a simple yes/no (Y/N) response allows progression through consultation. Having received the answer to a question from the user or by accessing a database, the system locates the applicable rules by comparing the answer with the knowledge base and produces a decision or executes a function.

In real situation, while consulting, the user would generally want to discuss some points in detail with the expert. Unfortunately the system is not yet fully developed to facilitate wide ranging communication and therefore at present only reports can be included to explain the reasons behind the consultation by tracing and presenting the rules it fired along with the relevant reason stored in the system while rules were generated.

An example of a building project is presented here as a proof of the concept presented in this study and to illustrate the operation of ESCHEDULER.

5.2.1 Project Description

A sample project is chosen with the dual purpose of illustrating the essential features and the operation of ESCHEDULER and to validate the system. It is an actual project of a multi-storey building with 'as planned' and 'as built' schedule prepared by the project management consultants who handled the claims defence originated from the execution of this project.

The project, a commercial plaza, was built in the outskirts of the City of Greenville in the state of South Carolina. It consisted of ten storeys and housed underground parking facilities, two floors of shopping mall and eight floors of office space, in the initial design. Sub-surface investigation showed sandy silty material. Construction was to begin in April 1982 and to be completed at the end of September 1983. For the purpose of this illustration, the year of commencing construction has been taken as 1988, due to the limitation in the database CALENDAR. This database can be increased to cover any period. As database WEATHER simulates annual average climatic pattern for any year, this change in the period of construction would not affect the results, obtained by this system.

5.2.2 Activity Break-down

The input to the system, i.e. activity break-down and durations are taken from the 'as planned' schedule, prepared by the consultants. These were found to be suited to the illustration intended for this chapter, and hence no changes are made. Fig. 5.1 provides the time-scaled network prepared by the consultants. Table 5.1 shows the activity descriptions and their durations. The activity codes required for consultation are also shown in this table.

5.2.3 User-Input

The user begins the consultation by simply typing **escheduler**. The system, after displaying the header, requests the user to insert a floppy diskette in drive A. Most of the data required to be transferred between different modules are temporarily stored in this disk to make it easier to be accessed by these modules. The user is requested to enter project information (Fig.5.2). If any holidays are to be entered, the system requests the user for calendar dates. Necessary changes are made in the database CALENDAR to be later used for adjusting the duration of weather sensitive activities. The same holiday data are automatically input to Primavera[tm] for schedule preparation. At this stage of consultation the system prepares two batch files for Primavera[tm]. 'Prim1' contains project information and 'prim3' contains instruction to perform network analysis. These two files are stored in the floppy diskette in drive A, as stated before.

After all the holidays are entered, the user is requested to choose the method he/she wants to use to enter the basic information about activities (Fig.5.3). If the user chooses to select activity description from a list of common activities invoked on the screen, the activities chosen are immediately written to the disk. If the user wishes to enter his/her own description, the module ACTIVITY TRANSLATOR checks them for system compatibility, and if found to be different, the user is informed of the change in description. In this method, if an activity description entered by the user is not in the system, the system requests the user to select a synonymous description from a list as described in the earlier method (Fig. 4.3). After all the activities are entered, the module to determine precedence relationship goes into operation.

5.2.4 Determination of Job Logic

The module JOBLOGIC HELPER checks with the user whether the duration or the activity code needs to be changed in the already input data on activities. This module creates a database, LISTACT and stores all the data entered by the user. It checks with the database LOGILIST for the existence of dependency between any two activities in LISTACT. During precedence setting, the user is asked if he/she wishes to consider partial or conventional relationship between any two interdependent activities (Fig.5.4) displayed on screen. If partial is chosen, the user will have to input the lag in number of days. Explanation for the determination of precedence between any two activities can be requested from the system (Fig. 5.5). Information on activities with activity description, duration and precedence record are written to the batch file 'prim2' in the floppy and are later processed by Primavera^{tm} (Fig. 4.4).

5.2.5 Baseline Schedule

Once precedence setting is completed ESCHEDULER exits GURU^{tm} and loads Primavera^{tm} and processes the files 'prim1','prim2' and 'prim3'. Schedule preparation is automated, using 'prim3'. The user is requested to prepare a schedule reoort in ASCII format (Table 5.2) and to store the file in PROJREC.PRN, interactively. The fields of this output file are activity code, activity description, duration, early start and early finish. Once the user has prepared the report, saved it and exited Primavera^{tm}, the system again enters GURU^{tm} to modify the duration of

activities expected to be affected by conditions at job site.

5.2.6 Realistic Activity Duration

DURATION MODIFIER uses a FORTRAN program (TARGET1) to format the ASCII output from Primavera™ (PROJREC.PRN) to an input file to attach to PROJREC table in GURU™ which stores project record pertaining to each activity in the project. In modifying the duration of activities, the conditions prevailed at the time of construction and described in the report prepared by the consultants are applied. But normally the user will have to enter the condition, expected to prevail at site in order to prepare an 'as possible' schedule. Project history provides following information (Table 5.3). Even though delay due to adverse weather is attributed to only one activity, viz., Piling-Pilecapping, all weather sensitive activities are considered in this exercise.

Before considering the activities for the adjustment of duration, the system displays a list of factors which are accounted for by ESCHEDULER (Fig. 5.6). If the user can quantify the delays due to any other factors, facility is provided in this system to incorporate them, later in the calculation of revised duration. Fig 5.7 shows the 'request form' which appears for each time consuming activity. The user is requested to select the factor(s) he/she wishes to consider for the activity displayed. The particular sub-modules containing knowledge on the factors chosen are accessed for consultation. System queries are about overtime, site congestion, re-assignment of labor and learning curve. Durations of weather sensitive activities are modified based on their calendar early start and early finish dates. Fig. 5.8 shows the list of possible responses, the user has to choose to enter to most of the queries on site condition. DURATION MODIFIER queries the user on site conditions, particular to the factor(s) chosen (Fig.5.9) and modifies activity duration in accordance with the appropriate productivity related factor(s) contained in the system. For weather sensitive activities, probable average temperature and humidity for each day of the activity duration are first extracted from database WEATHER and then used to arrive at a productivity level for that activity, based on previously described equations.

Whenever an activity is chosen for the calculation of revised duration with respect to overtime, the theoretical reduction on the duration is performed by the system, if the user chooses to input the total number (normal + overtime) of work hours. Based on this new duration, the impact of other factors are then considered. When a weather sensitive activity is identified by the user, the system exits GURU^{tm}, loads Primavera^{tm} and updates the schedule with the revised duration of the activities, to determine the revised start date of that activity. The system again enters DURATION MODIFIER with new activity records, and modifies duration for that particular activity, based on the factors chosen.

After the required number of iterations are performed for weather sensitive activities by the scheduling software and the relevant consultation by DURATION MODIFIER, the scheduling software prepares the 'as possible' schedule (Table.5.4).

5.3 Validation of ESCHEDULER

5.3.1 Issues in Validation

Validation of an ES refers to a formal test to determine how well it makes decisions for which it is designed. Ideally, it is carried out under authentic consulting conditions, and the test cases cover a wide and typical range of input situations. A library of test cases of expert decisions is extremely valuable during the iterative expert system building stage.

Expert system validation is often difficult since there are no universally accepted or unbiased formal specifications against which the system can be judged. This should be evident from the purpose of developing an expert system. It could be expected that the legal issues surrounding expert systems may arise from the creation of the knowledge base itself. Whoever defines the rule becomes responsible for subsequent failure (ENR, 1988a). The biggest drawback to rule-based systems is the problem of system verification and validation. Because pattern matching is the criteria by which processing is performed, exhaustive testing is the only way to perform a complete verification and validation of the system.

Some attempts are made in this study to commence the validation process of ESCHEDULER. The important dimension in validation is to test the performance of the system, completeness and its accuracy. A critical performance and validation check would be to execute several test scenarios to see if the expert system produces the correct results. It is important to note that such validation requires completeness of the knowledge base and availability of documented test cases. For the purpose of the study, one documented test case is utilized.

5.3.2 Validity of Knowledge and Knowledge Processing

As ES are designed to impart knowledge, it is very important to determine the accuracy of the knowledge and the correctness of the system execution. Hence validity check on ESCHEDULER is performed to test the accuracy of the knowledge bases, database and the program execution.

Accuracy of KB: Knowledge modules in ESCHEDULER consist of information on different descriptions used for a particular work task, construction methods and on productivity levels associated with different site conditions. Knowledge on different descriptions and construction methods were accumulated by comparing construction schedules prepared by contractors and from various text books referenced in this thesis. Information on productivity levels were extracted from refereed journals and bulletins. The equations employed to determine the productivity level due to weather conditions were checked for their applicability. Fig. 5.10 shows the productivity levels under different temperatures at 60% relative humidity. This curve matches with similar graphs found in many text books.

Accuracy of Database: ESCHEDULER accesses the database, WEATHER to simulate the daily weather conditions. The weather pattern stored (Fig. 5.11) is compared for verification with similar data on climatic behaviour published in "The Climate of Montreal" by Environment Canada (Fig. 5.12). It should be noted that the weather pattern obtained is based on day time (7 am - 5 pm) climatic data and Fig. 5.12 shows the pattern based on a 24-hour day.

Correctness of Execution: A sample network with five activities is used to check whether the execution of the program matches the program flow intended. Fig. 5.13 shows the sample network. Impact of each factor on task 'Activity B' and the combined impact of all five factors on the same task were derived using ESCHEDULER and checked against the knowledge base and the database. The schedules in Table 5.5 were prepared for each execution with Primavera^{tm}.

After establishing the validity of the system, performance of ESCHEDULER on an actual project was evaluated. The schedules prepared with ESCHEDULER are compared with the actual project schedule. The results are reported below.

5.3.3 Comparison with the As-Built Schedule

The same input used in the illustration are utilized with the actual start date of construction to prepare the revised 'as possible ' schedule. The impact of the factors are considered on activities whose scope of work and job logic remained the same to make a realistic comparison. For activities with change of job logic, the respective actual start dates and planned durations are used for this purpose. The revised durations obtained after consultation with ESCHEDULER are compared with the actual durations shown in the 'as built' schedule prepared by the consultants (Fig.5.14).

The following activities are chosen for comparison: Clear Site, Excavation, Piling-Pilecapping, Erection of Steel in all three levels and Roofing. As the job logic for activity Roofing has been changed, its actual start date is used for comparison. Table 5.6 shows the results obtained, by applying the conditions prevailed at the site during construction. Some similarities and discrepancies can be noticed between Table 5.6 and Fig. 5.14.

Even though the activities taken for comparison are weather sensitive, consultation shows that all of them are not impacted by the climatic conditions. Hence, durations of activities Clear Site and Excavation are the same in both cases. Piling-Pilecapping is reported to have been affected by an unusual rainfall. The same duration is obtained for this activity after adding this delay. Erection of Steel for Level-1 and Level-2 had taken 60 days. The consultation with ESCHEDULER shows that these activities would take 67 days. The discrepancy may be attributed to various other factors in weather. It should be noted that weather record was limited to temperature and humidity and to a particular location, Montreal. In addition, the various activities are given different amounts of protection from weather, etc. and their raw durations can be based upon different standards, used by the consultants who prepared the initial schedule. Other weather variables, such as precipitation and snowfall, are also important.

The 'as built' schedule prepared by the consultants shows a change in the precedence logic. Due to the delay and the change in the scope of work in Steel Erection - Lev 3, Concreting for all levels, which was to commence after the completion of steel erection was done concurrently. Many other activities planned for linear job logic have also been done concurrently (Fig.5.14). The reasons of change in the scope and job logic can be attributed to the discrepancy in the duration for Erect Steel-Lev 3.

It is interesting to note that the duration derived for activity Roofing is the same, as shown in the 'as built' schedule. The impact of three factors: overtime, re-assignment of labour and weather, are considered for this activity.

Even though it may be too early to commence validation on ESCHEDULER, the attempt on this task will definitely help in gradual refinement of the system.

5.4 Use of ESCHEDULER

The application of ESCHEDULER can be easily extended to other problem domains in construction management. It can also be used to train field engineers for further assignments. Its possible application in three areas of construction management are briefly mentioned below.

5.4.1 Claim Analysis

A great potential in the application of ESCHEDULER can be seen for claims analysis and defence. In delay claims, the analysis method requires the identification of the events that caused the delays. Each delay-causing event is analyzed individually and the time/delay involved is quantified accordingly. Later, the schedule incorporating the delays is compared with the schedule prepared prior to incorporation of the delays and the difference is calculated as the delay to the project caused by the event under consideration.

A refined and properly validated ESCHEDULER can be used in claims defence by inputting the delay-causing events during modifying the duration of an activity to arrive at a legally accepted, quantifiable delay period for the activity under consideration. This task is similar to preparing an 'as possible' schedule, but entering the actual site conditions.

5.4.2 Schedule Update

ESCHEDULER may be used for schedule updating during the progress of a building project. It can be used to forecast the duration of activities and by inputting the prevailing site conditions, the possible project completion time. This replaces intuitive reviews of duration estimates and permits less experienced personnel to forecast activity duration with a degree of accuracy and consistency. It will make the management aware of the need to revise the original schedule and its network topology.

5.4.3 'What - If' Analysis

An analysis of the schedule at the tactical plan level can be more valuable and meaningful to a contractor and/or an owner. If changes in the project environment can at best be predicted prior to construction and their effects are known, it will bring more benefits to the parties concerned. It will also help in making a realistic estimate of contingency time allowance for the project.

The application of ESCHEDULER can be extended to schedule analysis, prior to or during construction of the project as mentioned in the above section to study the impact of changing the project environment on the completion date and the project cost. A simple example can be shown from the illustration used in this chapter. Table 5.7 shows a comparison of 'as possible' schedules with different project start dates. Even though the same site conditions are applied in the preparation of these schedules, the differences in activity durations can easily be noticed. This is due to the difference in the period when the activities will be worked on. Further, effects of accelerating a project can also be studied by choosing the factors which are generated by this action, such as overtime, congestion, re-assignment of labour, or recruiting more workers.

5.6 Summary

An example application is presented in this chapter to illustrate the essential features of ESCHEDULER. Performance of ESCHEDULER is measured by comparing the example with the 'as built' schedule. The extension of the application of the prototype in other areas of construction management is also briefly described. It is not an easy task to validate a system without its completeness. This can be seen by the absence of this topic in papers published on similar developments. But it was deemed important to make an attempt on validation to establish the reliability of the system.

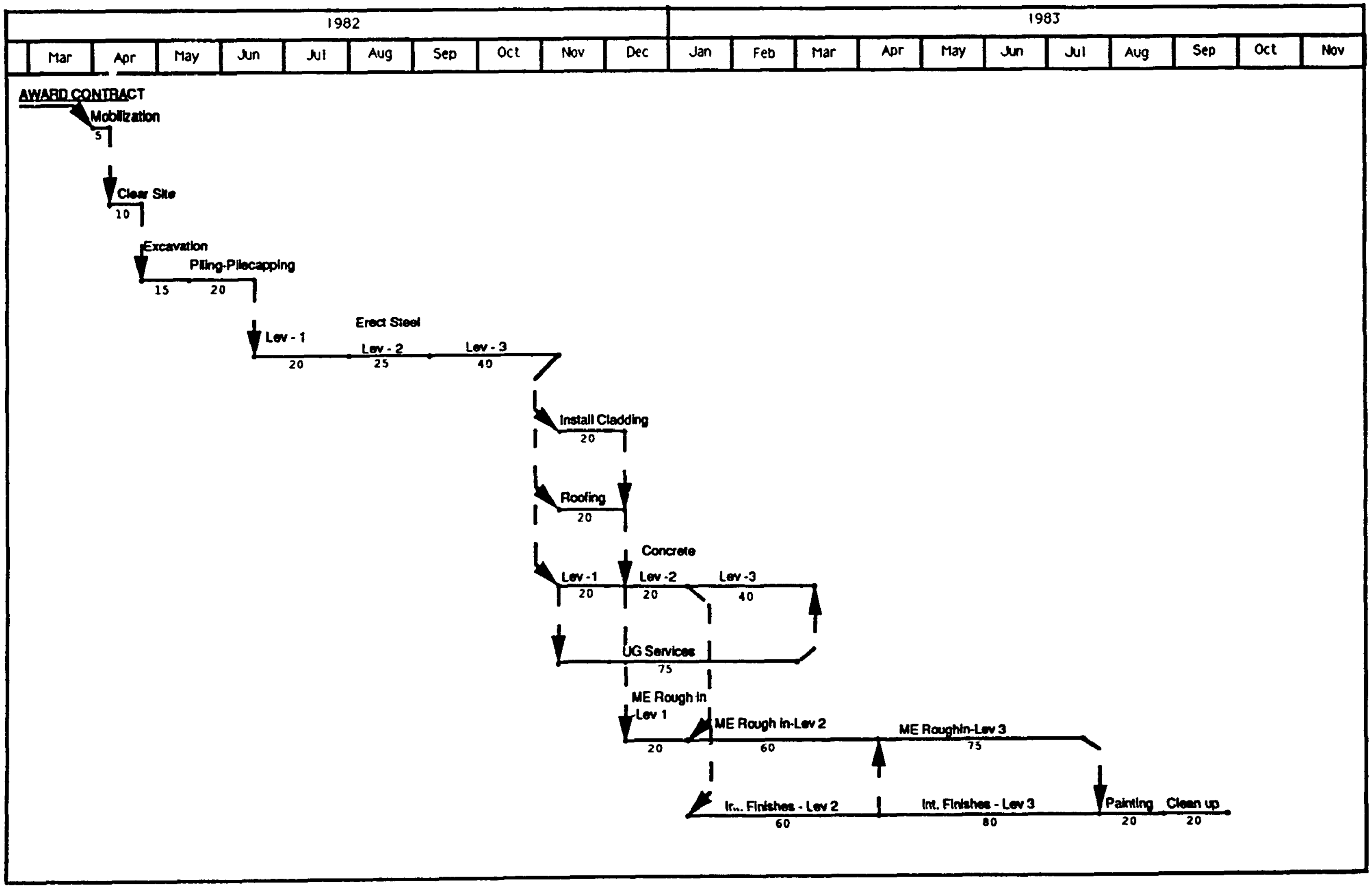


Fig. 5.1 Time Scaled 'As Planned' Network

CODE	ACTIVITY DESCRIPTION	DURATION (days)
ES010	Award Contract	0
ES020	Mobilization	5
ES030	Clear Site	10
ES040	Excavation	15
ES050	Piling and Pilecapping	20
ES060	Erect Steel - Lev 1	30
ES070	Erect Steel - Lev 2	25
ES080	Erect Steel - Lev 3	40
ES090	Install Cladding	20
ES100	Roofing	20
ES110	Concrete - Lev 1	20
ES120	Concrete - Lev 2	20
ES130	Concrete - Lev 3	40
ES140	UG Services	75
ES150	ME Rough in - Lev 1	20
ES160	ME Rough in - Lev 2	60
ES170	ME Rough in - Lev 3	75
ES180	Int Finishes - Lev 2	60
ES190	Int Finishes - Lev 3	80
ES200	Painting	20
ES210	Clean up	20

TABLE 5.1 Activity Break-down

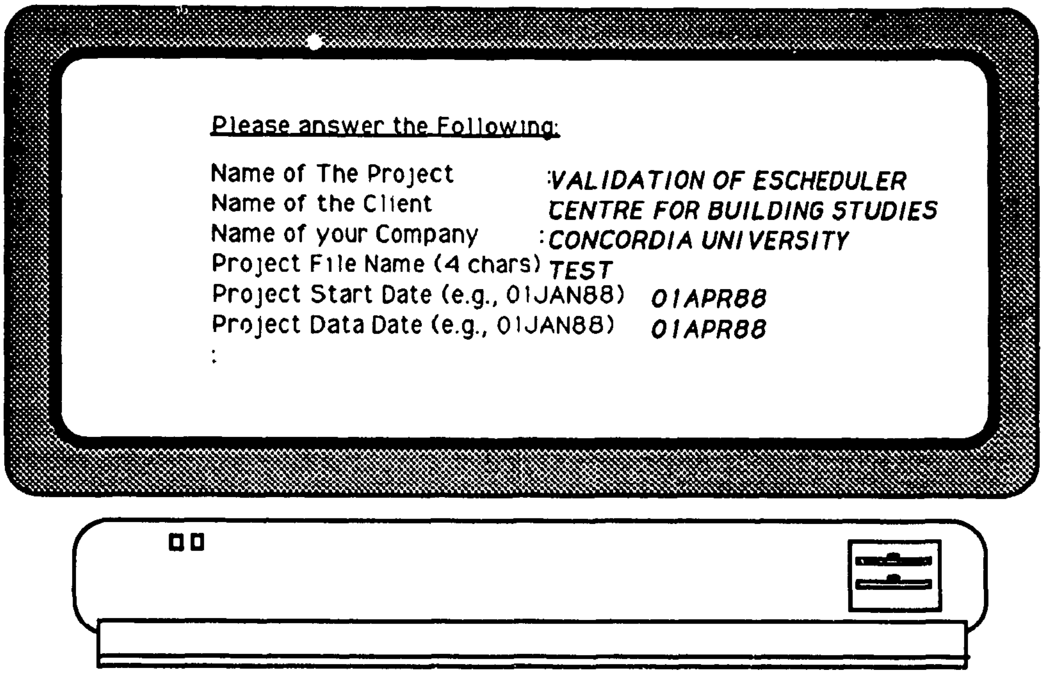


Fig 5.2 Project Information

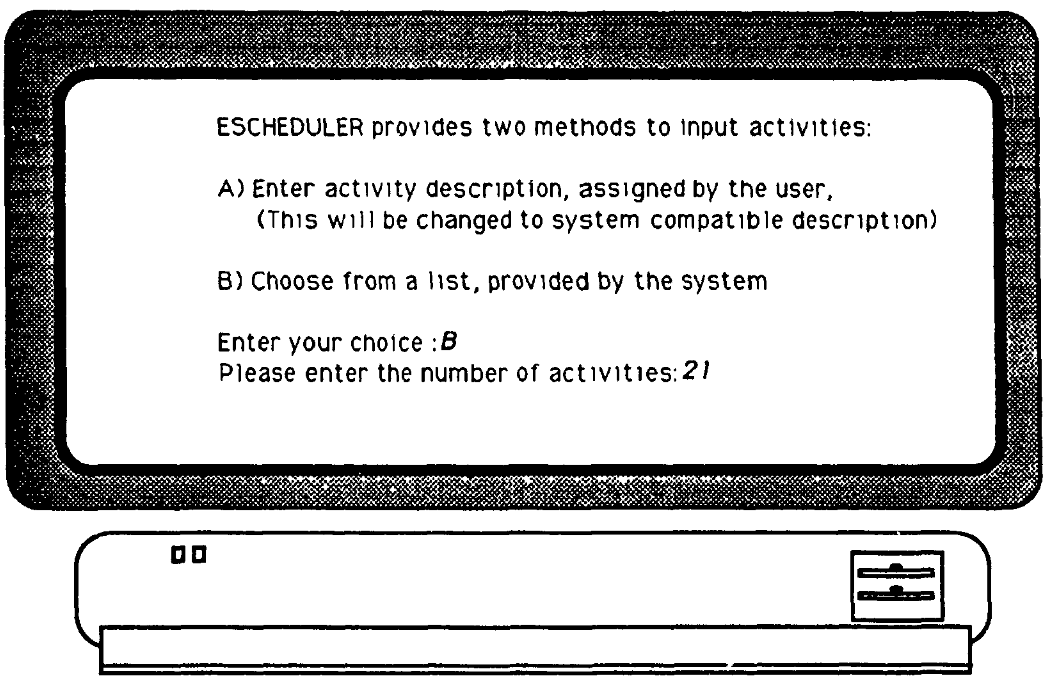


Fig 5.3 Method of Entering Activity Description

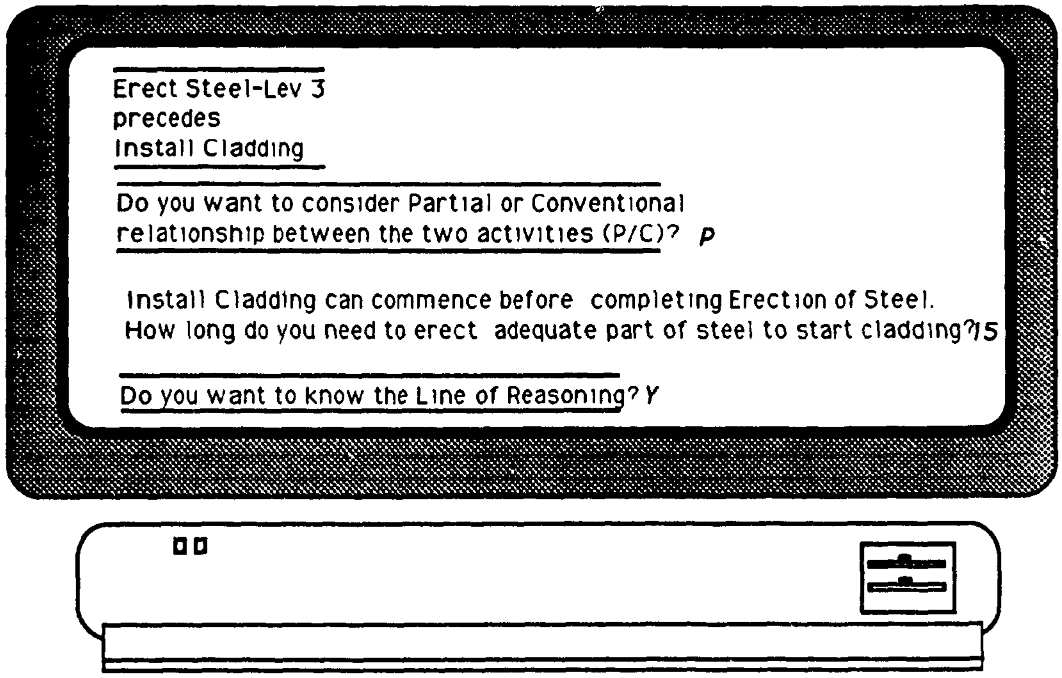


Fig 5.4 System Query to Determine Link and Lag

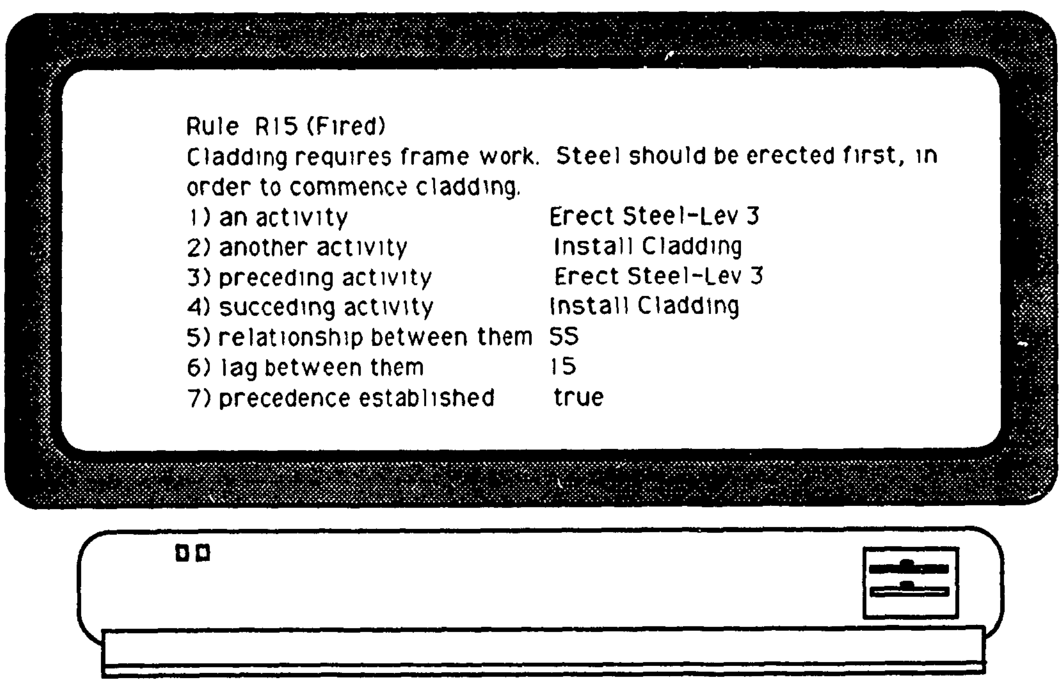


Fig. 5.5 Explanation for Precedence Setting

ES010	Award Contract	0	1APR88	1APR88
ES020	Mobilization	5	1APR88	7APR88
ES030	Clear Site	10	8APR88	21APR88
ES040	Excavation	15	22APR88	12MAY88
ES050	Piling-Pilecapping	20	13MAY88	9JUN88
ES060	Erect Steel-Lev 1	30	10JUN88	21JUL88
ES070	Erect Steel-Lev 2	25	22JUL88	25AUG88
ES080	Erect Steel-Lev 3	40	26AUG88	20OCT88
ES090	Install Cladding	20	21OCT88	17NOV88
ES100	Roofing	20	21OCT88	17NOV88
ES110	Concrete-Lev 1	20	21OCT88	17NOV88
ES120	Concrete-Lev 2	20	18NOV88	15DEC88
ES130	Concrete-Lev 3	40	16DEC88	9FEB89
ES140	UG Services	75	21OCT88	2FEB89
ES150	ME Rough in-Lev 1	20	18NOV88	15DEC88
ES160	ME Rough in-Lev 2	60	16DEC88	9MAR89
ES170	ME Rough in-Lev 3	75	10MAR89	22JUN89
ES180	Int Finishes-Lev 2	60	16DEC88	9MAR89
ES190	Int Finishes-Lev 3	80	10MAR89	29JUN89
ES200	Painting	20	30JUN89	27JUL89
ES210	Clean up	20	28JUL89	24AUG89

Table 5.2 ASCII Report of 'AS Planned' Schedule

Activity Description	Factors Affecting Productivity: Overtime	Congestion	Reassigm't of Labour	Learning Curve	Weather	Others	Comments	Delay
Award Contract	-	-	-	-	-	X	Delay in securing additional funding	3 mnths
Mobilization	-	-	-	-	-	-	No delay reported	
Clear Site	-	-	-	-	X	-	No delay reported	
Excavation	-	-	-	-	X	X	Permit to relocate gas main, relocate gas main and rock removal.	25 days
Piling & Pilecapping	-	-	-	-	X	-	Rainfall (12 days requested)	10 days
Erect Steel - Lev 1	-	-	-	-	X	-	No delay reported	
Erect Steel - Lev 2	-	-	-	-	X	-	No delay reported	
Erect Steel - Lev 3	-	-	Sev.	-	X	X	Change orders, additional work, period of indecision, design & material delay	20 days
Install Cladding	X	Ave.	Ave.	-	X	-	Out of sequence, acceleration, 6-10 hr work schedule.	
Roofing	X	Ave.	Ave.	-	X	-	Out of sequence, acceleration, 6-10 hr work schedule.	
Concrete - Lev 1	-	-	Ave	-	X	-	Out of sequence	
Concrete - Lev 2	-	-	Ave.	-	X	-	Out of sequence	
Concrete - Lev 3	-	-	Ave.	-	X	-	Out of sequence	
UG Services	X	Ave.	Ave.	-	-	-	Out of sequence, acceleration, 6-10 hr work schedule.	
ME Rough in - Lev 1	X	Ave.	Ave.	-	-	-	Out of sequence, acceleration, 6-10 hr work schedule.	
ME Rough in - Lev 2	X	Ave.	Ave	-	-	-	Out of sequence, acceleration, 6-10 hr work schedule.	
ME Rough in - Lev 3	X	Ave.	Ave.	-	-	-	Out of sequence, acceleration, 6-10 hr work schedule.	
Int Finishes - Lev 2	X	Ave.	Ave.	-	-	-	Out of sequence, acceleration, 6-10 hr work schedule.	
Int Finishes - Lev 3	X	Ave.	Ave.	-	-	-	Out of sequence, acceleration, 6-10 hr work schedule.	
Painting	X	Ave.	Ave.	-	-	-	Out of sequence, acceleration, 6-10 hr work schedule.	
Clean up	X	-	-	-	-	-	No delay reported	

X - Affected, - Not Affected, Ave. - Average, Sev. - Severe

Table 5.3 Project History

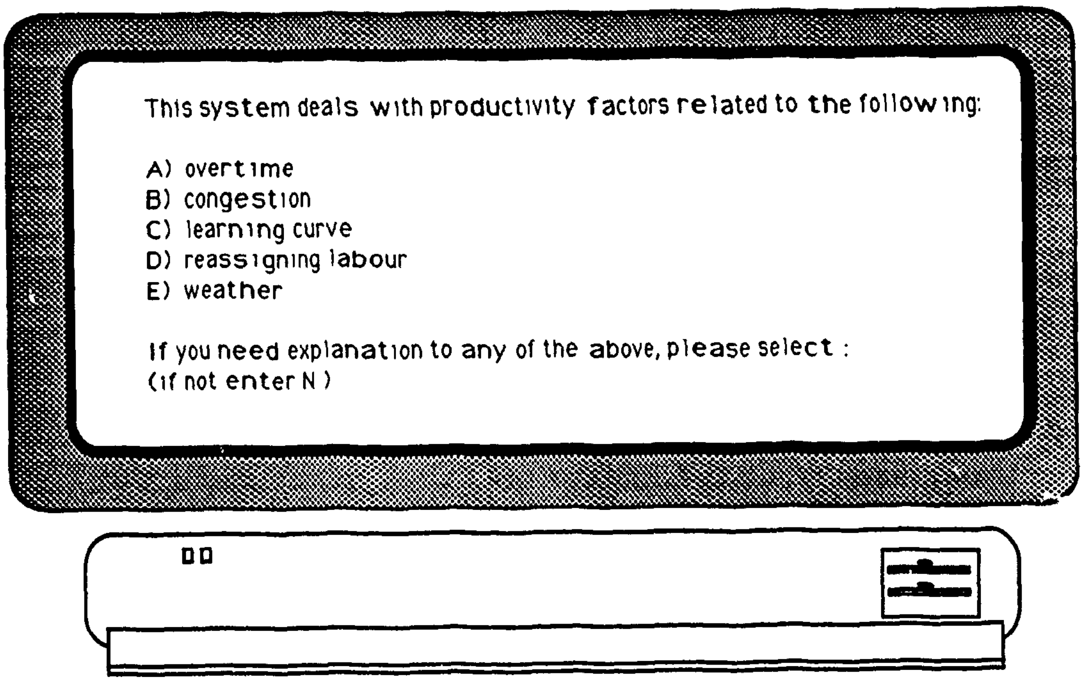


Fig. 5.6 Factors Considered in ESCHEDULER

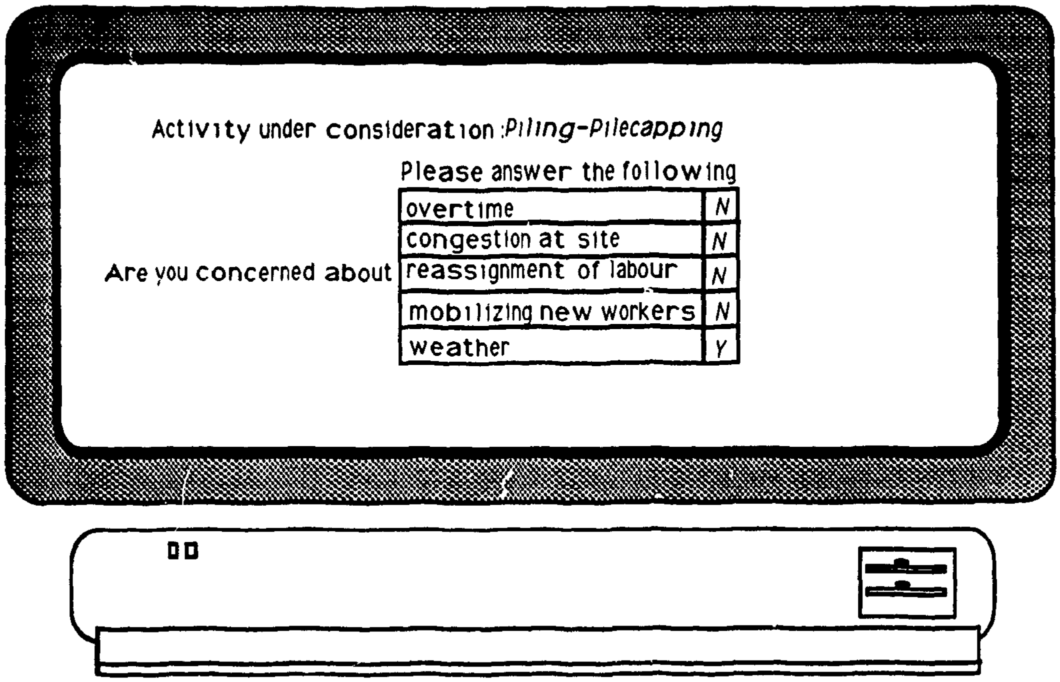


Fig 5.7 Factor(s) to be Considered

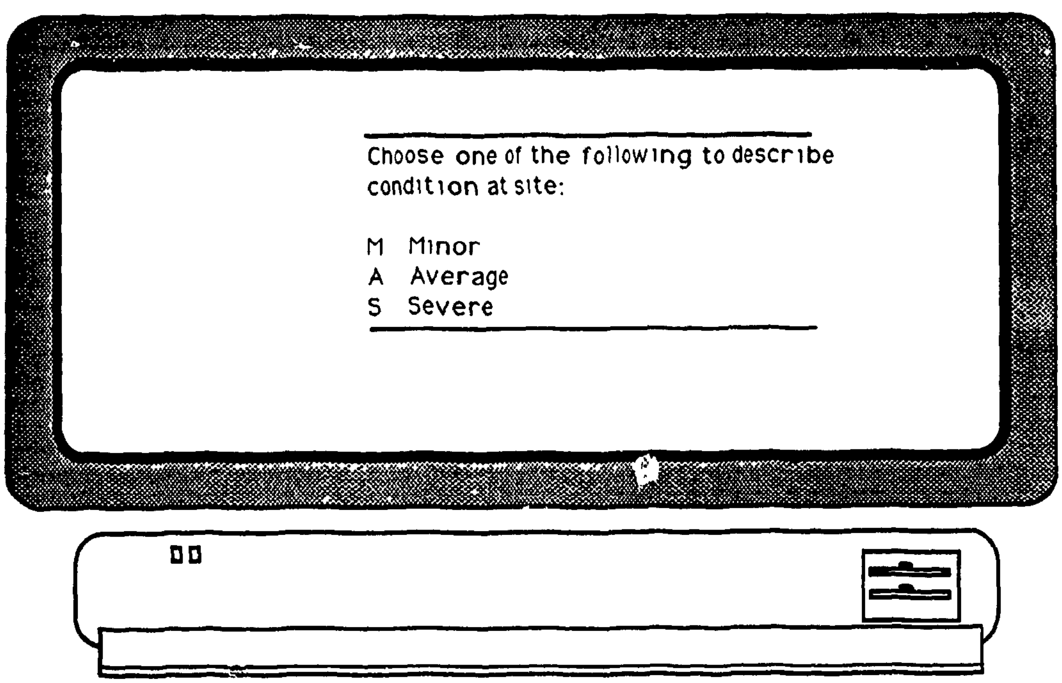
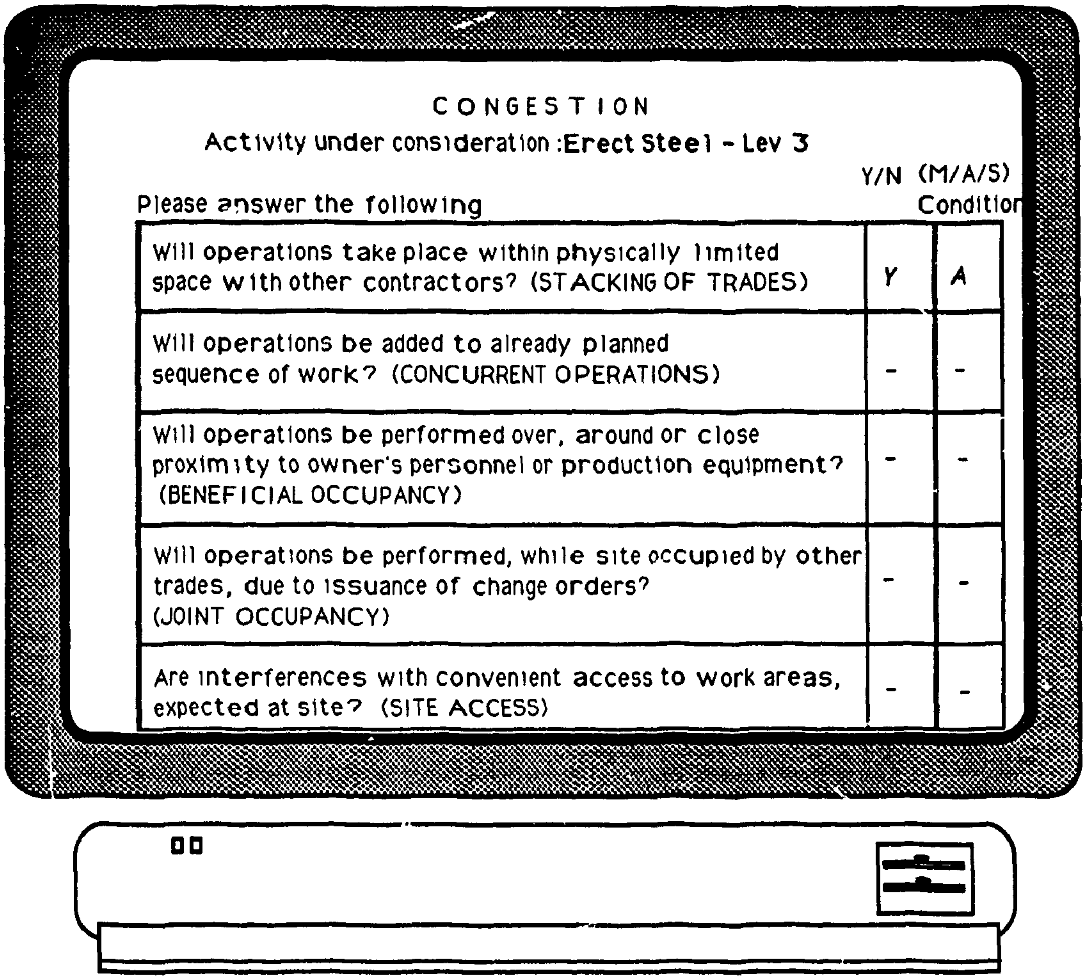


Fig 5.8 Condition at Site



CONGESTION

Activity under consideration :Erect Steel - Lev 3

Please answer the following

	Y/N	(M/A/S) Condition
Will operations take place within physically limited space with other contractors? (STACKING OF TRADES)	Y	A
Will operations be added to already planned sequence of work? (CONCURRENT OPERATIONS)	-	-
Will operations be performed over, around or close proximity to owner's personnel or production equipment? (BENEFICIAL OCCUPANCY)	-	-
Will operations be performed, while site occupied by other trades, due to issuance of change orders? (JOINT OCCUPANCY)	-	-
Are interferences with convenient access to work areas, expected at site? (SITE ACCESS)	-	-

Fig 5.9 Input to KBES sub-module, CONGESTION

PRIMAVERA PROJECT PLANNER				OPERATION OF ESCHEDULER
REPORT DATE 6JUL89 RUN NO. 4		CONCORDIA UNIVERSITY		START DATE 1APR88 FIN DATE 14DEC89
CLASSIC SCHEDULE REPORT - SORTED BY ES, TF				DATA DATE 1APR88 PAGE NO. 1

ACTIVITY ID	ORIG DUR	REM DUR	PCT	CODE	ACTIVITY DESCRIPTION	SCHEDULED START	SCHEDULED FINISH
ES010	0	0	0		Award Contract	1APR88	1APR88
ES020	5	5	0		Mobilization	1APR88	7APR88
ES030	10	10	0		Clear Site	8APR88	21APR88
ES040	40	40	0		Excavation	22APR88	16JUN88
ES050	30	30	0		Piling-Pilecapping	17JUN88	28JUL88
ES060	30	30	0		Erect Steel-Lev 1	29JUL88	8SEP88
ES070	25	25	0		Erect Steel-Lev 2	9SEP88	13OCT88
ES080	47	47	0		Erect Steel-Lev 3	14OCT88	19DEC88
ES090	31	31	0		Install Cladding	20DEC88	31JAN89
ES100	31	31	0		Roofing	20DEC88	31JAN89
ES110	31	31	0		Concrete-Lev 1	20DEC88	31JAN89
ES120	30	30	0		Concrete-Lev 2	1FEB89	14MAR89
ES130	46	46	0		Concrete-Lev 3	15MAR89	17MAY89
ES140	85	85	0		UG Services	20DEC88	17APR89
ES150	23	23	0		ME Rough in-Lev 1	1FEB89	3MAR89
ES160	68	68	0		ME Rough in-Lev 2	15MAR89	16JUN89
ES170	85	85	0		ME Rough in-Lev 3	19JUN89	13OCT89
ES180	68	68	0		Int Finishes-Lev 2	15MAR89	16JUN89
ES190	90	90	0		Int Finishes-Lev 3	19JUN89	20OCT89
ES200	23	23	0		Painting	23OCT89	22NOV89
ES210	16	16	0		Clean up	23NOV89	14DEC89

Table 5.4 As-Possible Schedule

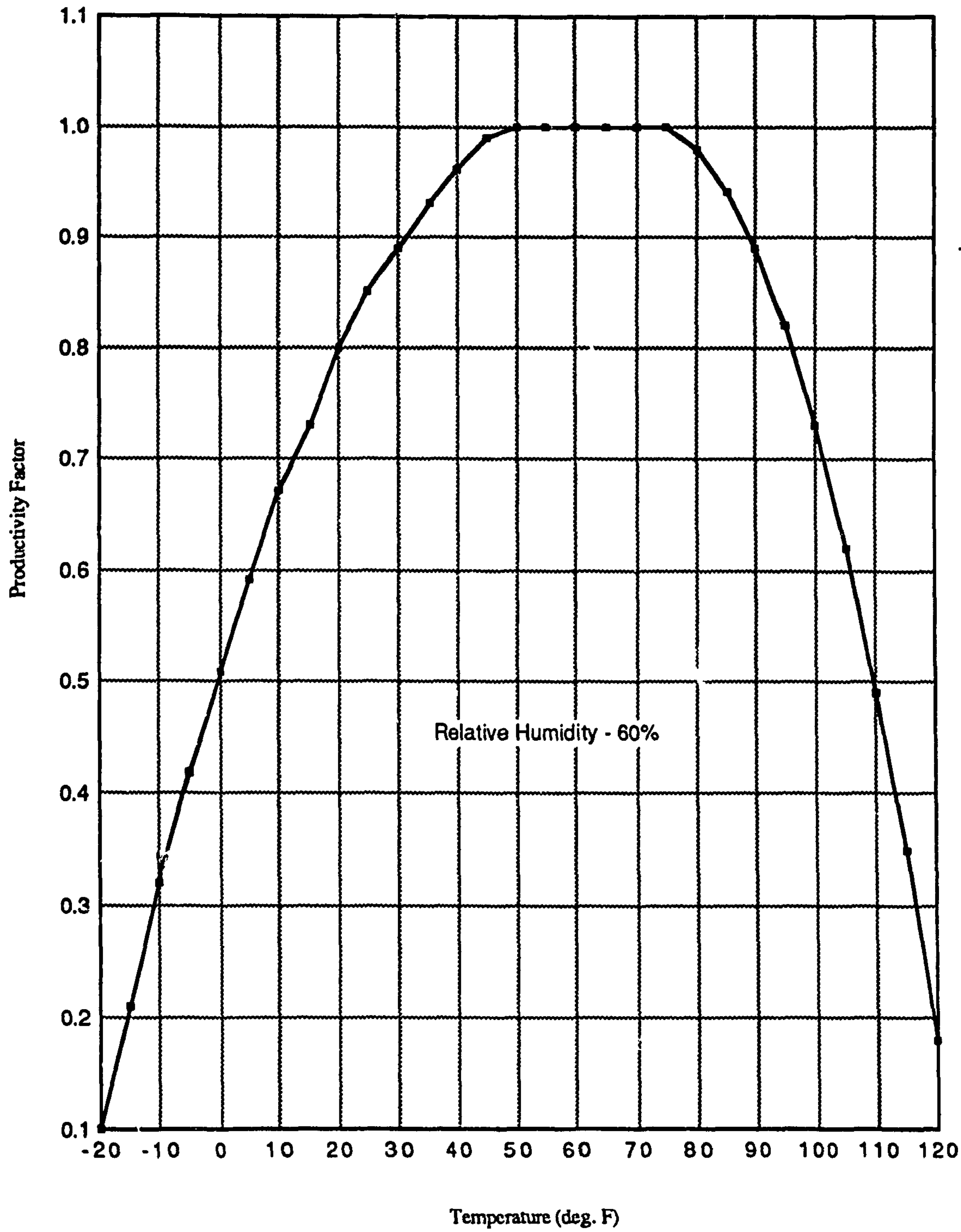


Fig. 5.10 Productivity Factors (Koehn's Model)

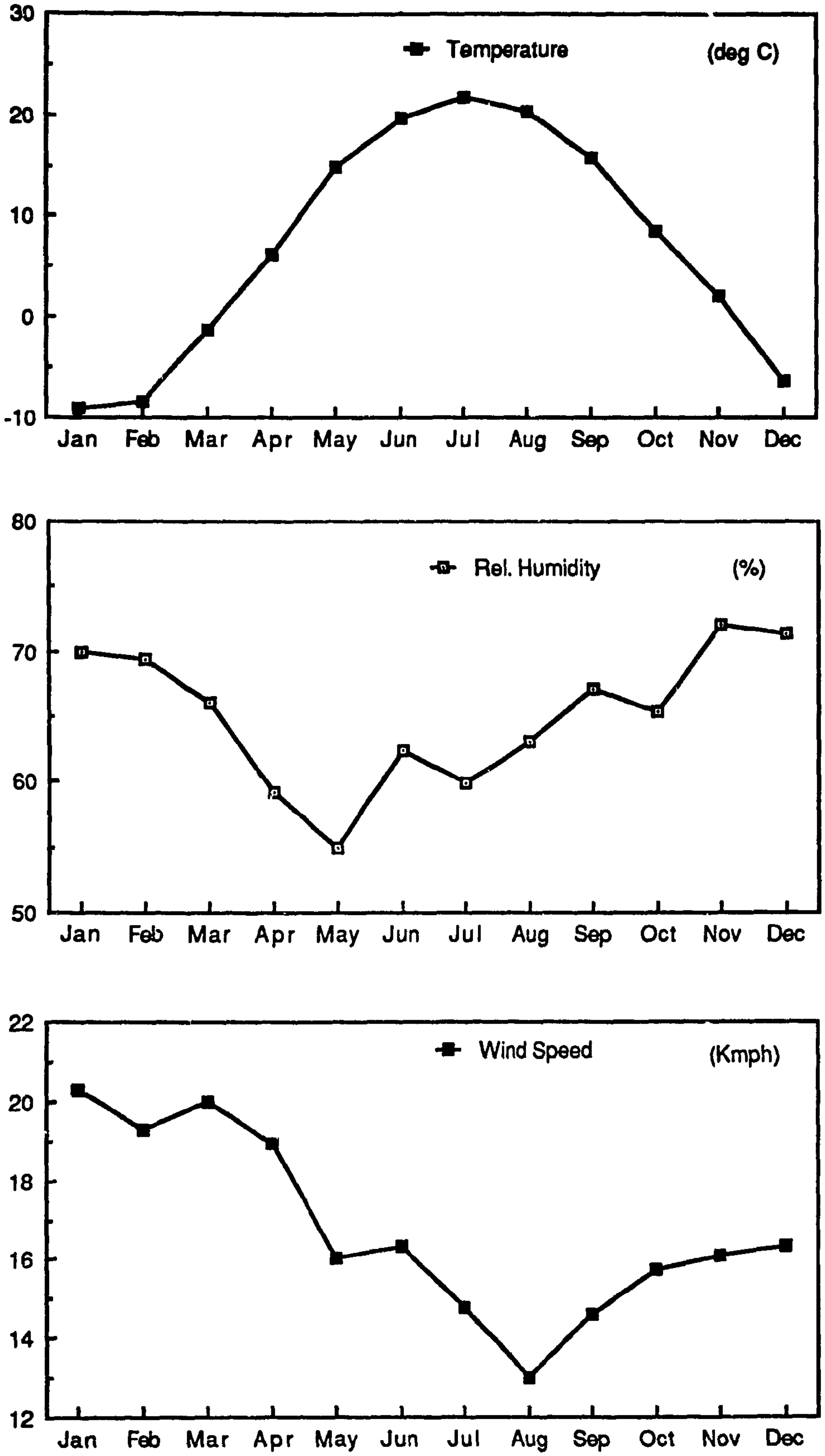
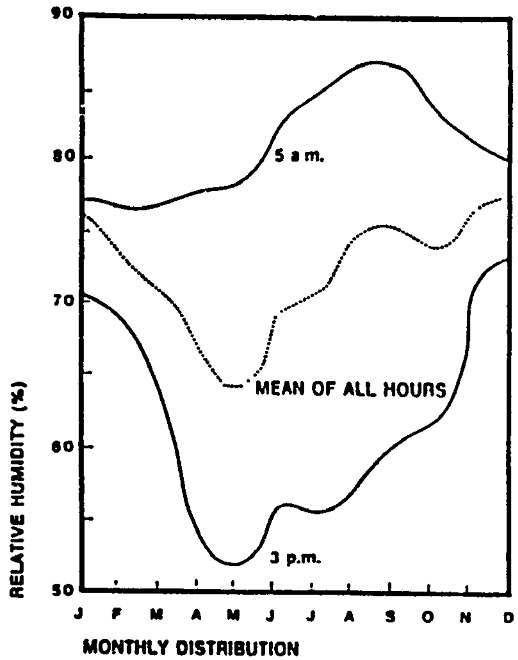
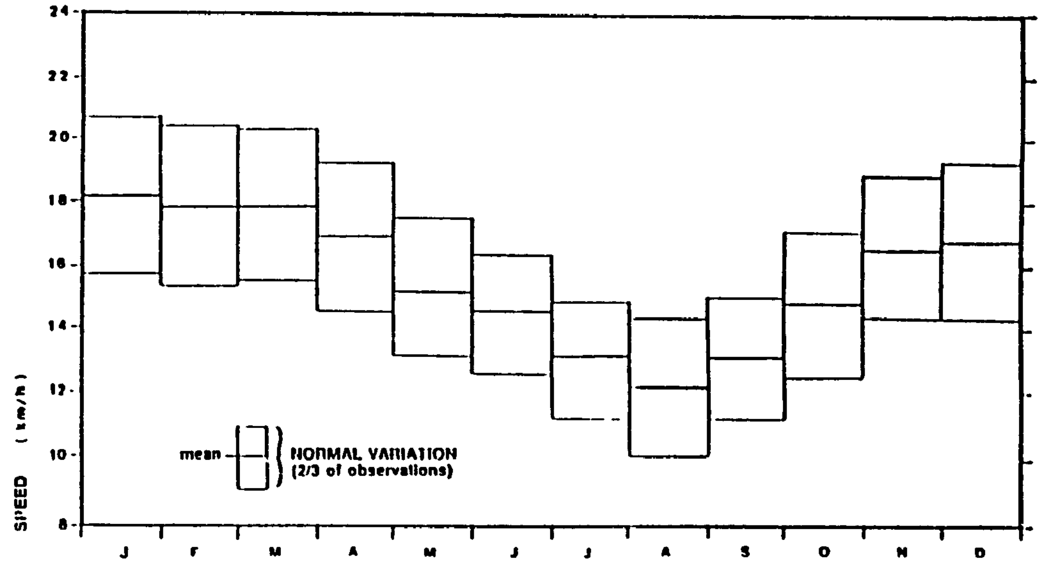
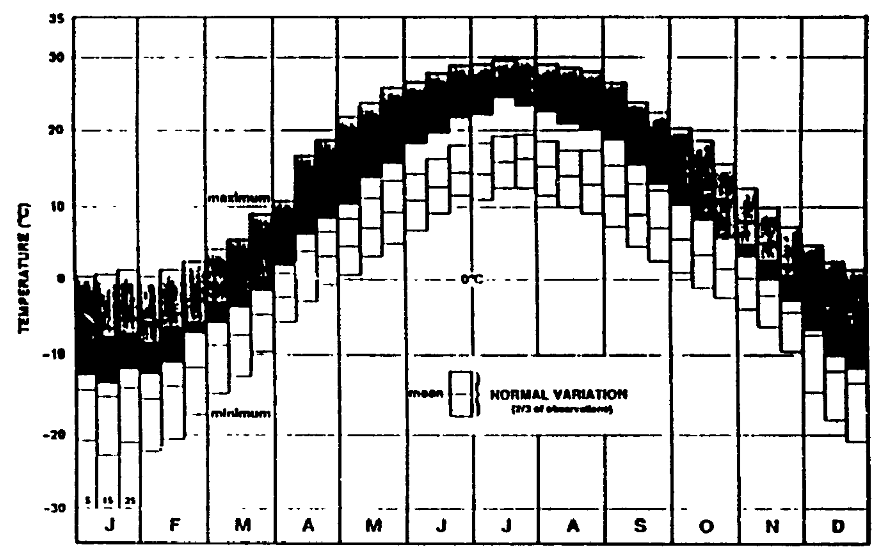


Fig 5.11 Data on Weather in ESCHEDULER





Monthly distribution of wind speeds for all directions at Dorval



Maximum and minimum temperatures at Dorval (1951-1980)

Fig. 4.12 Weather in Montreal

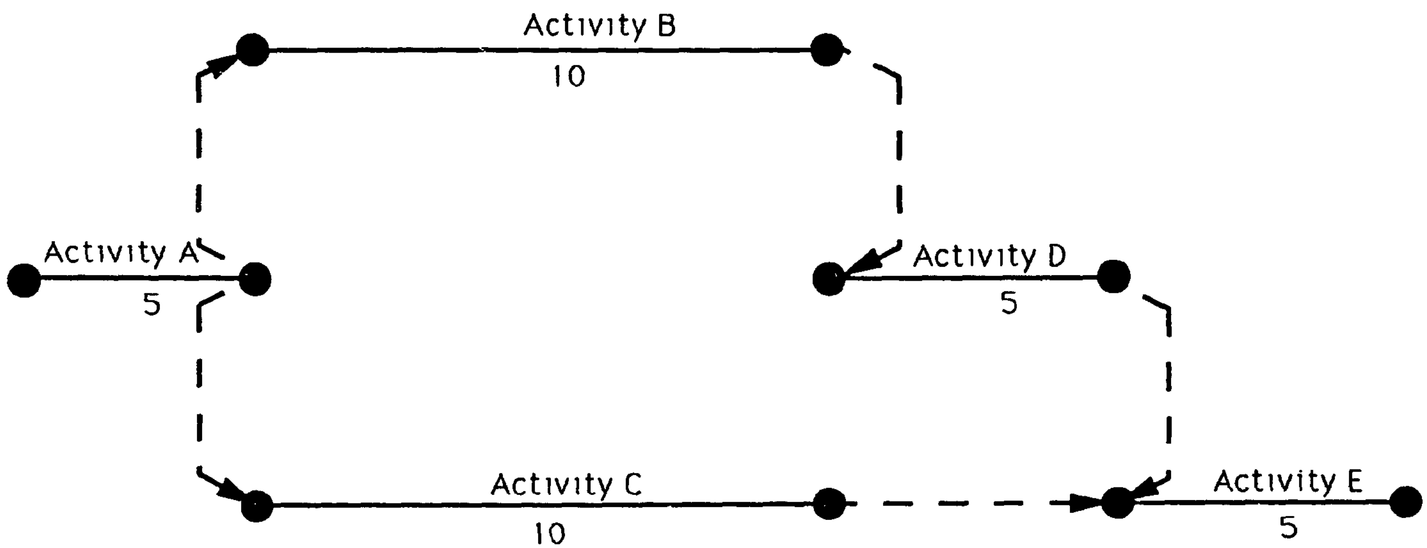


Fig. 5.13 Sample Network (duration in days)

ACTIVITY ID	ORIG DUR	ACTIVITY DESCRIPTION	SCHEDULED START	SCHEDULED FINISH
AB001	5	Activity A	1JUL88	7JUL88
AB002	10	Activity B	8JUL88	21JUL88
AB003	10	Activity C	8JUL88	21JUL88
AB004	5	Activity D	22JUL88	28JUL88
AB005	5	Activity E	29JUL88	4AUG88

Initial Schedule

ACTIVITY ID	ORIG DUR	ACTIVITY DESCRIPTION	SCHEDULED START	SCHEDULED FINISH
AB001	5	Activity A	1JUL88	7JUL88
AB002	12	Activity B	8JUL88	25JUL88
AB003	10	Activity C	8JUL88	21JUL88
AB004	5	Activity D	26JUL88	1AUG88
AB005	5	Activity E	2AUG88	8AUG88

Factor: Learning Curve

ACTIVITY ID	ORIG DUR	ACTIVITY DESCRIPTION	SCHEDULED START	SCHEDULED FINISH
AB001	5	Activity A	1JUL88	7JUL88
AB002	12	Activity B	8JUL88	25JUL88
AB003	10	Activity C	8JUL88	21JUL88
AB004	5	Activity D	26JUL88	1AUG88
AB005	5	Activity E	2AUG88	8AUG88

Factor: Overtime

ACTIVITY ID	ORIG DUR	ACTIVITY DESCRIPTION	SCHEDULED START	SCHEDULED FINISH
AB001	5	Activity A	1JUL88	7JUL88
AB002	11	Activity B	8JUL88	22JUL88
AB003	10	Activity C	8JUL88	21JUL88
AB004	5	Activity D	25JUL88	29JUL88
AB005	5	Activity E	1AUG88	5AUG88

Factor: Re-assignment of Labour

ACTIVITY ID	ORIG DUR	ACTIVITY DESCRIPTION	SCHEDULED START	SCHEDULED FINISH
AB001	5	Activity A	1JUL88	7JUL88
AB002	13	Activity B	8JUL88	26JUL88
AB003	10	Activity C	8JUL88	21JUL88
AB004	5	Activity D	27JUL88	2AUG88
AB005	5	Activity E	3AUG88	9AUG88

Factor: Congestion

ACTIVITY ID	ORIG DUR	ACTIVITY DESCRIPTION	SCHEDULED START	SCHEDULED FINISH
AB001	5	Activity A	1JUL88	7JUL88
AB002	10	Activity B	8JUL88	21JUL88
AB003	10	Activity C	8JUL88	21JUL88
AB004	5	Activity D	22JUL88	28JUL88
AB005	5	Activity E	29JUL88	4AUG88

Factor: Weather (Productivity:100 %)

ACTIVITY ID	ORIG DUR	ACTIVITY DESCRIPTION	SCHEDULED START	SCHEDULED FINISH
AB001	5	Activity A	1JUL88	7JUL88
AB002	18	Activity B	8JUL88	3AUG88
AB003	10	Activity C	8JUL88	21JUL88
AB004	5	Activity D	4AUG88	10AUG88
AB005	5	Activity E	11AUG88	17AUG88

Factor: All

Information in ESCHEDULER

	Severe	Average	Minor
Learning Curve	75 %	85 %	95 %
Congestion	70 %	80 %	90 %
Re-assignment of Labour	85 %	90 %	95 %
Overtime	80 %	85 %	90 %
Weather	(Koehn's Model)		

Method of Combining Impacts: Multiplicative Model

Table 5.5 Accuracy of Execution

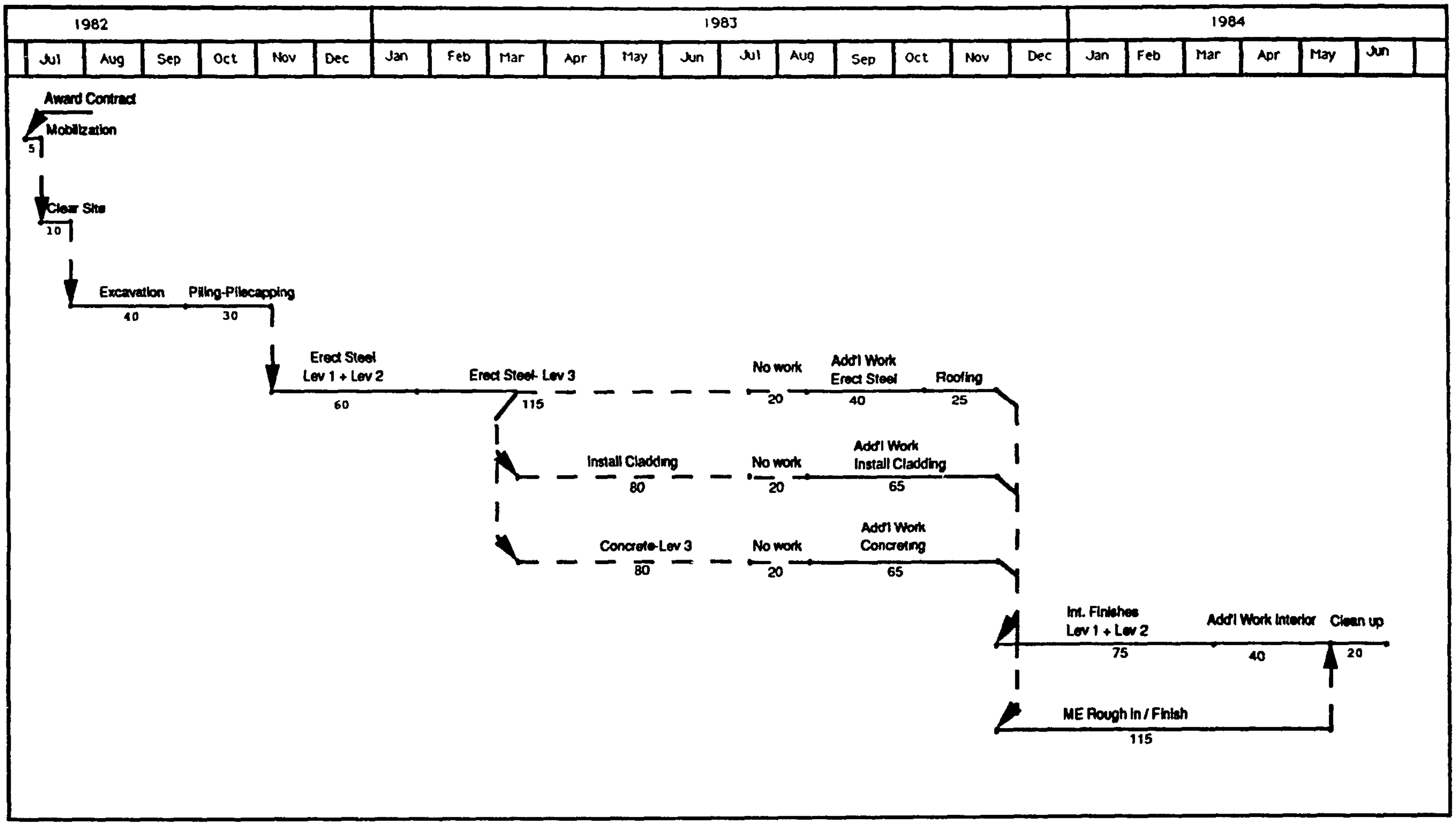


Fig. 5.14 Time Scaled 'As Built' Network

Activity Data		Activities with same Scope and Job Logic			Activity with change in Job Logic (As Planned)			Activity with change in Job Logic (As Possible)		
ACTIVITY ID	ACTIVITY DESCRIPTION	ORIG DUR	SCHEDULED START	SCHEDULED FINISH	ORIG DUR	SCHEDULED START	SCHEDULED FINISH	ORIG DUR	SCHEDULED START	SCHEDULED FINISH
ES010	Award Contract	0	1JUL88	1JUL88	0	1JUL88	1JUL88	0	1JUL88	1JUL88
ES020	Mobilization	5	1JUL88	7JUL88	5	1JUL88	7JUL88	5	1JUL88	7JUL88
ES030	Clear Site	10	8JUL88	21JUL88	10	8JUL88	21JUL88	10	8JUL88	21JUL88
ES040	Excavation	40	22JUL88	15SEP88	40	22JUL88	15SEP88	40	22JUL88	15SEP88
ES050	Piling-Pilecapping	30	16SEP88	27OCT88	30	16SEP88	27OCT88	30	16SEP88	27OCT88
ES060	Erect Steel-Lev 1	33	28OCT88	13DEC88	33	28OCT88	13DEC88	33	28OCT88	13DEC88
ES070	Erect Steel-Lev 2	34	14DEC88	30JAN89	34	14DEC88	30JAN89	34	14DEC88	30JAN89
ES080	Erect Steel-Lev 3	57	31JAN89	19APR89	57	31JAN89	19APR89	57	31JAN89	19APR89
ES090	Install Cladding	20	20APR89	17MAY89	20	1NOV89	28NOV89	20	7NOV89	4DEC89
ES100	Roofing	20	20APR89	17MAY89	20	1NOV89*	28NOV89	24	1NOV89*	4DEC89
ES110	Concrete-Lev 1	20	20APR89	17MAY89	20	20APR89	17MAY89	20	20APR89	17MAY89
ES120	Concrete-Lev 2	20	18MAY89	14JUN89	20	18MAY89	14JUN89	20	18MAY89	14JUN89
ES130	Concrete-Lev 3	40	15JUN89	9AUG89	40	15JUN89	9AUG89	40	15JUN89	9AUG89
ES140	UG Services	75	20APR89	2AUG89	75	20APR89	2AUG89	75	20APR89	2AUG89
ES150	ME Rough in-Lev 1	20	18MAY89	14JUN89	20	18MAY89	14JUN89	20	18MAY89	14JUN89
ES160	ME Rough in-Lev 2	60	15JUN89	6SEP89	60	15JUN89	6SEP89	60	15JUN89	6SEP89
ES170	ME Rough in-Lev 3	75	7SEP89	20DEC89	75	7SEP89	20DEC89	75	7SEP89	20DEC89
ES180	Int Finishes-Lev 2	60	15JUN89	6SEP89	60	15JUN89	6SEP89	60	15JUN89	6SEP89
ES190	Int Finishes-Lev 3	80	7SEP89	27DEC89	80	7SEP89	27DEC89	80	7SEP89	27DEC89
ES200	Painting	20	28DEC89	24JAN90	20	28DEC89	24JAN90	20	28DEC89	24JAN90
ES210	Clean up	20	25JAN90	21FEB90	20	25JAN90	21FEB90	20	25JAN90	21FEB90

Table 5.6 Validation of ESCHEDULER

Activity Data		Start Date: 1 July, 88			Start Date: 1 April, 88		
ACTIVITY ID	ACTIVITY DESCRIPTION	ORIG DUR	SCHEDULED START	SCHEDULED FINISH	ORIG DUR	SCHEDULED START	SCHEDULED FINISH
ES010	Award Contract	0	1JUL88	1JUL88	0	1APR88	1APR88
ES020	Mobilization	5	1JUL88	7JUL88	5	1APR88	7APR88
ES030	Clear Site	10	8JUL88	21JUL88	10	8APR88	21APR88
ES040	Excavation	40	22JUL88	15SEP88	40	22APR88	16JUN88
ES050	Piling-Pilecapping	30	16SEP88	27OCT88	30	17JUN88	28JUL88
ES060	Erect Steel-Lev 1	33	28OCT88	13DEC88	30	29JUL88	8SEP88
ES070	Erect Steel-Lev 2	34	14DEC88	30JAN89	25	9SEP88	13OCT88
ES080	Erect Steel-Lev 3	57	31JAN89	19APR89	47	14OCT88	19DEC88
ES090	Install Cladding	23	20APR89	22MAY89	31	20DEC88	31JAN89
ES100	Roofing	23	20APR89	22MAY89	31	20DEC88	31JAN89
ES110	Concrete-Lev 1	24	20APR89	23MAY89	31	20DEC88	31JAN89
ES120	Concrete-Lev 2	22	24MAY89	22JUN89	30	1FEB89	14MAR89
ES130	Concrete-Lev 3	44	23JUN89	23AUG89	46	15MAR89	17MAY89
ES140	UG Services	85	20APR89	16AUG89	85	20DEC88	17APR89
ES150	ME Rough in-Lev 1	23	24MAY89	23JUN89	23	1FEB89	3MAR89
ES160	ME Rough in-Lev 2	68	26JUN89	27SEP89	68	15MAR89	16JUN89
ES170	ME Rough in-Lev 3	85	28SEP89	24JAN90	85	19JUN89	13OCT89
ES180	Int Finishes-Lev 2	68	23JUN89	26SEP89	68	15MAR89	16JUN89
ES190	Int Finishes-Lev 3	90	27SEP89	30JAN90	90	19JUN89	20OCT89
ES200	Painting	23	31JAN90	2MAR90	23	23OCT89	22NOV89
ES210	Clean up	16	5MAR90	26MAR90	16	23NOV89	14DEC89

Table 5.7 'What-If' Analysis

CHAPTER 6

CONCLUSION

6.1 Conclusion

ESCHEDULER is developed to assist project managers in planning and scheduling construction projects. It is only a prototype system. There are several notable features in this system such as the ES for precedence setting. What is to be noted more is the basic architecture which allows flexible expansion of the system. In such a system, which has been developed in a modular and flexible manner, changes can be carried out quickly and easily without impacting the rest of the system and new modules can be integrated. Unlike other expert systems developed in this domain, ESCHEDULER integrates, builds on, and makes full use of current industry practice and its available traditional software such as the one used for project scheduling.

The potential benefits of this system are substantial as its application can be extended to other problem areas in construction management. Analysis of construction claims involves the preparation of 'as planned plus delays' which is comparable to the revised 'as possible' schedule output by ESCHEDULER, as shown in the preceding chapter. Hence this system can be successfully utilized to assist in preparing construction claims and claims defence and in analysing the 'cause-effect' relationships associated with changes resulting from unforeseeable conditions on site or as initiated by owners or contractors. As KBES provides a way for valuable project management experience to be captured and passed along, ESCHEDULER can be used in teaching and training in this domain. It can be considered as an intelligent decision support tool for resident engineers at site.

This prototype was developed to provide a frame work for a feasible KBES in the area of construction management. It can be clearly seen that ESCHEDULER proves the feasibility of an integrated KBES. KBES with more industrial heuristics may be developed to make them more applicable to construction industry. This may not be an easy task. Development of such an expert system requires substantial resources. Expert knowledge relating to construction is held personally by experienced practitioners and therefore is accessible only piecemeal. An expert system is an attempt to counter this disadvantage by bringing together as many strands of expertise as possible, structured in a manner that helps a user to steer a step-by-step course in learning and solving problems that are largely judgement dependent. Hence knowledge elicitation is perhaps the most ambitious, important, time-consuming, laborious, ill-structured, challenging and complex task. If successfully achieved and superimposed on to a well-designed computer program, an expert system can simulate a consultation as though the computer were the tutor and the user the pupil (Alkass and Harris 1988). The potentials of the system for generating schedules are clearly manifold, but most importantly, results of trials with the system indicate that the concept provides a disciplined method of transferring knowledge and expertise to young and untrained construction engineers.

The study also indicates that pure rule based systems are only useful for small problems where all the knowledge can be represented in several hundred rules. One benefit of the rules approach is the ease of modification and extension of the system; rules can be added independently at any time. In addition, an explanation of how the system arrived at a particular conclusion is available for the user by tracing the rules that were used in the process (Golden et al, 1986). The problem with the rule based system is that their effeciency degrades exponentially with knowledge base size (Niwa et al, 1984). Checking for applicable rules also takes longer as the knowledge base size increases. Since the system is designed to be integrated with other systems, this form of knowledge representation may not be efficient. The frame based structure may provide an effective tool for planning paradigms. Scenarios of conditions, actions, and their effectiveness can be stored as an historical knowledge base. Validation and maintenance of the system will become easier because rule based systems require exhaustive test of all rules, directly or indirectly concerned with the change.

Natural language translation is obviously a technology closely linked to all applications. Its use is for more natural, user-friendly communication with these systems to provide knowledge capture, data input, and processing control. Natural language interface provided in the ESBT, GURU should be enhanced to serve the construction personnel who are not skillful enough in programming.

It should be also noted that the set of criteria established for the selection of the tool, even though for a particular domain, can be further expanded and applied in other domains. With regard to the ESBT utilized for the development of the system, more knowledge representation and inferencing techniques are required to readily represent the nature of construction knowledge and its related experience in addition to processing of this knowledge. The technical problem involved in the implementation of expert systems is undoubtedly reduced by the advent of such sophisticated commercially available ESBTs (Moselhi and Nicholas, 1988). This situation, together with optimistic accounts in the popular press (ENR, 1988a) gives the impression that the construction of new expert systems has become a routine activity, well within the reach of current technology. Despite a number of impressive and widely publicized successes, reports on large scale application of expert systems are conspicuously absent from the literature.

While the feasibility of an integrated hybrid system is demonstrated here, more research is required to enhance this system and to bring it up to operational level.

6.2 Future Research

The objective of this research is to automate some of the network generation task. In order to achieve complete automation more necessary modules have to be attached. The architecture of ESCHEDULER allows for additional software such as those used for cost estimation to be integrated for further application in costing and resource allocation. Many front-end systems can be suggested for further integration to ESCHEDULER. An activity generator is one of them. Activity generation may be performed from a computerized 3-D graphic model of a building which has already been reviewed for its constructability by another KBES. The same 3-D model can be used to prepare the necessary input to a cost estimation software which may later require experience-based modification or analysis performed by a KBES. Storage of the necessary information in a CAD file will allow electronic transmission of input data which is being done manually in ESCHEDULER. Interfacing expert systems with design databases in integrated CAD systems is now becoming an important issue (Rehak and Howard, 1985).

The frame representation reduces the number of rules in the system by eliminating rules required for expressing the relationship between objects/variables. Transferring ESCHEDULER to a frame based tool may help in easy expansion of the system. It will also help in representing multiple activities of the same type. As planning is dominated by a large number of constraints, frame-based systems will be a feasible option (Milne, 1985).

ACTIVITY TRANSLATOR may be further enhanced to employ generic parsing tool, and could be used to interpret a great deal of information contained or implied in the activity description. The technique of recognizing the word(s)in the activity description will be basically an attempt to categorize the word by searching through a tree structred KB to match it with a word about which the system has some knowledge. This should be an interactive process, because one word can have more than one interpretation.

The model which is used to combine the impact of different site conditions on an activity to arrive at a realistic duration needs further study. It assumes that various factors that affect an activity are independent of each other. However, some factors are correlated and a suitable model which could embody the real world situation may be adopted in ESCHEDULER.

There has been a significant problem with the expert system technology and research. It is its inability to characterize the nature of the problems for which it has solutions (Chandrasekaran, 1985). Some seem to think that expert systems are yet another solution to a problem that doesn't exist in the construction industry. Based on the inquiries the firm Stone & Webster Engineering Corp. had over the last two years, it is noted that the construction firms are definitely developing the attitudes that expert systems are a very real part of solving engineering problems (ENR 1988). It was mentioned as a counterpoint that while good thinking by a human expert sees the whole forest, expert system makes its way through the thicket by hopping from tree to tree. But one should remember that trees make a forest.

It should be noted that, because the development of an ES is usually an interactive process between knowledge engineer and expert, the function and performance of an ES evolves over time. It is only through use that the needed refinement of knowledge base is discovered and added interactively. It should be remembered that developing an expert system will change the process and product, and thereby will create more opportunity.

Although this work has been on a prototype and thus can only be seen as a "proof of concept", the demonstrated potential suggests that a continued development is justified.

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*******************************************
* Knowledge Base in ACTIVITY TRANSLATOR *
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R1
IF: A ="DIG FOUNDATION" OR A="EXCAVATE FOUNDATION" OR
    A ="EXCAVATION"  OR A="EXCAVATE"
THEN: activity = "Excavation"


R2
IF: A="CLEAR SITE" OR A="GROUND CLEARING" OR A="SITE CLEARING"
    OR A="SITE PREPARATION" OR A="PREPARE SITE"
THEN: activity="Clear Site"


R3
IF: A="FOUNDATION LAYOUT" OR A="LAYOUT FOUNDATION" OR
    A="SITE SETOUT" OR A="JOB LAYOUT"
THEN: activity= "Job Layout"


R4
IF: A="AFC DRAWINGS"  OR  A="APPROVAL FOR CONSTRUCTION DWGS" OR
    A="CITY APPROVED DWGS" OR A="AFC DWGS"
THEN: activity= "AFC Dwgs"


R5
IF: A="PREPARE SHOP DWGS" OR A="SHOP DWGS PREPARATION" OR
    A="SHOP DRAWINGS" OR A="DETAIL DRAWINGS" OR A="SHOP DWGS"
THEN: activity= "Shop Dwgs"


R6
IF:  A="SHOP DWGS APPROVAL"  OR A="DETAIL DRAWINGS APPROVAL" OR
     A="APPROVE DRAWINGS"   OR A="SHOP DWGS-APPROVAL"
THEN: activity= "Shop Dwgs-Approval"


R7
IF: A="FABRICATE REINFORCEMENT" OR A="BEND STEEL" OR
    A="FABRICATE STEEL"  OR A="FAB & DELIVER STEEL"
THEN: activity= "Fab & Deliver Steel"


R8
IF: A="FABRICATE FORMWORK" OR A="FAB & DELIVER FORMWORK" OR
    A="FABRICATE FORMS"  OR A="FAB & DELIVER FORMS"
THEN: activity= "Fab & Deliver Forms"
```

```
R9
IF:  A="MOBILIZATION" OR A="MOBILIZE" OR  A="MOVE IN"
THEN: activity= "Mobilization"


R10
IF:  A="FORMWORK PREPARATION" OR A=" PREPARE FORMWORK"
THEN: activity= "Formwork Preparation"


R11
IF:  A="DELIVER REINFORCEMENT" OR A="SUPPLY REINFORCEMENT"
THEN: activity= "Deliver Reinforcement"

R12
IF:  A="REBAR"  OR A=" PLACE REINFORCEMENT"
THEN: activity= "Rebar"

R13
IF: A="CONCRETING" OR A="POUR CONCRETE" OR
    A="PLACE CONCRETE"
THEN: activity= "Concreting"

R14
IF: A="STRIKE FORM" OR A="REMOVE FORMWORK" OR
    A="STRIKE FORMWORK"
THEN: activity= "Strike form"


R15
IF: A="CURING" OR A="CURING TIME" OR
    A="CURE CONCRETE"
THEN: activity= "Curing"


R16
IF:  A="FRP FTGS & PERIM.WALLS" OR  A="BUILD FOUNDATION"
THEN: activity= "FRP Ftgs & Perim.Walls"


R17
IF:  A="AWARD CONTRACT" OR A="CONTRACT AWARD"  OR A="SIGN CONTRACT"
THEN: activity= "Award Contract"


R18
IF:  A="CURTAIN WALL" OR A="INSTALL CLADDING"
THEN: activity= "Install Cladding"


R19
IF:  A="COMPACT SOIL" OR A=" BACKFILL"
THEN: activity= "Compact Soil"
```

R20
IF: A="PILING-PILECAPPING" OR A=" PILING" OR A="DRIVE PILES"
OR A="PILE DRIVING"
THEN: activity= "Piling-Pilecapping"

R21
IF: A="INT FINISHES" OR A="FINISH INTERIOR" OR A="FINISHES"
THEN: activity= "Int Finishes"

R22
IF: A="ROOFING" OR A="ROOF" OR A="INSTALL ROOF"
THEN: activity= "Roofing"

R23
IF: A="UG SERVICES" OR A="UNDERGROUND SERVICES"
THEN: activity= "UG Services"

R24
IF: A="ME ROUGH-IN" OR A="MECH/ELEC ROUGHIN"
THEN: activity= "ME Rough-in"

R25
IF: A="FRP COLUMNS" OR A="COLUMNS" OR A="POUR COLUMNS"
THEN: activity= "FRP Columns"

R26
IF: A="FRP FLOOR" OR A=" FLOOR" OR A="POUR FLOOR"
THEN: activity= "FRP Floor"

R27
IF: A="SLAB ON GRADE" OR A="UNDERGROUND SLAB" A="SOG"
OR A="S.O.G."
THEN: activity= "Slab on Grade"

R28
IF: A="EXT MASONRY" OR A="EXTERIOR MASONRY" OR A="MASONRY-EXTERIOR"
THEN: activity= "Ext Masonry"

R29
IF: A="STAIRS" OR A="STEPS" OR A="STAIRCASE"
THEN: activity= "Stairs"

R30
IF: A="INT MASONRY" OR A="INTERIOR MASONRY" OR A="MASONRY-INTERIOR"
THEN: activity= "Int Masonry"

```
***************************************
* Knowledge Base In JOBLOGIC HELPER *
***************************************
```

VARIABLES:

A1: an activity | A2: another activity

LAG: lag between the two | LINK: relationship between them

PRECEDACT: preceding activity | SUCCEDACT: succeding activity

PREC: Partial or Conventional relationship (query)

RULES

```
R1
IF: A1={"Award Contract","Mobilization"}  &  A2={"Award Contract","Mobilization"}
THEN: precedact="Award Contract"
    succedact="Mobilization"
    if prec="P" then
    @ 14,2 ? "Mobilization can begin, only after contract is signed."
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif

R2
IF: A1={"Mobilization","Clear Site"} & A2={"Mobilization","Clear Site"}
THEN: precedact="Mobilization"
    succedact="Clear Site"
    if prec="C" then  lag=0;link="C"; endif
    if prec="P" then
    @ 14,2 ? "Site can be cleared before completing mobilization."
    @  15,2  input lag int with "How many days of mobilization is  required  to  begin
    site clearance?"
    link="S"
    endif

R3
IF: A1={"Clear Site","Excavation"} & A2={"Clear Site","Excavation"}
THEN: precedact="Clear Site"
    succedact="Excavation"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "Excavation can be done while site is being cleared."
    @  15,2  input  lag  int with "How many days of  site  clearance  is  required  to
    begin excavation?"
    link="S"
    end

R4
IF:      A1={"Excavation","Piling-Pilecapping"} & A2={"Excavation","Piling-
             Pilecapping"}
THEN: precedact="Excavation"
    succedact="Piling-Pilecapping"
```

```
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "Piling can be done while excavating the site."
    @ 15,2 input lag int with "How many days of site excavation is required to
    begin piling?"
    link="S"
    endif

R5
IF:    A1={"Piling-Pilecapping","Erect Steel-Lev 1"} & A2={"Piling-
       Pilecapping","Erect Steel-Lev 1"}
THEN: precedact="Piling-Pilecapping"
    succedact="Erect steel-Lev 1"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "Conventional relationship is assumed."
    link="C";lag=0
    endif

R6
IF: A1={"Erect Steel-Lev 1","Erect Steel-Lev 2"} & A2={"Erect Steel-Lev 1","Erect
       Steel-Lev 2"}
THEN: precedact="Erect Steel-Lev 1"
    succedact="Erect Steel-Lev 2"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif

R7
IF: A1={"Erect Steel-Lev 2","Erect Steel-Lev 3"} & A2={"Erect Steel-Lev 2","Erect
       Steel-Lev 3"}
THEN: precedact="Erect Steel-Lev 2"
    succedact="Erect Steel-Lev 3"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif

R8
IF:  A1={"Erect Steel-Lev 3","Install Cladding"} & A2={"Erect Steel-Lev
       3","Install Cladding"}
THEN: precedact="Erect Steel-Lev 3"
    succedact="Install Cladding"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif

R9
IF: A1={"Erect Steel-Lev 3","Roofing"} & A2={"Erect Steel-Lev 3","Roofing"}
THEN: precedact="Erect Steel-Lev 3"
```

```
    succedact="Roofing"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif

R10
IF:   A1={"Erect   Steel-Lev   3","Concrete-Lev   1"}   &   A2={"Erect   Steel-Lev
          3","Concrete-Lev 1"}
THEN: precedact="Erect Steel-Lev 3"
    succedact="Concrete-Lev 1"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif

R11
IF:  A1={"Concrete-Lev 1","Concrete-Lev 2"} & A2={"Concrete-Lev  1","Concrete-Lev
         2"}
THEN: precedact="Concrete-Lev 1"
    succedact="Concrete-Lev 2"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "Conventional relationship is assumed."
    link="C";lag=0
    endif

R12
IF: A1={"Concrete-Lev 3","Concrete-Lev 2"} & A2={"Concrete-Lev 3","Concrete-Lev 2"}
THEN: precedact="Concrete-Lev 2"
    succedact="Concrete-Lev 3"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "Conventional relationship is assumed."
    link="C";lag=0
    endif

R13
IF:  A1={"Concrete-Lev  1","ME  Rough  in-Lev 1"}  &  A2={"Concrete-Lev  1","ME  Rough
         in-Lev 1"}
THEN:precedact="Concrete-Lev 1"
    succedact="ME Rough in-Lev 1"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif

R14
IF: A1={"Concrete-Lev 1","UG Services"} & A2={"Concrete-Lev 1","UG Services"}
THEN: precedact="Concrete-Lev 1"
    succedact="UG Services"
    if prec="C" then lag=0;link="C";endif
```

```
    if prec="P" then
    @ 15,2 ? "These two activities can start at the same time."
    lag=0;link="S"
    endif

R15
IF:  A1={"Concrete-Lev 2","ME Rough in-Lev 2"} & A2={"Concrete-Lev  2","ME  Rough
         in-Lev 2"}
THEN: precedact="Concrete-Lev 2"
    succedact="ME Rough in-Lev 2"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif

R16
IF:  A1={"Concrete-Lev 3","ME Rough in-Lev 3"} & A2={"Concrete-Lev  3","ME  Rough
         in-Lev 3"}
THEN: precedact="Concrete-Lev 3"
    succedact="ME Rough in-Lev 3"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif

R17
IF:  A1={"Concrete-Lev  2","Int  Finishes-Lev  2"}  &  A2={"Concrete-Lev  2","Int
         Finishes-Lev 2"}
THEN: precedact="Concrete-Lev 2"
    succedact="Int Finishes-Lev 2"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif

R18
IF:  A1={"Concrete-Lev  3","Int  Finishes-Lev  3"}  &  A2={"Concrete-Lev  3","Int
        Finishes-Lev 3"}
THEN: precedact="Concrete-Lev 3"
    succedact="Int Finishes-Lev 3"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif


R19
IF: A1={"Int Finishes-Lev 3","Painting"} & A2={"Int Finishes-Lev 3","Painting"}
THEN: precedact="Int Finishes-Lev 3"
    succedact="Painting"
    if prec="C" then lag=0;link="C";endif
```

```
    if prec="P" then
    @ 15,2 input lag int with "After how many days of Int Finishes Painting  can
    begin?"
    link="S"
    endif


R20
IF: A1={"ME Rough in-Lev 3","Painting"} & A2={"ME Rough in-Lev 3","Painting"}
THEN: precedact="ME Rough in-Lev 3"
    succedact="Painting"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 input lag int with "After how many days of Int Finishes Painting  can
    begin?"
    link="S"
    endif

R21
IF: A1={"Clean up","Painting"} & A2={"Clean up","Painting"}
THEN: precedact="Painting"
    succedact="Clean up"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "These two activities can be completed simultaneously."
    link="F";lag=0
    endif

R22
IF: A1={"Roofing","Install Cladding"} & A2={"Roofing","Install Cladding"}
THEN: precedact="Roofing"
    succedact="Install Cladding"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "These two activities can finish simultaneously."
    lag=0;link="F"
    endif

R23
IF:  A1={"ME Rough in-Lev 1","ME Rough in-Lev 2"} & A2={"ME Rough  in-Lev  1","ME
        Rough in-Lev 2"}
THEN: precedact="ME Rough in-Lev 1"
    succedact="ME Rough in-Lev 2"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @  15,2 input lag int with "After how many days of work in Lev-1  can
    you begin rough in Lev-2?"
    link="S"
    endif

R24
IF:  A1={"ME Rough in-Lev 2","ME Rough in-Lev 3"} & A2={"ME Rough  in-Lev  2","ME
        Rough in-Lev 3"}
THEN: precedact="ME Rough in-Lev 2"
    succedact="ME Rough in-Lev 3"
```

```
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @  15,2 input lag int with "After how many days of work in Lev-1  can
    you begin rough in Lev-2?"
    link="S"
    endif

R25
IF:A1={"Int Finishes-Lev 2","Int Finishes-Lev 3"} & A2={"Int Finishes-Lev 2","Int
       Finishes-Lev 3"}
THEN: precedact="Int Finishes-Lev 2"
    succedact="Int Finishes-Lev 3"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 input lag int with "After how many days working in lev 2 can you start
    on lev 3?"
    link="S"
    endif

R26
IF: A1={"Award Contract","AFC Dwgs"} &  A2={"Award Contract","AFC Dwgs"}
THEN: precedact="Award Contract"
    succedact="AFC Dwgs"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @  14,2 ? "Drawings approved for construction are handed over after  contract
    is signed."
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif


R27
IF: A1={"Mobilization","Site   Installation"}    &    A2={"Mobilization","Site
       Installation"}
THEN: precedact="Mobilization"
    succedact="Site Installation"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @  14,2  ? "Construction site can be equipped while mobilization  is  carried
    out."
    @ 15,2 input lag int with "How many days of mobilization is required,  before
    equipping the    site?"
    link="S"
    endif

R28
IF: A1={"AFC Dwgs","Mobilization"} & A2={"AFC Dwgs","Mobilization"}
THEN: precedact="AFC Dwgs"
    succedact="Mobilization"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif
```

```
R29
IF: A1={"AFC Dwgs","Shop Dwgs-Approval"} & A2={"AFC Dwgs","Shop Dwgs-Approval"}
THEN: precedact="AFC Dwgs"
     succedact="Shop Dwgs-Approval"
     if prec="C" then lag=0;link="C";endif
     if prec="P" then
     @ 14,2 ? "Drawings can be sent to A/E for approval as and when they are
     completed."
     @ 15,2 input lag int with "How many days do you require to send the first set
     of drawings?"
     link="S"
     endif

R30
IF: A1={"Site Installation","Clear Site"} & A2={"Site Installation","Clear Site"}
THEN: precedact="Site Installation"
     succedact="Clear Site"
     if prec="C" then lag=0;link="C";endif
     if prec="P" then
     @ 8,2 ? "Site may be cleared before completing equipping the site."
     @ 10,2 input lag int with "Number of days required to adequately equip the
     site to start site clearance?"
     link="S"
     endif

R31
IF: A1={"Mobilization","Job Layout"} & A2={"Mobilization","Job Layout"}
THEN: precedact="Mobilization"
     succedact="Job Layout"
     if prec="C" then lag=0;link="C";endif
     if prec="P" then
     @ 14,2 ? "Foundation can be be laid out while mobilizing resources."
     @ 15,2 input lag int with "How many days of mobilization are required to
     start laying out the foundation?"
     link="S"
     endif

R32
IF: A1={"Site Installation","Job Layout"} & A2={"Site Installation","Job Layout"}
THEN: precedact="Site Installation"
     succedact="Job Layout"
     if prec="C" then lag=0;link="C";endif
     if prec="P" then
     @ 14,2 ? "Foundation layout can begin before completing equipping the site."
     @ 15,2 input lag int with "Number of days required to adequately equip the
     site to start foundation layout:"
     link="S"
     endif

R33
IF: A1={"Job Layout","Excavation"} & A2={"Job Layout","Excavation"}
THEN: precedact="Job Layout"
     succedact="Excavation"
```

```
    if prec="C" then lag=0;link="C";endif
    if prec="P"  then
    @ 14,2 ? "Excavation can begin before completing foundation layout."
    @ 15,2 input lag int with "Number of days required to layout adequate
    foundation to start excavation:"
    link="S"
    endif

R34
IF:   A1={"Shop Dwgs-Approval","Fab,Deliver Steel"} & A2={"Shop Dwgs-
      Approval","Fab,Deliver Steel"}
THEN: precedact="Shop Dwgs-Approval"
    succedact="Fab,Deliver Steel"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "Shop drawings should be completed before placing orders for steel."
    @ 15,2 ? "Conventional relationship is assumed."
    link="C";lag=0
    endif

R35
IF:  A1={"Shop Dwgs-Approval","Fab,Deliver Forms"} & A2={"Shop Dwgs-Approval"
        ,"Fab,Deliver Forms"
THEN: precedact="Shop Dwgs-Approval"
    succedact="Fab,Deliver Forms"
    if prec="P" then
    @ 14,2 ? "Shop drawings should be completed before placing order for forms."
    @ 15,2 ? "Conventional relationship is assumed."
    link="C";lag=0
    endif

R36
IF:A1={"Shop Dwgs-Approval","Fab,Deliver Cladding"} & A2={"Shop Dwgs-
     Approval","Fab,Deliver Cladding"}
THEN: precedact="Shop Dwgs-Approval"
    succedact="Fab,Deliver Cladding"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "Shop drawings should be completed before placing orders."
    @ 15,2 ? "Conventional relationship is assumed."
    link="C"; lag=0
    endif

R37
IF:A1=  {"Fab,Deliver Forms","FRP Ftgs,Perim Walls"} & A2={"Fab,Deliver
         Forms","FRP Ftgs,Perim Walls"}
THEN: precedact="Fab,Deliver Forms"
    succedact="FRP Ftgs,Perim Walls"
    if prec="C" then lag=0;link="C";endif
    if proc="P" then
    @ 14,2 ? "Form-Reinforce-Pour for footings and perimeter walls"
    @ 15,2 ? "can be done only after forms are ready at the site."
    @ 16,2 input lag int with "After placing the order, how long do you need to
    wait to receive the forms?"
    link="S"
```

```
endif

R38
IF: A1={"Fab,Deliver Forms","FRP Columns-Lev 1"} & A2={"Fab,Deliver Forms"  ,"FRP
        Columns-Lev 1"}
THEN: precedact="Fab,Deliver Forms"
    succedact="FRP Columns-Lev 1"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "Form-Reinforce-Pour for ground floor columns"
    @ 15,2 ? "can be done only after forms are ready at the site."
    @  16,2 input lag int with "After placing the order, how long do you need  to
    wait to receive     the forms?"
    link="S"
    endif

R30
IF:  A1={"Fab,Deliver Forms","FRP Columns-Lev 2"} & A2={"Fab,Deliver  Forms","FRP
        Columns-Lev 2"}
THEN:precedact="Fab,Deliver Forms"
    succedact="FRP Columns-Lev 2"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "Form-Reinforce-Pour for first floor columns"
    @ 15,2 ? "can be done only after forms are ready at the site."
    @  16,2 input lag int with "After placing the order, how long do you need  to
    wait to receive the forms?"
    link="S"
    endif

R40
IF:  A1={"Fab,Deliver  Forms","FRP Floor-Lev 1"} &  A2={"Fab,Deliver  Forms","FRP
        Floor-Lev 1"}
THEN:precedact="Fab,Deliver Forms"
    succedact="FRP Floor-Lev 1"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "Form-Reinforce-Pour for ground floor"
    @ 15,2 ? "can be done only after forms are ready at the site."
    @  16,2 input lag int with "After placing the order, how long do you need  to
    wait to receive the forms?"
    link="S"
    endif

R41
IF:  A1={"Fab,Deliver  Forms","FRP Floor-Lev 2"} &  A2={"Fab,Deliver  Forms","FRP
        Floor-Lev 2"}
THEN: precedact="Fab,Deliver Forms"
    succedact="FRP Floor-Lev 2"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "Form-Reinforce-Pour for first floor"
    @ 15,2 ? "can be done only after forms are ready at the site."
    @  16,2 input lag int with "After placing the order, how long do you need  to
    wait to receive the forms?"
```

```
link="S"
endif

R42
IF:   A1={"Fab,Deliver  Steel","FRP  Ftgs,Perim  Walls"}  &  A2={"Fab,Deliver
        Steel","FRP Ftgs,Perim    Walls"}
THEN: precedact="Fab,Deliver Steel"
    succedact="FRP Ftgs,Perim Walls"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "Form-Reinforce-Pour for footings and perimeter walls"
    @ 15,2 ? "can be done only after steel is ready at the site."
    @  16,2 input lag int with "After placing the order, how long do you need  to
    wait to receive steel?"
    link="S"
    endif

R43
IF:  A1={"Fab,Deliver Steel","FRP Columns-Lev 1"} & A2={"Fab,Deliver  Steel","FRP
       Columns-Lev 1"}
THEN: precedact="Fab,Deliver Steel"
    succedact="FRP Columns-Lev 1"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "Form-Reinforce-Pour for ground floor columns"
    @ 15,2 ? "can be done only after steel is ready at the site."
    @  16,2 input lag int with "After placing the order, how long do you need  to
    wait to receive steel?"
    link="S"
    endif

R44
IF:  A1={"Fab,Deliver Steel","FRP Columns-Lev 2"} & A2={"Fab,Deliver  Steel","FRP
Columns-Lev 2"}
THEN: precedact="Fab,Deliver Steel"
    succedact="FRP Columns-Lev 2"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "Form-Reinforce-Pour for first floor columns"
    @ 15,2 ? "can be done only after steel is ready at the site."
    @  16,2 input lag int with "After placing the order, how long do you need  to
    wait to receive steel?"
    link="S"
    endif

R45
IF:  A1={"Fab,Deliver  Steel","FRP Floor-Lev 1"} &  A2={"Fab,Deliver  Steel","FRP
        Floor-Lev 1"}
THEN: precedact="Fab,Deliver Steel"
    succedact="FRP Floor-Lev 1"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "Form-Reinforce-Pour for ground floor"
    @ 15,2 ? "can be done only after steel is ready at the site."
    @  16,2 input lag int with "After placing the order, how long do you need  to
```

```
    wait to receive steel?"
    link="S"
    endif

R46
IF:  A1={"Fab,Deliver  Steel","FRP Floor-Lev 2"} &  A2={"Fab,Deliver  Steel","FRP
Floor-Lev 2"}
THEN: precedact="Fab,Deliver Steel"
    su cedact="FRP Floor-Lev 2"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "Form-Reinforce-Pour for first floor"
    @ 15,2 ? "can be done only after steel is ready at the site."
    @  16,2 input lag int with "After placing the order, how long do you need  to
    wait to receive steel?"
    link="S"
    endif

R47
IF:  A1={"Fab,Deliver Steel","Slab on Grade"} & A2={"Fab,Deliver Steel","Slab  on
        Grade"}
THEN: precedact="Fab,Deliver Steel"
    succedact="Slab on Grade"
    putform plogic;getform plogic
    if prec="C" then
    lag=0;link="C"
    endif
    if prec="P" then
    @ 14,2 ? "Basement floor can be concreted after steel is ready at the site"
    @  15,2 input lag int with "After placing the order, how long do you need  to
    wait to receive steel?"
    link="S"
    endif

R48
IF:  A1={"Excavation","FRP Ftgs,Perim Walls"} & A2={"Excavation","FRP  Ftgs,Perim
        Walls"}
THEN: precedact="Excavation"
    succedact="FRP Ftgs,Perim Walls"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
     @  14,2 ? "Foundation should be excavated to pour concrete for footings  and
    perimeter walls."
    @ 15,2 input lag int with "How long do you need to excavate adequate part  of
    the site?"
    link="S"
    endif

R49
IF:  A1={"FRP  Ftgs,Perim  Walls","FRP  Columns-Lev  1"}  &  A2={"FRP  Ftgs,Perim
        Walls","FRP Columns-Lev 1"}
THEN: precedact="FRP Ftgs,Perim Walls"
    succedact="FRP Columns-Lev 1"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
```

```
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif

R50
IF:  A1={"FRP Ftgs,Perim Walls","FRP Floor-Lev 2"} & A2={"FRP Ftgs,Perim
        Walls","FRP Floor-Lev 2"}
THEN: precedact="FRP Ftgs,Perim Walls"
    succedact="FRP Floor-Lev 2"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif

R51
IF:  A1={"FRP Columns-Lev 2","FRP Floor-Lev 2"} & A2={"FRP Columns-Lev 2","FRP
        Floor-Lev 2"}
THEN: precedact="FRP Columns-Lev 2"
    succedact="FRP Floor-Lev 2"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif

R52
IF: A1={"FRP Floor-Lev 2","UG Services"} & A2={"FRP Floor-Lev 2","UG Services"}
THEN: precedact="FRP Floor-Lev 2"
    succedact="UG Services"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? " It is better to start laying UG pipes after struts are removed for
    Gr.Flr."
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif

R53
IF:  A1={"FRP Floor-Lev 2","Slab on Grade"} & A2={"FRP Floor-Lev 2","Slab on
     Grade"}
THEN: precedact="FRP Floor-Lev 2"
    succedact="Slab on Grade"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? " It is better to pour for Slab on grade after struts are removed
    for Gr.Flr."
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif

R54
IF: A1={"UG Services","Slab on Grade"} & A2={"UG Services","Slab on Grade"}
THEN: precedact="UG Services"
    succedact="Slab on Grade"
```

```
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif

R55
IF: A1={"Slab on Grade","ME Rough in"} & A2={"Slab on Grade","ME Rough in"}
THEN: precedact="Slab on Grade"
    succedact="ME Rough in"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif

R56
IF: A1={"FRP Columns-Lev 1","Roofing-Lev 1"} & A2={"FRP Columns-Lev 1","Roofing-
        Lev 1"}
THEN: precedact="FRP Columns-Lev 1"
    succedact="Roofing-Lev 1"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif

R57
IF: A1={"FRP Columns-Lev 2","Roofing-Lev 2"} & A2={"FRP Columns-Lev 2","Roofing-
        Lev 2"}
THEN: precedact="FRP Columns-Lev 2"
    succedact="Roofing-Lev 2"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif

R58
IF: A1={"Roofing-Lev 1","Ext Masonry"} & A2={"Roofing-Lev 1","Ext Masonry"}
THEN: precedact="Roofing-Lev 1"
    succedact="Ext Masonry"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif

R59
IF: A1={"Roofing-Lev 2","Stairs"} & A2={"Roofing-Lev 2","Stairs"}
THEN: precedact="Roofing-Lev 2"
    succedact="Stairs"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed."
```

```
lag=0;link="C"
 endif

R60
IF: A1={"ME Rough in","ME Finish"} & A2={"ME Rough in","ME Finish"}
THEN: precedact="ME Rough in"
    succedact="ME Finish"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif

R61
IF: A1={"ME Rough in","Int Masonry"} & A2={"ME Rough in","Int Masonry"}
THEN: precedact="ME Rough in"
    succedact="Int Masonry"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "ME Rough in should be done before interior masonry work"
    @ 15,2 input lag int with "How long do you need to Rough in adequate part  of
    the floor:"
    link="S"
    endif

R62
IF: A1={"ME Rough in","Dry Walls"} & A2={"ME Rough in","Dry Walls"}
THEN: precedact="ME Rough in"
    succedact="Dry Walls"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "ME Rough in should be done before dry walls can be put up"
    @ 15,2 input lag int with "How long do you need to Rough in adequate part  of
    the floor:"
    link="S"
    endif

R63
IF: A1={"ME Rough in","Piping,Fixtures"} & A2={"ME Rough in","Piping,Fixtures"}
THEN: precedact="ME Rough in"
    succedact="Piping,Fixtures"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @  14,2  ?  "ME  Rough in should be done before  piping  &  fixtures  can  be
    installed."
    @ 15,2 input lag int with "How long do you need to Rough in adequate part  of
    the floor:"
    link="SS"
    endif

R64
IF: A1={"ME Finish","Wall,Floor Finish"} & A2={"ME Finish","Wall,Floor Finish"}
THEN: precedact="ME Finish"
    succedact="Wall,Floor Finish"
    if prec="C" then lag=0;link="C";endif
```

```
if prec="P" then
@ 14,2 ? "ME and Wall,Floor can be finished in parallel."
@ 15,2 input lag int with "How long do you need to finish adequate part of ME."
link="S"
endif

R65
IF: A1={"Fab,Deliver  Cladding","Install  Cladding"}  &  A2={"Fab,Deliver
    Cladding","Install Cladding"}
THEN: precedact="Fab,Deliver Cladding"
    succedact="Install Cladding"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @  14,2 ? "Exterior cladding can be done only after cladding is ready at  the
    site."
    @  15,2 input lag int with "After placing the order, how long do you need  to
    wait to receive cladding:"
    link="S"
    endif

R66
IF: A1={"Install Cladding","ME Finish"} & A2={"Install Cladding","ME Finish"}
THEN: precedact="Install Cladding"
    succedact="ME Finish"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "These two activities may be finished one after the other."
    @ 15,2 input lag int with "How long do you need to finish ME after installing
    cladding?"
    link="F"
    endif

R67
IF: A1={"Piping,Fixtures","ME Finish"} & A2={"Piping,Fixtures","ME Finish"}
THEN: precedact="Piping,Fixtures"
    succedact="ME Finish"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif

R68
IF: A1={"Piping,Fixtures","Ceiling"} & A2={"Piping,Fixtures","Ceiling"}
THEN: precedact="Piping,Fixtures"
    succedact="Ceiling"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "Piping & Fixtures should be in place before installing ceiling."
    @  15,2  input  lag int with "How long do you need  to  install  fixtures  to
    commence ceiling?"
    link="S"
    endif

R69
```

```
IF: A1={"Ext Masonry","Install Cladding"} & A2={"Ext Masonry","Install Cladding"}
THEN: precedact="Ext Masonry"
    succedact="Install Cladding"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "Exterior cladding can be done once the exterior masonry is done."
    @  15,2 input lag int with "How long do you need to complete  ext.masonry  on
    one side of thee bldg.?"
    link="S"
    endif

R70
IF:  A1={"Ext  Masonry","Windows,Ext  Doors"}  &  A2={"Ext  Masonry","Windows,Ext
     Doors"}
THEN: precedact="Ext Masonry"
    succedact="Windows,Ext Doors"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "Conventional relationship is assumed. "
    lag=0;link="C"
     endif

R71
IF:    A1={"Windows,Ext    Doors","Install    Cladding"}    &    A2={"Windows,Ext
       Doors","Install Cladding"}
THEN: precedact="Windows,Ext Doors"
    succedact="Install Cladding"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @  14,2  ?  "Cladding,Ext door and windows should be completed  at  the  same
    time."
    @ 11,2 ? " Finish-Finish assumed."
    lag=0;link="F"
    endif

R72
IF: A1={"Int Masonry","ME Finish"} & A2={"Int Masonry","ME Finish"}
THEN: precedact="Int Masonry"
    succedact="ME Finish"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed "
    lag=0;link="C"
    endif

R73
IF: A1 =  {"Int Masonry","Carpentry,Millwork"} & A2={"Int  Masonry",
       "Carpentry,Millwork"}
THEN: precedact="Int Masonry"
    succedact="Carpentry,Millwork"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "Carpentry,millwork can begin after masonry has started "
    @ 15,2 input lag int with "How long do you need to complete adequate part  on
    masonry?"
```

```
    link="S"
    endif

R74
IF: A1={"Stairs","Floor,Wall Finish"} & A2={"Stairs","Floor,Wall Finish"}
THEN: precedact="Stairs"
    succedact="Floor,Wall Finish"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif

R75
IF: A1={"Carpentry,Millwork","Floor,Wall Finish"} &
    A2={"Carpentry,Millwork","Floor,Wall Finish"}
THEN: precedact="Carpentry,Millwork"
    succedact="Floor,Wall Finish"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0
    link="C"
    endif

R76
IF: A1={"Dry Walls","ME Finish"} & A2={"Dry Walls","ME Finish"}
THEN: precedact="Dry Walls"
    succedact="ME Finish"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif

R77
IF: A1={"Dry Walls","Carpentry,Millwork"} & A2={"Dry Walls","Carpentry,Millwork"}
THEN: precedact="`ry Walls"
     succedact="Carpentry,Millwork"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "Carpentry,millwork can begin after dry walls has started."
    @ 15,2 input lag int with "How long do you need to complete adequate part  of
    dry walls?"
    link="S"
    endif

R78
IF: A1={"Ceiling","Painting"} & A2={"Ceiling","Painting"}
THEN: precedact="Ceiling"
    succedact="Painting"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
```

```
    endif

R79
IF: A1={"Wall,Floor Finish","Painting"} & A2={"Wall,Floor Finish","Painting"}
THEN: precedact="Wall,Floor Finish"
    succedact="Painting"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "These two activities should be completed at the same time."
    @ 15,2 ? " Finish-Finish assumed."
    lag=0;link="F"
     endif

R80
IF: A1={"Painting","Landscape"} & A2={"Painting","Landscape"}
THEN: precedact="Painting"
    succedact="Landscape"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "These two activities can be done in parallel."
    @ 15,2 ? " Finish-Finish assumed."
    lag=0;link="F"
    endif

R81
IF: A1={"Landscape","Demobilization"} & A2={"Landscape","Demobilization"}
THEN: precedact="Landscape"
    succedact="Demobilization"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "These two activities can be done in parallel."
    @  15,2  input  lag  int  with "How long  do  you  need  to  demobilze  after
    landscaping is done?"
    link="F"
    endif

R82
IF: A1={"Roofing-Lev 2","Ext Masonry"} & A2={"Roofing-Lev 2","Ext Masonry"}
THEN: precedact="Roofing-Lev 2"
    succedact="Ext Masonry"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif

R83
IF: A1={"Roofing-Lev 1","Stairs"} & A2={"Roofing-Lev 1","Stairs"}
THEN: precedact="Roofing-Lev 1"
    succedact="Stairs"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif
```

```
R84
IF: A1={"Mobilization","Demolition"} & A2={"Mobilization","Demolition"}
THEN: precedact="Mobilization"
     succedact="Demolition"
     if prec="C" then lag=0;link="C";endif
     if prec="P" then
     @ 14,2 ? "These two activities can be done in parallel."
     @ 15,2  input  lag int with "How long do you need  to  mobilze  to  demolish
     existings bldgs?"
     link="S"
     endif

R85
IF: A1={"Demolition","Clear Site"} & A2={"Demolition","Clear Site"}
THEN: precedact="Demolition"
     succedact="Clear Site"
     if prec="C" then lag=0;link="C";endif
     if prec="P" then
     @ 14,2 ? "These two activities can be done in parallel."
     @ 15,2  input  lag int with "How long do you need to  demolish  to  commence
     clearing the site?"
     link="S"
     endif

R86
IF: A1={"Clear Site","Surveying"} & A2={"Clear Site","Surveying"}
THEN: precedact="Clear Site"
     succedact="Surveying"
     if prec="C" then lag=0;link="C";endif
     if prec="P" then
     @ 14,2 ? "Conventional relationship is assumed"
     link="C";lag=0
     endif

R87
IF: A1={"Surveying","Job Layout"} & A2={"Surveying","Job Layout"}
THEN: precedact="Surveying"
     succedact="Job Layout"
     clear;putform loginfo;tally loginfo
     putform plogic;getform plogic
     if prec="C" then lag=0;link="C";endif
     if prec="P" then
     @ 14,2 ? "Conventional relationship is assumed."
     link="C";lag=0
     endif

R88
IF:   A1={"Job   Layout","Piling-Pilecapping"}   &   A2={"Job   Layout","Piling-
         Pilecapping"}
THEN: precedact="Job Layout"
     succedact="Piling-Pilecapping"
     if prec="C" then lag=0;link="C";endif
     if prec="P" then
     @ 14,2 ? "Conventional relationship is assumed."
     link="C";lag=0
```

```
    endif

R89
IF: A1={"ME Finish","ME Commission"} & A2={"ME Finish","ME Commission"}
THEN: precedact="ME Finish"
    succedact="ME Commission"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "Conventional relationship is assumed."
    link="C";lag=0
    endif

R90
IF:  A1={"ME Commission","Wall,Floor Finish"} &  A2={"ME  Commission","Wall,Floor
        Finish"}
THEN: precedact="ME Finish"
    succedact="Wall,Floor Finish"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "Conventional relationship is assumed."
    link="C";lag=0
    endif

R91
IF: A1={"Carpentry,Millwork","Int Doors"} & A2={"Carpentry,Millwork","Int Doors"}
THEN: precedact="Carpentry,Millwork"
    succedact="Int Doors"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "Conventional relationship is assumed."
    link="C";lag=0
    endif

R92
IF: A1={"Int Doors","Clean up"} & A2={"Int Doors","Clean up}
THEN: precedact="Int Doors"
    succedact="Clean up"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "Conventional relationship is assumed."
    link="C";lag=0
    endif

R93
  IF: A1={"Wall,Floor Finish","Int Doors"} & A2={"Wall,Floor Finish","Int Doors"}
THEN: precedact="Wall,Floor Finish"
    succedact="Int Doors"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "Conventional relationship is assumed."
    link="C";lag=0
    endif

R94
IF: A1={"Wall,Floor Finish","Clean up"} & A2={"Wall,Floor Finish","Clean up"}
```

```
THEN: precedact="Wall,Floor Finish"
     succedact="Clean up"
     if prec="C" then lag=0;link="C";endif
     if prec="P" then
     endif
     @ 15,2 input lag int with "How long do you need to finish adequate  part  to
     commence clen up?"
     link="S"

R95
IF: A1={"Clean up","Demobilization"} & A2={"Clean up","Demobilization"}
THEN: precedact="Clean up"
     succedact="Demobilization"
     if prec="C" then lag=0;link="C";endif
     if prec="P" then
     @ 14,2 ? "These two activities can be completed simultaneously."
     link="F";lag=0
     endif

R96
IF:  A1={"FRP  Ftgs,Perim  Walls","Erect  Steel-Lev  1"}  &  A2={"FRP  Ftgs,Perim
        Walls","Erect Ste., Lev 1"}
THEN: precedact="FRP Ftgs,Perim Walls"
     succedact="Erect Steel-Lev 1"
     if prec="C" then lag=0;link="C";endif
     if prec="P" then
     @ 15,2 ? "Conventional relationship is assumed."
     lag=0;link="C"
     endif

R97
IF: A1={"Erect Steel-Lev 1","Roofing-Lev 1"} & A2={"Erect Steel-Lev  1","Roofing-
        Lev 2"}
THEN: precedact="Erect Steel-Lev 1"
     succedact="Roofing-Lev 1"
     if prec="C" then lag=0;link="C";endif
     if prec="P" then
     @ 15,2 ? "Conventional relationship is assumed."
     lag=0;link="C"
     endif

R98
IF: A1={"Erect Steel-Lev 2","Roofing-Lev 2"} & A2={"Erect Steel-Lev  2","Roofing-
        Lev 2"}
THEN: precedact="Erect Steel-Lev 2"
     succedact="Roofing-Lev 2"
     if prec="C" then lag=0;link="C";endif
     if prec="P" then
     @ 15,2 ? "Conventional relationship is assumed."
     lag=0;link="C"
     endif

R99
IF:  A1={"Erect Steel-Lev 3","Roofing-Lev 3"} & A2={"Erect  Steel-Lev  3","Roofing-Lev
        3"}
```

```
THEN: precedact="Erect Steel-Lev 3"
    succedact="Roofing-Lev 3"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif

R100
IF: A1={"Erect Steel-Lev 1","Conc  Panels-Lev 1"} & A2={"Erect Steel-Lev 1","Conc
        Panels-Lev 1"}
THEN: precedact="Erect Steel-Lev 1"
    succedact="Conc  Panels-Lev 1"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed "
    lag=0;link="C"
    endif

R101
IF: A1={"Erect Steel-Lev 2","Conc  Panels-Lev 2"} & A2={"Erect Steel-Lev 2","Conc
      Panels-Lev 2"}
THEN: precedact="Erect Steel-Lev 2"
    succedact="Conc  Panels-Lev 2"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed "
    lag=0;link="C"
    endif

R102
IF: A1={"Erect Steel-Lev 3","Conc  Panels-Lev 3"} & A2={"Erect Steel-Lev 3","Conc
       Panels-Lev 3"}
THEN: precedact="Erect Steel-Lev 3"
    succedact="Conc  Panels-Lev 3"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed "
    lag=0;link="C"
    endif

R103
IF:   A1={"Erect   Steel-Lev   2","Concrete-Lev  2"}   &   A2={"Erect   Steel-Lev
         2","Concrete-Lev 2"}
THEN: precedact="Erect Steel-Lev 2"
    succedact="Concrete-Lev 2"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed "
    lag=0;link="C"
    endif

R104
IF:   A1={"Erect   Steel-Lev   3","Concrete-Lev  3"}   &   A2={"Erect   Steel-Lev
        3","Concrete-Lev 3"}
```

```
THEN: precedact="Erect Steel-Lev 3"
    succedact="Concrete-Lev 3"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed "
    lag=0;link="C"
    endif

R105
IF: A1={"ME Rough in-Lev 1","Int Finishes-Lev 1"} & A2={"ME Rough in-Lev  1","Int
       Finishes-Lev 1"}
THEN: precedact="ME Rough in-Lev 1"
    succedact="Int Finishes-Lev 1"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed "
    lag=0;link="C"
    endif

R106
IF: A1={"Int Finishes-Lev 1","Painting"} & A2={"Int Finishes-Lev 1","Painting"}
THEN: precedact="Int Finishes-Lev 1"
    succedact="Painting"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed "
    lag=0;link="C"
    endif

R107
IF: A1={"Int Finishes-Lev 2","Painting"} & A2={"Int Finishes-Lev 2","Painting"}
THEN: precedact="Int Finishes-Lev 2"
    succedact="Painting"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed "
    lag=0;link="C"
    endif

R108
IF:  A1={"Fab,Deliver Forms","FRP Columns-Lev 3"} & A2={"Fab,Deliver  Forms","FRP
        Columns-Lev 3"}
THEN: precedact="Fab,Deliver Forms"
    succedact="FRP Columns-Lev 3"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "Form-Reinforce-Pour for second floor columns"
    @ 15,2 ? "can be done only after forms are ready at the site "
    @  16,2 input lag int with "After placing the order, how long do you need  to
    wait to receive the forms?"
    link="S"
    endif

R109
IF: A1={"Clear Site","Job Layout"} & A2={"Clear Site","Job Layout"}
```

```
THEN: precedact="Clear Site"
    succedact="Job Layout"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 14,2 ? "Conventional relationship is assumed"
    link="C";lag=0
    endif

R110
IF: A1={"Erect Steel-Lev 2","Concrete-Lev 1"} & A2={"Erect Steel-Lev 2", "Concrete-Lev
        1"}
THEN: precedact="Erect Steel-Lev 2"
    succedact="Concrete-Lev 1"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed "
    lag=0;link="C"
    endif

R111
IF:  A1={"UG Services","Erect Steel-Lev 3"} & A2={"UG Services","Erect  Steel-Lev
        3"}
THEN: precedact="Erect Steel-Lev 3"
    succedact="UG Services"
    if prec="C" then lag=0;link="C";endif
    if prec="P" then
    @ 15,2 ? "Conventional relationship is assumed."
    lag=0;link="C"
    endif
```

****
* Knowledge Base In Sub-modules of DURATION MODIFIER *
****

Congestion: Operations take place within physically limited space with other contractors. Results in congestion of personnel, inability to locate tools conveniently, increased loss of tools, additional safety hazards and increased visitors. Optimum crew size cannot be utilized.

Reassignment of Labour: Loss occurs with move-on, move-off men because of unexpected changes, excessive changes, or demand made to expedite or reschedule completion of certain work phases. Preparation not possible for orderly change.

Learning Curve: Period of orientation in order to become familiar with changed condition. If new men are added to project, effects more severe as they learn tool location, work procedures, etc. Turnover of crew.

Overtime: Lowers work output and efficiency through physical fatigue and poor mental attitude.

Factor	Percent of Loss if Condition		
	Minor	Average	Severe
Congestion	10%	20%	30%
Reassignment of Labour	5%	10%	15%
Learning Curve	5%	15%	30%
Overtime	10%	15%	20%

Weather Data in ESCHEDULER

********* MONTREAL *******

No	Month	Date	Wind speed (kmphr)	Temperature (deg C)	Humidity (%)
1	1	1	17	-7	75
2	1	2	14	-8	73
3	1	3	14	-7	73
4	1	4	20	-7	73
5	1	5	18	-9	68
6	1	6	17	-11	65
7	1	7	21	-7	75
8	1	8	19	-12	65
9	1	9	18	-11	71
10	1	10	20	-11	69
11	1	11	26	-8	72
12	1	12	25	-12	62
13	1	13	16	-11	64
14	1	14	24	-6	76
15	1	15	17	-10	69
16	1	16	21	-13	67
17	1	17	17	-15	61
18	1	18	21	-12	69
19	1	19	21	-8	72
20	1	20	20	-11	63
21	1	21	19	-9	70
22	1	22	25	-9	69
23	1	23	24	-7	75
24	1	24	16	-8	70
25	1	25	23	-5	75
26	1	26	27	-3	75
27	1	27	26	-6	73
28	1	28	21	-8	74
29	1	29	22	-9	75
30	1	30	24	-10	67
31	1	31	16	-13	64
Mnthly Aver.	1		20.3	-9.2	70.0
32	2	1	22	-12	64
33	2	2	26	-15	60
34	2	3	21	-12	64
35	2	4	18	-12	65
36	2	5	23	-12	66
37	2	6	21	-11	65
38	2	7	18	-10	66
39	2	8	17	-8	71
40	2	9	17	-11	65
41	2	10	11	-11	64
42	2	11	16	-10	68
43	2	12	11	-9	67
44	2	13	20	-6	68
45	2	14	20	-9	65
46	2	15	16	-8	62

Weather Data in E[illegible]DULER

********* MONTREAL *******

No	Month	Date	Wind speed (kmphr)	Temperature (deg C)	Humidity (%)
47	2	16	14	-10	57
48	2	17	20	-11	62
49	2	18	17	-6	68
50	2	19	23	-4	74
51	2	20	20	-4	74
52	2	21	16	-4	67
53	2	22	18	-4	72
54	2	23	22	-7	68
55	2	24	18	-5	75
56	2	25	12	-6	72
57	2	26	21	-5	70
58	2	27	22	-4	67
59	2	28	21	-4	67
Mnthly Aver.	2		19.3	-6.5	69.4
60	3	1	22	-6	65
61	3	2	20	-8	66
62	3	3	19	-5	69
63	3	4	21	-2	75
64	3	5	20	-1	76
65	3	6	24	-3	71
66	3	7	21	0	74
67	3	8	23	-2	67
68	3	9	18	-4	57
69	3	10	16	-1	68
70	3	11	18	-2	64
71	3	12	18	-2	62
72	3	13	21	-2	64
73	3	14	22	-1	65
74	3	15	22	-1	66
75	3	16	2[illegible]	-2	70
76	3	17	20	-1	69
77	3	18	23	-2	61
78	3	19	20	0	64
79	3	20	14	0	62
80	3	21	20	0	70
81	3	22	26	-1	66
82	3	23	20	1	67
83	3	24	23	0	66
84	3	25	18	0	67
85	3	26	22	0	66
86	3	27	21	-1	59
87	3	28	16	0	56
88	3	29	14	2	66
89	3	30	19	4	70
90	3	31	18	4	66
Mnthly Aver.	3		20.0	-1.2	66.1

Weather Data in ESCHEDULER

********* MONTREAL *******

No	Month	Date	Wind speed (kmphr)	Temperature (deg C)	Humidity (%)
91	4	1	17	3	63
92	4	2	19	2	74
93	4	3	21	3	69
94	4	4	19	1	70
95	4	5	23	2	73
96	4	6	22	0	61
97	4	7	20	1	58
98	4	8	22	0	55
99	4	9	20	1	54
100	4	10	18	3	61
101	4	11	21	3	61
102	4	12	18	4	54
103	4	13	21	6	64
104	4	14	19	6	62
105	4	15	23	7	61
106	4	16	15	8	60
107	4	17	19	9	54
108	4	18	14	11	48
109	4	19	18	10	50
110	4	20	20	11	49
111	4	21	16	10	50
112	4	22	20	11	62
113	4	23	24	9	60
114	4	24	15	9	61
115	4	25	14	8	57
116	4	26	15	9	59
117	4	27	18	11	57
118	4	28	17	11	54
119	4	29	20	10	60
120	4	30	18	11	53
Mnthly Aver.	4		18.9	6.3	59.1
121	5	1	23	12	50
122	5	2	16	11	62
123	5	3	18	11	61
124	5	4	19	9	59
125	5	5	17	10	55
126	5	6	16	12	56
127	5	7	18	11	50
128	5	8	17	13	45
129	5	9	20	14	59
130	5	10	14	14	55
131	5	11	19	16	51
132	5	12	18	15	57
133	5	13	22	14	55
134	5	14	19	15	51
135	5	15	15	17	51

Weather Data in ESCHEDULER

********* MONTREAL *******

No	Month	Date	Wind speed (kmphr)	Temperature (deg C)	Humidity (%)
136	5	16	20	17	57
137	5	17	14	16	61
138	5	18	14	16	62
139	5	19	16	17	62
140	5	20	12	19	54
141	5	21	17	18	60
142	5	22	17	18	51
143	5	23	14	18	55
144	5	24	14	17	52
145	5	25	23	16	58
146	5	26	15	15	60
147	5	27	14	17	58
148	5	28	17	17	59
149	5	29	13	18	58
150	5	30	12	19	61
151	5	31	15	20	66
Mnthly Aver.	5		16.0	14.8	54.9
152	6	1	16	17	64
153	6	2	14	16	58
154	6	3	15	17	63
155	6	4	13	19	59
156	6	5	16	19	59
157	6	6	14	18	55
158	6	7	18	20	63
159	6	8	18	18	72
160	6	9	15	18	62
161	6	10	18	18	59
162	6	11	22	18	60
163	6	12	16	17	65
164	6	13	17	19	54
165	6	14	17	20	56
166	6	15	21	21	55
167	6	16	19	20	64
168	6	17	15	20	62
169	6	18	16	20	63
170	6	19	14	21	68
171	6	20	17	21	68
172	6	21	14	21	69
173	6	22	16	21	65
174	6	23	17	21	65
175	6	24	16	21	66
176	6	25	17	20	62
177	6	26	14	21	63
178	6	27	16	22	63
179	6	28	13	23	57
180	6	29	15	23	66
181	6	30	19	21	68

Weather Data in ESCHEDULER

********* MONTREAL *******

No	Month	Date	Wind speed (kmph/hr)	Temperature (deg C)	Humidity (%)
Mnthly Aver.	6		16.3	19.8	62.4
182	7	1	17	22	62
183	7	2	15	20	67
184	7	3	18	21	61
185	7	4	16	21	57
186	7	5	15	22	60
187	7	6	17	22	55
188	7	7	17	24	54
189	7	8	18	23	66
[illegible]	7	9	16	23	61
191	7	10	15	22	61
192	7	11	16	21	60
193	7	12	[illegible]	21	60
194	7	13	16	23	66
195	7	14	17	23	65
196	7	15	16	24	65
197	7	16	12	23	61
198	7	17	15	22	65
199	7	18	15	23	57
200	7	19	16	24	61
201	7	20	17	24	62
[illegible]	7	21	14	23	63
203	7	22	14	23	54
204	7	23	15	23	60
205	7	24	14	23	67
206	7	25	15	23	59
207	7	26	14	21	68
208	7	27	15	22	67
209	7	28	16	23	59
210	7	29	14	21	67
[illegible]	7	30	12	22	65
212	7	31	13	23	65
Mnthly Aver.	7		14.8	21.7	59.9
213	8	1	15	24	64
214	8	2	12	23	67
215	8	3	10	23	74
216	8	4	15	22	64
217	8	5	16	22	63
218	8	6	14	21	62
219	8	7	14	22	61
220	8	8	11	22	71
221	8	9	18	22	64
222	8	10	18	21	66
223	8	11	12	22	62
224	8	12	15	21	65

Weather Data in ESCHEDULER

*********** MONTREAL *********

No	Month	Date	Wind speed (kmphr)	Temperature (deg C)	Humidity (%)
225	8	13	13	21	65
226	8	14	15	21	67
227	8	15	12	20	63
228	8	16	12	21	60
229	8	17	13	21	67
230	8	18	13	21	64
231	8	19	1[illegible]	21	62
232	8	20	13	21	63
233	8	21	11	22	61
234	8	22	15	21	64
235	8	23	13	21	62
236	8	24	14	19	67
237	8	25	12	21	65
238	8	26	10	21	65
239	8	27	13	21	72
240	8	28	14	21	71
241	8	29	15	22	67
242	8	30	16	20	67
243	8	31	12	20	63
Mnthly Aver.	8		13.0	20.5	63.1
244	9	1	13	21	66
245	9	2	12	20	67
246	9	3	14	19	71
247	9	4	12	18	68
248	9	5	13	20	65
249	9	6	14	18	69
250	9	7	13	17	59
251	9	8	14	17	61
252	9	9	17	16	59
253	9	10	16	16	65
254	9	11	17	17	68
255	9	12	12	15	67
256	9	13	13	17	69
257	9	14	15	16	72
258	9	15	15	17	65
259	9	16	14	16	64
260	9	17	17	17	67
261	9	18	13	15	68
262	9	19	15	15	66
263	9	20	18	14	76
264	9	21	13	14	71
265	9	22	16	13	70
266	9	23	13	12	63
267	9	24	14	12	62
268	9	25	16	13	68
269	9	26	14	14	75
270	9	27	15	15	68

Weather Data in ESCHEDULER

********* MONTREAL *******

No	Month	Date	Wind speed (kmphr)	Temperature (deg C)	Humidity (%)
271	9	28	15	13	67
272	9	29	19	15	71
273	9	30	17	14	65
Mnthly Aver.	9		14.6	15.9	67.1
274	10	1	9	13	72
275	10	2	13	12	78
276	10	3	14	12	68
277	10	4	15	12	69
278	10	5	13	15	68
279	10	6	18	14	68
280	10	7	17	9	69
281	10	8	19	8	65
282	10	9	18	8	68
283	10	10	16	8	68
284	10	11	13	9	69
285	10	12	18	10	74
286	10	13	14	9	70
287	10	14	23	8	72
288	10	15	19	7	71
289	10	16	19	7	66
290	10	17	16	6	68
291	10	18	18	7	63
292	10	19	15	6	63
293	10	20	13	7	72
294	10	21	17	10	68
295	10	22	19	11	65
296	10	23	19	10	61
297	10	24	13	7	63
298	10	25	16	9	70
299	10	26	20	8	71
300	10	27	13	7	61
301	10	28	15	7	65
302	10	29	14	8	60
303	10	30	16	6	65
304	10	31	15	7	70
Mnthly Aver.	10		15.7	8.5	65.4
305	11	1	15	7	68
306	11	2	16	7	68
307	11	3	14	8	69
308	11	4	19	7	70
309	11	5	14	5	63
310	11	6	15	5	69
311	11	7	14	5	74
312	11	8	16	3	75
313	11	9	12	3	69

Weather Data in ESCHEDULER

*********** MONTREAL *********

No	Month	Date	Wind speed (kmphr)	Temperature (deg C)	Humidity (%)
314	11	10	18	4	75
315	11	11	18	2	71
316	11	12	14	2	70
317	11	13	14	2	78
318	11	14	19	2	78
319	11	15	16	0	71
320	11	16	16	1	66
321	11	17	16	2	74
322	11	18	18	3	73
323	11	19	17	2	70
324	11	20	16	0	70
325	11	21	18	0	76
326	11	22	14	-1	70
327	11	23	15	0	68
328	11	24	14	1	82
329	11	25	15	0	73
330	11	26	18	0	73
331	11	27	24	-1	75
332	11	28	14	0	83
333	11	29	16	-2	72
334	11	30	19	0	75
Mnthly Aver.	11		16.1	2.2	72.1
335	12	1	17	-2	71
336	12	2	18	-4	69
337	12	3	20	-5	72
338	12	4	12	-5	70
339	12	5	15	-5	78
340	12	6	16	0	79
341	12	7	11	-3	70
342	12	8	15	-5	75
343	12	9	18	-4	74
344	12	10	16	-7	74
345	12	11	19	-7	69
346	12	12	8	-5	73
347	12	13	24	-6	70
348	12	14	15	-5	75
349	12	15	17	-6	78
350	12	16	19	-4	75
351	12	17	18	-9	73
352	12	18	25	-9	71
353	12	19	18	-1[illegible]	66
354	12	20	17	-1[illegible]	73
355	12	21	18	-8	79
356	12	22	16	-9	73
357	12	23	13	-5	75
358	12	24	11	-5	81
359	12	25	23	-10	71

Weather Data in ESCHEDULER

********* MONTREAL *******

No	Month	Date	Wind speed (kmphr)	Temperature (deg C)	Humidity (%)
360	12	26	16	-6	81
361	12	27	21	-8	74
362	12	28	17	-8	73
363	12	29	13	-7	76
364	12	30	22	-9	70
365	12	31	14	-9	74
Mnthly Aver.	12		16.3	-6.4	71.3