A PROPOSED INFORMATION SYSTEM FOR CONCRETE CONSTRUCTION:

A PROJECT AND ACTIVITY PLANNING SPECIFICATION

By

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We accept this thesis as conforming to the required standard.

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ABSTRACT

Current useage of construction information systems is largely confined to Critical Path Method scheduling, accounting systems, and cost control database systems. The function of activity planning is not directly addressed by any of these systems while information from all three systems is required for activity planning.

Activity planning is the iterative process of selecting construction elements from the project work breakdown structure, addressing the available details from the plans and specifications, assembling existing experiential information on methods, productivities, and production rates, brainstorming for new and or appropriate existing methods, and deciding on a course of action for each item in the breakdown structure. The focus is on a construction activity planning framework to be utilized by superintendent level personnel. This thesis examines the literature and existing software to identify the technologies that are relevant to detailed activity planning.

The concept of utilizing "Planning Models" to address activity planning for repetitious concrete construction is introduced. The "General Activity Planning Model" provides the functions and instructions required for detailed project and activity planning of a generic concrete construction project. "Specific Planning Models" ensue from the general model and two examples are provided to illustrate the process. The first example is of a

post-tensioned concrete bridge project. The second is of a cut and cover subway tunnel project. From the two examples, the key planning system attributes of function and flexibility are demonstrated.

The functions required include:

1. Project level work breakdown structure and initialization.
2. A two pass system for estimating and planning.
3. Early calculation of target activity durations from milestone constraints.
4. Activity level, continuous crew scheduling, where appropriate, prior to detail design of methods.
5. Operation level input: major resource (formwork quantity) requirements, decision variables, crew size variation to implement duration control, and equipment levelling.

The flexibility of the General Planning Model is illustrated by the successful planning of two dissimilar prototype projects from one general model. Specific issues pertaining to each project are structured and solved by example.

Computer system issues are discussed. A database system is identified as the software of choice for the construction planning problem. Several commercially available programs are evaluated. Integration of activity planning with other construction specialities is identified in flow chart form.

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ACKNOWLEDGEMENTS

"Thank God I'm done at last."

I wish to take this opportunity to recognize those who have contributed their support during the writing of this thesis:

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to each of these I express my gratitude.

James R. Turnham

CHAPTER 1 INTRODUCTION

Activity planning is the process of determining how, when, and with what resources a work breakdown structure component will be constructed. "In its simplest form, activity planning involves the determination of an activity's duration as a function of crew sizes, equipment inputs, and productivity rates. In its most complex form, it may involve the use of simulation(5) or work process models similar to precedence networks."(16) Typically, activity planning involves the following steps:

1. input of contractual plans and specifications;
2. consideration of the site conditions and constraints;
3. identify decision variables;
4. development, detailing, and drafting of a plan for the work;
5. allocation of resources: manpower, equipment, materials, and sub-contractors;
6. communication of the plan and schedule to site supervisors for construction; and
7. follow-up with a monitoring program.

The objective of this research is to devise a construction information system that addresses the day to day problems and requirements of activity planning.

1.1 Scope of the Research

Conceptually, this research has been confined to the general area of repetitious, concrete construction. The choice of concrete construction springs from the observation that concrete work usually involves multiple operations and crews and therefore requires an additional level of complexity to be modelled in the work breakdown structure. The point here is that if a breakdown structure can model concrete construction, it will be applicable to a broad range of civil engineering projects.

An effort has been made to generalize and validate the concepts developed by applying them to ongoing, real life, projects. The following projects were examined:

1. The Cambie Bridge Project; a multispan, post-tensioned, concrete bridge constructed from 1983 to 1986 in Vancouver, BC.

2. The Downtown Seattle Tunnel Project; A cut and cover subway tunnel project begun in 1987 and presently under construction in Seattle, Washington.

These two projects provided the construction activities, constraints, problems, and exposure to some of the solutions that, as a whole, form the background for this thesis.

Repetition adds a significant dimension to the scope of planning, scheduling, and control requirements on a construction project. Repetition has the effect of adding a breakdown of the activity into units called "unit-activities" herein. While not extensively encountered in the search of the literature, utilization of repetitious construction planning techniques within construction information systems is one of the central issues of this thesis. The repetition factor also forces one to imagine, plan and finally implement efficient methods to accomplish the work. This tenet follows from economies of scale principles. With large scale repetition, one can afford to spend time and money up front in the activity design phase to minimize unit expenses in the construction phase. The more repetitious the work, the more detail that can be justified in the planning process. With the need for planning comes the need for systems to provide a structured planning environment and at the same time the flexibility to accomodate change.

1.2 Statement of the Problem

What is required to accomplish the design and planning of a construction activity? How can the activity planning process best be structured? How can a computer be utilized to provide a framework and decision support system for the activity planning process?

This thesis began with the above three questions. While examining these questions, the following issues became apparent:

i) Standardization

Use of a computer in activity planning would require some standardization of the planning process. The goal is to identify an efficient methodology for planning and a software framework from which to address all the nuances of all conceivable activity plans. One issue to address early on is that of providing sufficient flexibility in the planning system to allow construction planners to be creative and imaginative while still working within computerized confines.

ii) Source of Data and Records

Analysis of the planning process will indicate that the planning process cannot operate in a vaccuum. It is but one of many aspects of a construction project. Firstly, activity planning requires time-cost data with which to evaluate each alternative considered for all aspects of the construction project. What are the sources of this time-cost information? The following sources are highlighted:

1. Project Control

Historically, time-cost records have come from paper files on jobs that a company has previously constructed. Therefore a link is required from the historical time-cost records developed in the project control phase, to the activity planning function. The relevance of such data to the project at hand must be carefully assessed.

2. Estimating and Planning

Another obvious link exists between estimating and planning. The estimator must price the activities for which the construction superintendent must later develop detailed plans. A planning system that utilizes the framework supplied first by the estimator reaps the benefits of the estimator's initial data input and his broad brush conceptions of how the job might be built.

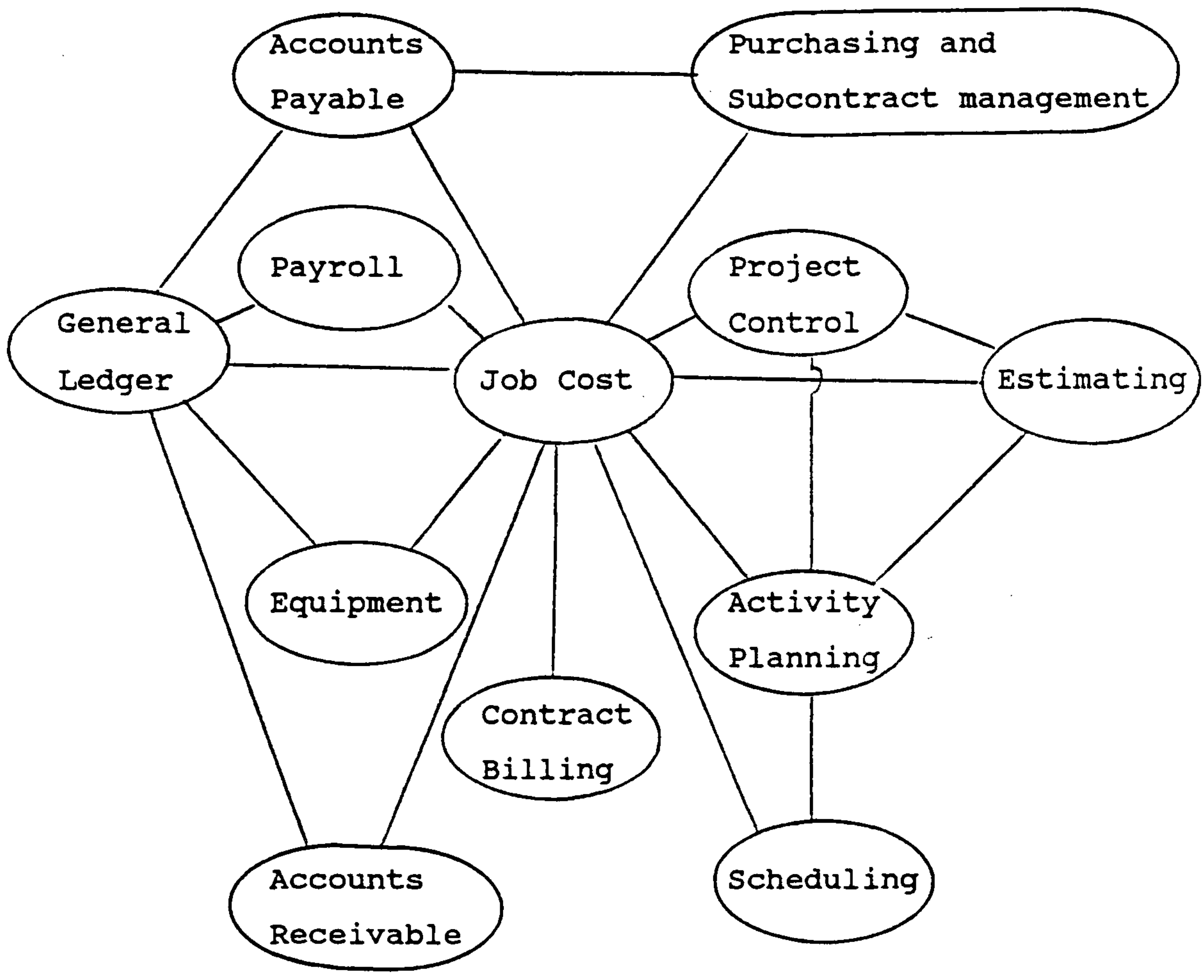
3. Planning and Scheduling

A data link also exists between planning and scheduling. The schedule will often dictate the plan and vice versa and because of that fact, the two functions are often grouped into one.

4. Integration

Planning is one of many interrelated aspects of the construction process and, as such, activity planning is most efficiently treated as part of an integrated system.

The relationships between the various construction functions are illustrated in figure 1. It also shows the communication links required by a construction information system.



Communication data links between construction sub-systems(1).

Figure 1.

Since one of the goals of this thesis is to develop a practical, coherent statement for use in developing a useful construction planning system, the decision was made to expand the scope of the topic to include the interface of activity planning with the related functions of scheduling, estimating, and project control. Thus the problem statement needs to be expanded.

1.3 The Expanded Problem Statement

Design a specification for a construction information system. Specific tasks to be treated include the following:

1. Provide a conceptual overview of the estimating function considering the overlapping relationship with the activity planning function.

2. Provide project inputs to the planning process. Provide the means to guide the planning process through the many phases of construction: from estimating to project award to target project durations to activity cycle design to detailed activity plans to project control to estimating.

3. Identify and describe the activity planning function and specify an information system that addresses the key inputs, design processes, and required outputs.

4. Provide the conceptual interface from project control records to the activity planning function.

5. Provide the applicable interface for payroll, accounts payable, and accounts receivable .

6. Illustrate the planning / scheduling interface capability.

7. Develop a detailed list of functions including descriptions and examples for all system capabilities.

8. Determine which environment or software would be best suited for system development.

CHAPTER 2 LITERATURE AND SOFTWARE SEARCH

2.0 Introduction

In this chapter, existing software and the literature pertaining to the subject of construction planning are examined. The software search yielded information on computer environments applicable for activity planning. The literature search examines both computer environments and functions that are applicable for construction activity planning.

2.1 Software Search

2.1.1 Spreadsheet Technology

Lotus 123, being easy to use and one of the most popular spreadsheet programs, was the beginning place for this research project. Other research including J. L. Rounds(15), indicated that spreadsheets were a useful and efficient tool in the preparation of construction estimates for tender. Could Lotus also be useful for project control and scheduling? The short answer vis-a-vis project control is that Lotus 123 can handle the data recording function but not efficiently. Using Lotus would require that timesheet information would have to be input cell by cell with much scrolling through the sheet to locate the proper area for data entry. The same scrolling would be necessary when one wanted to find the pertinent data for a particular operation or activity. The conclusion arrived at is that spreadsheets are not efficient for this kind of data storage.

When attempting to use Lotus as a scheduling tool, the task of presenting information graphically in barchart form was found to be difficult and awkward.

Lotus 123 does an excellent job at compiling material quantities from contract drawings. The matrix format for compiling dimensions versus items and summing totals works well. Another possible avenue worth exploring is side by side comparison of identified construction methods. The analysis of construction technologies with respect to costs, durations, and resource requirements would likely prove spreadsheets to be useful and efficient at this task. This aspect of construction information analysis will be covered in detail in Chapter 4.3.

2.1.2 Multidimensional Spreadsheets

A relatively new breed of spreadsheet, the 3 dimensional and multidimensional spreadsheet such as Lucid, Boeing Calc, and TM1 are environments of interest.

Boeing Calc is organized by the familiar row/column format with the addition of the "page" dimension which makes it three dimensional. It was the first of these three products on the market and has a highly respected graphics package that accompanies it.

Lucid is a three dimensional spreadsheet with a number of interesting features:

1. Memory resident. It resides in computer memory at all times, even during execution of another program. It can be activated to the foreground and returned to the background with one keystroke.

2. Any cell can contain a complete spreadsheet of the next lower level. For instance, the upper sheet would contain a cell containing the formula that totalled the costs of the lower sheet. Then any change to the values in the lower sheet will be reflected in the value of the total which is displayed on the upper sheet. This is called nested spreadsheets.

3. Notepad contained behind every cell. (This concept would be an efficient method of storing methods or descriptions pertaining to activities or resources in a construction information system.)

TM1 is a true multidimensional database that calls itself a table manager. Data is stored in the table with dimensions making up the axes for row, column, page, etc. Each dimension is a list of common items that would be used to form the column or row headers. Tables are used to store data with up to 8 dimensions of data identity. With this software, a piece of information could be categorized, for instance, by 1. Project, 2. Division, 3. Activity, 4. Operation, 5. Location, 6. Resource, 7. Time or Cost, 8. Phase, (Bid estimate, Current estimate, or Actual). With such an organization capability, one could query the system for the following:

all Projects, Activity = beams, Operation = rebar, all Locations, Resource = laborer, Costs, Phase = actuals.

For this example, one would receive a list of all the actual, labor, cost records for placing rebar in beams for all projects in the company records at all locations specified.

The power and flexibility of such a database would appear to be useful for the multidimensional nature of construction projects.

2.1.3 Project Management Software

There are many useful project management / scheduling software packages commercially available. Timeline and Primavera Project Planner have been singled out here as examples representing two ends of the project management software spectrum. Timeline is well respected for its user friendliness, thorough documentation, on-line tutorial, functionality and inexpensive price. With very little training, a manager can model a construction project in considerable detail, set durations, lags, precedence relations, assign resources and costs, and get both barchart and precedence schedules as output. On the down side, it does not have coding capability which is usually considered essential for most medium and large construction companies.

Primavera, for its part, has established a reputation for being one of the most extensive, powerful, and versatile project management tools on the market. Its drawbacks include a much larger purchase price and a steeper learning curve associated with the greater array of functions and capabilities.

The following is a brief description of the some of the attributes of Project Management Software in general.

i) **Systems capabilities**

Activity description
Duration input
Milestone or precedence input
Lead-lag input
Resource input by trade or item
Costing by resource time unit
Calendar flexibility
Reports by many different formats

Float calculation

Resource levelling

Project cash flow modelling

ii) **General systems limitations:**

Limited database capability.

Data stored by archived schedules.

No retrieval of data by field name as per a database system

Project management software occupies a cornerstone in construction information systems. Most of these software systems are built around a network processor and organize activities, associated costs and resources according to the resulting network schedule. However, most of these scheduling systems require that you, the scheduler, bring all of the necessary information to the network. Only with durations, lags, and precedence input will it calculate a schedule.

Access to detailed information concerning methods, costs, durations, and productivities at the activity level is required for efficient activity planning. The use of archived schedules to help reconstruct past project activities, methods, production rates, labor rates and use of overtime is possible but tedious with most systems. No micro computer system has been found that contains a built in database to expedite the retrieval of historical information. Project management software has a definite place in a construction information system. It is an essential tool for the organization of the big picture involving many logic links. However, for the collection and retrieval of experience based information, existing project management software is not the answer.

2.1.4 Database Software

Since construction projects require the tracking of time and money expenditures for a large number of activities, it follows that database software could be an appropriate tool for organizing, storing and retrieving project construction information. The general capabilities and limitations of database software available for today's microcomputers lists as follows.

i) **Capabilities**

1. Data retrieval by criteria or combination of criteria.
2. Programmable language facilitating user friendly prompting and customization.
3. Spreadsheet importing: estimate spreadsheet easily interfaced with project control database.
4. Automated transfer of data between files.
5. Easily tailored data structure to accomodate the data requirements of various projects.

ii) **Limitations:**

1. Graphics very marginal on the programs researched herein although some new software has recently appeared on the market to address this inadequacy.
2. Logic between activities not easily represented.
3. Not sophisticated as scheduling tools.

Database software would seem made to order for construction information storage and retrieval. Lo(9) used Dbase II to construct an information system for residential housing construction. There are many database programs available on the market. Among them dBase III+, Rbase System 5 are noteworthy.

2.2 Literature Review

Specialized or customized software is perhaps the main environment for investigation when the goal is a construction information system. This software is hard to find in a demonstration format or at a price that could be tolerated by all but the richest of researchers, but the literature reviews are available that document software developments in many areas of the construction industry. Those which are of interest to this thesis pertained to the following areas of construction:

1. Estimating.
2. Planning and scheduling.
3. Productivity forecasting and enhancement.
4. Decision support and expert systems
5. Project management and cost control.
6. Integrated construction systems.

In each of the above areas, the following questions were of interest to this research:

1. What framework or environment is proposed?
2. What functions are proposed within each system to provide or utilize the information required?
3. How would the system in question interface to the activity planning function?

The following represent a summary of the findings from a review of the literature.

2.2.1 Estimating

Estimating is an element of a construction information system which is quite well supported in the literature and in existing software systems. The following systems are outlined to stimulate interest in the estimating / planning interface. This research does not elaborate on the subject of estimating except to outline these basic findings.

The simplest system was mentioned in Chapter 2.1 and uses spreadsheet technology to construct quantity survey, pricing, and recap templates.(15)

A software system called Interactive Estimating for Civil Engineering(2) lists the following types of estimates and features required by an estimating system:

a) Operational estimate: build up operational resource groups and calculate their total cost on an elapsed-time basis, then apportion this cost to bill of quantity items.

b) Unit rate estimate: build unit rate estimates using resources and the appropriate output or usage rates from first principles on the screen.

c) Unit rate estimate: use build-ups stored on the computer files and recall them to the screen.

d) Spot rate estimate: supply labor, plant, and material rates without calculation.

e) Sub-contract: supply sub-contract quotations.

f) "Included in" capability: include the bill item in the estimate for another item.

g) Include nominated sub-contractors' and suppliers' rates with attendances and profits.

i) Provisional sums.

Another estimating system called INES (Interactive Estimating Systems) is of interest because of its use of a decision support system to aide the estimator in identifying the exact nature of a cost item.(6) INES is built on 3 files:

1. Library of standard items.
2. Cost analysis of standard items.
3. Cost database of standard items.

The library of standard items includes Item number, Item code, Item description, and Item unit of measure.

The Cost analysis of standard items file contains for each item a progression of questions to be used by INES. The function of these questions is to breakdown the estimate of the item into an analysis of its component parts.

The cost database file contains information required by INES in order to perform the analysis progression stored for a particular item in the cost analysis file. Information in this file may include:

1. material prices,
2. wages for different trades,
3. waste percentages,
4. productivity rates,
5. equipment costs,
6. subcontractor prices, and
7. other information selected by the estimator.

The information in this file is the data for the decision support system and the data for the answers to questions contained in the analysis file.

The Analysis file uses a question and answer procedure to lead the estimator through the estimate. The following is an example:

Project title?

Date of Estimate?

Item code?

Ans. 033009.

Item 033009 = reinforcing steel, #4 bar.

Quantity/unit?

Ans. 10.01 tons.

Basic price in database = $410.00 / ton. Last update = 11/2/85.

Do you want to use this price? Y/N ___

Ans. No

What price will you use?

Ans. $415.00 / ton.

Do you want to change the database to this value? Y/N?

Ans. No.

Etc.

The system is a form of decision support system with built in knowledge in the form of questions and pre-identified answers. The system is flexible as is evidenced by the ability of the estimator to change the data and the questions in the database. A shortcoming is the ability to provide only a single value for an answer instead of a matrix of values for different circumstances.

2.2.2 Planning and Scheduling

Two articles of conflicting philosophy are examined here.

<u>Optimization as a Planning Strategy</u>

The first article, Construction Planning and Scheduling System for Civil Engineering Works (18), presents a system for optimization of construction resource allocation, (ie. manpower, materials, and equipment) on earthwork and heavy civil projects. The program utilizes the following work breakdown structure:

1. work areas: breakdown of locations;
2. work categories: 400 divisions of work divided into a three tier hierarchy;
3. local conditions: climatic, geographical, and geological conditions; and
4. equipment kinds and classes: (self explanatory).

A database containing materials, worker skills, worker capacities, equipment production rates, and unit prices is utilized to provide the input data upon which the optimization will be performed.

The program utilizes the technique of linear programming to optimize the resource allocation problem. The following procedure is given for the construction of a solution set.

1. Network analysis.
2. Formulation of nonlinear mathematical models.
3. Construction of a linear approximation from the nonlinear mathematical models by reducing the original problem to a set of linear programming problems (LPs).
4. Optimal solution search by a branch and bound algorithm. Simplex method, dual simplex method and postoptimal technique are used to solve these LPs.

For the three resources, manpower, equipment, and materials, the objective function is the total expenditure of the resource in question. Optimal allocation is the allocation which needs minimal expenditure on the resource.

System outputs include:

1. allocation graphs for manpower, equipment, material, and work.
2. progress graphs for construction areas and work areas.
3. work schedules for every construction area.
4. combination of construction equipment for every works in every month.

The authors of the above reviewed article claim that the above system is being used successfully on heavy construction projects. The concept of using linear programming for optimizing the allocation of heavy equipment on large scale earth moving jobs sounds reasonable. Many kinds of machines are available. Capacities of the machines in different soil conditions are quantifiable. The payoff for an optimal or near optimal solution certainly exists.

The question arises, "How extensively and to which elements of concrete construction can linear programming be efficiently applied?"

Implication Planning as a Strategy

The second article, "Construction Planning and Control, Current Practice and Continuing Challenges"(17), sets out to debunk the notion that optimization can be effectively applied outside of construction academic institutions.

> "Optimization is not being achieved in the industry and it is the writer's contention that it should not be sought."

The philosophy put foreward is "Implication planning", a strategy of conventional planning to be refined by computer capability.

> "The concept of implication planning is to continually assess the implications of intuitive-based decisions rather than to attempt to create the decisions through mathematical analysis."

"The single most important feature of this process is that the faster and more efficient utilization of human assessment is combined more effectively with the slower and more rigid mathematical processes."

This article provides the following list of procedures:

1.."Select activity format", select level of detail.
2. "Compile logic diagram", an iterative procedure.
3. "Calculate durations", based on:
   quantity of work
   resource application
   productivity and output
   method statement
   environmental restraints
4. "Resource analysis - smoothing

Stapelberg's main conclusions are as follows:

1. The complexity of planning a project is generally underestimated by the theorist and the computer analyst.

2. The computer user/planner should be given the facility to process policy decisions simply and effectively in a mode which does not replace logical thinking but magnifies and analyses the implications of such decisions.

3. Computer systems should facilitate a mixture of bar chart, critical path, pert and line of balance systems simultaneously in a joint and several association.

4. Data preparation should be kept at the most simplistic level possible.

5. Reporting should be graphical where possible and should contain comprehensive implication analyses.

6. It is vital to remember that planning systems are essentially 'decision support systems' and, therefore, the timely delivery of the goods is as important, if not more important, than the accuracy of the results.

The above article espousing implication planning is quite contrary to the previous article on optimization using linear programming. This thesis chooses a tack more in line with implication planning than with optimization. The premise for this direction is "One step at a time". Research may show that the optimization approach may one day be viable for construction management. For this thesis, the effort is directed toward a system whereby management initiates the methods and the computer assists with analysis of the resulting plan.

2.2.3 Productivity Forecasting and Enhancement Systems

The literature gathered indicates that this topic is software independent. Systems involved in productivity forecasting and enhancement may or may not utilize a computer. Nevertheless, this topic is important for construction and for construction activity planning information systems.

Two articles are discussed regarding productivity. Both are of interest to this research to the extent that they involve activity planning. The first, <u>Labor Productivity and Manpower Forecasting</u>(3), discusses the impact and cost of overtime useage. Cited in the article is the high cost of the use of scheduled overtime. A 1980 study by a task force of the Business Roundtable indicates that 60 hour weeks worked over a prolonged period may cause productivity to drop to 65% of that obtained on normal 40 hour weeks. The drop is influenced by the increase in wages and by the drop in production per hour.

The article also mentions 6 other productivity factors within management control:

- worker density
- craft training
- work planning
- proper and sufficient tools
- correct materials
- supervision quality

These are nuts and bolts issues for construction management to the point where they may often be inadvertantly taken for granted in the quest for higher profile and more powerful management systems. The point is, these are the details that lead to efficient or inefficient operations on the job site. Management systems and information systems need to address these issues.

The second article, Improved Productivity Through Integrating Work Instructions With Progress Control(14), primarily addresses the problem of translating the project level planning systems to meaningful work instruction plans. The major points of the translation framework are as follows:

1. The "work instruction plan" is based on the commonly used "short cycle schedule" covering a three week interval.

2. The front page contains the information necessary for efficient time management, i.e. barchart, quantity estimates, and resource distribution forecasts (see figures 2 and 3).

3. Manpower and equipment categories contain space for both planned and actual resource allocation. The foremen are required to record the actuals on a daily basis.

4. Side 2 contains the following:
   a) a comprehensive bill of materials.
   b) a schedule of interphasing, and
   c) a listing of applicable drawings and specifications.

5. The schedule of interphasing represents, in the words of its author, "the most important improvement over the run of the mill short cycle schedules used today". Its key functions include:

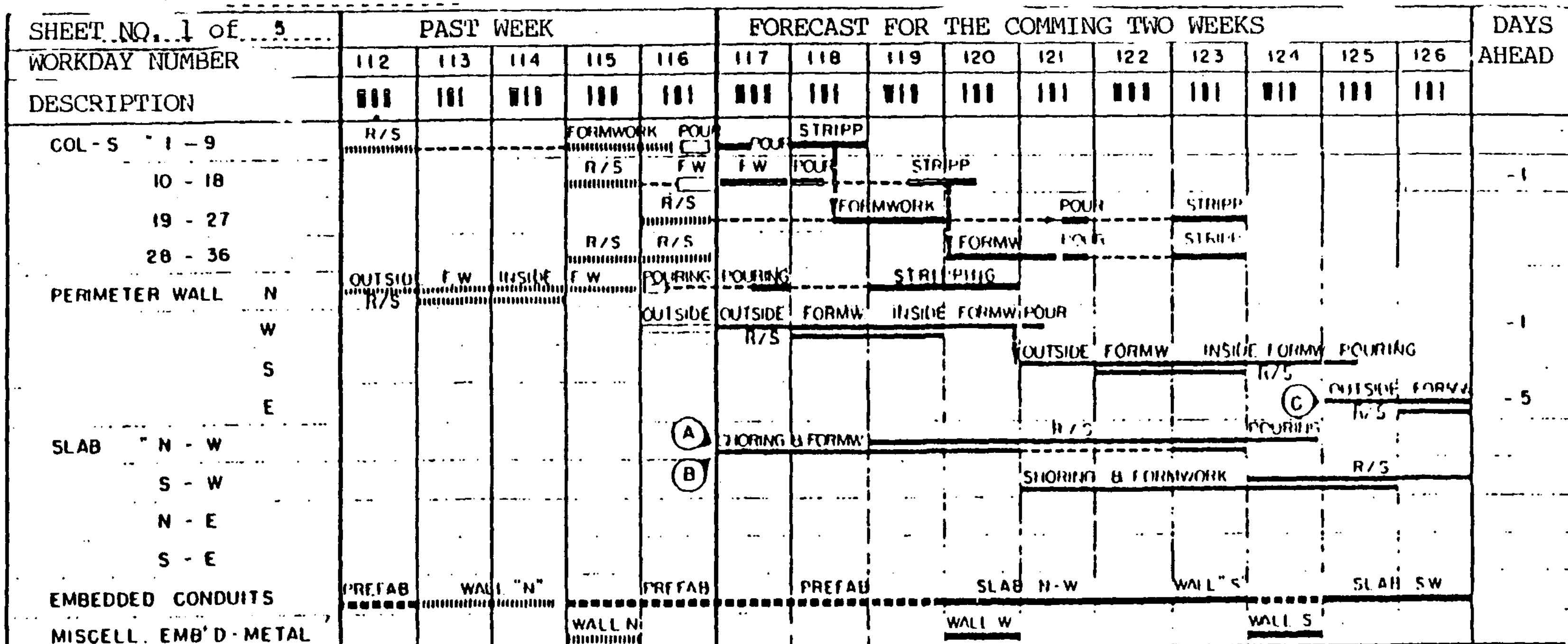
PROJECT: CONVENTION CENTRE

WORK INSTRUCTION SHEET

FACILITY / STRUCTURE: PARKING LOT

APPLICABLE FROM: AUG 14 to: AUG 25

SHEET NO. 1 of 5



	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	
QUANTITY																**QUANTITY COMPLETE**
FORMWORK-VERTICAL	550 SF	620 SF	630 SF	850 SF	900 SF	1104 SF	912 SF	1104 SF	1104 SF	912 SF	720 SF	720 SF	720 SF	720 SF	720 SF	
FORMWORK-HORIZONTAL	–	–	–	–	–	400 SF	2000 SF	2000 SF	2000 SF	400 SF	1200 SF	1560 SF	1200 SF	1200 SF	–	
RE-STEEL	3240'	4260	4260'	4860'	4860'	–	4260'	2260	8000	8000	12260	12260	8000	8000	12260	
EMBEDDED CONDUITS			216'	–		–	–	216'	400'	400'	400'	216'	–	400'	400'	
CONCRETE	–	–	–	–	–	82 CUYD				93 CUYD			[illegible]5 CUYD	71 CUYD		
MAN-POWER																**ENTER ACTUALS RIGHT OF SLASH**
LABOURERS	4/5	4/4	4/5	6/5	8/9	8/	8/	8/	8/	10/	10/	10/	10/	10/	10/	
CARPENTER & HELPERS	8/6	8/7	8/7	14/10	14/12	20/	24/	30/	30/	20/	22/	22/	22/	22/	/	
STEEL SETTERS	4/4	6/5	6/6	6/6	6/6	–/	6/	20/	14/	14/	20/	20/	14/	14/	20/	
ELECTRICIANS	3/–	3/2	3/4	3/4	3/2	3/	3/	4/	4/	4/	4/	4/	4/	4/	4/	
MISCELL. OTHERS	4/5	4/5	4/4	8/7	4/4	6/	6/	8/	8/	8/	8/	8/	8/	8/	8/	
EQUIPMENT																
TOWER CRANE	/	/	/	/	/1	1/	1/	1/	1/	1/	1/	1/	1/	1/	1/	
MOBILE CRANE	1/1	1/1	1/1	1/1	1/1	1/	1/	1/	1/	1/	1/	1/	1/	1/	1/	
CONCRETE PUMP	/	/	/	/	1/–	1/	1/	/	/	1/	1/	1/	/	/	/	

FIGURE 2 WORK INSTRUCTION SHEET BY S. REVAY (14)

WORK INSTRUCTION SHEET – APPLICABLE FROM: AUG 14 TO: AUG 25 SIDE 2

BILL OF MATERIAL:

DESCRIPTION	UNIT	M	T	W	TH	F	M	T	W	TH	F
16" INTERNAL TIE RODS	EA				150	150	150		150	150	150
SHORING-TUBULAR-6'H	SET				63						
SARMA HORIZONTAL SHOR.	EA				20	100	65				
4'X 8'X 3/4" PLYWOOD	SH					100	100				
ELECTRIC CONDUIT 3/4"Ø	LF						240				
PULL BOX	EA							6			
ELECTRIC CONDUIT 1 1/2"	LF								400	400	400
PULL BOX	EA										10

PROBLEMS

SCHEDULE OF INTERPHASING:

ACTIVITES WHICH CONTROL SCHEDULE PROGRESS

INTERFERING ACT.	M	T	W	T	F	M	T	W	T	F
TOWER CRANE OPERATIONAL	A									
DELIVERY SHORING	B									
CITY SERVICES TO BE CONNEC								C		
RAMP BY OTHERS								C		

APPLICABLE DWGS:

1: SC - 4001
2: SR - 5001
3: SC - 4002
4: SR - 5002
5: SC - 4003
6: E - 9001 - 9002

GOVERNING SPECS:

1: SC - 4
2: SC - 5
3: E - 1

FIGURE 3 WORK INSTRUCTION SHEET BY S. REVAY (14), MODIFIED BY TURNHAM

i) provide sub-network schedule without requiring field supervisors to cope with the complexity of a network plan;

ii) flag possible problem areas with trades to be coordinated; and

iii) force management to prepare adequate trade interference and coordination drawings in a timely fashion.

2.2.4 Decision Support and Expert Systems

In this thesis the distinction between decision support systems and expert systems is made as follows.

> "Ordinary 'decision support systems' organize knowledge in data and in the program, with specialized domain specific knowledge implicitly included in the program code. In contrast, expert systems organize knowledge on three levels. Information is contained in data, the knowledge base, and the control procedure. This architecture enables expert systems for different domains to be easily constructed."(10)

2.2.4.1 Decision Support Systems

Gordon Law, in his thesis entitled Decision Support System for Construction Cycle Design(8), identifies five processes of decision making:

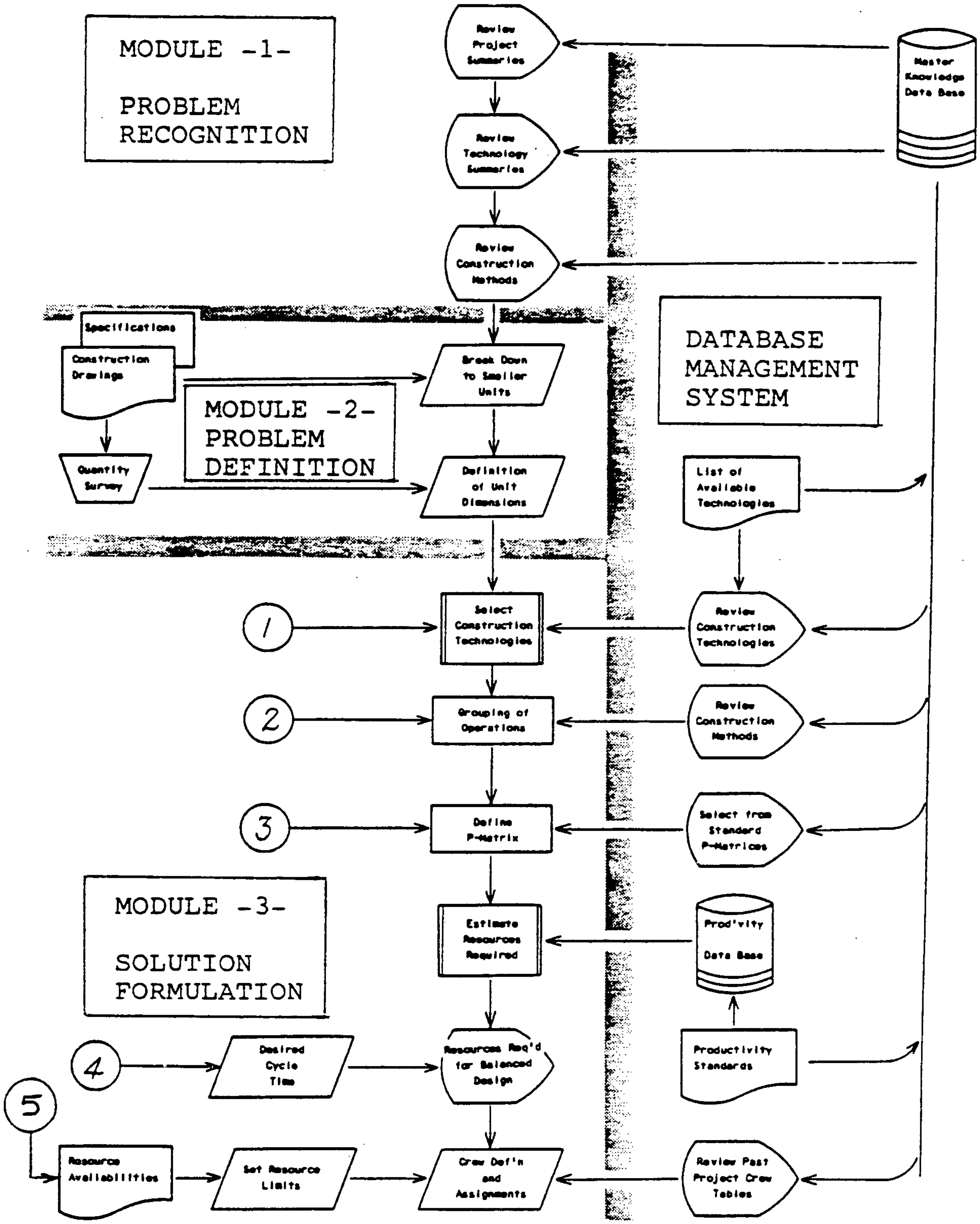


Figure 4 Decision Support System Flowchart.
By G. Law (8)

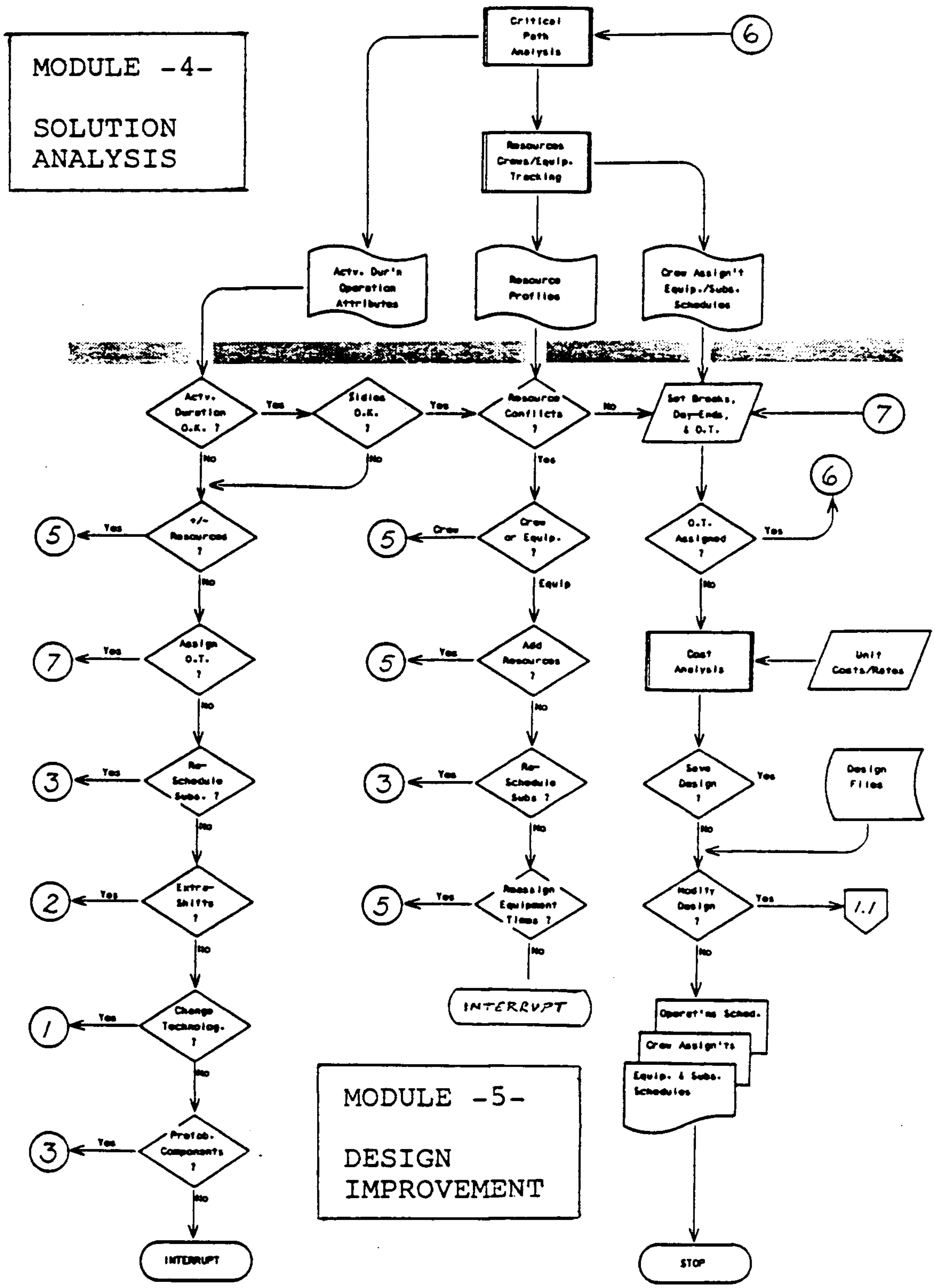


Figure 5 <u>Decision Support System Flowchart.
By G. Law (8)</u>

1. problem recognition,
2. problem definition,
3. solution formulation,
4. solution analysis,
5. design improvement and enrichment.

He then constructs five modules of a decision support system utilizing the five processes mentioned. The goal is to provide the construction manager with a decision support system for the design of highrise construction activities. The flow chart for this decision support system is reproduced here in figures 4 and 5 to show the procedures utilized. Mr. Law gives a very extensive treatment to the theoretical aspects of cycle design for highrise construction using a computerized framework (decision support system).

2.2.4.2 Expert Systems

A paper entitled Expert Systems for Construction Project Monitoring(10), compares expert knowledge based systems to algorithmic procedures in the area of project monitoring and control.

> "While some project monitoring can be accomplished by algorithmic procedures, the capability of knowledge based expert systems to deal with ill-structured problems and to be extensively modified over time make them desireable for application in this area."

Knowledge-based expert systems are programs that can undertake intelligent tasks currently performed by highly skilled people.

> "Expert systems use domain specific knowledge and heuristics to perform many of the functions of a human expert. The success of any expert system relies mainly on the ability to formalize and represent the knowledge within a discipline. Often the knowledge is a collection of subjective, incomplete, ill-defined, and informal information. Indeed, a side benefit of expert system development is the formal organization of information that was previously unexpressed." (Ibid. p294).

Elements of Expert Systems

There are several components common to most expert systems. They are: 1. knowledge base; 2. short term memory; 3. inference engine; 4. explanation module; and 5. knowledge aquisition module. (Ibid.)

The knowledge base contains general information as well as heuristic or judgmental knowledge. For rule-based systems, this knowledge can be represented in the form of IF <condition> THEN <action> rules.

Short term memory is often referred to as the fact base. This is a dynamic data base that represents the current state of the system. As the actions of the rules are executed, the facts in the short term memory are changed to reflect these actions.

<u>The inference engine</u> or executor is responsible for the execution of the system through manipulation of the rule base and the short term memory. In general, the inference engine selects an "active" rule (one in which the premise is satisfied) and executes the indicated action. Three types of interrelated components may be used to locate active rules:

i) A Change Monitor detects changes in the short memory that may require attention.

ii) A Pattern Matcher compares the short term memory with the knowledge base.

iii) A Scheduler decides which action is the most appropriate.

<u>The explanation module.</u> In order for the user to have confidence in any conclusion reached by the expert system, it is essential that the system be capable of explaining its reasoning. Thus the explanation module is a very important part of any expert system.

The explanation module is not necessarily a separate entity. An explanation of the systems' actions is actually contained in the rules that are fired. As a minimum, the explanation module should be capable of repeating the last rule. In reality, the system must be able to convince the planner or his supervisor as to the reasoning behind any conclusions given or the system will not be used.

The knowledge acquisition module is the final component required by the expert system. In order to accomodate the acquisition of future expertise, an expert system should be capable of adding rules to the knowledge base in a simple and graceful fashion. Current research is attempting to develop a knowledge acquisition module that allows the expert to build the knowledge base rather than require a computer programmer for assistance.

Potential Role of Expert Systems in Project Monitoring

Most contractors feel that computers are not capable of making the subjective judgments required throughout the project monitoring process. The reviewed article disputes this premise.

> "While it is true that computers cannot substitute for or eliminate the need for project managers, they can perform beyond their current algorithmic and accounting functions." (Ibid. p.297)

The following items characterize the domain of expert systems:

1. Algorithmic methods are either not feasible, too cumbersome or too restrictive.
2. There are recognized experts in the field.
3. The task requires from ten minutes to a few days when performed by an expert.
4. The task is primarily cognitive with reasonably high level concepts or objectives involved.
5. The task has substantial payoff.

Many of the functions of project monitoring fulfill these conditions. Three areas of project monitoring are exceptionally well suited to the applications of expert systems: cost control, time control, and purchasing and inventory control (Ibid).

2.2.6 Integrated Construction Systems

Two articles on the topic of integrated construction systems are briefly reviewed.

The first, Means Computer Assisted Design and Costing Program - Cad/Cost(11), describes an existing computer application which integrates design and drafting with costing. It utilizes a CAD (computer aided design system) with a database costing system. Using the features found on a dedicated CAD system such as zoom, rotate, snap and define grids, an object can be drawn. Using the color graphics provided, the estimator can identify areas on the drawing for pricing. The library feature provides the ability to assign and save costs associated with the object. Once an object has been created, and saved, it may be retrieved and positioned anywhere on the screen. All associated line items and costs are automatically applied against the estimate. Upon completion of the design, the costs are fed into an estimating program which calculates costs. It is then possible to experiment with a number of alternatives, thus making the planning and design process more productive and efficient, (Ibid p. 25).

The second article entitled Integrated Computer Systems(12), covers a much broader scope of construction information system. The paper presents some of the system design issues related to computer applications for construction which integrate cost, schedule, production control and accounting into unified data processing applications.

> "The challenge is to develop and implement a fully integrated computer system that will provide all disciplines with instant access to information required for making accurate and timely decisions concerning project performance and control."

The following list of disciplines is given for a construction organization:

1. Business management.
2. Project management.
3. Sales and marketing.
4. Design and engineering.
5. Estimating.
6. Purchasing.
7. Contract administration.
8. Field construction.
9. Financial management.

These disciplines are then targeted in the article for inclusion in the construction information system.

The paper singles out the activity as the basic unit of information pertaining to all disciplines in a construction company.

> "Each activity file can store cost information and schedule information. By combining the cost and schedule information at this level, the powerful integrating of both cost and schedule has been achieved."

The concept sounds great. Its the bigger is better philosophy. However, the author fails to point out the down side of cost - schedule integration which is complication and loss of flexibility. An example of this integration and ensuing loss of flexibility was experienced in the project discussed in Chapter 6, The Seattle Subway Project. In this case the owner specified in the contract that the contractor shall have the "schedule of values" tied electronically to the "schedule". The contractor used a program that had this capability. However, problems arose when it came time to refine the schedule. Any addition or deletion of an activity would pose an additional problem of readjusting the "schedule of values". Consequently, the main schedule was largely frozen and used only where no changes were required to the activities. Obviously this is a huge constraint on the viability of the scheduling capacity.

The above problem source can also be deflected away from the computer capability and placed on the lack of ability of the contractor, in this case, to scope the project correctly in the first place. Having said that, the virtue of flexibility in a contractors planning capability and in his systems for representing those plans is indisputable.

The paper goes on to discuss two basic summaries of the activities, "summary by job", and "summary by work package". The "job" grouping is generally geographic or structural component related. The "work package" is a breakdown by sub-contractor or vendor. These two summaries would form a matrix of information if plotted one against another. On a concrete bridge project, for instance, the footings, columns, and beams would be jobs in the information summary system. Place rebar, erect forms, and pour concrete would be sub-contractor or vendor work packages. Both summary categories would be useful to management.

The tool for collecting information for the above summaries is called the turnaround document.

> "The turnaround document provides the data input vehicle which crosses the boundary between the field production and the computerized cost and schedule control system." (Ibid)

The paper discusses the information pieces to be collected and the importance of the document in bridging the gap between the daily field work and the accounting system which operates necessarily on a one or two month delay.

A description of a technique called "Exception Reporting" is given in which actuals of time and cost are compared to estimated time and costs. Those items that are of noteworthy difference (eg greater than 15% between actual and estimate) are highlighted in the exception report to management.

A final item contained in the paper is a description of "performance models".

> "The budget for a project is a cost performance model. The project schedule is a time performance model. The integration of cost and schedule information allows the automatic generation of many performance models derived from these data. These performance models include the <u>cost curve</u>, the <u>production curve</u>, the <u>schedule of values curve</u>, the <u>cash income curve</u>, and the <u>cash requirements curve</u>." (Ibid)

The integrated monitoring of cost and schedule allows these performance models to be generated as a by-product of system integration with little additional input required.

One large item of omission in this paper is the lack of any reference to the database utilized in the collection of time and cost information. It was not made clear how the software allows one to search the database for time or cost information. The actual interface between schedule network processor and database is not communicated.

2.3 Not Found in the Literature

The most conspicuous absence in the literature and in available software is the absence of a description of the interface between

"Database" and "Project scheduling" program. In the literature, the modules of "Database" and "Schedule" are often included together under the auspices of "Integrated construction information systems" but the reality of such systems and how they operate, has not been seen. This research points out the need for such a program and offers a less ambitious solution, Database and Schedule programs running in parallel.

Also absent from the literature is any reference to the use of an "off the shelf" database program being used as the environment or framework under which a customized "construction information system" would be developed for use in heavy construction. Lo(9) used this method to develop a construction information system applicable for residential housing construction, but the logical extension to heavy civil-structural work is not evident in the literature.

Finally, very little was found about the activity design problem and detailed planning issues.

CHAPTER 3 CONSTRUCTION INFORMATION SYSTEM FORMULATION

3.0 Introduction

Treated in this chapter is a specification for a Concrete Construction Planning System with an interface to the functions of estimating and project control. The objective is to specify a system that will accomodate the conceptual and practical aspects of concrete construction project planning.

3.1 Work Breakdown Structure

The work breakdown structure prototype used in this thesis originated from Dabbas and Halpin(4) as follows: Organization, Project, Activity, Operation, Process, and Work Task. This WBS hierarchy was then modified to suit the perceived needs of repetitious, concrete construction as follows:

Source	Level	Example
Contractor	Project	Brooklyn Bridge
Owner	Division	Payment categories
Contractor	Activity	Structural component eg. beam or footing
Contractor	Operation	Trade related eg. rebar.
Contractor	Location	Repetitious construction address
Contractor	Resource	Manpower, Machines, Materials, Subcontractors
Contractor	Descriptor	Time, cost, Method, description.
Contractor	Phase	Bid estimate, current plan, actual, archive

Figure 6. Work Breakdown Structure Hierarchy

The Project, Activity, Operation and Location levels of the hierarchy are used for in-house coding and organization. The level of "Division" is inserted for the owners' coding and is not, strictly speaking, a level of the hierarchy at all but is included for the owner's convenience. The bottom levels, Resource, Descriptor, and Phase, are levels or dimensions of monitoring system hierarchy and are shown as dotted to discriminate from the breakdown required for the planning system hierarchy.

An "<u>Activity</u>", as used in the context of this paper, is usually identified as a major structural component of the project, eg. a bridge footing, column, or beam. An "<u>Operation</u>" as a breakdown of an activity, is usually a trade related unit, eg. rebar, formwork, or concrete placement. Operations will often form the basis of work packages for subcontractors and, or vendors.

For reasons pertaining to repetitious construction, the breakdown of the activities by "<u>Location</u>" is also used in this system.

The above definition for an activity is not the norm in the industry. Typically, an activity is defined as the smallest element of work and involves action. The following illustration shows how this thesis has utilized three levels of hierarchy to more clearly depict the various aspects of the typical activity.

This thesis:		Typical in the industry:	
Component ┐		Beam ┐	
Location ┼	> Activity	3rd Floor ┼	> Form 3rd floor Beam
Operation ┘		Form ┘	

These levels of the work breakdown structure hierarchy are used to create a data structure that will easily categorize the work breakdown. The advantages to this system will become apparent through the course of this thesis.

For each operation on a concrete job, there exist a variety of "<u>Resources</u>" required to complete the work. These resources in general can be contained in the following headings:

1. Manpower
2. Materials
3. Equipment
4. Management
5. Sub-contractors

Each of these resource headings contains many different elements that could be chosen, invented, or otherwise procured to fulfill a role in the completion of the work. In the design phase of a project, the specific resources need to be selected for use on an activity or operation. In the project control phase of a project, the resource needs to be accounted for.

To describe and account for the above resources, parameters called "Descriptors" are introduced to store and collect information on the various resources. These descriptors fall into four categories:

1. Time (duration, production rates, start/finish times)
2. Cost (expenditures, productivity, unit costs, etc)
3. Description (supplier, size, address, contact, etc)
4. Methods (equipment, crew composition, means).

Methods are further broken into "decision variables" that address all of the decisions that are involved in method design. The list of decision variables forms a checklist of decisions required. An example checklist is found in 4.3.0.1.

"Phase" is the last breakdown and it addresses information storage at prominent stages of the project, (bid estimate, current or forecast plan, actual, and archive.)

The work breakdown structure hierarchy is modeled after the TM1 multidimensional hierarchy containing 8 levels or dimensions. The reason for this is that construction is truly a multidimensional reality and fits the model nicely. All of the dimensions need not be utilized for every activity. But the system has been organized to provide a unique database address for storing past, present, and future information, in order to facilitate the planning process.

The first task of system formulation is to outline the sub-systems and functions required for a detailed planning system. As stated in the introduction, the construction sub-systems that are considered interrelated and thus essential to the nucleus of activity planning are Project control, Estimating, Planning, and Scheduling. These then form the core information system to which other sub-systems can be added.

3.2 Methodology

The methodology employed for the initial system formulation is simply to construct a spread sheet (figure 7) of functions required by the core sub-systems of the information system. The spreadsheet lists the function categories, functions, computer

CONSTRUCTION INFORMATION SYSTEM FORMULATION:
SPREAD SHEET OF FUNCTIONS VERSUS ENVIRONMENT AND DATA REQUIREMENTS

FIGURE 7

Abreviations:

SCH	= Scheduling program	TARG ACT DUR	= Target activity duration
SP SHEET	= Spread sheet program	DB	= Data base program
W SHEET	= Work sheet	ACT W SHEET	= Activity worksheet
TEMPLATE	= Formatted screen with or without data	OPER W SHEET	= Operation worksheet
SUM	= Summary file	ARCH, EDIT	= Archive file, edit to suit present project

FUNCTION CATEGORY	FUNCTIONS	ENVIRONMENT	DATA SOURCE	ADDITIONAL FILE DATA DESTINATION
	TIME AND COST CONTROL MODULE			
DATA ENTRY	Daily time sheets	DB	INPUT	OPER FILE
	Purchase orders and invoices	DB	INPUT	OPER FILE
PROJECT CONTROL	Operation data collection	DB	TIME SHEET	SUM FILE
	Summarized project control database	DB	OPER FILE	
	Forecasting project costs	DB	SUM FILE	
	Monthly payment data structure	DB	SUM FILE	SUB CONT FILE
ARCHIVES	Company archives of project summaries	DB	SUM FILE	
	ESTIMATING AND PLANNING MODULE			
	PROJECT LEVEL			
PROJECT ORGANIZATION AND INPUT	Project definition input	PROJ W SHEET	INPUT	
	Work breakdown structure (project)	DB & SCH	ARCH, EDIT	ACT W SHEETS
	Quantity survey spread sheet	SP SHEET	ARCH, EDIT	ACT W SHEETS
	Project time constraints and milestones	DB & SCH	INPUT	SCH
	Schedule: target activity durations	W SHEET	INPUT	SCH & ACT W SHEET
	ACTIVITY LEVEL			
ACTIVITY ORGANIZATION AND DESIGN PARAMETERS	Activity definition input (identity, constraints and conditions)	ACT W SHEET	ARCH, EDIT	
	Work Break-down Structure. Open a file for each operation	ACT W SHEET	ARCH, EDIT	OPER W SHEET
	Hierarchical menus of typical options.	OPER W SHEET	ARCH, EDIT	
	User defined options available	OPER W SHEET	ARCH, EDIT	
	Summarize activity plan. (Decision tree shown)	ACT W SHEET	FROM ABOVE	
REPETITIOUS CONSTRUCTION PARAMETERS	Repetitious const. and continuous crew scheduling? If no skip.		INPUT	
	Standard crew cycle duration: calculation		TARG ACT DUR	OPER W SHEET
	Unit activity cycle duration: calculation	ACT W SHEET	TARG ACT DUR	OPER W SHEET
	Test for feasibility of standard crew cycle duration		ARCHIVE	OPER W SHEET
ACTIVITY SCHEDULING	Network	SCH	ARCH, EDIT	PRINTOUT
	Bar chart	SCH	FROM ABOVE	PRINTOUT
	Line of balance graph	SCH	FROM ABOVE	PRINTOUT

FIGURE 7 CONTINUED

FUNCTION CATEGORY	FUNCTIONS	ENVIRONMENT	DATA SOURCE	ADDITIONAL FILE DATA DESTINATION
ACTIVITY COST-PLANS (USED WHEN OPERATION REQUIRED)	Develop cost plans at activity level? If no go to Operation Edit activity worksheet to include feasible options Calculate cost per unit for each feasible option based on: Labor, Materials, Equipment, and Sub-contractors Choose minimum cost option Produce detailed activity design Calculate crew size based on productivity duration Check assumptions of productivity with selected crew size Repeat for all (detail not required) activities	ACT W SHEET COMPUTER AIDED DESIGN PROGRAM	ARCH, EDIT	COST CONTROL
	OPERATION LEVEL			
OPERATION LEVEL COST-PLANS	Edit operation worksheet to include feasible options Calculate controlling resource requirements (ie falsework units) Obtain design input (ie beam and form sizing) Calculate cost for each feasible option based on: Labor, Material, Equipment, and Sub-contractors Choose minimum cost option. List methods Produce detailed activity design Calculate crew size based on productivity duration Check assumptions of productivity with selected crew size Repeat for all operations of the activity	OPER W SHEET COMPUTER AIDED DESIGN PROGRAM	ARCH, EDIT	COST CONTROL
	ACTIVITY LEVEL SCHEDULING			
ANALYSE COMPOSIT ACTIVITY	Compile histogram of equipment hours Level equipment resource useage Update schedules. Check activity duration v target duration Analyse resulting activity plan. Alternatives to explore? Repeat for all activities	ACTIVITY SCHEDULE	FROM ABOVE REFINE	PRINTOUT
	PROJECT LEVEL SCHEDULING, ANALYSIS, AND SUBMITTAL			
PROJECT SCHEDULE	Network Barchart Pert technique Line of balance analysis Contract duration specified? Activity crashing required?	PROJECT SCHEDULE	FROM ABOVE, REFINE	PRINTOUT
PROJECT RESOURCE USEAGE	Cash flow Financial analysis Manpower Equipment Level project resources	PROJ SCH OR W SHEET	FROM ABOVE, REFINE	PRINTOUT
TENDER ESTIMATES	Sub-totals of costs Overhead, profit, and contingencies Distribute totals among pay items Calculate unit rates for tender	PROJECT W SHEET	OPERATION AND ACTIVITY W SHEETS	PRINTOUT
FINISH	Tender submitted			

environments, data sources, and additional file data destinations. This then gives an overview of the requirements of the system as a whole.

3.3 Functions Required For The Proposed System

For the initial system layout, the spreadsheet is divided into two modules: "Project control" which generates time and cost information, and "Estimating, Planning, and Scheduling" which require time and cost information.

The "function category" is included to identify and label functions of like kind. The functions themselves are the tasks that an estimator or planner would pursue enroute to accomplishing the estimate, plan, or schedule.

One could argue that estimating is a task much different than planning and scheduling. The theory behind combining them in the same module is to treat it as a two pass module. The first pass (estimating) requires a broad brush plan and schedule to be able to assign costs. The second pass (planning and scheduling) requires a detailed plan and schedule in order to minimize costs to be incurred. Since the two tasks include the same functions, they are listed here under one module.

For a production system, the estimating function would require in-depth detail. For the purposes of this thesis, estimating is considered conceptually and is included with planning.

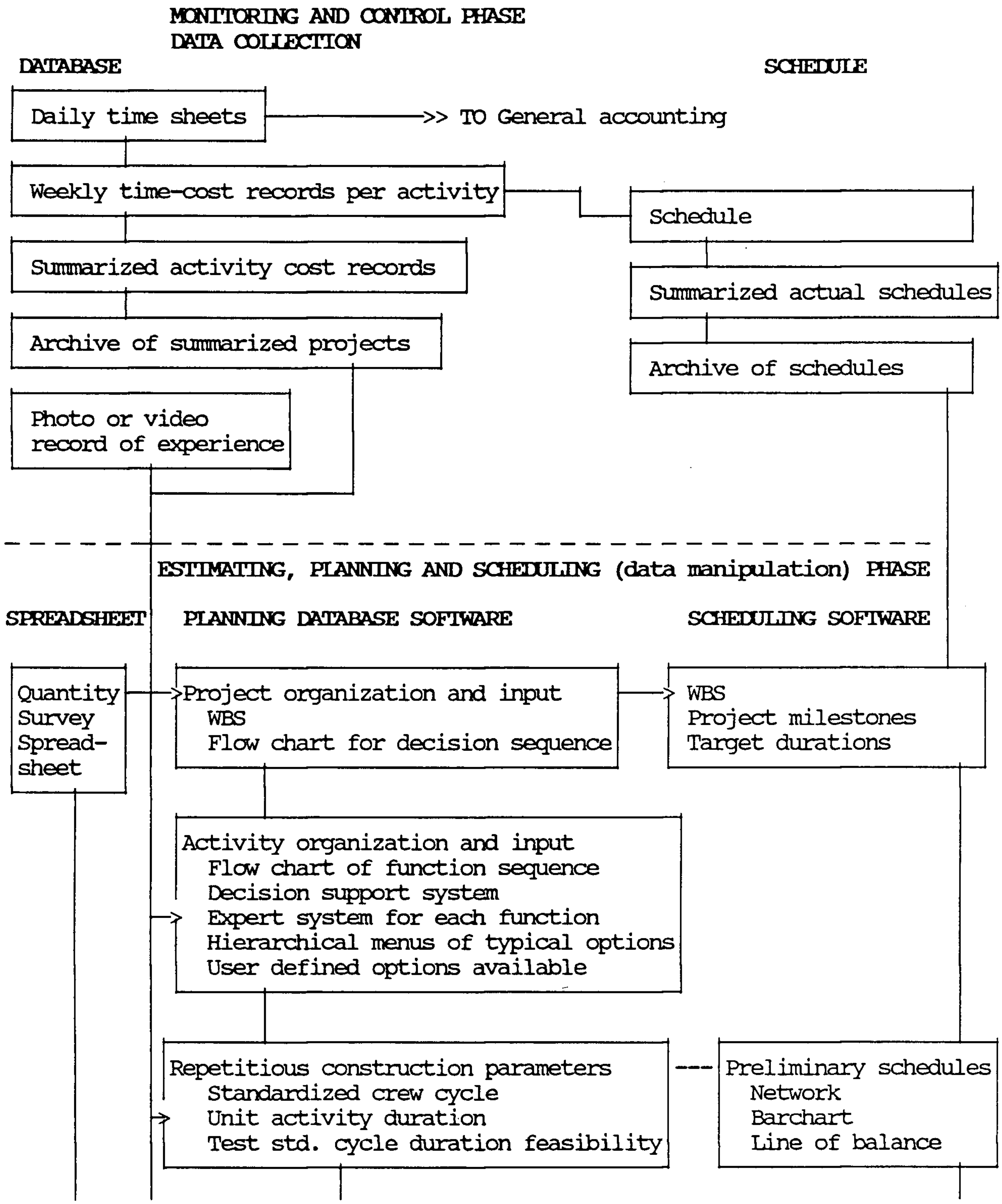
3.4 Computer Environment Requirements For The Proposed System

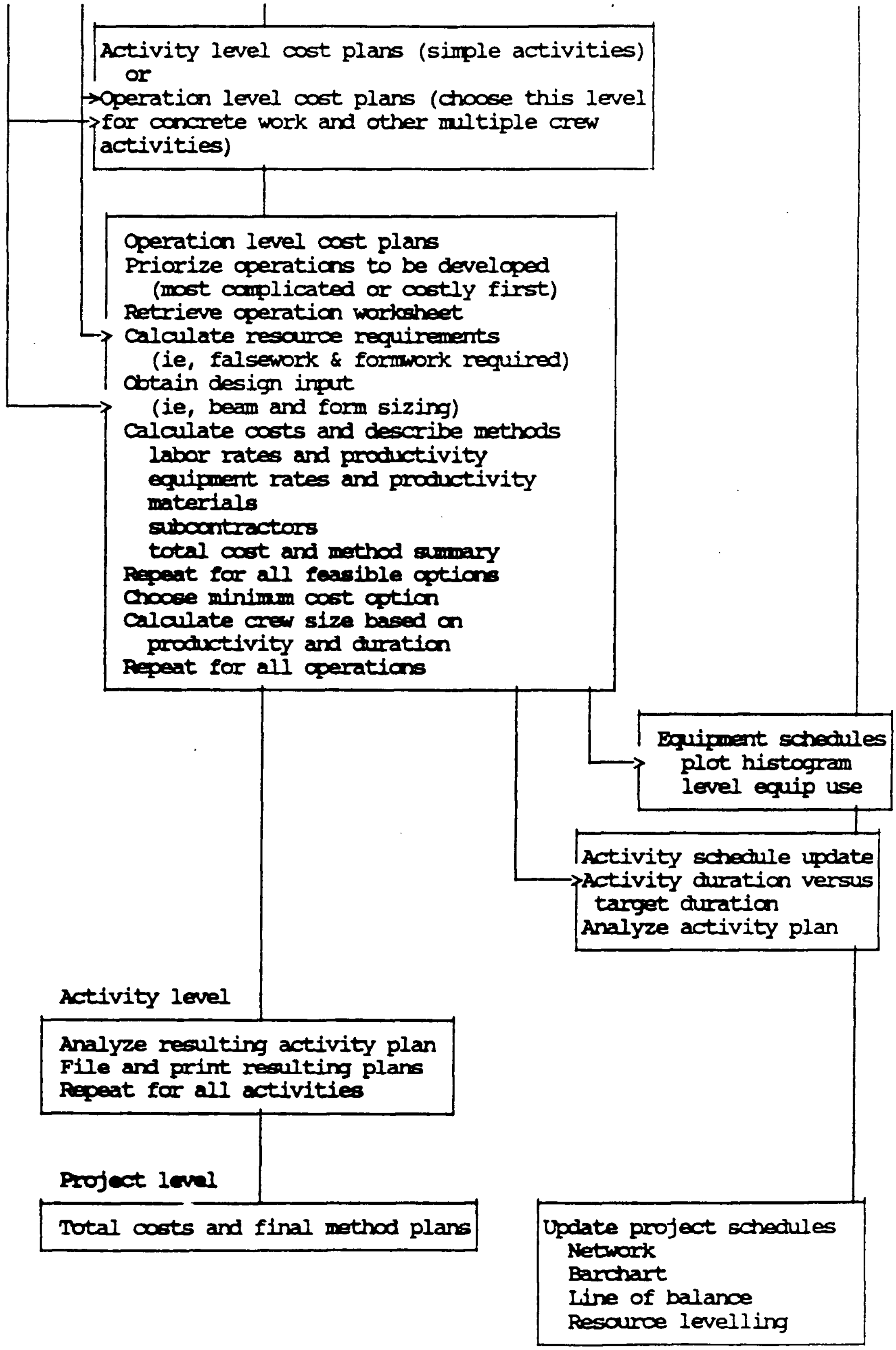
The above mentioned spreadsheet (figure 7) has three columns on the right of the functions which allow the system designer to assign attributes of the functions. The column titled ENVIRONMENT specifies the basic capability of the computer environment required by the function. The next column, DATA SOURCE, specifies the origin of the data required by the function. For example, the function "Daily time sheets" gets data from "Input" (manual keyboard input), and the function "Operation data collection" gets data directly from the file "Daily timesheets". In a similar manner, the third column, ADDITIONAL FILE DATA DESTINATIONS, identifies function data output which needs to be directed to another function.

Taken as a whole, the spreadsheet allows a view of some of the system formulation requirements. In summary, we need Database, Project worksheet, Schedule, Quantitiy takeoff spreadsheet, Activity worksheet, Operation worksheet, and Computer aided drafting and design capabilities.

Analysis of the above capabilities with a least common denominator approach yields a division of program environments that appears to simplify the solution. The use of a database program in conjunction with a scheduling program will provide most of the functional needs of the system. The database with a customized program will have the capability to structure the project control, estimating, and planning process with screen prompting and automatic data transfer amongst existing files. The scheduling program will handle the logical construction sequence, durations, start and finish times, and will profile resources against activities.

Figure 8 shows the spreadsheet restructured and sorted by software requirements. It shows the parallel uses of schedule and database functions listed in chronological order of useage.


MONITORING AND CONTROL PHASE
DATA COLLECTION
DATABASE
SCHEDULE
Daily time sheets
>> TO General accounting
Weekly time-cost records per activity
Schedule
Summarized activity cost records
Summarized actual schedules
Archive of summarized projects
Archive of schedules
Photo or video record of experience
ESTIMATING, PLANNING AND SCHEDULING (data manipulation) PHASE
SPREADSHEET
PLANNING DATABASE SOFTWARE
SCHEDULING SOFTWARE
Quantity Survey Spread-sheet
Project organization and input
WBS
Flow chart for decision sequence
WBS
Project milestones
Target durations
Activity organization and input
Flow chart of function sequence
Decision support system
Expert system for each function
Hierarchical menus of typical options
User defined options available
Repetitious construction parameters
Standardized crew cycle
Unit activity duration
Test std. cycle duration feasibility
Preliminary schedules
Network
Barchart
Line of balance


Activity level cost plans (simple activities)
or
Operation level cost plans (choose this level for concrete work and other multiple crew activities)
Operation level cost plans
Priorize operations to be developed
(most complicated or costly first)
Retrieve operation worksheet
Calculate resource requirements
(ie, falsework & formwork required)
Obtain design input
(ie, beam and form sizing)
Calculate costs and describe methods
labor rates and productivity
equipment rates and productivity
materials
subcontractors
total cost and method summary
Repeat for all feasible options
Choose minimum cost option
Calculate crew size based on productivity and duration
Repeat for all operations
Equipment schedules
plot histogram
level equip use
Activity schedule update
Activity duration versus target duration
Analyze activity plan
Activity level
Analyze resulting activity plan
File and print resulting plans
Repeat for all activities
Project level
Total costs and final method plans
Update project schedules
Network
Barchart
Line of balance
Resource levelling

Two solutions to the system design problem are now apparent.

1. Utilize a combination of commercial database, scheduling, and spreadsheet programs.
2. Write a program that would combine the capabilities of a database program, scheduling program, and spreadsheet using a language like Basic, C, or Pascal.

While the second solution would provide an integrated system with the advantages of single data entry and interchangeable files between scheduling and database, this alternative is considered beyond the scope of this research.

3.5 A Proposed System In Two Parts: The 80 % Solution.

The proposed solution evolves from the observation that scheduling and database programs presently exist on the market which are extremely sophisticated in their own right. Present day construction management requires both of these functions and this research examines the merit of creating and maintaining parallel scheduling and database programs within the context of one information system. These systems could possibly share information files but this is unlikely without a concerted effort from a software house that would develop both packages. Lacking the ability to share files, this solution for construction systems would only be on the order of 80% efficient when compared to a completely integrated system.

The reason for the design of a system with two parallel software programs is the conceptual simplicity of the two system approach. By separating (1. scheduling) from (2. estimating, planning, and project control), one can easily follow the logic required to construct the system modules.

3.6 Planning Models

Thus far in Chapter 3, the emphasis has been on the requirements of the information system in terms of functions, environments, and specific software. We will now focus on a system that will aid in estimating, planning, and project control with emphasis on planning of projects and activities within projects.

The name selected for this planning vehicle is the "planning model" or the "planning algorithm". A planning model is defined to be step by step guideline for developing a construction methods plan for a project and the activities within that project. The most suitable environment for the planning model as mentioned earlier is commercially available database software.

The planning model database system provides the following features:

1. A conceptual and computational framework upon which to organize and sequence the modules and functions that make up the construction information system. Menu driven prompting provides order for the included functions.

2. A data system which collects, sorts, and performs arithmetic operations on construction information. It will have the programmed capabilities of automatic data transfer from timecard file to project datafile and employee payroll file. The ability to condense the project datafile to a summary file for analysis and archiving will also be available.

3. A decision support system that prompts the user through the module or function in question. By use of customized programming in the database language, decision support is available which will sequence the order of decisions to be made, and give historical data from previous project datafiles and supply construction technology information pertinent to concrete construction. From this data, appropriate production rates, cycle durations, costs per unit, etc. can be selected for the construction design problem at hand.

In essence, a planning model is first a menu for activity planning, second a storage vehicle for assembled plans, and third a database of collective company experience for various construction methods, costs, techniques, materials, time durations, and equipment.

The planning model utilizes information from scheduling software including critical path method output of barcharts, network diagrams, and line of balance diagrams. It also assimilates accounting data such as job cost data, productivity and labour rates, and production rates. Finally it collects construction technology information and provides an advantageous climate to plan and monitor the construction project.

3.6.1 Benefits of Using Planning Models

Similar problems that reoccur frequently are common in engineering. These problems are usually handled by developing general formulae and methods of solution so that the problem set-up time is minimized. The activity planning problem being studied in this thesis is of this nature. For a bridge contracting company, the analysis and design of each bridge construction activity will occur each time a proposal is made or a contract is won. By using a previously developed planning model to aid in the activity design, savings of time and money can be realized by substantially reducing the duplication of work common to all bridge projects. At the same time, the opportunity to explore more strategic alternatives in a timely and economical way is an additional benefit.

3.6.2 Graphical Techniques

The model uses a variety of graphical techniques to aid in the understanding of certain concepts. These illustrations give excellent conceptual clarity and allow instant recognition of trends in the solution. Techniques such as work breakdown structure, precedence networks, barcharts, decision trees, time-space diagrams, and resource histograms are used throughout the model.

3.6.3 The Models Presented

This thesis presents research on two similar transportation corridor construction projects and develops a planning model which, because of its generic approach, is suitable for both construction projects. The research was done sequentially. First, a planning model was developed for concrete, cast-in-place, multispan, bridge construction. At a later date, the bridge construction planning model was tested on a cut and cover tunnel project, and modified to suit the application of a tunnel project.

The issue of transportability of the model from one kind of construction project to another is of interest. The tradeoff always exists between specific and generic systems. The specific is immediately appropriate and useable, but narrow in the scope it addresses. While the generic needs to be tailored to the application to a certain degree prior to coming on line, but it addresses the basic requirements of all projects involving concrete construction.

Application in the real world ideally would begin with the generic model. Save it. Tailor the model to a specific applicication such as a bridge. Save it. When the next project comes along, use the model which most closely addresses the needs of the new project. Modify the model again, and so on. The need for flexibility has thus been addressed. The model needs to be in such a form that it can be easily changed to address different procedures or requirements that will inevitably occur from project to project.

CHAPTER 4.
THE GENERAL PLANNING MODEL FOR CONCRETE CONSTRUCTION

4.0 Introduction

The "General Planning Model" provides a sequence of design for a generic concrete construction project containing activities and operations. The model follows the work breakdown structure hierarchy. Through the process it serves as the framework prompting the user through the design process, the data system collecting and retrieving production rates, unit costs, etc, and the decision support system for the project and activity design problem.

Since a model without a context can become very abstract and hard to picture, this thesis has developed a worked example, the "Beam Construction" activity of a multispan, post-tensioned bridge project. As mentioned in Chapter 3, specific planning models would be derived from the general model by tailoring the model to the project at hand. The Concrete Bridge Project Example is included for clarity and can be thought of as a the result of a specific planning model.

The beam construction activity is selected because it is the most complicated of the bridge project activities. The general planning model is is therefore demonstrated while addressing the requirements of the most complicated activity.

4.0.1 General Planning Model Flow Chart

The General Planning Algorithm proposed in this paper is presented in flow chart form in figure 9. This flow chart clearly shows the step-by-step procedure to follow for planning the construction of the repetitive activities and is a

very useful tool to aid in the understanding of the model. By using this chart, it is relatively easy for one to grasp the method of solution without becoming lost in the detailed requirements at each step.

4.0.2 Example Overview: Cambie Bridge Vancouver, BC.

The City of Vancouver in British Columbia, Canada, decided to replace the ageing Cambie Bridge with a six lane, concrete structure spanning a 250 metre waterway and with a total length of 1 kilometre. The bridge design by N.D. Lea & Associates and modified by Stephenson Construction called for a central post-tensioned spine beam to be cast in place with the remaining width to be cast later with a travelling "wing" form. The centre span was 80 meters between columns and a 50 meter length was precast on a barge and lifted into place. The remaining 40 spans were formed on falsework approximately 10 metres above the ground, one span at a time. These repetitive spans and the plan for the activity of bridge beam construction are the focus of this planning model.

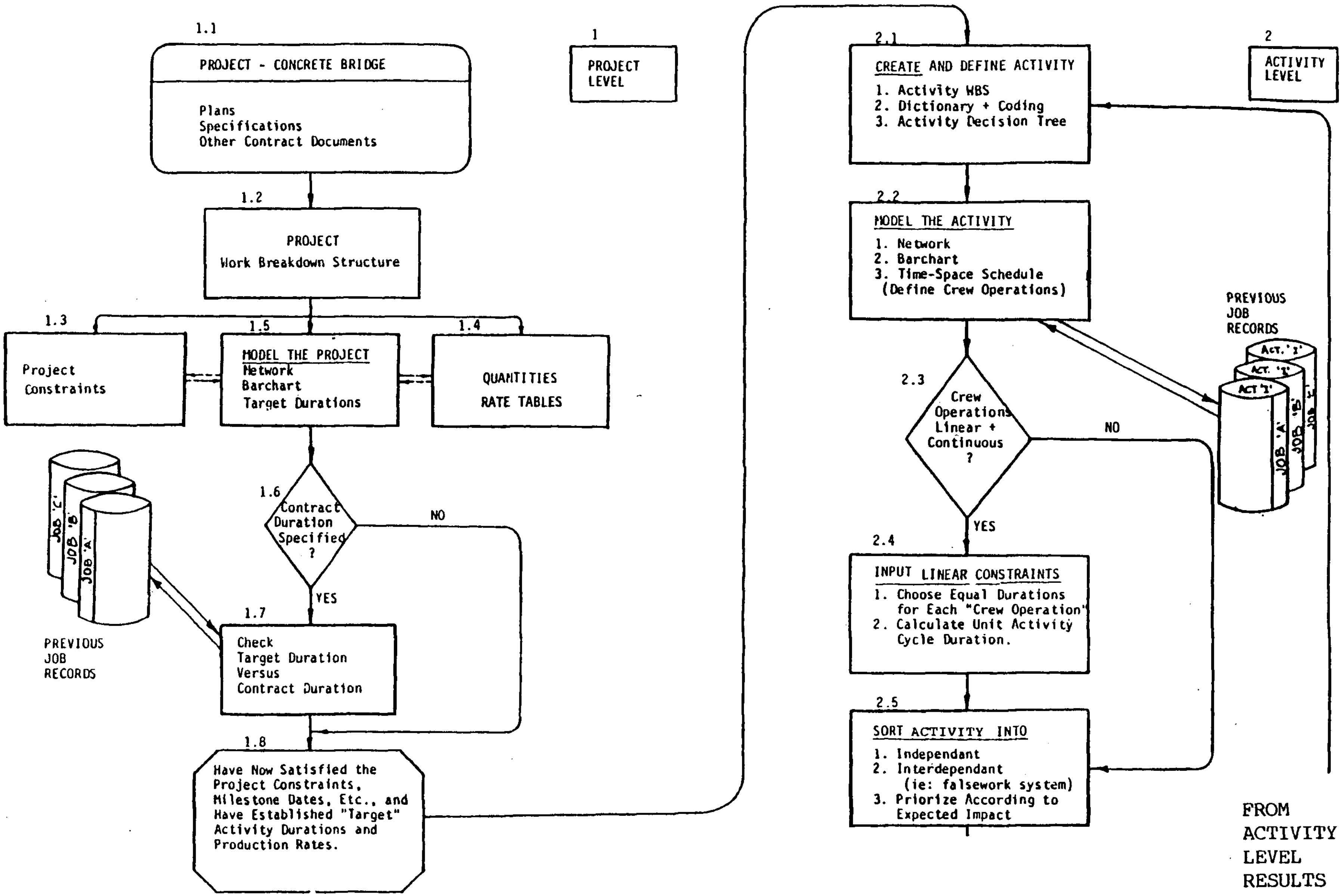


Figure 9 General Planning Model Flowchart

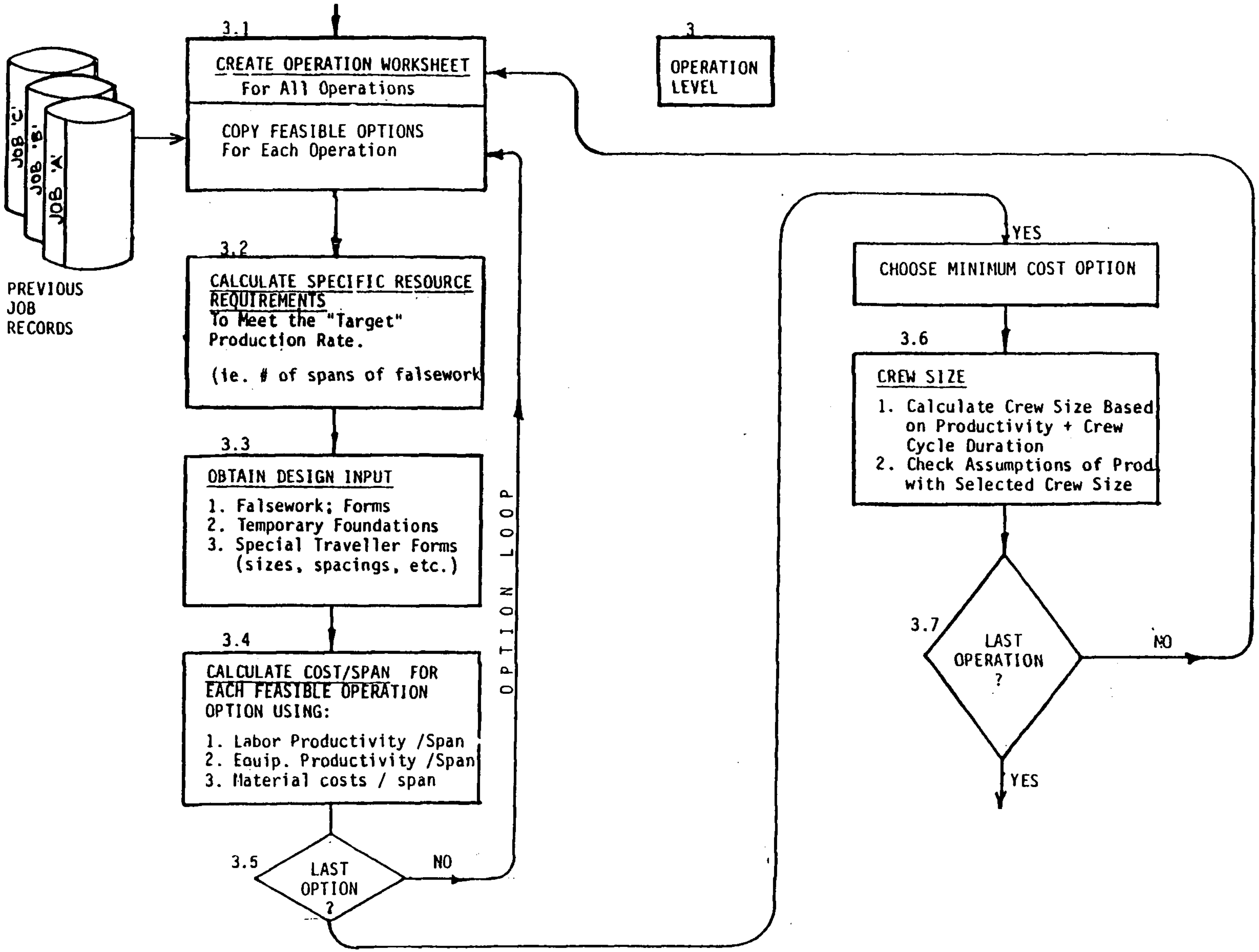


Figure 9 Continued

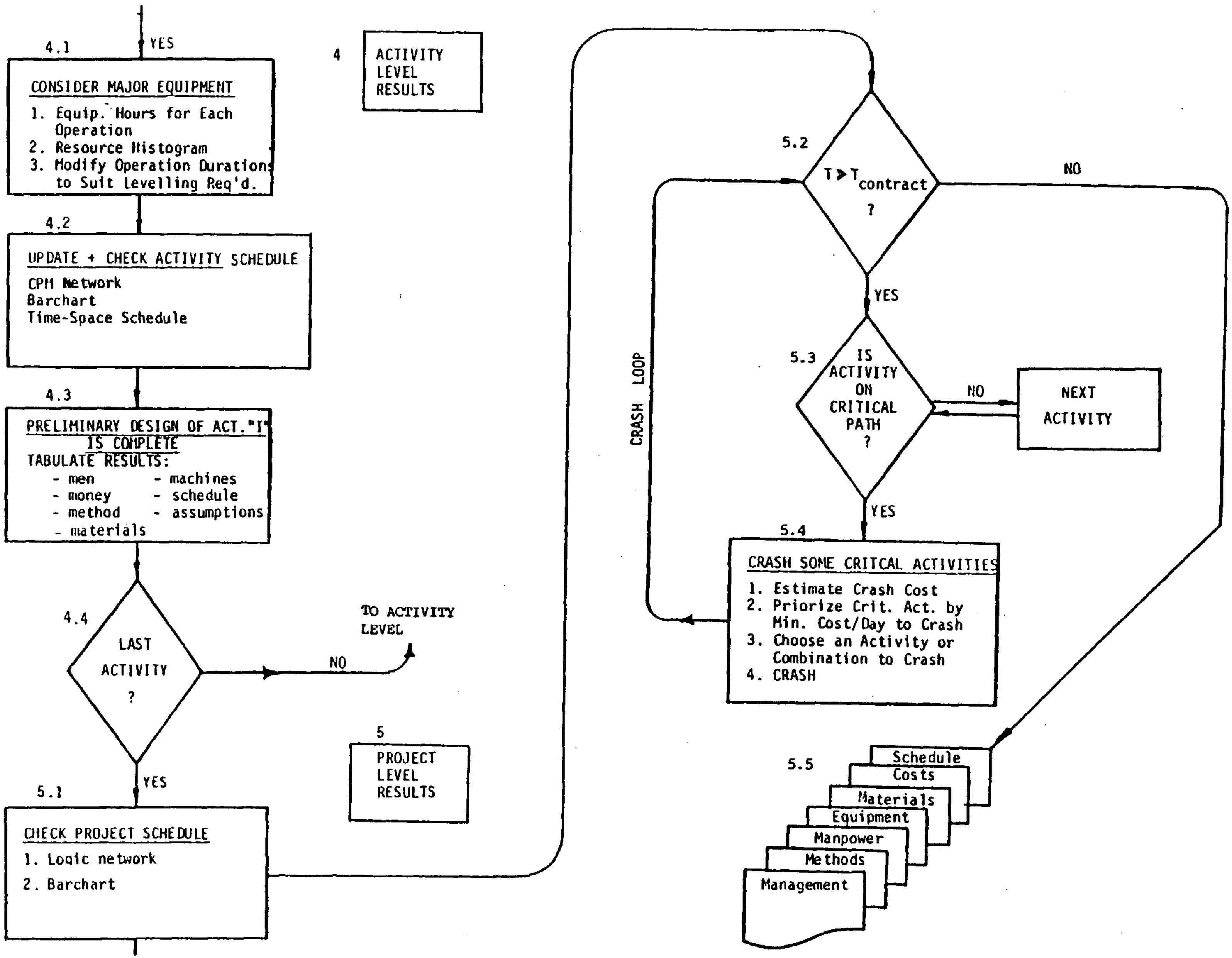


Figure 9 Continued

4.1 Project Level: Commencement of the Plan

While the planning algorithm focuses on the activity and operation levels of planning, there are project level inputs required for the planning process. The planning algorithm begins with these inputs.

4.1.0 The Estimate

The bulk of the elements that are required for estimating are the same as those required for planning. A list of elements common to both is as follows: quantity takeoff, method plan, productivity rates (Manhours / unit) applicable to the method selected, labor and equipment rates. The following are elements that would not necessarily be involved at the planning level but would be required for the estimate: inflation adjustment, mark-up and profit, economic, and political factors that might affect the bid price.

4.1.1 Project Award

The following project specific parameters are given for the activity planning example of "Beam construction".

Concrete Bridge: multi-span, cast-in-place, using post-tensioned and mild steel reinforcement.

Number of adjacent ramps: 2

Number of spans: 19 x 2 = 38

Number of beams/span: 1

Milestone completion date: 40 weeks = 200 working days

4.1.2 Project Work Breakdown Structure (WBS)

A work breakdown structure is developed by subdividing the project into construction components as shown in the typical bridge section in figure 10. Each component will require its own

construction methods, manpower, materials, equipment, etc., and is defined as an activity (see 3.1)

An example WBS example is displayed in figure 11 to provide a prototypical bridge project against which the planning model presented herein may be applied and tested.

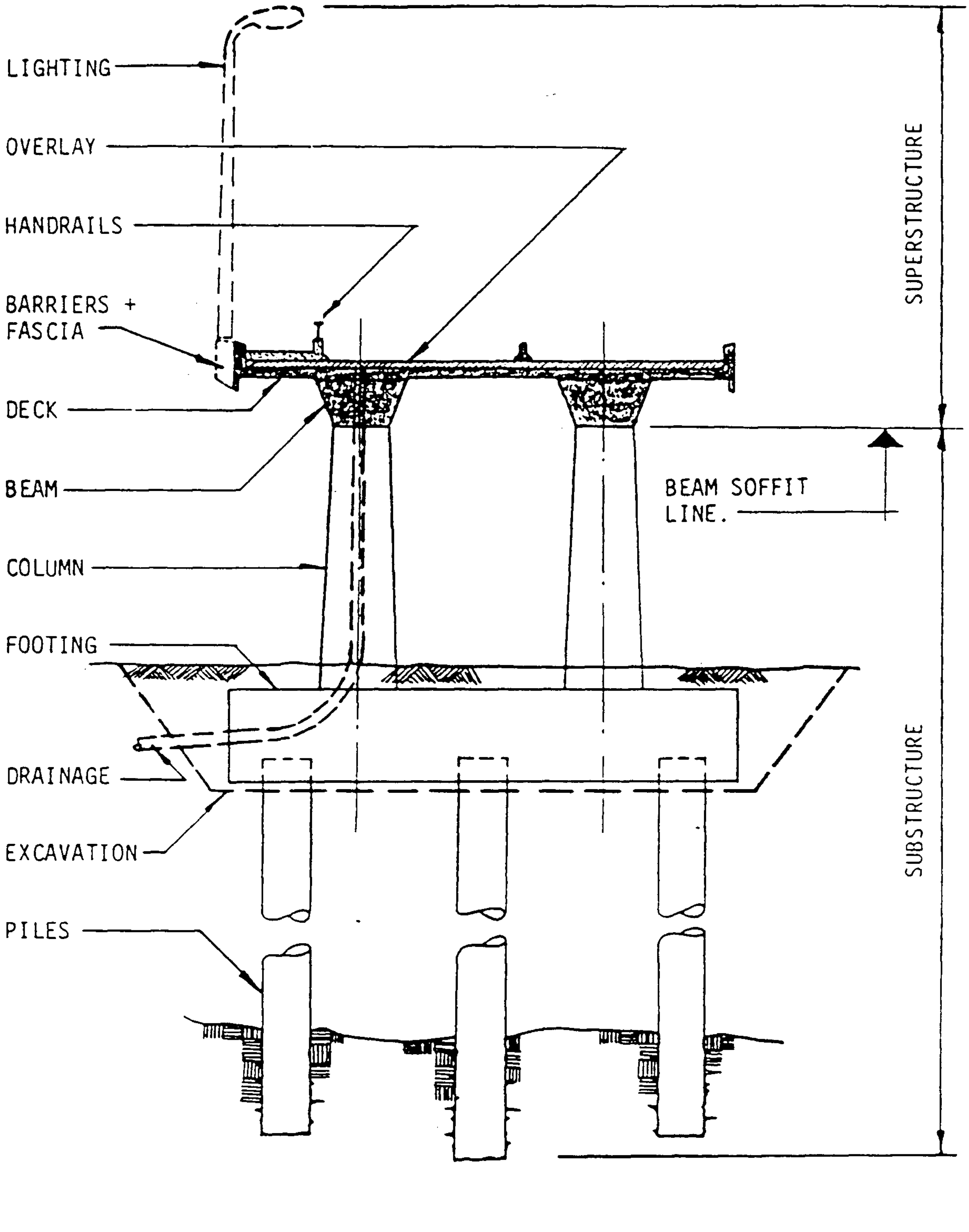


Figure 10 Section Through a Typical Concrete Bridge Showing The Activity and Project Level WBS Elements

Project Level	Activity Level	Operation Level

- Concrete Bridge
  - Piles
  - Excavation and backfill
  - Footings
  - Columns
  - Abutments
  - Drainage
  - Beams
    - Shore footings
    - Shore towers
    - Prefab forms
    - Erect towers
    - Free form
    - Rebar placement
    - Post-tension ducting
    - Concrete and cure
    - Post-tension stressing
    - Form removal
  - Deck
  - Barriers
  - Overlay
  - Handrails
  - Lighting and electrical

Figure 11 Example WBS For A Concrete Bridge Project

4.1.3 Project Constraints

Next, the project constraints must be listed. (e.g. milestone dates, difficult geometric shapes, height of structure above ground, site area available, expected weather conditions, etc.). This information will be required when assessing the comparability of the historical projects summarized in the database with the present project. As well, the constraint list will begin to focus the designer's attention on available methods of construction.

4.1.4 Quantity Takeoff and Rate Tables

Calculation of the number of units of primary materials to be used in the construction of each activity is required for the estimate and subsequent planning. (i.e. m^2 formwork, m^3 concrete, kg rebar, kg p.t. tendon, etc.). These values will be used later in conjunction with productivity information to determine production cost estimates.

Rate tables listing current total costs per manhour, or per equipment-hour, are input for all trades and for all feasible equipment required by the project.

4.1.5 Model The Project

Figure 12 shows an example precedence network for a concrete bridge with the logic between activities shown. At this point, the activity durations are not yet known as the construction methods for each activity have yet to be determined .

Target Durations

When constrained by contract milestones, it is sometimes useful to know the duration time available for lengthy activities. To do this one can obtain "target durations".

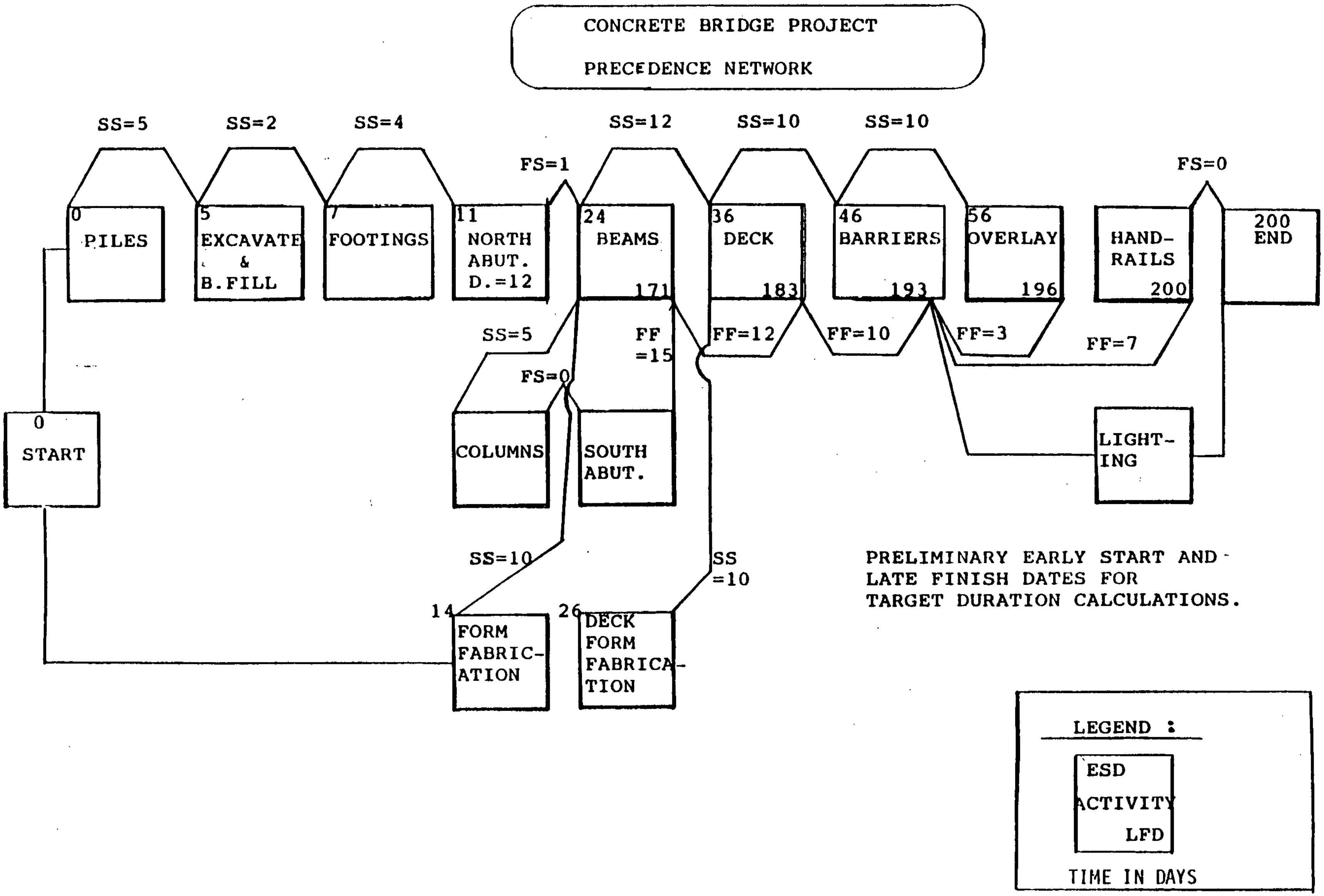


Figure 12 Precedence Network for a Concrete Bridge Project

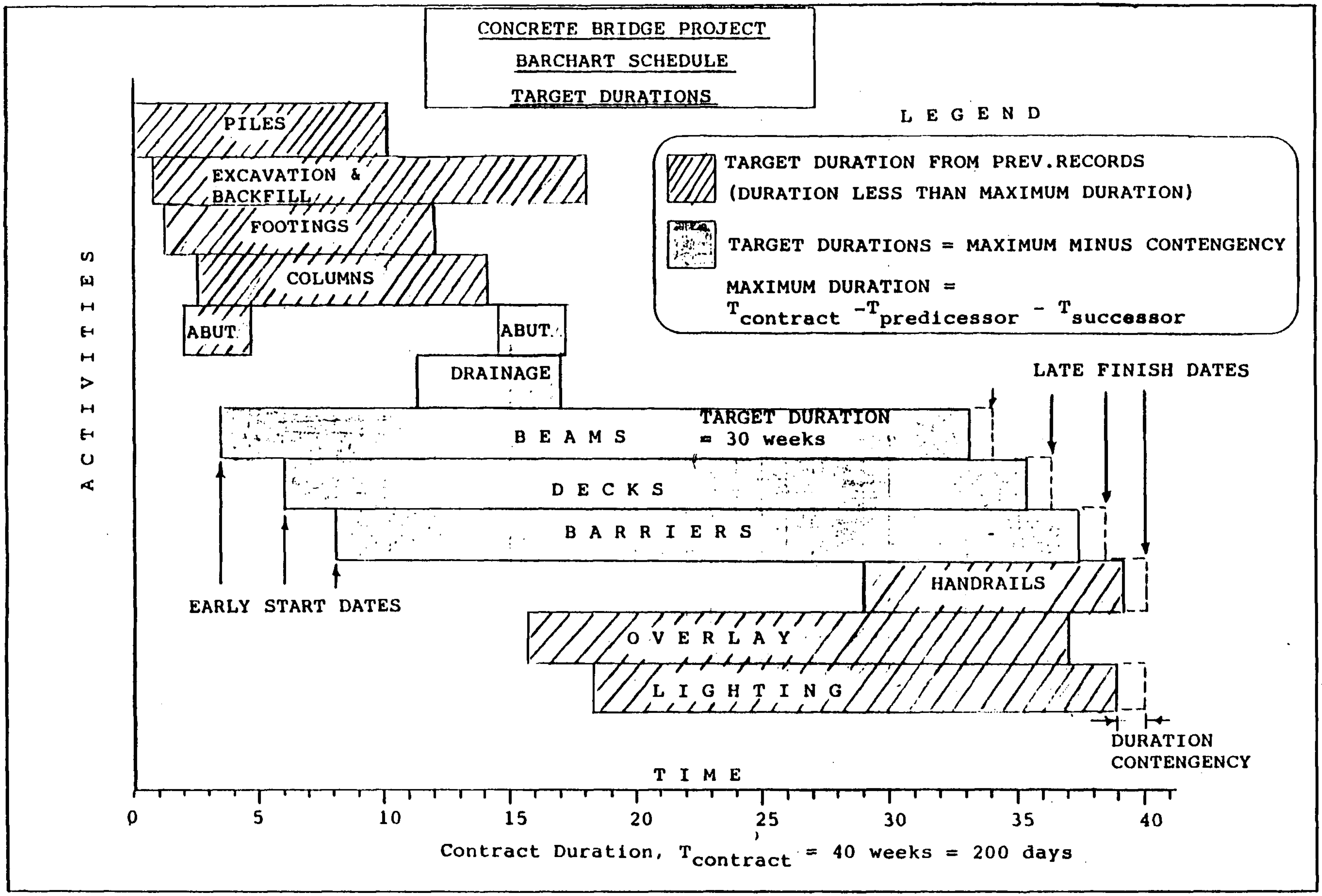


Figure 13 Barchart Schedule Showing Activity Target Durations

Target duration = contract duration minus (preceding activity lead time plus subsequent activity durations).

The assumption required here is that the leading and lagging activity durations as roughly estimated above are of the correct order of magnitude to yield a dependable result. For repetitious construction this is often not an unreasonable assumption. The example preliminary barchart for target durations (figure 13) shows that the early activities are only on the critical path for the first one or two unit activities. Likewise, the late activities are only on the critical path for the last one or two unit activities. The time remaining between early and late activities plotted in this manner is the remaining duration for the lengthy activity.

Project Bar Chart

An estimate of each activity duration can be made by taking the product of the average unit activity durations from the previous job records and the number of units of activity required for the present project. A factor for difficulty can be considered in this process. These durations are then plotted with overlapping to form a bar chart and are referred to as preliminary initial durations or "target durations". Target durations are useful in that they provide a starting point for estimating duration. Target durations allow the planner an overview of durations prior to detailed activity design.

4.1.6 Contract Duration Specified?

If contract duration (T contract) is specified, one needs to check that the target project duration is less than the contract duration. If T contract is not specified, go to 4.2.

4.1.7 Project Target Duration vs. Contract Duration

The project target duration is now compared to the contract duration. If the target duration is significantly less than the contract duration, then this fact is to be noted. Certain activities could be lengthened in duration if a reduction in cost could then be realized.

If the preliminary target duration is significantly greater than the contract duration, then the contract duration will dictate the final target durations to be used (ie: the time consuming activities will require shortening). Figure 13 shows an example barchart constructed to show target durations for the activities of a typical bridge project.

The activities shown cross hatched are on the critical path for only one or two unit activities and are therefore not candidates for reducing the project duration. Those activities shown shaded are on the critical path for their entire duration. For the three activities shown in the example, the early start date minus the late finish date yields the maximum duration. The target duration is then found by subtracting a contingency factor from the maximum duration. One would note for these activities that the target duration may not be significantly exceeded.

Beam example: Target Duration

previous records indicate	4.6 days per span
	* 38 spans
Target Duration	= 175 Days
Contract Duration	= 200 Days

T_{max} = (Tcontract - Tpredecessor - Tsuccessor) = 160 days.

Use target duration = 150 days.

Activity Production Rate

$$\text{Activity Production Rate} = \frac{\text{\# of unit activities}}{\text{target activity duration}}$$

$$\text{Beam Production Rate} = \frac{\text{\# of spans}}{\text{target duration}} = \frac{\text{38 spans}}{\text{150 days}}$$

Beam Production Rate = 0.253 beams/day.

This is a "ball park" minimum production rate since "beams" are on the critical path and the contract duration governs the project duration.

4.2 Activity Level Planning

4.2.1 Create and Define the Activity

Commencement of the Activity Level analysis begins with "Create WBS", "Create Dictionary and Coding System", and "Create Activity Decision Tree". Existing, standardized records will be utilized for these procedures. Modifications to the existing records will then be made to suit the present activity being considered.

Work Breakdown Structure (WBS)

This is a graphical representation of the activity subdivided into the basic operations that comprise the activity.

An example Activity WBS for Beam Construction is shown below.

- Beam Construction
  - Shore footings
  - Shore towers
  - Prefab forms
  - Erect towers
  - Free form
  - Rebar placement
  - Post-tension ducting
  - Concrete and cure
  - Post-tension stressing
  - Form removal

Figure 14 Example WBS For Beam Construction Cycle

Dictionary and Coding

All elements of the WBS must be clearly defined and coded with respect to the company's established.

Activity Decision Tree

This is a graphical technique used to represent alternative methods (also called method options) for all operations of an activity. It is a useful technique with which to visualize the activity as a whole and to see the range of method options for each operation of the activity. It is an extension of the work breakdown structure. The decision tree forms a hierarchy of decisions to be made for the selection and design of method options.

Figure 15 shows an example decision tree for beam construction. In the process of developing the decision tree, some of the dependencies between operations will become obvious. For instance, stripping is a function of forming system. These two operations will later be combined for the design process. The decision tree has helped with the visualization and organization process.

4.2.2 Model the Activity

To facilitate conceptual activity planning, the general planning model requires an illustrative method that allows visualization of the following: logical dependencies, feasible durations, and feasible production rates for each operation.

Activity Network

A network model is used to represent the links between operations and repetitions of the activity.

Figure 16 shows an example logic network. Only the logic is shown as durations will be applied later. Crew operations are identified at this time.

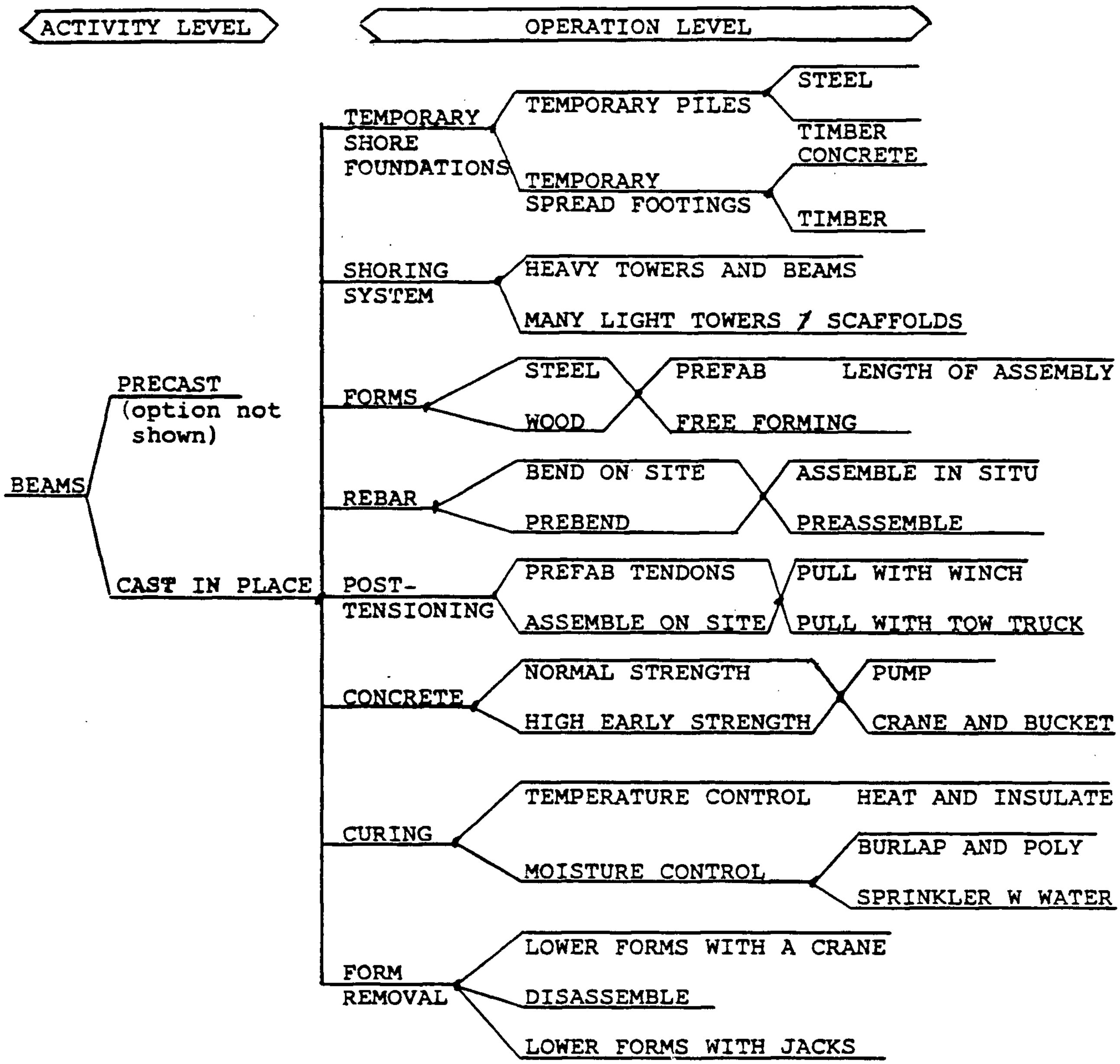


Figure 15 Example Decision Tree for Activity Design

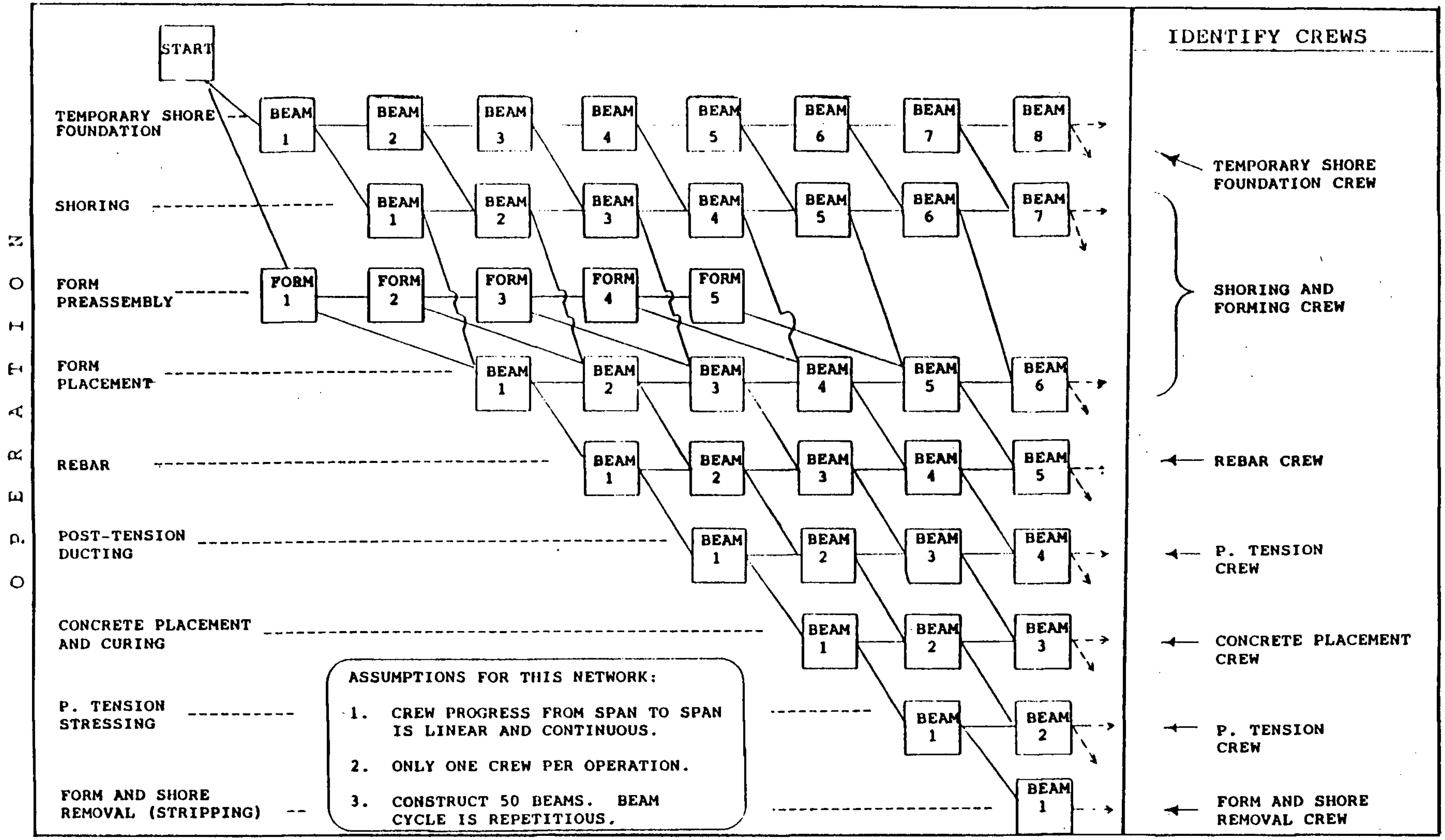


Figure 16 Activity Precedence Network for the Activity "Beam Construction"

<u>Barchart for the Unit Activity Cycle</u>

A "unit activity" is defined as one repetition of an activity. For example, one span of the activity "construct bridge beams" is a unit activity. A schematic barchart is now constructed for the unit activity. Feasible operation durations from previous job records are included to aid in the conceptual design of the activity.

An example preliminary barchart for the unit activity of beam construction is shown in figure 17.

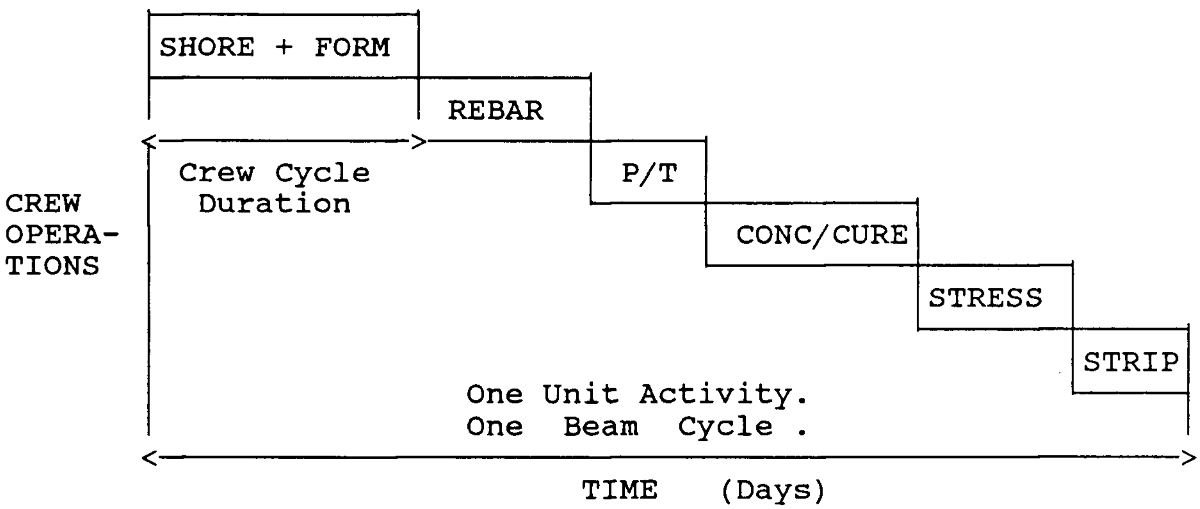


Figure 17 : <u>Barchart for a Unit Activity of Beam Construction</u>

Time-Space Diagram

A time-space diagram can be constructed for the unit activity to show rates of production of the various crew operations. This thesis uses the term "crew operation" interchangeably with the term "operation". In the example given below, the time-space diagram represents operations of an activity beginning at location 1 and progressing at a constant rate. Each operation starts one day after its predecessor.

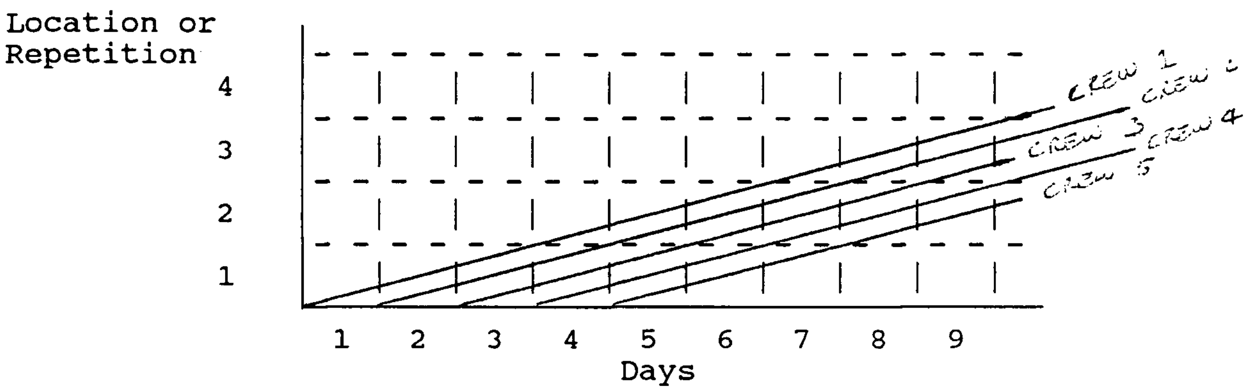


Figure 18 Example Time-Space Diagram

4.2.3 Crew Operation Schedule To Be Linear and Continuous?

Crew progress is said to be linear when the slope of the time-space diagram is constant. Crew progress is said to be continuous because no pause appears between work locations for each operation. Usually a work continuity constraint suggests that work on an operation must proceed continuously.

Linear planning can be useful for the following reasons:

1. Learning curve effects are maximized by dedicating each crew to one task and thus productivity is increased.

2. Crew cycle durations must be standardized for efficient implementation of linear scheduling. If the standard crew cycle duration is attained, a beneficial rhythm of construction is established which may also increase productivity. An increase in productivity while maintaining a standard cycle duration implies that the crew size decreases as the number of repetitions increases.

In order for linear crew scheduling to be feasible, the activity itself must be cyclical, repetitious, and have linear network logic. If the activity is constrained by the number of forms available for placement, which most activities would be, then the operations are likewise constrained. For efficient implementation of a linear schedule on such an activity, each operation ideally would proceed at the same rate as all the other operations. Each unit of operation must be capable of being efficiently completed in the same amount of time as all other operations. This duration is called the standard crew cycle duration.

4.2.4 Input Linear Constraints

Linear constraints, as previously mentioned, impose duration constraints. To develop linear scheduling for an activity, one is forced to select a standard crew cycle duration for all operations before considering the methods utilized by each crew operation. The steps involved include 1) deriving the crew cycle duration, 2) testing for feasibility, 3) treating non-continuity, 4) computing unit activity cycle duration, and 5 computing falsework requirements where appropriate. These steps are elaborated upon below.

<u>Step 1 Deriving the Crew Cycle Duration</u>

Definition: "Concurrent crews" refers to the number of crews employed on the same operation at the same time.

$$\frac{\text{1 concurrent crew}}{\text{Standard Crew Cycle Duration}} = \text{Target Activity Production Rate}$$

Beam Activity Example: Activity target duration = 45 days
Number of repetitions = 10
Target activity production rate
= .222 beams per day

$$\text{Standard Crew Cycle Duration} = \frac{\text{1 concurrent crew}}{\text{0.222 beams/day}} = 4.5 \text{ days / crew cycle}$$

The above expression is inexact and unconservative because, while the first crew will finish their part of the activity cycle in 4.5 days, the first activity cycle is not complete until the last crew is finished. A better expression for the standard crew cycle duration is then:

$$\frac{\left[\text{activity target duration} - \text{unit activity duration}\right] * \left[\text{\# of concurrent crews}\right]}{\text{Number of Activity Units}} \geq \text{standard crew cycle duration}$$

For the same example:

$$\frac{\left[45 - 15\right] * 1}{10} = 3 \text{ days crew cycle duration}$$

Figure 19 gives a graphical representation of this expression.

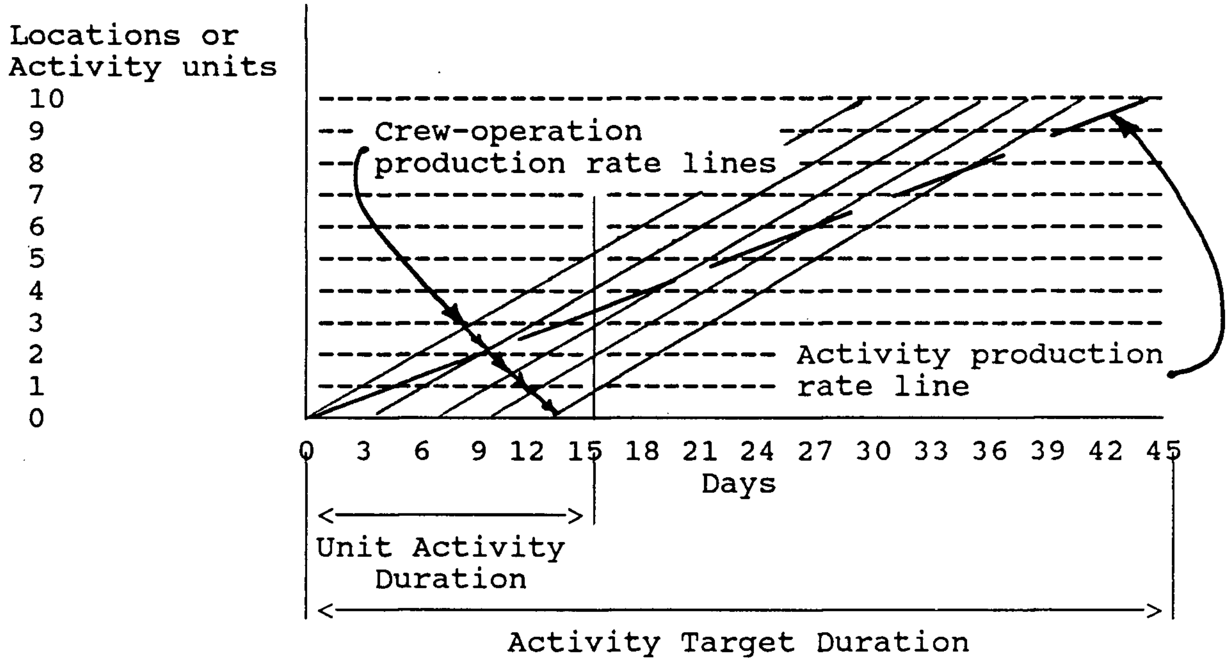


Figure 19 <u>Time-Space Diagram Deriving the Standard Crew Cycle</u>

Figure 19 shows graphically that the production rate for the crew-operation involved in an activity has to be greater that the activity production rate (4.1.5) because of the crews that have to start after the activity start date.

$$\text{Crew-operation production rate} = \frac{1}{\text{Standard crew cycle duration}}$$

Step 2 Test for Feasibility of Standard Crew Cycle Duration

One must now check previous records to see if the calculated crew cycle duration is attainable for all crew operations. If the calculated standard crew cycle duration is less than the duration that the productivity records indicate is feasible, the following options are available:

1. Add an additional shift for those operations that require additional manhours.
2. Find methods that require less time for construction.
3. Multiply the formwork system, manpower and equipment resources (i.e.: increase the # of concurrent crews)

If the calculated value for the crew cycle duration is larger than optimal for the majority of the operations, and only one concurrent crew has been used, the choices are as follows:

1. Use the calculated crew cycle duration with smaller crews.
2. Reduce the activity target duration thus reducing the crew cycle duration.
3. Opt for non linear scheduling. Buy fewer forms. Schedule other work tasks for the unassigned crew time.

Step 3 Allowable Deviation from Standard Crew Cycle Duration

If one or more crews have cycle durations less than the standard crew cycle duration, then this crew will have a discontinuity of schedule and will require a filler task for the off days. A crew may not have a cycle duration greater than the standard because all of the other crews would have to wait for this crew. Some change in method or resources would be required for this long duration operation in order to adjust it to the standard cycle duration.

Step 4 Determine Unit Activity Cycle Duration

With the standard crew cycle duration selected, and with crew operations overlapped where feasible, a duration for the activity cycle can be determined. A barchart with overlapping is the source of unit activity cycle duration determination. It is important to realize that the amount of overlapping will influence the number of falsework units required for the case of linear activity scheduling.

Step 5 Determine the Number of Falsework Units Required

Since the number of falsework units often has large costs associated with it, the number of units required needs to be calculated at this point to gain a proper feel for the effects of the activity cycle and the crew cycles on the number of falsework units required.

<u>Case 1: No overlapping of operations occurs on the unit activity barchart, standard crew cycle durations utilized.</u>

$$\text{\# of Falsework Units} = \frac{\text{Unit Activity Cycle Duration}}{\text{Standard Crew Cycle Duration}}$$

Beam Activity Example:

$$\text{\# of Spans of Falsework} = \frac{\text{Beam Cycle Duration}}{\text{Standard Crew Cycle Duration}} = \frac{\text{15 Days}}{\text{3 Days/Span}} = \text{5 Spans}$$

Figure 20a shows an activity barchart with no overlapping between operations where the above formula for falsework requirement calculation is appropriate.

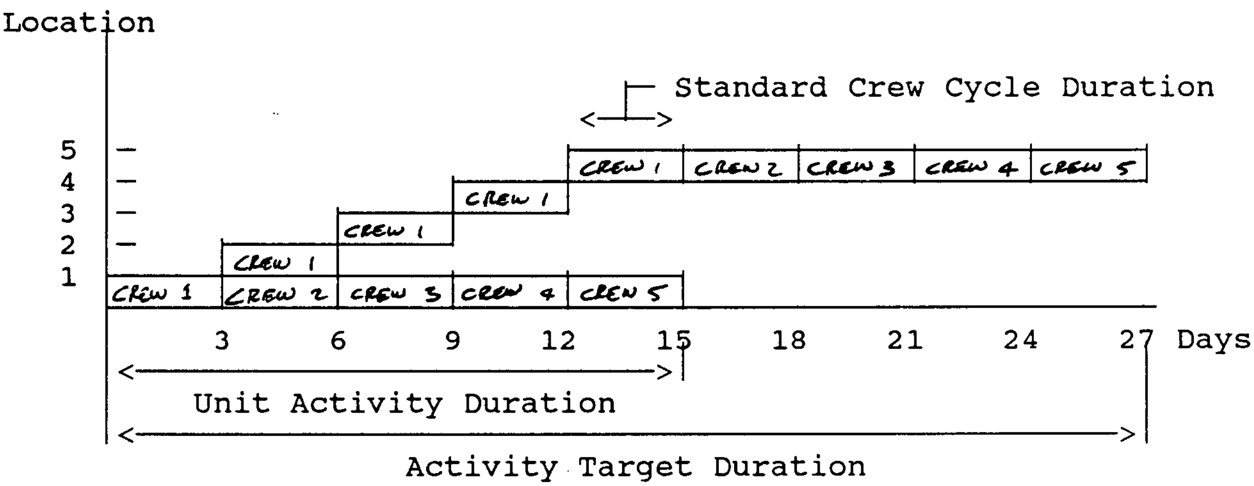


Figure 20a <u>Barchart Showing No Overlapping of Operations. Falsework Requirement Calculation Example.</u>

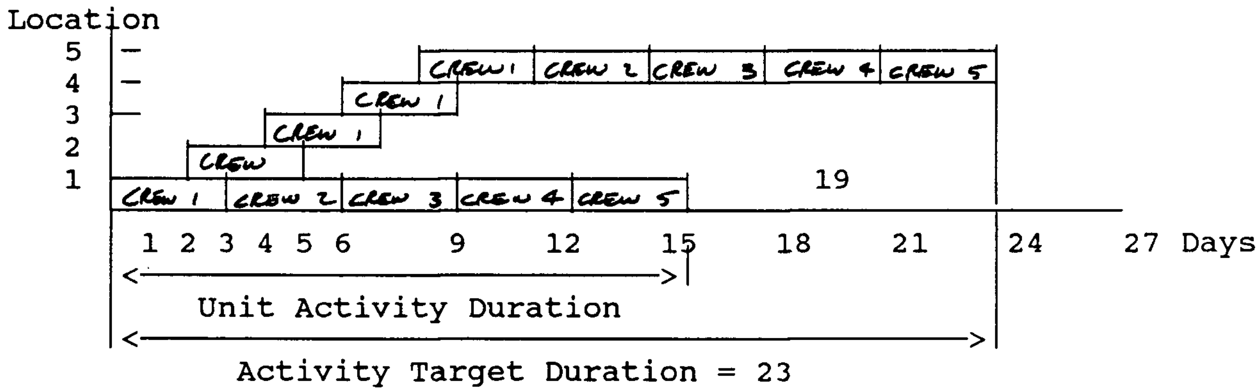


Figure 20b Barchart Showing Overlapping of Operations. Falsework Requirement Calculation Example.

Case 2: Overlapping of operations on the unit activity barchart

Figure 20b shows the same activity with overlapping of operations applied. The above expression for falsework requirement is no longer valid. If we substitute (Crew-operation Production Rate) for (1 / Crew Cycle Duration), we again have a correct expression for falsework units.

Falsework units = (Unit Activity Duration)(Crew-oper. Prod. Rate)

Falsework Spans = 15 days x 0.5 span per day = 7.5 Spans

Use 8 Spans

Another method of calculating the falsework requirement without first knowing the crew-operation production rate is as follows:

$$FU = \frac{(NUA - 1) \times UAD}{ATD - UAD}$$

Where:
FU = Falsework Units
NUA = Number of Unit Activities
UAD = Unit Activity Duration
ATD = Target Activity Duration

$$\left[\frac{NUA - 1}{ATD - UAD}\right]$$ is the slope of the crew-operation production rate line.

The product of that slope and the unit activity duration gives the number of unit activities started and also the number of falsework units required prior to the completion of the first unit activity.

The calculation of falsework unit requirement is an iterative process with the design of the activity cycle. Steps 1 through 5 will likely need to be repeated until the most cost effective combination of activity and crew-operation cycles, together with falsework procurement is reached. The design will not be finalized until after the operations have been individually assessed in section 4.3 and are judged to be able to achieve the cycle durations calculated in this exercise.

4.2.5 Sort Operations

Before entering the option loop for each operation to find a minimum cost option, it is desireable to sort the operations into independant and interdependant groups. The independant operations will be treated individually while the interdependant operations will be combined and costing developed for the combined operations. In this way the falsework system, for example, is treated as one combined operation and the different system options are evaluated for the minimum cost system. Operations are then priorized to arrive at a sequence for method selection. Analysis will be performed first on those operations with the greatest expected cost impact.

4.3 Operation Level

4.3.0 Introduction to Operation Level Design Parameters

Until now the General Planning Model has directed the process through levels of project overview, and activity organization and scheduling where the elements involved are known. The project is given. The activities of the project are shown on the drawings. The constraints affecting each activity are discernable through the drawings. The project and activity levels have been largely concerned with organizing and sequencing the work to be done.

The operation level is where the design of the methods, materials, equipment, and sub-trades happens.

4.3.0.1 Decision Variables

The design work required at the operation level concerns the following issues or variables:
How?, How much?, How strong?, How many men?, How many crews?, What equipment?, What cost?, Exactly what material?, What sequence?, What methods?

These questions require decisions to be made about several variables which constitute the design process.

The following list of decision variables relate to manpower and schedule considerations.

1. hours per shift
2. shifts per day
3. men per crew
4. supervision per crew

Decision variables dealing with hoisting requirements include:

1. crane size
2. reach required
3. mobile or tracked crane
    a. mobility required
    b. mobilization charges
4. duration and frequency of lifts

Decision variables pertaining to the basic concrete construction operations of (i) Formwork, (ii) Rebar, and (iii) Concrete placement are listed as follows.

(i) Formwork

1. form material: steel, wood, other
2. technology of form assembly
   a. manufacturer
   b. type: one sided, two sided, tied,
   c. size of 1st component (eg. plywood form)
   d. size of 2nd component (eg. wale material)
   e. fasteners used: bolts, welds, nails, wedges
   f. means of assembly
   g. means of stripping

3. rental, purchase, or company owned?
4. geometric design of the form system
5. number of reuses of forms
6. transport method between locations
   a. craning required?
   b. sliding or wheeled forms?
   c. hand carried?
7. towers required?
8. labor trade to utilize

Since there are many sub-operations involved in formwork (shore footings, towers, prefab, erect, freeform, and strip), a spreadsheet of sub-operations versus decision variables would provide a concise format for this information. Figure 21 shows such a spreadsheet.

DECISION VARIABLES	SUB-OPERATIONS Footings	Tower	Prefab	Erect	Freeform	Strip
Manpower						
Hrs/shift	8	8	10		10	8
Shifts/day	1	1	1		2	1
Men/crew	5	6	12		12	6
Foreman/crew	1	1	1		1	1
Crane						
Crane size req	no	50T	10T	50T	10T	50T
Reach req	no	25	20	25	25	25
Mobile/tracked						
Freq of lifts	no	1/hr	continu	3/day	2/day	5/day
Lift duration	no	1hr	cont	1hr	1/4hr	1/2hr
Material						
Material type	conc.	Efco	steel	steel	plywood	steel
Material quant	4yds/ftg	4/bay	20	5/bay	20shts/bay	na
Reuses	1	500	na	30	1	na
Technology						
Manufacturer	Stoneway	Efco	Efco	Efco	na	na
Type	3000psi	heavy	welded	plates	carpentry	lower
Size 1st comp.	12"x4'x4'	20'hi				
Size 2nd comp.						
Fasteners req	no	bolted	welded	bolted	nailed	bolted
How assembled						
Procurement	purchase	owned	rent	rent	purchase	na
Transport						
crane		Y	Y	Y		Y
Sliding						
Wheeled						
Hand carried					Y	
Trade	labors	Bridgemen	Br	Br	Carps	Labors

Figure 21 Sub-operations Versus Decision Variables For Operation = Formwork

(ii) Reinforcing steel variables

Reinforcing steel supply and assembly is often subcontracted out but the following functions still need attention by the general contractor.

1. subcontract or in-house manpower?
2. detailing criteria.
   a. construction joint location: direction required from the general contractor when joints have not been located by the design engineer.
   b. rebar assembly details.
3. rebar placer same firm as supplier or detailer?
4. laydown area available or off-load at exact location?
5. prebending or preassembly of rebar?
6. material handling: getting the steel to the point of placing.
7. quantities of steel to batch to site at a time.
8. coordination of rebar deliveries in a timely manner.
9. hoisting requirements as above.
10. jigs to hold rebar until tied.

(iii) Concrete placement variables

These variables include:

1. mix design: strength, aggregate size, cement and water content

2. add mixtures
    a. superplasticizer
    b. retarders
3. placing method
    a. crane and bucket
    b. pump
    c. tailgate from truck
4. weather contingencies
5. delivery rate from plant
6. truck access to site
7. pour rate
8. vibration or consolidation technique
9. finishing methods
10. cure time
11. cure method
    a. water containment
    b. heat requirements

The above decision variables are the ingredients of operation methods design. Given the constraints and particulars of the job, (owner, site, work force, weather, climate, plans and specifications) the rational combination of the above decision variables constitutes the operation method plan.

The overriding criteria for method plan construction is simple in concept and universal throughout the construction industry:

1. minimize cost,
2. minimize the time duration,
3. and maximize quality.

The above decision variables each have components of time, cost, and quality associated with them. The difficulty or the challenge lies in being able to identify what costs, time durations and quality of product are directly applicable to an individual decision variable. But regardless of whether the correct cost or duration of a choice between two decision variables (methods) is known, the decision has to be made.

How can the costs and duration consequences of the decision variables best be measured or calculated? This question is somewhat addressed in the monitoring and control chapter of this thesis, but on a more global scale. The missing portion is any attempt to separate out the effects of each individual decision variable. This is a real problem in the construction industry. Because of the large number of decision variables, the interaction between variables and lack of an analytical framework in which to link these variables, predictions of cost and time performance is a complex task. Regression analysis is a procedure that might yield results given a detailed, well documented, construction database - an unlikely occurance.

This research outlines the framework required for construction of a detailed database and a method of comparing and contrasting the data. Sections 5.2 and 5.3 and especially figures 26, 27, and 28 show more detail concerning datafile design and data manipulations available to the system user. These data systems will afford the user the ability to utilize more analytical methods for decision variable quantification. The implementation of the data collection framework and a method of quantifying the time-cost characteristics of decision variables is left to future research.

To aid the activity design process in the short term, the activity planning model provides for checklists to quickly insure that all of the standard variables have been considered. These checklists can be easily made a part of the information system and displayed for the operation under consideration.

4.3.0.2 Required Output From Operation Planning

We now look at the output required from the planning process. The shop drawing is the conventional vehicle for conveying information to the owner, the general contractor, and the foremen and crews in the field. The following information is usually included on the shop drawings for the referenced operation:

1. excavation: excavation sequence drawing for tunnel structures, shoring of the excavation where required.
2. shoring: formwork details, bill of materials, maximum concrete placing rates, stripping procedures.
3. rebar: rebar drawings, bar lists, splice locations.
4. concrete: mix design, construction joints, lift drawings.
5. post-tensioning: tendon and duct layout, stressing force and elongation calculations.

From the viewpoint of the general contractor, rebar and post-tensioning are often sub-contracted out, and with it the responsibility for supplying such information. It is often in the general contractor's interest to have input to these drawings so that his forming details are not adversely affected by rebar or post-tension tendon placement. With a lump sum sub-contract arrangement, the general contractor loses control over the means and methods with which the work will be accomplished unless such criteria are included as a part of the sub-contract documents. With a time and material sub-contract, control over means and methods is retained by the general. Therefore the decision to sub-contract the work and the type of contract utilized would in some circumstances be a part of the activity design.

From the output listed above, one can see that drafting and drawing production are an integral part of the design process. Depending on the amount of standardization between drawings, a computer aided design (CAD) system may be considered for the purpose of aiding the information output system. Another view of the process would have the CAD system as an integral part of the information system. In this situation the system would store drawings of parts, components, operations, or activities thus reducing the work required to recreate it for another location or for a future project.

For certain applications, one could envision an information system that would have the CAD system interfaced with a database system so that as components are assembled on the shop drawing, the costs of the items are listed to a file, an inventory is kept, and useful information concerning production rates, productivities and durations are instantly available on screen. Later, during the construction process, the same system could be used to track the procurement of the components.

CAD systems are most beneficial when duplication of drawings, and alterations of the duplications, are required. When architects and engineers begin using CAD systems, (and some are) and make their drawings available to the contractor via electronic disk storage, then the contractor and shop drawing process will really benefit from the use of CAD.

4.3.1 Create Operation Worksheet

In what follows, a scenario describing the use of a computer based activity design system is presented. From this scenario, several of the attributes required of such system can be deduced.

To begin the activity design process, we call up the operation planning worksheet screen. It has the following information areas available:

1. Address: Project, Activity, and Operation to identify the activity design area.

2. Activity constraint listing.

3. Archived listing of identical or similar datafile summaries (Project, Activity, and Operation), including applicable methods and decision variables. All records of feasible method options are copied to the screen and examined for applicability against the activity constraint listing, and availability. A method option (an alternative method of construction) is a combination of specific values of applicable decision variables. The most promising options would then be processed through the option costing loop.

4. The costing loop is the process of entering the number of units of the operation for the work in question, consulting the checklist of decision variables, selecting the lowest unit cost method for the decision variable in question and entering that method on the option worksheet. The cost and duration are entered automatically on the record.

For reliable output, the costing loop requires the relationships between productivity rates and the applicable decision variables to be known. In practice and in the activity planning model proposed, what will be known is the productivity rates achieved previously utilizing certain methods, equipment, crew size, and materials for a job having certain constraints. But the effects of individual decision variables are indeterminate.

To be useful, the contractor then needs to be able to translate the previous productivities into accurate precdictions of productivity for the project at hand. As mentioned in section 4.3.0.1 Decision Variables, this planning model provides a framework for collecting, organizing, comparing and contrasting the data on decision variables. The process of translating the data to a new project is left to the system users. Chapter 5, System Design Issues, discusses these issues more thoroughly.

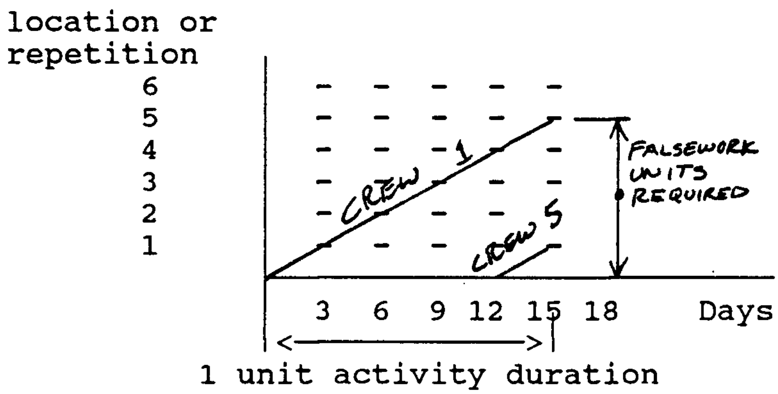
5. A library index of photos and videos that show previous operations being constructed is available. The project photo file is consulted for the candidate options. This photographic record may be on video cassette to permit continuous viewing in real or compressed time. Use of time lapse photography may also be employed for record keeping and productivity analysis.

6. The CAD drawing program is activated with a keystroke and drawings of the candidate method options can be called up from memory or created on screen. A first trial shop drawing can then be produced, cost calculated, and options compared.

4.3.2 Calculate Major Resource Requirements

Major resource requirements refer to major equipment, falsework units, or any special apparatus required for a specific option. The following discussion applies specifically to calculation of the number of falsework units require in order to illustrate the concepts involved.

If linear scheduling has been used, then a unit activity duration has been estimated in section 4.2. If one chooses not to schedule the activity linearly, then time/duration constraints are not imposed. One has the flexibility to wait until the options for each operation are considered before establishing the operation duration. However, an estimate of the activity cycle duration is required to calculate the falsework resource requirement. This is accomplished by selecting the average unit activity duration from the past job record of the option being considered. Check the constraints and site conditions of the previous job and compare them to the present job conditions. Modify the previous unit activity duration so as to be consistent with the present conditions. The formula for deriving the number of units of falsework required is best illustrated with a time-space diagram.



Assumptions:

1. The slowest crew in the activity is able to achieve the production rate shown.
2. Falsework is required for the total length of the activity duration.

Figure 22 Time-space Diagram Showing Falsework Requirements

The activity is completed when the last operation (crew 5) has completed the first repetition. Crew 1 has just completed repetition 5 at that time. So formwork for repetitions 1 through 5 need to be available to keep all five crews working continuously.

The formula for the number of falsework units required is slope of the crew-operation production line times unit activity duration equals the number of falsework units required. See section 4.2.4 step 5 for a calculation procedure for falsework requirements.

Beam Activity Examples :

Option 1 : wood forms, activity unit duration = 25 days, nonlinear scheduling.

(25 days * 0.253 beams/day) = 6.3, say 7 span lengths

Option 2 : steel forms, activity unit duration = 15 days, nonlinear scheduling.

(15 days * 0.253 beams/day) = 3.8, say 4 span lengths

Option 3 : steel forms, activity unit duration = 15 days, crew cycle duration = 3.0 days, linear scheduling.

(15 days * 1/3days) = 5 span lengths

Check the feasibility of utilizing the calculated number of falsework units concurrently due to space and buildability constraints. The number of units of falsework required for the considered option is now known.

Since the cost of falsework systems is often very significant in terms of the total activity cost, additional iterations through the costing and activity design loop are likely to be cost effective.

4.3.3 Design Parameters

Is design input required for an operation ? If "yes", continue. If "no", go to 4.3.4.

Identify the members to be sized and the materials presently in the company inventory. Identify rental materials, if available, and rate structure. From historical records, identify previously utilized assemblies and the components required for their make-up. Beginning with materials owned by the company, devise a design that meets the requirements of the operation in question. Consider the following shore and form example.

As previously mentioned in 4.3.0.2, the activity design system would have the ability to select an assembly, say a 200 kip, 16 foot high shore tower, from the CAD drawing records. With the available CAD functions, the assembly can be positioned and duplicated as required. Since the company owns this tower, we assume that the costs of transportation, assembly, erection, and stripping are well known. Whether these costs should be stored in the integrated drawing/cost database or in the more conventional planning algorithm database is not addressed here.

Rental equipment poses more variables than with company owned equipment as prices change, rental companies vary from city to city, and different equipment comes on line. These rental items are easily categorized, dated, and stored with the associated supplier information in the database by the person who makes the inquiry. The challenge is to keep it current.

The net result of the above process is a sketch or shop drawing showing the work to be built, the associated cost and duration, and the option or revision number.

4.3.4 Cost Calculations

With the quantity take-off in units per span from 4.1.5, rate tables from 4.1.5, major resource requirements from 4.3.2, design inputs from 4.3.3, and the job record for the option in question, cost calculations for the method option can now be made.

4.3.4.1 Material Cost Calculations

List the components of the operations and options being costed. A spread sheet format would be used to compile the data and perform the calculations. This model proposes to sum the material costs and divide by the number of activity units to get cost per unit activity, (i.e. $/span). Regardless of which units are utilized, the same units must be used for all items of the same type.

4.3.4.2 Labour Cost Calculations

This model assumes that productivity records are available for each operation option. If this is not the case, then productivity estimates or a further breakdown to the work task level will be required. Productivity would be available in spans/manday and units/manday, both of which would be useful. (Units here refer to m, m^2, m^3, kg, etc.) The formula for labour cost is:

$$\frac{\text{Labour Cost}}{\text{Span}} = \frac{(\text{Avg. Units/span * Labour Rate})}{\text{Productivity}}$$

Formwork Example:

$$\text{\$/Span} = \frac{(\text{Avg. } m^2\text{/span * \$/manday})}{m^2\text{/manday}}$$

4.3.4.3 Equipment Cost Calculations

Again we assume that we have equipment productivity records for the major operations and especially for options that have been used in previous jobs. Productivity records would include type and size of equipment, cost per hour, hours charged to the operations in questions per span or per pier and hours per unit. The formula for equipment cost is:

$$\text{Equipment Cost/span} = \frac{(\text{\# of units/span} * \text{\$/hour})}{\text{Equipment Productivity}}$$

Concrete Pump Example:

$$\text{\$/span} = \frac{(m^3\text{/span} * \text{\$/hour})}{m^3\text{/hour}}$$

Falsework Crane Cost Example:

$$\text{\$/span} = \left[\frac{\text{towers/span}}{\text{tower/hour}} + \frac{\text{forms/span}}{\text{forms/hour}}\right] * \left[\text{\$/hour}\right]$$

4.3.4.4 Total Cost Per Option

Having derived material, manpower and equipment costs, it is a simple matter to sum these results and get a total cost per span for the option being considered.

4.3.5 Last Option? Choose Minimum Cost Option

The option loop repeats itself until all the options have been analysed and a total cost derived. The work sheet containing the cost option analysis, major assumptions, and the preliminary drawings are now presented to the construction team for consideration. Often times, ideas from these other players will influence the details and even major aspects of the design. Iteration seems to be the nature of good activity design. Finally, the minimum cost option is tentatively selected and final drawings prepared for the operation.

4.3.6 Calculate Crew Size and Test Duration

The crew size required is a function of the estimate of productivity of the crew operation and the time available to accomplish the operation. The following methods are utilized to calculate crew size depending on whether or not the crew operations are linear and the crew cycle durations are specified.

4.3.6.1 Crew Cycle Duration Specified, (Linear Planning)

The assumption here is that unit productivity is independent of crew size. And for a certain range of crew size, this assumption will generally be true. However, the assumption must be tested.

$$\text{Crew Size} = \frac{\text{Average \# Units/span}}{\left[\text{Crew Cycle Duration}\right] * \left[\text{\# of Concurrent Crews}\right] * \left[\text{Productivity}\right]}$$

<u>Formwork Example:</u>

$$\text{Crew Size} = \frac{250\ m^2/\text{span}}{(3\ \text{days/span}) * (1\ \text{crew}) * (12\ m^2/\text{manday})} = \frac{\text{men}}{\text{crew}}$$

$$= 6.94\ \text{men/crew:}\quad \text{use 7 man crew}$$

Test the calculated crew size against the past record crew size of the selected option. If the present calculated crew size is significantly larger, then there is a good chance that the present productivity will be less than that of the previous job and the calculated crew size will be insufficient. Should this happen, one needs to critically examine the assumptions made concerning crew cycle duration and productivity.

Solutions to the problem may involve adding a night shift or changing construction methods to increase productivity. Another solution would involve another pass through the option loop looking for a faster method of construction and trading minimum cost for a shorter duration.

4.3.6.2 Crew Cycle Duration Not Specified

In this case one would choose a crew size that is known from experience to yield near optimal productivity. The operation duration is then calculated.

With the option selected, and the cost, crew size, and duration estimated, the initial design of the operation is complete. The essential information and major assumptions can then be assembled for review purposes.

4.3.7 Last Operation

The operation loop is repeated until all operations of the activity are designed based on one of the following:

1. linear scheduling: selected crew cycle duration, minimum cost given crew cycle duration, and feasible crew size.

or

2. non-linear scheduling: minimum cost, optional crew size, and duration dependent on productivity and crew size.

4.4 Activity Level Results

At this point the various operation methods have been selected and the costs are known. A critical inspection of the selected operations is now performed. Since all operations of an activity interact to some degree, one must check that there are no major conflicts and that the operations can be constructed as planned. In dealing with conflicts, one may have to check the interaction between operations on an hour by hour basis, particularly for resource conflicts such as crane useage.

4.4.1 Major Equipment Resource Levelling

Equipment hours have already been computed in a previous step. By calculating the required equipment hours for all operations of the activity, one can construct a resource histogram. With the histogram developed, one can level the equipment resource by altering the schedule of the operations. Two points need to be addressed prior to levelling.

1. Float is required to perform levelling of resources. Is float available in the schedule of operations to be levelled?

2. Which proceedure has the higher priority, crane resource levelling or maintenamce of linear and or continuous scheduling for the operations of an activity?

An example for the activity "BEAM CONSTRUCTION" has been developed and is shown in figure 23. In the example, the crane resource schedule compiles activity bar charts for beams 1 through "n". The barchart for beam 1 can be identified by the heavy outline. For each day and each operation on the barchart the number of expected hours of crane use is entered.

The column at the left shows the size of crane required for each operation of the beam activity. The crane requirements in this example can be adequately met with one 100 ton (large) crane and one 10 ton (small) crane. The summation of crane hours is shown

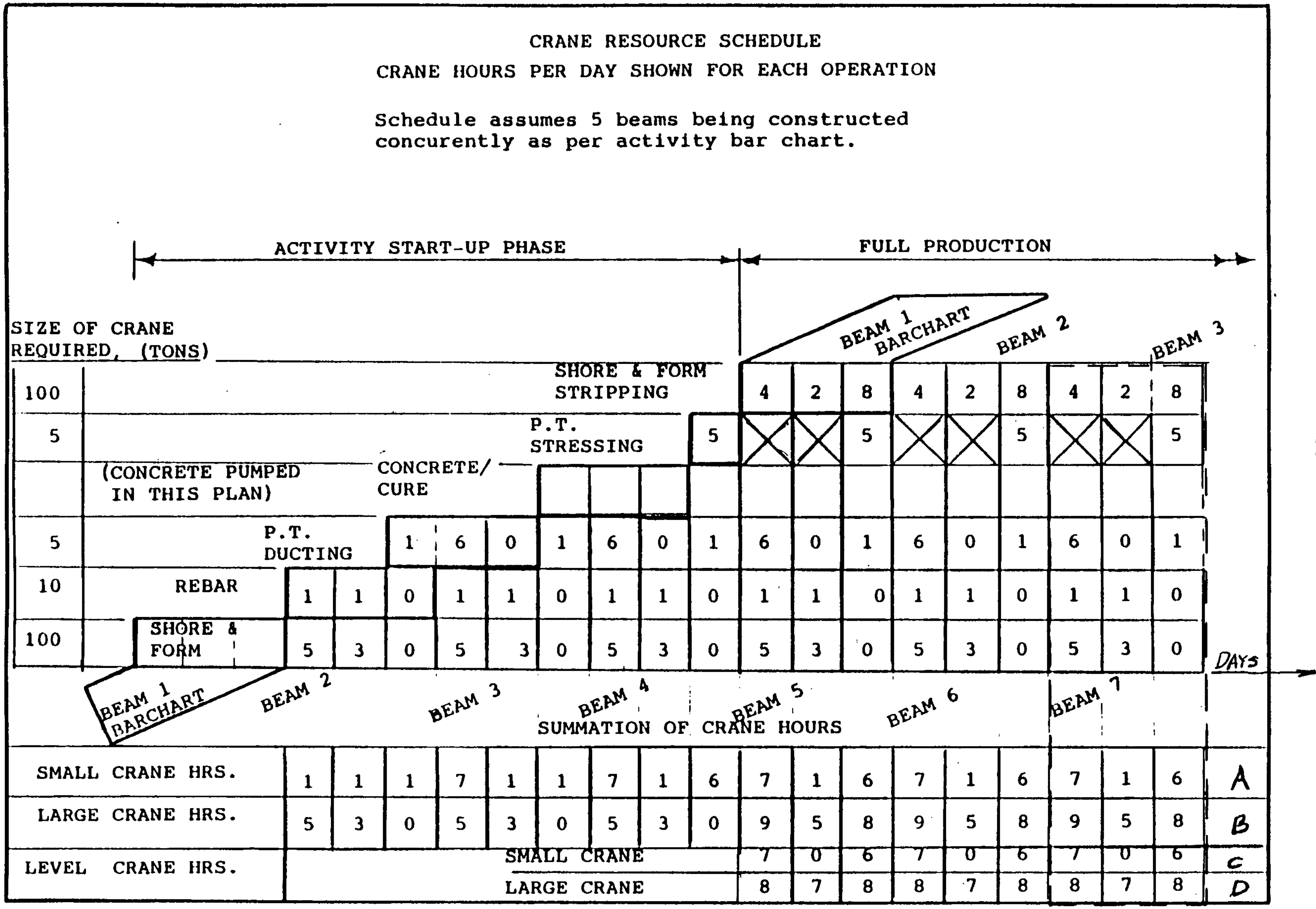


Figure 23 Example Barchart and Resource Levelling Diagram Showing Crane Hours Per Operation

in rows A and B. When the summation is known for a typical cycle duration (shown in dotted outline), the resource can be levelled. An example of the levelled crane hours is shown in rows C and D. In this case the levelling required is very moderate and could be accomplished with minor changes to the operation schedule and, or methods.

4.4.2 Refinement of Activity Schedule

The critical path network, barchart and time-space diagrams have all been described in section (4.2.2). The refinement procedures performed now are the same as described in that section except that now we have operation methods and duration estimates based on detailed analysis at the operation level. The logic between operations and the durations can now be input into these scheduling methods. The output will be refined unit activity durations that can be checked against the duration assumptions previously made.

4.4.3 Preliminary Design of Activity i is Complete

The results would be filed to computer disk and organized for review. Included will be all assumptions and constraints pertaining to the activity. Presentation of the final design of the activity is now made to the construction team.

4.4.4 Last Activity?

The activity design process is repeated until all activities have been designed.

4.5 Project Results

With the activity methods, equipment, costs, and durations closely estimated, one must examine the results from the project level to ensure the following criteria are met:

1. The project plan is logically correct.
2. The schedule meets the milestone requirements (activity crashing may be necessary if the scheduled duration exceeds the contract duration).
3. Resources are reasonably levelled.
4. Early start vs. late start strategies are addressed for risk management.
5. Activity and project assumptions, methods, costs, materials, equipment, and schedules are reviewed and approved by the construction team.

The planning phase of the construction information system ends here. The model now enters the monitoring and control phase and addresses data collection and project control issues.

CHAPTER 5. SYSTEM DESIGN ISSUES

5.0 Introduction

In this chapter we will discuss datafiles and information storage requirements for a comprehensive construction information system. The subset of information required for the activity design problem is highlighted. The dominant issues are as follows:

1. Type of information required and categories to contain it (see section 5.1 for conceptual datafile design).

2. Type of software system to use as the database (for a database system see 5.2; for a multidimensional spreadsheet system see 5.3.)

3. Number of tiers of hierarchy in which to store the information (for a 5 tier system see 5.2; for an 8 tier system see 5.3.)

5.1 Conceptual Datafile Design

The following file categories, headings, and descriptions show the organization and type of information required in an integrated construction information system.

Category Name	Description / Content
Definition files Project Activity Operation	Information entered once. e.g. full name, code number, description, conditions, methods of construction, etc. (see figure 25)
Information files Employee Equipment Subcontractor Vendor	Identification number, address, phone number, hourly rate, contractual information, etc.
Transaction files Timesheet Purchase order	One record per transaction. This is the data source for most of the information system. (see figure 26)
Accounting summary Payroll Accounts payable	Summary for accounting purposes
Data collection summary files	Summary of transactions cross tabulated by project, division, activity, operation, location, resource, descriptor, phase. (see figure 27)
Data transformation files	Take archived records and create present dollar value records from the previous costs. Files required to compare historical costs with new project estimated costs. (see figure 28)

Figure 24 Datafile Overview For an Integrated Construction Information System

There are many feasible methods of organizing data for construction information systems. Two examples of file design are discussed herein. The first uses a database concept such as Dbase III+ and identifies the fields required for datacollection. The second uses the TM1 multidimensional spreadsheet as a model and shows the data organized in an eight tier hierarchy.

In both examples, the information stored is identical. The difference is that where the 5 tier hierarchy requires 40 plus columns of data, the 8 tier hierarchy requires only eight. The 8 tier hierarchy will need more rows to display all the data. The key is how the chosen system will be able to compare and contrast the data items of interest.

5.2 Datafile Design: Dbase Format and 5 Identity Fields.

Figures 25 through 28 present example files with fields (column headings) required for data storage in a database format.

The principle of the relational database is that one is able to utilize multiple databases and to relate data records via common elements in the designated field. For instance, "from project files 'Cambie Bridge' and 'Queens Bridge', select records where activity = beams and operation = concrete."

With this statement, all records that fulfill the above requirements will be displayed on the screen.

This principle is utilized for the organization of the activity data collection file. The records or rows would have the first five fields as unique or identifying fields. These correspond to the hierachy of **project, division, activity, operation, and location.** The three remaining dimensions, **resource**(labor, equipment, material, sub-contractor), **descriptor**(time, cost, method), and **phase**(bid, estimate, forecast, actual, archive) are shown with all of their elements displayed as fields.

In the paragraphs to follow, the file categories necessary to the information system are discussed.

5.2.1 Definition files

(see figure 25)

These files are required to describe the global (overview) parameters for projects, activities, and operations. They contain information on constraints, general conditions, contract type, owner, etc. These files should have sentence and memo capabilities. They generally do not collect volumes of numerical data.

5.2.2 Timesheet File

(see figure 26)

Data collection from the project control module is one of the main sources of information for an information system. This file shows the typical data required from timesheets for an on-going construction project. The data is transactional (one record for one transaction). In this case there is one record per timesheet for each employee or each piece of equipment. Notice that in the example timesheet file, labor, equipment, and sub-contractor time can be entered and coded within the same file.

Project definition File

Project Code # eg 5100.	Project Name	Tender Date	Owner Name	Project Location	Estimate Type eg lump sum	Engineer or Architect Name	Contract $

Activity definition File

Proj Code	Activity Code #	Activity Name	Activity Descriptn	Conditions	Time Constraints	Physical Constraints	Method Memo

Operation definition File

Proj Code	Operation Code	Operation Name	Operation Description	Conditions	Comments	Method Memo

Figure 25 <u>**Definition File Structures**</u>

Daily Timesheet File
(Includes Labor, Equipment, and Sub-contractors)

Date	Proj Code xxxx	Division Code xxx	Activity Name	Operation Name	Location Number xxx	Name (labor) (Equip) (Subs)	Code Labor - L Equip - E Sub - S	Hrly Rate	Rate incl Bfts	Time Reg	Time OT (1.5)	Time OT (2.0)	$ Reg	$ OT

Figure 26 <u>**Daily Timesheet File Structure**</u>

5.2.3 Activity-Operation Data Collection File (see figure 27)

The activity-operation data collection file appears next and contains all necessary data fields for controlling an activity or an operation of a construction project. In figure 27 the fields are so numerous that they do not fit on one line and in that instance the fields are shown wrapped and occupying two lines. The forty plus fields within the file are organized by description and code numbers, quantity takeoff, time and date, manpower, equipment, material, sub-contractor, totals, and methodology. The data would be automatically transmitted from the timesheet file using project, activity, operation, and location name and numbers to code the destination file and record. Thus for every project code, activity name, and operation name, for which labor, equipment, or sub-trades are coded, there would exist a file and a field to collect data. For every location code where the activity is repeated, there would be a record containing the cumulative amounts of each item for every field. When the activity-operation is completed, the file for that activity-operation will contain one record for every location. In this way direct comparison of production values between locations is possible.

The last records of each file will contain statistical summaries of the field values for all locations. Cumulative, mean, and standard deviation values would be kept current. These summary records are then posted to the activity data collection summary file. Its is a method of condensing the data to meaningful quantities.

Activity-Operation Data Collection File
(records contain data of each location)

Proj Code	Divsn Code	Activity Name	Operatn Name	Loc #	Unit Meas	Units this Rep	Start Date	End Date	Crew Size	Est Crew Hrs	Fore cast Crew Hrs	Crew Reg Hrs T D	Crew OT Hrs (1.5)	Crew OT Hrs (2.0)	Est Crew $	Fore cast Crew $	Crew Reg $ T D	Crew OT $ T D	Est Equip $
xxxx	xxx			xxx															

Eqp Fore cast $	Eqp1 Name	Eqp1 Hrs T D	Eqp1 $ To Date	Eqp2 Name	Eqp2 Hrs T D	Eqp2 $ To Date	Est Matl $	Fore Cast Matl $	Matl $ To Date	Est Sub Ctr $	Fore cast Sub $	Sub Hrs T D	Sub $ To Date	Est Total $	% Complt	Fore cast Totl $	Totl Hrs T D	Totl Comit $ To Date	Var ience	Method

Figure 27 <u>Activity - Operation Data Collection File Structure</u>

Data Transformation Fields
(Create current $ value records from past activities)
(These fields to be added to archived fields when creating new records from old data

Record Date	Date of Cost Adjustment	Productivity (past) mhs/unit	Unit Cost P V	Equipment Productivity E hrs/unit	Equip Unit Cost P V E $/unit	Material P V M $/unit	Sub-Contactor PV S $/unit	Total P V L$+E$+M$+S$ $/unit

Figure 28 <u>Data Transformation File Structure</u>

5.2.4 Activity Data Collection Summary File

The Activity Data Collection Summary File, as the name implies, is simply a compilation of all cumulative records for each of the operations of an activity. This would be a good vehicle for upper management to compare original estimate versus present forcast expenditures for all fields of interest. Those that don't compare favorably are to be highlighted in the form of an exception report and addressed to the managers responsible.

5.2.5 Project Data Collection File Summary

This file is identical to the above except that it is a compilation of all the summarized activities of a project.

5.2.6 Archived Data Collection File

This file is stored with other finished project files and contains records of projects, activities, and operations for future reference. At completion of the project, it is very important to up-date the "method" field in all records to ensure that the methods used and conditions encountered are recorded. The method fields will be memo fields in the database thus enabling paragraphs to be written describing applicable facts and factors. These methods are then to be cross tabulated with a photo album or video tape library to show the details of the activity-operation in the description.

5.2.7 New Estimating and Tendering Files

In the process of estimating and tendering for a new project, historical data from previously archived projects is now required. One can easily sort through the database for jobs that contain a WBS similar to that required by the new project. Once selected, the estimator copies the previous WBS structure (the field names) to the estimating module. Editing the WBS structure to exactly fit the new project is the next step. With the sort and edit finished, the structure of the estimate is now established.

The process of estimating requires that costs be calculated for labor, equipment, and material for each of the activities and operations to be encountered in the project. If a company has previously performed the work in question, the archived records of productivity (units / hour) adjusted for the present site conditions (difficulty factor) and multiplied by the quantity of units and by the present hourly rates give a reasonably accurate estimate of the costs to be incurred in performing the work.

5.2.8 Data Transformation File

(see figure 28)

This datafile is useful in the process of transforming the manpower and equipment productivities achieved in archived projects to values that can be achieved on the present project. The parameters involved will be site conditions, weather conditions, congestion between trades and workmen, material storage space, rate of production required, and overtime required. A numerical multiplication factor needs to be assigned that will equate that past productivity to the estimated productivity for every activity-operation.

Costs can be translated by applying the inflation rate experienced in the elapsed time between projects.

Subcontractor costs would usually be quoted but could be factored and estimated for small scope work.

Documentation of the transformation process is very important to the confidence level of the estimate. This documentation in the form of record source, date, factor, estimator, etc. provide the chief estimator with the means to check the work of his subordinates.

The final process in the estimate would then be the extension and summation of costs, summarized by operation, activity, and project.

5.2.9 Planning and Scheduling Files

Assuming the estimate is successful, the process is now shifted to the project planning and scheduling phase. The estimate is archived, superfluous information stripped away and the estimate records are now available for use by the project management team to design and schedule the details of the activities.

5.3 Datafile Design Using a Multidimensional Spreadsheet

In this section, an information system with similar content but with a different arrangement of the data hierarchy is described. The purpose of this discussion is to show the effects of a different data hierarchy on the system.

The software selected for comparison was reviewed in the literature -software search and is called TM1. The software is a multidimensional spreadsheet also called a table manager. It has the capacity of up to eight "dimensions" per spreadsheet. Figure 29 shows a listing of the dimensions across the top and a list of headings under each dimension. Since the table (spreadsheet) displayed on the monitor is only two dimensional, only two of the available dimensions can be displayed in matrix form at one time. Of the dimensions not included in the two dimensional matrix, one of the headings of each dimension is selected as active and is denoted by its listing in row two. The active heading will be selected and the values that are dependent on that heading element will be displayed when the table is called with the "view" command.

```
                                        active heading identified
Activity  Operatn     Loc  Resource  Phase        Descript
Beams     Shore Ftg    1   Labor     *lin*        *col*  <

Footings  Shore Ftg    1   Labor     Est. total    Units
Columns   Shore tower  2   Equip     Fcast totl    MHrs
Beams     Prefab form  3   Material  % complete    Costs
Wings     Erect forms  4   Subctr    To date total
Barriers  Free form    5   Overhead
Decking   Rebar        6   Total
Total     P Tension
          Concrete
          PT stressing
          Form remove
          Total
```

Figure 29 Multidimensional Spreadsheet Screen Showing Dimensions Across the Top and Headings Within the Dimension Below.

The symbols *lin* and *col* denote the dimensions which will occupy the rows and columns of the matrix. In figure 29, the following headings are active for each dimension:

Heading:	Beams	Shore Ftg	1	Labor	*lin*	*col*

The result is a tabulation of the values of "Phase" versus "Descript" for activity = beam, operation = shore footing, location = 1, resource = labor.

The resulting spreadsheet is shown in figure 30.

Activity = Beams
Operatn = Shore footings
Location = 1
Resource = labor

Descriptor-> Phase	Manhours	Costs	Methods
Estimate total	35	$700.	Concrete spreadfooting
Forecast total	30	$600.	Timber 12 x 12 footing
% complete	90%		
Projected total	32.5	$650.	Timber 12 x 12 footing

Figure 30 Multidimensional Spreadsheet Screen Showing Phase Versus Description for the Identified Activity, Operation, Location, and Resource.

This format would be of interest in the monitoring phase of the project when comparisons from estimate to current forecast to actual would be required.

The points to be mentioned regarding the advantages of the foregoing data structure are as follows:

1. A spreadsheet format is very good at comparing and contrasting like values.
2. The eight tier hierarchy allows the database to appear less crowded on the screen. Fewer headers need to be displayed at once. Yet all are available.

3. The TM1 system does not store the values in the spreadsheet, it stores them in tables. In the table there is one unique value for the union of all combinations of all eight dimensions.
4. The spreadsheet above is composed of formulae that identify the tables, headings and cells from which to recall data values. Since the data is independent of the spreadsheet, the spreadsheet is then a template in which to import information from any dimension heading that is appropriate. To change the data, simply change the name of one of the headings of the spreadsheet.

To illustrate this point, change the operation from "shore footings" to "concrete", see figure 31.

Activity = Beams
Operatn = **Concrete**
Location = 1
Resource = labor

Descriptor / **Phase**	Manhours	Costs	Methods
Estimate total	100	$2000.	Crane and bucket
Forecast total	50	$1000.	Pump
% complete	100%		
Projected total	65	$1300.	Pump

Figure 31 Multidimensional Spreadsheet: Phase Versus Descriptor for the Identified Parameters.

When the spreadsheet is recalculated, the values are copied from the appropriate table and the spreadsheet template is refreshed with the new values.

Now lets create a spreadsheet so that the dimension "location" will be selected to fill column headings and the dimension "descriptor" will be set so that "costs" are active. It will appear as shown in figure 32.

Activity = Beams
Operatn = Concrete
Descript = Costs
Resource = labor

Location --->	1	2	3
Phase			
Estimate total	$2000.	$2500.	$5000
Forecast total	$1000.	$2500.	$2500
% complete	100%	80%	50%
To date total	$1300.	$2000.	$1200.
Projected total	$1300.	$2500.	$2400
% Variance	+30%	0%	-4%

Figure 32 Multidimensional Spreadsheet, Phase Versus Location for the Identified Parameters.

Notice that with this spreadsheet, some rows have been added to calculate the projected total and the % variance using typical spreadsheet capabilities. This database / spreadsheet capability gives the user a free hand in selecting the data and structuring the output. As can be seen, this software provides a database which can be recalled to fill cells of a spreadsheet and then manipulated with relative ease to the format desired. It is a useful tool.

5.4 Software Command (Menu) Structure

The ability of a software package to interact with the user is always an important issue. The ease (or difficulty) which the user finds when trying to operate the system is every bit as important as the functions contained within the system.

The menu of system commands is the road map offered by the system designer to guide the user to the appropriate functions and files. A menu of functions and commands has been included in the appendix to provide an example of the detail required in the design of a construction information system. The menu is included in Appendix 1 in order to minimize confusion with the different numbering system found in the "general planning model" which has a lesser level of detail. For final system design, which is not part of the scope of this research, one would match the numbering schemes of the model to the menu.

CHAPTER 6. TESTING THE MODEL, THE SEATTLE CUT AND COVER TUNNELING EXAMPLE

6.0 Introduction

The planning algorithm detailed in Chapter 4 was specific to concrete multispan bridge construction. In this chapter another form of repetitious concrete construction is examined in terms of planning requirements. Tunnels and bridges have some interesting differences and similarities. Obviously, one is below ground and the other above. This does pose differences in the techniques required to construct the activities. However, the profile difference does not pose differences to the planning methods utilized. A major similarity lies in the fact that both structures are transportation corridors and as such are linear and repetitious in nature and able to utilize the benefits of linear sequencing in their construction.

Because the tunnel project is similar yet different from the bridge project, it is a good candidate for testing of the planning model. Evaluation of the general planning algorithm via the Seattle Cut and Cover Tunnel Project case study yields some useful observations and recommendations regarding:

1. the robustness of the concepts and functions of the model; and
2. the portability of the model to another type of project.

Useful viewpoints for evaluation

The following viewpoints are useful in evaluation of the planning model vis-a-vis the Tunnel Project case study:

1. What are the additional activity planning problems presented by the tunnel project?
2. Are the functions and capabilities required for cut and cover tunnel planning available in the planning model?
3. Are additional graphical techniques required to permit visualization of the excavation process?
4. What additional bodies of knowledge are required in the planning process?
5. Determine the value of the bridge planning algorithms for planning other types of construction projects. Are there principles behind the algorithms that are useful for the whole scope of construction planning?

With the above viewpoints in mind we enter the General Planning Model as per the flow chart in 4.0, figure 9 for the specific application of "Cut and Cover Tunneling". It is not the intent to proceed step by step through the model. Discussion is limited here to the differences between planning for bridges and planning for tunnels.

The numbering system used for Chapter 6 coincides with those used in the Chapter four headings. Not all Chapter four sections are discussed here, only those of interest to the testing of the planning system.

6.1 Project: Seattle Cut and Cover Tunnel

6.1.1 Project Award: Brief Description of the Project.

The cut and cover tunnel observations are based on work done by SCI Contractors Inc. in 1987 on a 800 foot section of the Downtown Seattle Tunnel Project. The site for the tunnel was a three block length of Pine Street on an eighty foot right-of-way between Westlake and Convention Center stations. The contract called for the closure of Pine Street for a six month construction period, removal or support of the existing utilities, shoring of the tunnel walls as per contractor design, and excavation to 60 feet below street grade. The contractor elected to drill 30" holes at 8 foot intervals, place steel H section piles in the drilled holes and backfill the piles with a weak "lean mix" concrete. During the excavation process, 4" by 12" lagging was placed between piles to retain the soil. Steel walers and struts were welded to the piles to provide lateral bracing to the shoring system. The reinforced concrete tunnel structure has a rectangular section 38 feet wide and 16 feet high, inside dimensions. It was designed, formed, and poured in fifty foot segments comprised of 5 foot floor slab, 3 foot thick walls and 5 foot roof.

6.1.2 Project Work Breakdown Structure (WBS)

The work breakdown structure for the tunnel sub-project is represented as follows:

Pine Street Tunnel Structure

Piles and bracing systems submittal

Soldier piles

Surface utility

Excavation

Deep utilities as encountered with the excavation

Lagging

Bracing wales and struts

Working floor

Base slab

C level struts and walers

Walls

Roof

Remove B and A level struts and walers

Backfill

Street restoration

6.1.3 Project Constraints

Site Specific Constraints

The sequence of excavation, lagging, and bracing had site condition and contract constraints imposed. In the case of the Pine Street Tunnel, the requirement was excavation not allowed to proceed deeper than 10 feet below the lagging nor deeper than 12 feet below the bracing. Since the lagging equipment could not occupy the same space as the excavation equipment, these two activities were constrained to follow leap-frog sequencing to reach the required 60 foot depth. The bracing was generally done on the same shift as the lagging. See figure 33, section 6.1.5 for a time-space diagram that illustrates the sequence.

Geometric Constraints

The confinement caused by tunneling 60 feet deep with only 38 feet of width imposes constraints on the contractor's ability to move equipment and formwork in any direction other than the direction of the tunneling.

The following activities on the Pine Street Tunnel sub-project, Working floor, Base slab, C level bracing, Walls, and Roof exhibited finish-start relationships for unit activities. The result is a linear activity sequence where an activity must follow its predecessor in both time and space. See figure 34.

The tunnel sub-project, as a whole, stepped foreward in a centipede style of movement where one activity finished, the equipment or formwork was moved foreward, and the succeeding activity equipment or formwork was moved into the location newly vacated.

6.1.5 Model The Project

The Submital, Piles, and Utilities activities are not of interest to this discusion. Figure 33 shows a time-space diagram that illustrates the sequence for the Excavation, Lagging, and Bracing activities of the sub-project.

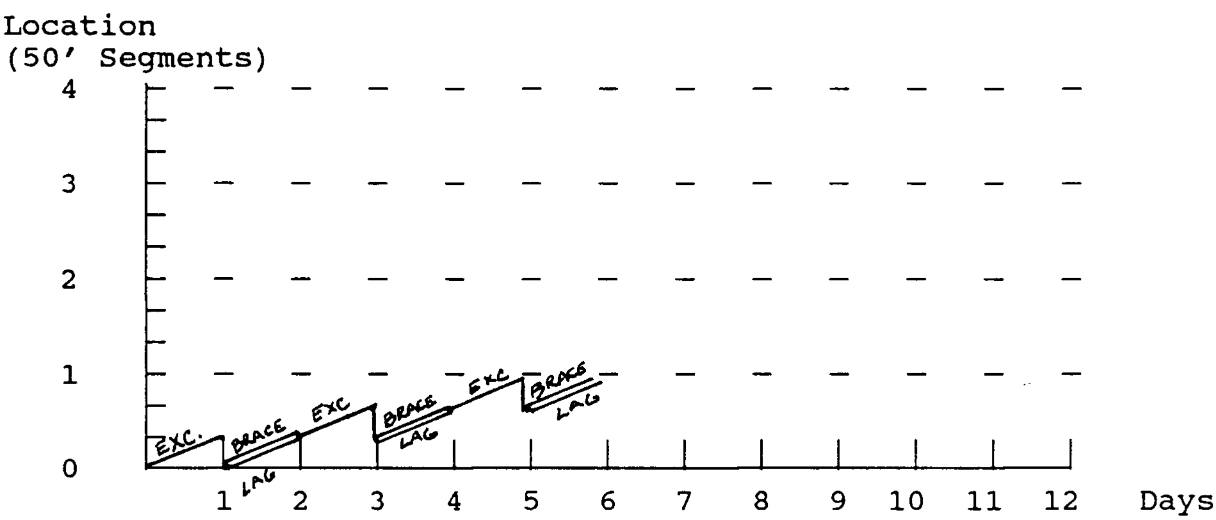


Figure 33 Time-Space Diagram: Excavation, Lagging, and Bracing Activities for Sub-project Tunnel.

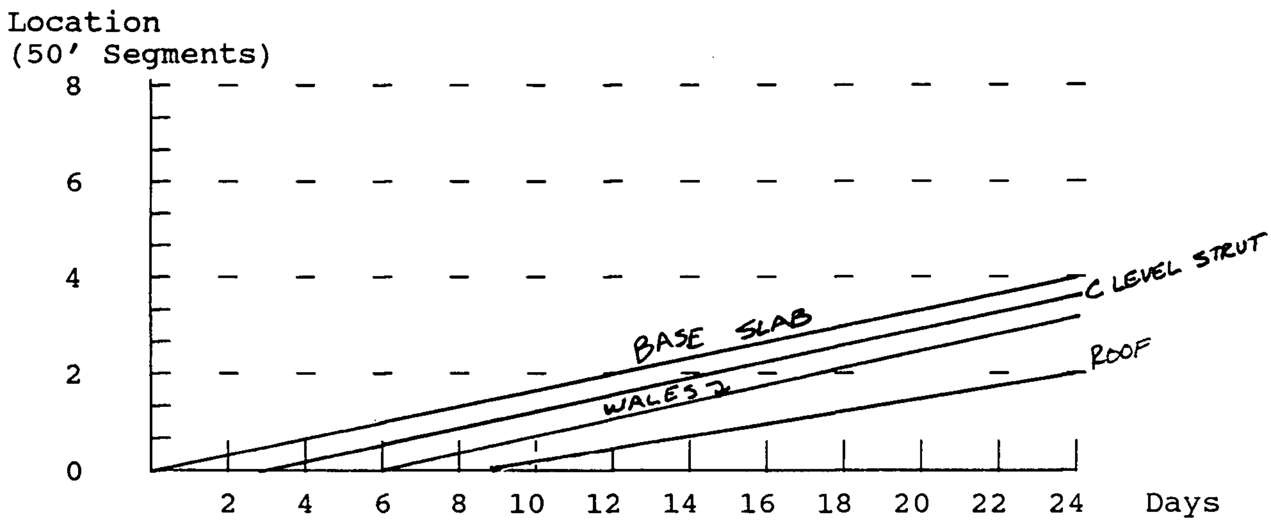
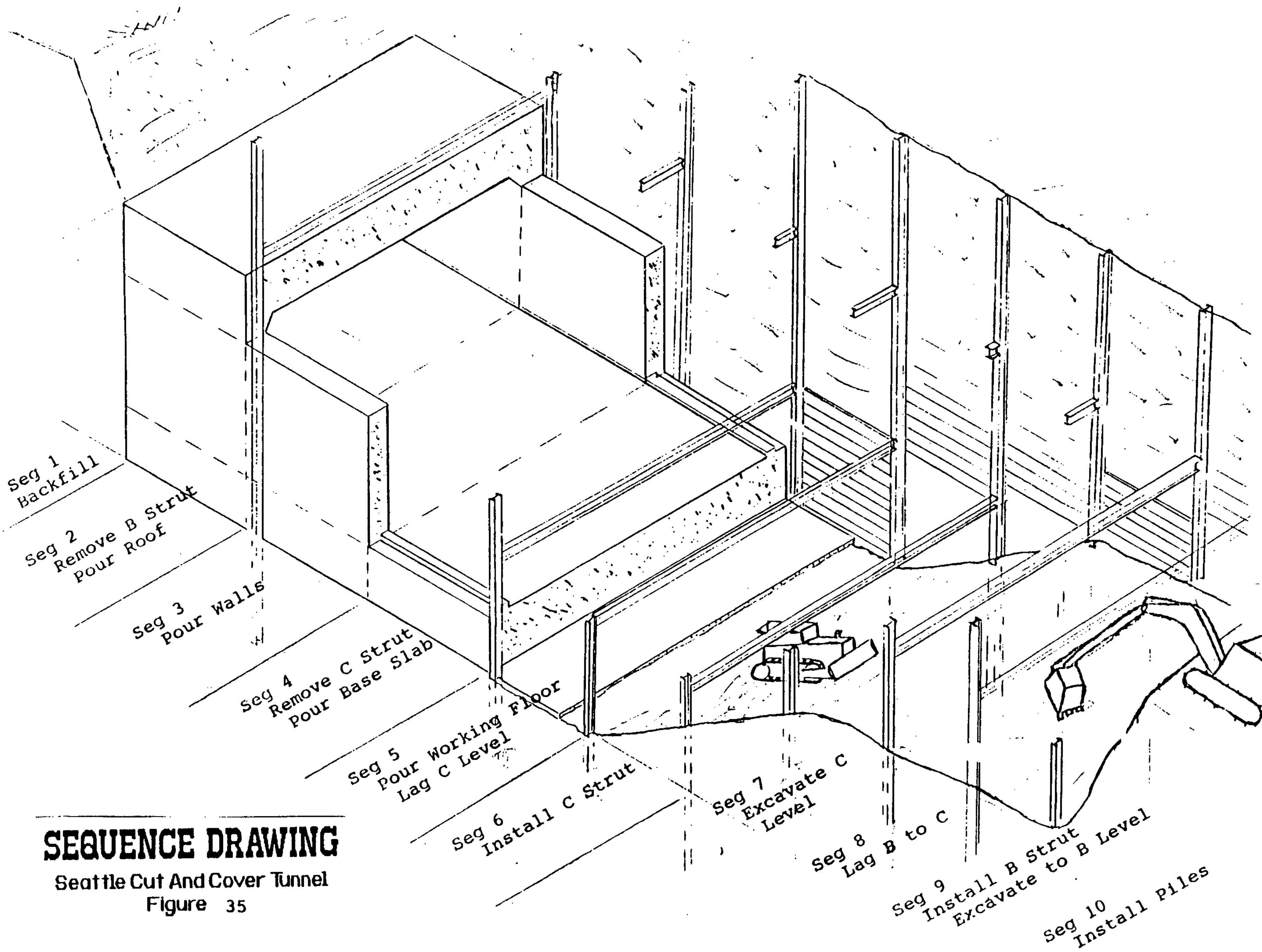


Figure 34 Time-Space Diagram: Base slab, C Level strut, Walls, and Roof Activities for Sub-project Tunnel

The above diagrams show the sequences as constrained by the conditions mentioned in section 6.1.3. They also show the first rough pass at estimating relative durations.

In addition to the modelling techniques shown in 4.1.5, this Tunnel case study points out the need for a profile drawing showing the construction sequence.

Figure 35 shows the sequence drawing for the early stages of tunnel activity planning. This sequence drawing is particularly useful for tunnel planning in that it provides a method for visualization of the excavation process.



SEQUENCE DRAWING

Seattle Cut And Cover Tunnel

Figure 35

6.1.7 Target Duration

Barchart Schedule Showing Target Duration

The barchart in figure 36 shows target durations for tunnel segments 20 to 8 as per the discussion in chapter 4.1.7. These segments are constrained by milestones that allow construction to take place on city streets from May 1 to November 1, 1987. This then becomes the criteria for establishing the sub-project target duration.

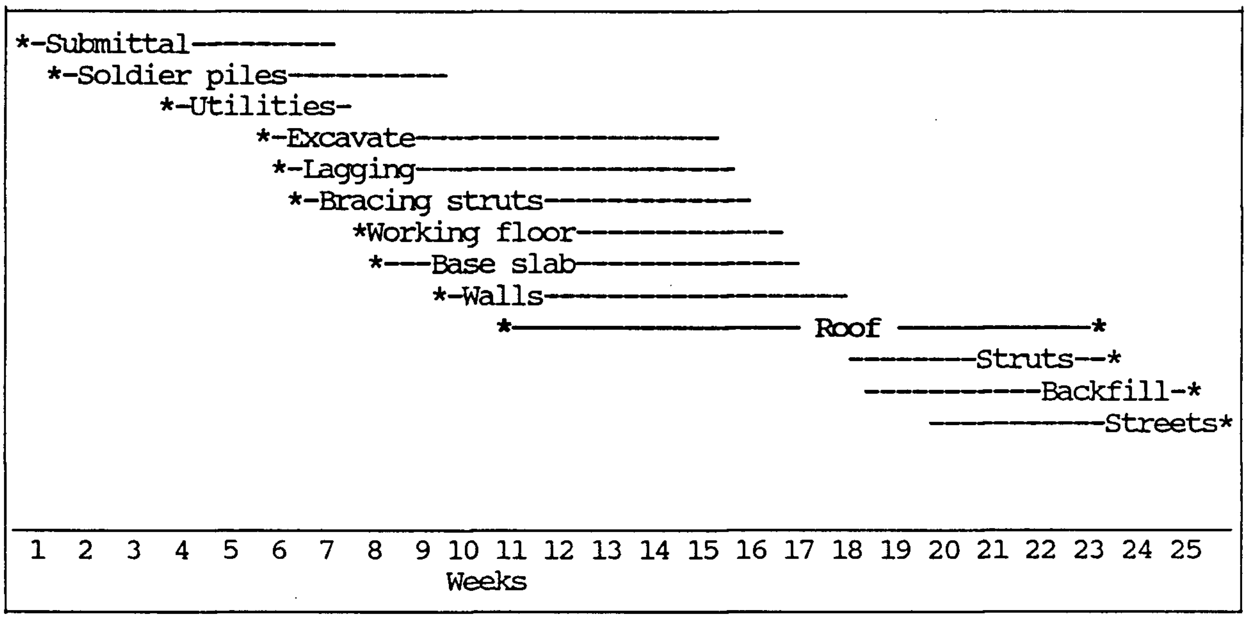


Figure 36 Tunnel Subproject Barchart Showing Target Durations

The logic behind the target duration barchart is briefly described as follows:

1. Identify the activity or activity that require the longest durations per repetition. For this tunnel project, the "pour roof" activity is very likely to require the longest duration if for no other reason than it must cure for 3 to 4 days prior to stripping. Figure 34 reflects a large duration for Roof in that the slope of the production line for roof is flatter that the other operations.

2. Estimate the start-up durations of the activities preceding the "pour roof" activity. Since the space constraint mentioned above confines the activities to finish-start precedence logic, the first repetition of each activity is on the critical path at least until its sucessor is allowed to begin. Plot the first repetitions of these activities.

3. Estimate the finish duration of the activities succeeding "pour roof". The last of these activities will be on the critical path. Plot the last repetitions of these activities.

4. The time remaining between the predecessor and successor activities of "pour roof" is the maximum target duration allowed for that longest duration activity.

5. The derived target duration for "pour roof" can now be divided by the number of pour segments to get the maximum unit activity target duration.

The available duration for "pour roof" is approximated on the barchart by the time remaining between constraining activities (13 weeks). The required production rate is then 12 segments / 13 weeks = + - 1 segments per week.

6.1.8 Subproject Continuity? Linear Scheduling Required?

The subject of continuity and linear scheduling was present in the bridge project model but only at the activity level for sequencing operations. As indicated in 6.1.3, linear sequencing may be possible at the subproject level for a group of activities. The sequence Base slab, C strut, Walls, and Roof exhibit linear traits in that one must follow its predecessor in time and space. The general planning model is deficient in this regard as it only addresses linear scheduling for unit activities in sequence from one location to the next. To accomodate this additional capability, the algorithm must be amended to include linear scheduling at the sub-project level. The change is shown to be necessary for tunnel activities but it is also a valuable addition to a general planning model. Figure 37 shows a revision to the general planning flow chart to make these project level changes.

Modifications to the Activity Planning Algorithm

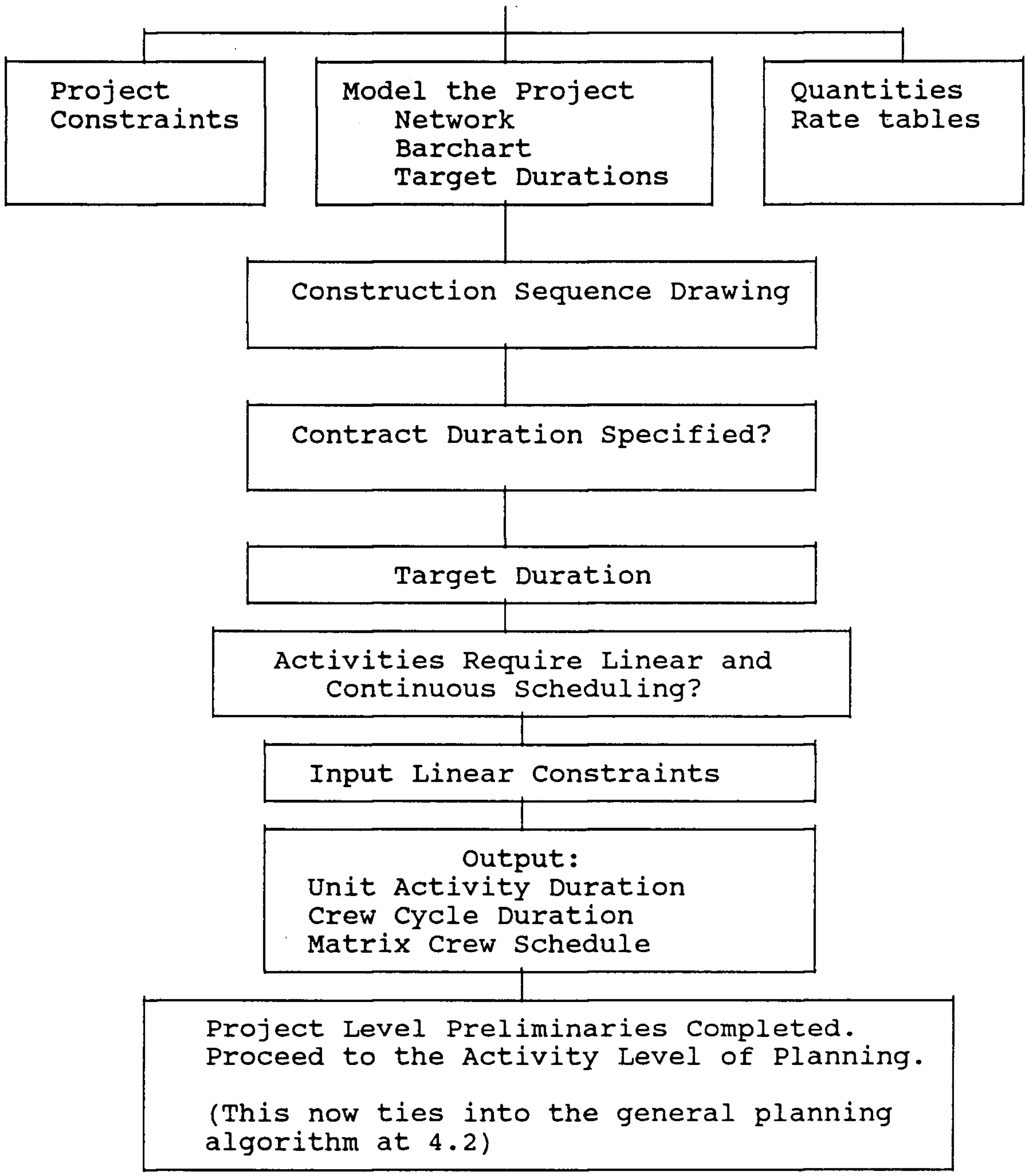


Figure 37 Project Level Revision to the General Planning Model

6.1.8.1 Cycle Recognition

As shown in the construction sequence drawing and as mentioned under constraints above, the activities in the tunnel subproject follow each other in step. It can be said that the activities involved are "interrelated" and in the context of this thesis, that means the activities are constrained by the duration of the preceeding activity. The duration of the activities may now be syncronized by providing a standard cycle duration for the activities to follow in unison. This cycle is again called the "unit activity cycle", but this case it represents the cycle of a series of activities.

In general, the slowest activity sets the cycle duration. Another way of thinking about this is that the slowest activity deserves the most attention to speed it to the production rate of the other activities. It then becomes efficient, in terms of subproject early finish, for all activities to follow at the same cycle duration. If the last activity or activities have a shorter unit activity cycle time, they then could be allowed to start later as they have float in their schedule.

6.1.8.2 Cycle Design Efficiencies

Efficiencies from the above linear sequencing can be realized if it is feasible and practical to design a unit activity cycle duration that is the same for all activities in the sub-project. The cycle design efficiencies are a function of the favorable rhythm that allows the project to roll on due to self-generated momentum. As discussed in 4.2.3, a tangible benefit can be obtained from the establishment of a rhythm that maximizes the productivity of the crews.

For the case study in question, the problem arises in that the duration for "roof pour" is significantly longer than the duration of floor slab or wall pour. This situation is inherent in a roof or supported slab structure because of the curing time required before stripping can be allowed. Both the floor slab and the walls require much less cure time prior to stripping. The question then becomes "Does our activity design system allow the planner the flexibility to list and price the various alternatives that could decrease the activity duration?"

The actual costs of the activity "roof" will be analyzed in the activity and subtrade operation levels of the planning model. One additional question needs to be addressed from the project level, "Is it a viable solution to share the crews between the wall activity and the roof activity?" For this alternative, the walls would be slowed because of crew time-sharing. The roof duration, for which timely progress is critical, may not be affected because the wall work could conceivably happen during the roof curing time. This is another example of a great number of crew scheduling schemes that can be imagined and implemented. For each situation, intuitive solutions can be devised that maximize the useage of the manpower and equipment for the activities at hand. The interconnection of activities and operations with useful cycles of work can be termed cycle recognition and is an important part of activity design.

6.1.8.3 Crew Cycle

Before theoretical efficiencies of crew productivities can be realized, the unit activities have to be broken down to the operation (sub-trade) level, where sub-trade crews must also experience a favorable cycle of repetition. This concept, as expressed in 4.2.3, is called "crew cycle duration". When a crew is shared between different activities, such as walls and roofs in the example above, and maintains a constant crew cycle, this can be called "multi-activity crew scheduling".

6.1.8.4 Multi-activity Crew Scheduling

Multi-activity crew scheduling can best be expressed by an example, see figure 38.

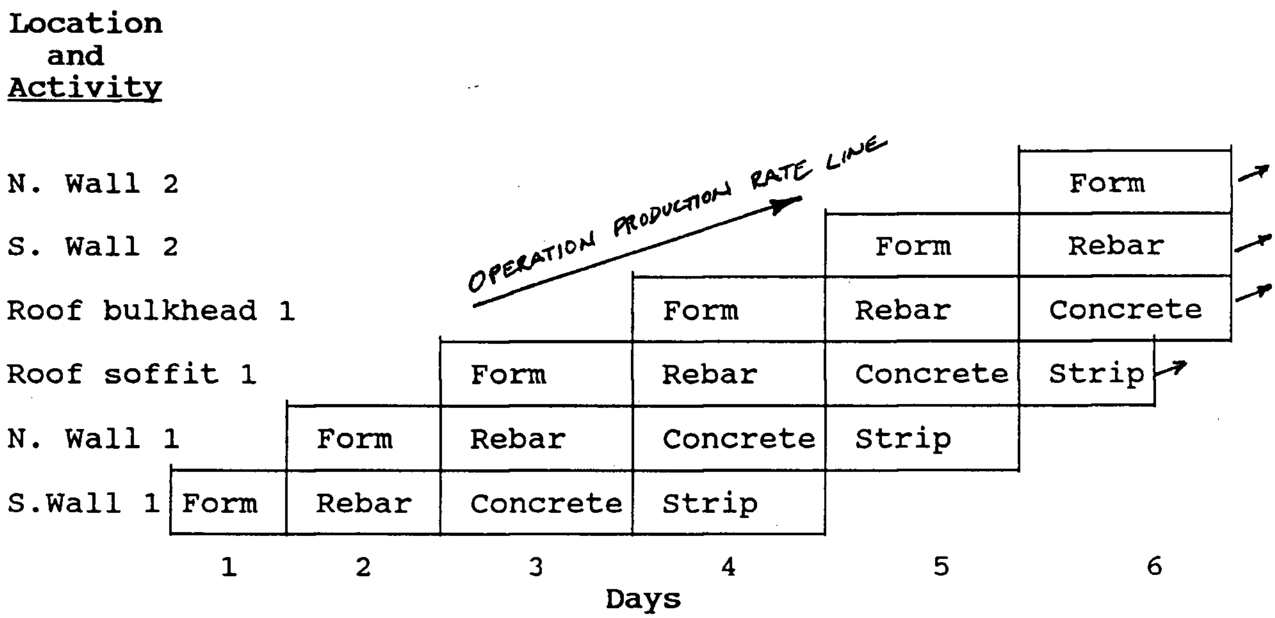


Figure 38 Time-space Diagram: Multi-activity Crew Scheduling

The theory expressed here is identical to that of chapter 4.2.4, linear constraint input, except that more than one activity is involved. With the above schedule, all of the involved crews rotate from activity to activity, instead of from location to location as per 4.2.4. From the activity planning point of view the problem is to design the construction procedures to contain the same amount of crew hours so that a standard crew cycle with a constant crew size works efficiently. The theory is useful. The application of the theory is obviously constrained by site conditions and the similarity between activities.

6.1.8.5 Contingencies

With linear scheduling, it must be mentioned that it's greatest asset will turn into it's greatest liability if some obstacle stands in the path of the construction of the chain of activities. The previously mentioned momentum generated by the chain will translate into a costly standstill if a delay in one activity causes the chain of activities to halt. A contingency plan would be useful in the event of an activity delay. One means of accomplishing this is by utilizing a night shift to overcome unforseen delays in production and thus keeping the linear schedule on track.

6.2 Activity Level Planning

At this level one assesses the interdependencies between operations of the same activity. The relevant procedures as per the general planning model are:

1. Create and define the activity.
   (i) WBS
   (ii) Constraints
   (iii) Decision tree
   (iv) Dictionary and coding system.

2. Model the activity.

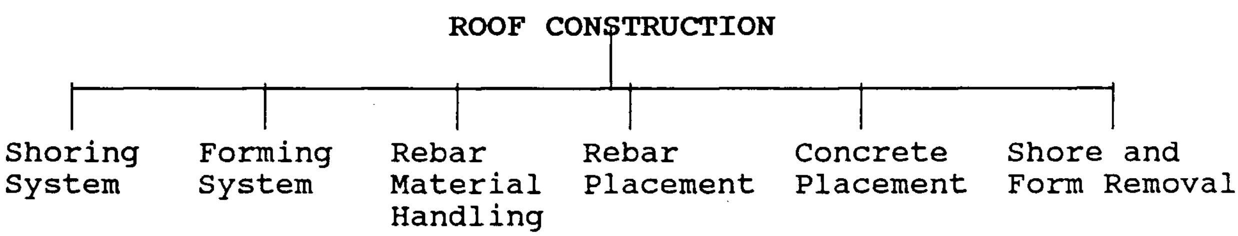
3. Linear and continuous scheduling?

All the activities will receive this analysis. The roof activity is selected here for discussion as it is the most difficult of those activities in the sequence.

6.2.1 Create and Define the Activity

Work Breakdown Structure

The following operations appear in the work breakdown structure of "roof construction":



Constraints Listed

1. Loading: 5 foot thick roof equates to (5 * 150pcf) Dead load
                                                                        50psf Live load
                                                                        ----
                                                                        800 psf design load

2. Sequence
   i) Floor and walls must be done prior to roof construction. (Sub-project level)

   ii) All operations except rebar handling exhibit finish-start relationships.

3. Material handling: Rebar
   i) Since no entry to the tunnel has yet been constructed, the decision has been made to begin tunnelling against a bulkhead. This has implications for material handling systems in that no entry for ground transportation is available at the bulkhead end.
   ii) No ground transportation is available from the digging end for activities following base slab as access over the slab is not possible.
   iii) Crane setups are also limited by the street corridor and the buildings on each side. The alleys and the cross streets are available for set-ups but not in between.

Decision tree

Shoring systems	i)	Many light 20 kip towers.
	ii)	Heavy towers, beams and plate girders.
	iii)	Wheeled tower assemblies.
Form systems:	i)	Plywood skin forms.
	ii)	Steel skin.
Number of segments to form at once	i)	One
	ii)	Two
	iii)	Three

Material handling

Rebar

i) Drag rebar trailer to bottom of the dig behind a dozer.

ii) Crane from alleys.
Gantry crane to run on rails on top of piles.

Concrete Pumping

i) boom pump

ii) slick line and pump

iii) slick line to a portable boom

6.2.2 Model the Activity

The model of the "construct roof" activity is quite simple. The activity must follow the walls for structural support reasons. The activity must follow the previous roof segment for access and continuity reasons. The logic for both these precedence relationships is finish-start. As has been mentioned under target duration (6.1.7 above), the roof construction activity has the longest duration and is on the critical path for the entire length of time is takes to construct it. Therefore it should be recognized early-on that a plan for roof construction that minimizes time duration will be required. One option available to minimize duration is to construct multiple tunnel segments during each pour. This has advantages in that the time required to cure the concrete prior to stripping will be cut in half. Another advantage is the reduction in the number of bulkheads required. The tradeoff will be in the added expense of renting or purchasing more form capacity.

For the test example, the model of the roof activity in terms of its operations appears in preliminary barchart form as follows:

```
Assemble towers
     Place towers
           Erect beams
                Erect plate girders
                     Freeform between panels
                         Order and crane rebar to position
                              Place rebar
                                  Form bulkhead
                                       Pour concrete
                                           Cure
                                                Strip forms
```

Figure 39 Preliminary Barchart for Activity "Roof"

In the test case as described above, the first four operations would be done once and thereafter the tower-beam-plate assembly would be wheeled to the next location ahead. In this example, the operations and sequencing are known but the durations are not.

6.2.3 Continuous or Linear Crew Scheduling?

Because of the curing time of up to 4 days, and the finish-start relationship to the next roof segment, the crews cannot be scheduled continuously for a given activity. A filler project is required for the duration of the cure. One option would be to schedule "wall" operations and "roof" operations in a continuous manner. Were this option to dovetail cleanly, the multi-activity continuous scheduling format would be applicable. It would appear as follows:

```
      Days
1  2  3  4  5  6  7  8  9  10 11 12 13 14 15 16 17 18 19 20
-----------------------------------------------------------
C----C Position roof form assembly                        ┐
     C--C  Freeform between panels                        │
        I  Material handling, rebar                       │
         I----I Place rebar                           Roof│
         C------C    Form bulkhead                        │
                 L      Pour concrete                     │
                  *--------* Cure roof                    │
                           L--L  Strip roof forms         ┘
               I-------I  Rebar walls                     ┐
 Legend                 C---C Position wall form      Wall│
                             C--C   Form wall bulkhead    │
 C = Carpenters                  CC      Install tie rods │
 I = Ironworkers                   L  Pour concrete       │
 L = Laborers                       **   Cure             │
                                      L-L  Strip          ┘
                                   C----C  Position next roof etc
```

Figure 40 Multi-activity Crew Scheduling for "Wall" and "Roof" Activities.

In the case laid out here, the forming crew is almost working continuously between the two activities. The rebar crew exhibits greater continuity but still less than 100% utilization.

The above planning option is a good start on the planning of the roof and wall activities. And in keeping with the stated theory, the rough scheduling has occurred prior to the actual design of how the activity is to be constructed. An estimate of duration for the crew operations has been added to see if the continuous crew scheduling is feasible.

The last item from the General Planning Model, activity level, is to sort the operations by impact to the activity as a whole, greatest impact first. The shore-tower assemblies have the greatest impact on the speed of the activity. Therefore that activity will be examined first.

6.3 Operation Level Testing

First operation: Shore and form roof.

6.3.1 Create Operation Worksheet

At this point we want to list feasible options and contrast their methods, costs, and durations. The following figure provides the framework.

Option	Descriptor Method	Duration per unit	Unit Cost $
1	Rented light towers, alumajoist, plywood	5 days	1000
2	Efco 50 kip towers, header beams, plate girders	2 days	2000
3	Owned 100 kip towers, 12" beams, plate girders	7 days	1500

Note: Units refer to unit activities, 50′ segments.

Figure 41 Spreadsheet of 'Options Versus Descriptors' for Operation "Shore and Form Roof".

The values for the options (fictitious in this case) are derived from suppliers quotes, estimates of manhours, and previous experience to develop preliminary duration and cost estimates. Costs and durations in this case include all of the shoring and forming operations including stripping.

This case is interesting because we must now find the value of the difference in duration from a sub-project standpoint. The total of the additional duration required for #2 over #1 is 12 segments times 3 days = 36 days. The extra duration is simply not available in this project. So for this test case, the preliminary solution is #2, Efco Towers.

The shoring and forming system is now ready for refinement. Preliminary shop drawings would be produced and superintendents responsible for the "roof construction" would be included in discussions.

6.3.2 Calculate Major Resource Requirements

From 4.2.4. Step 5, the formula for determining the number of units of falsework required is:

$$FU = \frac{(NUA - 1)\ UAD}{(ATD - UAD)}$$

Where:
FU = # of Falsework Units
NUA = # of Unit Activities
UAD = Unit Activity Duration
ATD = Activity Target Duration

The assumption underlying this equation is that the falsework units are required to remain in place until the last operation of a particular unit activity (stripping) is finished.

We do not as yet know the unit activity duration. To estimate this duration, all operation durations must be estimated and combined with possible overlapping to get the preliminary unit activity duration. The effects of double or triple shifts is to be accomodated by the activity durations estimated. The barchart in figure 40 will provide this information when it is up-dated with operation duration estimates. In this case, the duration for the chosen method option for shoring and forming the roof coencides with the original barchart estimate. All operations have not yet been designed, but if we accept the barchart as current for the first iteration, the unit activity duration is seen to be 10 days. Note that a later iteration of the combine "roof" and "wall" barchart will be required if it is still feasible to share crews between the roof and the walls.

From 6.1.7 the Activity Target Duration (ATD) is shown to be 13 weeks or 65 days at 5 days per week. The Number of Unit Activities (NUA) is given as 12. And from above, the Unit Activity Duration (UAD) is 10 days.

$$FU = \frac{(NUA - 1)\ UAD}{(ATD - UAD)} = \frac{(12 - 1)\ 10}{(65 - 10)} = 2 \quad \text{Formwork Units}$$

If this were the final calculation, we would need 2 segments (100 feet) of roof forms. Let us see if this can be improved upon. Try two 50 foot segments placed and poured at one time.

```
Days
1  2  3  4  5  6  7  8  9  10 11 12 13 14 15 16 17 18 19 20
-----------------------------------------------------------
C----------C  Position roof form assembly
           C------C  Freeform between panels
              II  Material handling, rebar
               I----------I  Place rebar
                  C-------C  Form bulkhead
Legend                     LL   Pour concrete
C = Carpenters               *--------*  Cure roof
I = Ironworkers                       L------L  Strip
L = Laborers                                  C->Next roof
```

Figure 42 Barchart Showing the Effect of Doing Two Segments of the Roof Activity (100') at One Time.

Figure 42 was modelled by doubling the durations of all operations except "Form bulkhead" and "Cure" which remained the same. So two segments are completed in less than twice the time. Let's see what effect this has on the formwork requirements.

$$FU = \frac{(6 - 1)\ 15}{(65 - 15)} = 1.5 \text{ Form units}$$

The 100' segment option requires less that two units of falsework which is an improvement. We are not able to reduce the falsework requirement below two units but we now have some float in the schedule.

We have now established the unit activity target duration. In the process we have had to specify the durations of the operations. The planning model will direct the design process in turn to these operations and we will either:

1. Verify that the durations estimated here are feasible.

or 2. Return to this sheet for another iteration.

6.3.3 Operation Design Parameters

The design parameters for "shore and form roof" are largely the same as those developed in section 4.3.3 for bridge beam construction. The spreadsheet of shore operations versus design parameters will provide the same checklist of decision variables as in the design of the bridge beam. Additional repetitious detail is not required here.

Likewise the costing process is not elaborated on here as it is much the same as described in the planning model, Chapter 4, section 4.3.4. In general one would analyse the costs of the feasible options and highlight those options that are most cost effective.

The process of operation design is iterative in that no operation can be specified with complete certainty until all the operations that comprise an activity are analysed and methods determined. Therefore the list of operations is systematically processed until we have a solution for each that fits in with the other operations of the activity.

We have now established that the durations estimated for the various operations of the activity "roof" are feasible, have established methods, drafted preliminary shop drawings, and calculated cost estimates for the options of the operations in question. The operation level is nearly complete.

6.3.6 Calculate Crew Size

Referring to section 4.3.6 in Chapter 4, we are given a method of establishing a crew size if the cycle duration is specified earlier. The crew cycle was not specified in the activity linear scheduling section 6.2.3, because the crews were not continuously engaged in work on these operations.

Now is the time to investigate multi-activity crew scheduling between the activities "walls" and "roof". The "walls" activity will have already undergone an analysis similar to the "roof" activity. The methods, duration estimates, cost estimates, and preliminary drawings are completed.

Lets compare the barcharts of the two activities to see if they are at all compatible for crew sharing.

```
Days
1  2  3  4  5  6  7  8  9  10 11 12 13 14 15 16 17 18 19 20
------------------------------------------------------------
C----------C  Position roof form assembly                  ┐
           C------C  Freeform between panels               │
              II  Material handling, rebar                 │
               I----------I  Place rebar              Roofs│
                   C-------C  Form bulkhead           1 & 2│
                            LL   Pour concrete             │
                              *-------*  Cure roof         │
                                       L------L  Strip     │
                                               C->Next roof┘
    ┌─ I------I  Rebar walls
    │                       C          Position wall form
    │ Wall 3                 C-C  Form wall bulkhead
    │                           C-C  Install tie rods
    │                              L  Pour concrete
    │                               *-*  Cure
    └─                                 L-L  Strip
               Rebar Walls       I------I                  ┐
                    Position wall form    C                │
 LEGEND             Form wall bulkhead     C-C      Wall 4 │
 C = Carpenters     Install tie rods         C-C           │
 I = Ironworkers    Pour concrete               L          │
 L = Laborers       Cure                         *-*       │
                    Strip                             L-L  ┘
```

Figure 43 Barchart Showing Multi-activity Continuous Crew Scheduling.

It can be seen from the above barchart that the forming operations can be positioned so that they do not overlap between the two activities. The same is true for the rebar placing operation. So the concept of multi-activity, continuous crew scheduling appears to work with the above scenario. The next step would be to assign manpower to the crews so that the manpower required matches the manpower available.

These are hypothetical activities but they demonstrate how crews can be juggled on paper between activities to take advantage of continuity of crew sequencing while still delivering the same production rate. This example does not show all of the decisions variables that are present. Another case it might have necessitated the choice of a different forming system that would better utilize the crews available.

The same technique can be applied to equipment useage. Essentially, availability of equipment must be compared and fitted to the equipment requirement.

6.4 Testing the Model: Results

It seem fair to say that the model constructed for the Bridge Project performed reasonably well for analysis of the planning elements associated with Cut and Cover Tunnel Construction. Flexibility is certainly a very important element in the framework of a model or a computer system that uses the model. The concepts were largely unchanged from Bridge to Tunnel but the application of the concepts did change and the proceedures were not identical.

CHAPTER 7 CONCLUSIONS

7.1 Accomplishments

This thesis began by identifying construction information systems as an area of on-going development in the construction industry. Of particular interest to this work is the concept of activity planning. What is required to design and plan an activity? What theories are useful to develop a protocol for the establishment of activity design? And what tools are useful towards that end?

Chapter 3 assembles a table of functions and environments for the execution of these functions. It concludes that two computer environments, Database and Scheduler, are able to efficiently perform the required activity planning functions. This research proposes to operate these two environments in tandem as individual modules of an overall information system.

In Chapter 4, this thesis develops a specification for a "General Planning Model for Concrete Construction" that will utilize a programable database as an operating environment. The planning model then becomes the driver of the activity planning process. The planning model and establishes a structure to accomodate the myriad of details common to concrete construction. Three levels of hierarchy are utilized extensively (Project, Activity, and Operation) while four other levels (Location, Resource, Descriptor, and Phase) round out the capability of the data collection and analysis system.

From the project level of the planning hierarchy comes the development of a scheduling technique called "target activity duration allocation". This method distributes the milestone duration amongst activities by a rational approach and provides a feasible target duration for the planner to aim at while designing the activity.

A finding from the Activity Level of the hierarchy is a method of developing continuous crew schedules for operations involved in repetitive activities. As well, various commonly known scheduling methods are specified in the planning model for use at appropriate times.

A major section of the Operation Level hierarchy is devoted to the calculation of optimal formwork and shoring hardware requirements based on the continuous crew schedules previously derived. Another outcome of this level of analysis is a check list of decision variables that can be brought to play on the concrete construction operations of formwork, concrete placement, and rebar placement. Manipulation of these decision variables within the planning model is the essence of activity or operation design as laid out by this thesis. Finally, crew size calculation and equipment allocation are discussed and algebraic and graphical methods are employed to allocate these resources.

Chapter 5 presents the results of information system file organization given the functions of Chapter 4. Two types of data structures are illustrated, relational database files and multidimensional spreadsheet files. From the layout of the records and fields within these environments, one gets a feel for the quantity of data to be collected and utilized by the system.

Chapter 6 serves to verify that the planning model, as presented in Chapter 4, will be viable in other concrete construction applications. Whereas Chapter 4 provided examples from a concrete bridge project, Chapter 6 uses a cut and cover tunnel project to compare the portability and flexibility of the planning model. One major finding from schedule analysis of the tunnel is the need to be able to sequence activities in a sub-project on a continuous basis. This finding allows the planning model to accomodate the sequencing needs of cut and cover activities as discovered in the Seattle Subway case study. This example illustrated the additional capabilities required of the general planning model in order to better model reality.

The final finding from chapter 6 is that the "General Planning Model for Concrete Construction" is quite flexible and transportable. The model when applied to a cut and cover tunnel was easily molded to the planning tasks at hand. In fact, the actual planning processes proved to be very similar to those of a concrete bridge project.

7.2 Recommendations for Future Research

This thesis developed a framework from which to monitor and plan construction activities and operations. One task not addressed is a method of discerning the productivity values of the many decision variables that comprise an operation. Regression analysis is a possibility that may yield results. Decision variable productivity analysis is a task for future research.

The combination of database and CPM scheduling capabilities within the same program is a capability not seen in the literature and software search undertaken for this thesis. There would be benefits as well as additional complication to such a combination. It would seem to be an area well suited to future research.

Another area that beckons additional research is the subject discussed briefly in Chapter 2, section 2.2.2, optimization by means of a linear programing process. The authors of the reviewed article accomplished optimization using linear programming for an earth-moving construction project. The relevance of that technique to concrete construction is an area sugested for future research.

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APPENDIX A

CONSTRUCTION INFORMATION SYSTEM
MENU OF SYSTEM FUNCTIONS

MENU SCREEN TEXT	MAIN MENU	SUB MENUS	
M	0	EXIT PROGRAM	
M	1	TIME AND COST CONTROL MODULE:	
	1.0	Exit	
T	1.1	Introduction	
M	1.2	Data Entry:	
		.0	Exit
S		.1	Time sheets
S		.2	Purchase orders
		.3	Invoices
S		.4	Company inventory draw requests
		.5	Company inventory deliveries
S		.6	Indirect cost input
		.7	Reports
M	1.3	Cost Control Monitoring	
		.0	Exit
S		.1	View WBS hierarchy by record name
S		.2	Select sort mode (by trade or by structure)
		.3	Select records/fields for data editing
S		.4	Analyze costs
S		.5	Summarize costs
S	1.4	Forecasting project costs	
S	1.5	Monthly payment data structure	
		.0	Exit
		.1	General contractor
		.2	Sub-contractors
	1.6	Company archives of project summaries	
		ESTIMATING AND PLANNING MODULE:	
M	2.	PROJECT LEVEL DEFINITION	
	2.0	Exit	
	2.1	Select project	
M	2.2	Definition input:	
		.0	Exit
S		.1	Project

.2 Activities
.3 Operations
.4 Client Divisions
.5 Locations

M 2.3 Work breakdown structure
.0 Exit
S .1 Browse for suitable prototype
.2 Copy prototype
.3 Modify
.4 Add "Client Divisions"
.5 Add locations
.6 Report

M 2.4 Field structure (project, activity, operation):
.0 Exit
S .1 Browse for suitable prototype
.2 Copy prototype
.3 Modify
.4 Report

M 2.5 Quantity survey:
.0 Exit
S .1 Export WBS to spreadsheet
S .2 Import quantity survey from spread sheet

S 2.6 Outline of scheduling program functions
2.7 Schedule: target activity duration calculations

M 3. ACTIVITY LEVEL DEFINITION
3.0 Exit
3.1 Select activity
M 3.2 Activity definition:
.0 Exit
S .1 Proj code
.2 Activity code
.3 Activity name
.4 Activity description
.5 Conditions
.6 Time constraints
.7 Physical constraints
.8 Methods

M 3.3 Activity work breakdown structure:
.0 Exit
S .1 Browse for prototype: act'ys with nested oper'ns
.2 Copy prototype
.3 Modify (add or edit operations, etc)
.4 Add "Client Divisions"
.5 Add locations
.6 Report

S 3.4 Sort database for operation options and display
3.5 User defined options
S 3.6 Summarize activity plan. (decision tree shown)

M 4. REPETITION PARAMETERS
4.0 Exit
T 4.1 Repetitious and continuous crew scheduling.
S 4.2 Standard crew cycle duration: calc
4.3 Unit activity cycle duration: calc
S 4.4 Test feasibility of standard crew cycle duration

M 5. PRELIMINARY ACTIVITY SCHEDULES
5.0 Exit
S 5.1 Outline functions executed in scheduling program
5.2 Reports
5.3 Network
5.4 Bar chart
5.5 Line of balance graph

M 6. ACTIVITY LEVEL COST PLANS?
6.0 Exit
S 6.1 Develop cost plans at activity level? If no go to 7
6.2 Edit activity records to include feasible options
S 6.3 Calculate cost per unit for each feasible option
.1 Labor
.2 Materials
.3 Equipment
.4 Sub-contracators
6.4 Choose minimum cost option. List methods
S 6.5 Calculate crew size
S 6.6 Check assumptions of productivity with crew size
6.7 Repeat for all "no operation" activities

M 7. OPERATION LEVEL COST PLANS
7.0 Exit
7.1 Select operation
7.2 Edit option records to include feasible options
S 7.3 Calculate controlling resource requirements
ie. falsework
S 7.4 Obtain design input (ie beam and form sizing)
S 7.5 Calculate cost for each feasible option based on:
.1 Labor
.2 Material
.3 Equipment
.4 Sub-contracators
7.6 Choose minimum cost option. List methods
S 7.7 Calculate crew size based on productivity duration

S 7.8 Check assumptions: productivity versus crew size
7.9 Repeat for all operations of the activity

M 8. ACTIVITY SUMMARY
8.0 Exit
S 8.1 Activity level scheduling
S 8.2 Compile histogram of equipment hours
S 8.3 Level equipment resource useage
S 8.4 Update schedules.
8.5 Check target versus plan duration
S 8.6 Analyse resulting activity plan. Alternatives?
8.7 Repeat for all activities

M 9. PROJECT SCHEDULING
9.0 Exit
9.1 Project level scheduling
S 9.2 Network
S 9.3 Barchart
S 9.4 Pert technique
S 9.5 Line of balance analysis
S 9.6 Contract v.schedule duration? Crashing required?

M 10. RESOURCE LEVELLING
10.0 Exit
S 10.1 Compile resource histograms for project:
10.2 Cash flow
S 10.3 Financial analysis
10.4 Manpower
10.5 Equipment
10.6 Level project resources

M 11. TENDER SUBMITTAL OR COST UP-DATE
11.0 Exit
S 11.1 Sub-totals of costs:
11.2 Overhead, profit, and contingencies
S 11.3 Distribute totals among pay divisions
11.4 Calculate unit rates for tender
11.5 Tender submitted