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Improving Construction Project Scheduling Through the Use of a Fuzzy Expert System

by

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ABSTRACT

This research proposes a scheduling system that incorporates a fuzzy expert system to properly consider risk when scheduling a construction project. Through the use of fuzzy set theory, construction professionals can assess risk using natural language in a transparent system that is easily optimized according to the experience of the user. The developed system automatically produces risk-adjusted, summary-level schedules based on project characteristics and an assessment of risk by the user.

Testing results indicate that refinements are required to strengthen the performance of the scheduling system. Although the structure of the system is unique and fully developed, issues regarding the combined effects of multiple risk factors and availability of data require further study. However, the foremost objective of the research project was met, which was to provide a method for automatically scheduling construction projects that considers the impacts of schedule risk.

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Δ = delta

3-D = three dimensional

AC = actual costs

ATC = hybrid structural system of precast columns and beams with cast in place decks

BP = bid price

CER = Cost Estimating Relationship

cf = cubic feet

CII = Construction Industry Institute

CIP = cast in place structural system

COA = Centre of Area

CPM = Critical Path Method

cum = cumulative

cy = cubic yard

fdn = foundation

FES = fuzzy expert system

FIAPP = Fully Integrated and Automated Project Processes

GFA = gross floor area

GSF = gross square feet

hr = hour

LOM = Largest of Maxima

m^3 = cubic metre

max = maximum

MF = membership fuction

min = minimum

MOM = Middle of Maxima

N-D = "N" dimensional

num = number

PERT = Program Evaluation and Review Technique

PF = profit

PRE = precast structural system

RC = risk contingency

sf = square feet

SOG = slab on grade

SOM = Smallest of Maxima

sqrt = square root

sum = summation

var = variables

vol = volume

1. INTRODUCTION

The scheduling of work packages that are to be completed is one of the critical planning processes undertaken when initiating a construction project. Activity durations for the work packages, relationships between activities, and an analysis of the activities critical to the flow of work are all worked out on paper prior to physically undertaking the work. This allows for any potential scheduling problems to be uncovered in advance and dealt with as efficiently as possible.

A properly scheduled project reflects the balance of several interests that are in competition at any given time throughout the duration of a project including cost, quality, scope of work, and others. The development of an accurate schedule depends on correctly anticipating the interactions of these interests on a project and the subsequent effects on activity durations and relationships between activities in the schedule.

1.1. Background on Scheduling and Current Standard Practice

A project schedule is most effective when it is used to track progress during construction. It can be used as a tool to help determine if manpower and equipment are performing as expected during construction. If variations are noted in an activity's production rate, steps can be taken to bring the problem activity back into line before it affects other portions of the construction project. However, the schedule will only be effective for project control if it accurately reflects the conditions surrounding the construction project.

Often, productivities and relationships are calculated from historical projects and used as the basis of the schedule being developed for an upcoming project. Activity durations can be derived from productivity values that have been calculated from completed projects. This process does not consider project-specific conditions but provides a starting point from which to calculate a schedule.

In order to ensure that a schedule is tailored specifically to an individual project, information must be gleaned from other planning activities, such as resource allocation and risk analysis. There is a very obvious relationship between an activity's duration and the level of resources dedicated to the activity; an activity will usually take longer to complete if fewer resources are available. However, the potential impacts on a project schedule that a comprehensive risk analysis can indicate are much less crisply defined and more difficult to understand.

Assessing the precise effects of risk on schedule is also not easily done in the construction industry, where risk factors are often described using natural language. For instance, if "very" cold weather causes a "small" increase in an activity's duration, the exact change in activity duration is uncertain. This is a non-random uncertainty that is embedded in the variables used to describe the particular situation. The temperature can be considered "very" cold over a wide range of values to varying degrees. Increases in duration can also be considered "small" over a range of values. The non-random uncertainty arises from attempting to assign the degree to which a value matches the description of a variable used. Each individual person may have a different opinion of what these descriptions of the variables mean.

Normally, an expert in construction takes as many potential risk factors as possible into account when developing a project schedule. Historical productivities are used as a starting point and then modified accordingly. It takes a great deal of experience to be able to manipulate historical productivity values in this way to customize them to the specific conditions surrounding a new project. This kind of experience takes years to accumulate and is not always transferable to different types of construction. If a person finds themselves scheduling a project of a type that they have limited experience with, the activity durations and relationships between activities will end up being educated guesses at best, even if they are based on historical productivities.

It is desirable to empower those with limited experience in a certain type of construction to become effective schedulers for several reasons. The most obvious is to provide a means for people new to the industry or working in roles other than field staff to perform scheduling tasks. These types of people would be able to schedule projects without spending years acquiring the previously necessary experience. Another situation where scheduling assistance would be valuable is that where an experienced person is required to plan a project of a new or unfamiliar nature. Although these people have excellent general construction knowledge, they would not know the specific criteria that are important for successful completion of the new construction type. Risk analysis on project schedules could also be completed in a much less haphazard way with the use of a scheduling tool that assesses the effect of risk factors on activity durations. Various scenarios of risk could be analyzed in order to determine the changes they induce in the project schedule. One final reason for creating a method to allow less experienced people to schedule construction projects is that a large number of people in the industry are currently reaching the age of retirement. There are fewer young people in the industry to replace them and regardless of how adjustments are made to account for this change in demographics, a huge amount experience will be lost. It is therefore critical to be able to transfer this pool of experience to a new generation of construction professionals.

1.2. Objectives and Resulting Scope of Research

There were several objectives that shaped the definition of the scope of this research project. As detailed previously, a need was identified to transfer information between professionals within the construction industry. Meeting this need specifically for the domain of knowledge relating to project scheduling was the main objective of this research.

The capacity to perform a risk analysis on a project schedule created from historical productivities was identified as the component of scheduling that depends most heavily on expert knowledge. Other scheduling requirements, such as choosing activities and identifying relationships between activities, can be met through the use of project schedule templates. Expert systems lay out a procedure for capturing expert knowledge within a set of rules that can be easily accessed though a user interface. As such, it was determined that an expert system would be an effective tool for performing the risk analysis portion of the automated scheduling system.

It was important that the system would be intuitive and its calculations transparent for users to follow. This objective was set to increase the likelihood of producing a system that would be accepted by industry and immediately useable without extensive training. Fuzzy set theory enables natural language used by construction professionals to describe risk to be used in the calculations required by an expert system. It has been demonstrated over the past thirty-five years to be extremely effective in capturing non-random uncertainty for a wide variety of applications. When fuzzy set theory is incorporated into the structure of an expert system, the resulting fuzzy expert system is a powerful, yet flexible, tool for automating the process of scheduling a construction project. By nature, the calculations performed by a fuzzy expert system can be made transparent and are understandable to the user. This research intended to demonstrate that fuzzy set theory is a robust technique for accounting for construction risks.

It was also desired to develop the scheduling application using methods that allow it to be incorporated within an overall project planning system. Much of the current research in the construction industry is attempting to integrate the various components of project planning and control. A stand-alone scheduling tool is not as useful as one that can be combined with other systems to encompass the entire project planning process.

Other objectives were focused on the methods of research rather than the structure and results of the actual scheduling system. There are two scenarios that reoccur consistently within the literature produced by the fuzzy set theory research community. The first is that often models are proposed without fully developing the components that the model is comprised of. Therefore, very limited testing of the models is performed and applications are left for further development by industry, if desired. It was intended that each component of the envisioned scheduling system would be developed as fully as possible to allow for immediate use and testing.

Another aspect of research relating to fuzzy set theory is that it often relies heavily on surveys of expert knowledge. These surveys can vary widely in reliability, depending on factors such as quality of the format of the survey and the effort made by the surveyed experts. Some components of fuzzy expert systems must be defined through the capture of expert knowledge; however, it was believed that a fuzzy expert system could be structured for this scheduling application by minimizing the input required by experts. Data required for creating the system would be obtained to a greater extent by studying the actual events that occurred on completed projects. The intent of this strategy was to increase the quality and reduce the variability of the data used to develop the components of the fuzzy expert system.

To summarize, the objectives of this research project are as follows:

- develop a system for automating the production of construction project schedules that account for the effects of project-specific risk factors

- demonstrate the effectiveness of fuzzy set theory and expert systems for assessing the impacts of risk factors on schedule using linguistics
- ensure the calculations performed by the scheduling system are understandable and transparent to the user to increase the likelihood of acceptance within industry
- structure the scheduling system in a way that allows it to be integrated within an overall project planning and control system
- fully develop the components and test the performance of the system
- use case studies of completed projects to develop as many system components as possible

The scope of this research project was limited to the scheduling of parking structures. This limitation was accepted in order to keep the volume of data collection and analysis manageable, however, the concepts the scheduling system is based on can be easily adapted to other types of construction. Parking structures were chosen for the scheduling system because the structural portion of other types of construction is very similar. The majority of a system based on parking structures is therefore applicable to a wide variety of other types of projects. In addition, a large number of parking structures have been completed in North America over the past several years, compared to other institutional or commercial buildings. This allowed more sets of data to be included in the study than if another construction type was used.

1.3. Research Methodology

In order to be able to complete this research project and meet the stated objectives, it was necessary to have the support of a construction company that could provide access to information from a large number of projects. In addition, construction experts were needed to provide some of the information required for developing certain components of the fuzzy expert system. The research topic was therefore presented to one of the largest construction companies in North America for consideration as a worthwhile endeavour to support. With the approval of upper management, unlimited access was provided to historical project information, as well as to project staff for interviewing purposes.

The activities that were part of this research project were undertaken sequentially as follows. First, a literature review was completed to determine the direction and results of previous studies relating to fuzzy set theory and the automation of scheduling in the construction industry. Case studies of archived projects were then completed to obtain data required to develop the components of the planned model of the scheduling process. Remaining data that was necessary to complete portions of the model were obtained through interviews with project managers that worked on the completed projects under investigation. The components and overall structure of the model were then developed through various methods that are described in detail in later chapters. Finally, a method to test and calibrate the model was undertaken that was based on a series of project scenarios and related risk profiles. Activity duration variations predicted by the scheduling system were compared to those predicted by construction experts. The results of this testing were used to calibrate the performance of the system.

1.4. Outline of Thesis

This thesis outlines the research completed to develop and test the described scheduling system. It is divided into seven chapters, starting with this introductory chapter that outlines the research topic and methodology.

Chapter 2 provides background on fuzzy expert systems and explains fuzzy concepts in general. The mechanics of expert systems are explained and the additional functionality that fuzzy set theory can provide within the structure of an expert system is presented.

To offer some perspective to this research, Chapter 3 contains the summary of a literature review that describes other applications of fuzzy set theory developed by the construction research community. Scheduling applications are highlighted and other methods used to automate the scheduling process are introduced.

In Chapter 4, the structure of the scheduling system that has been developed is outlined. Individual components of the system are described in detail and specifics are given in relation to how the components interrelate. This chapter describes the overall function of the scheduling system.

The data collection and calculations completed to develop the system are described in Chapter 5. Each component of the scheduling system had different requirements for development. The data required by each component and the method utilized for collection and use is therefore detailed.

Chapter 6 explains the testing and calibration process that was carried out to improve the performance of the developed scheduling system.

Finally, conclusions and contributions made through this research are discussed in Chapter 7. In addition, future developments that could be made to enhance the performance of the scheduling system are recommended.

2. BACKGROUND ON FUZZY SET THEORY AND EXPERT SYSTEMS

The foundation of any type of expert system is a knowledge base consisting of conditional rules. The rules take the form of IF-THEN statements with the antecedent (IF) portion driving the consequent (THEN) portion of the rule. Fuzzy expert systems allow the variables in the antecedent and consequent of each rule to be described in natural language. This is very useful in the construction industry where parameters are most often described using natural language. The following example is used to illustrate this point.

A traditional expert rule would read as shown in Equation 2-1.

"IF productivity is less than 10 m^3 / hr THEN add 1 labourer"..................................[2-1]

A similar fuzzy expert rule would instead be constructed as shown in Equation 2-2.

"IF productivity is *poor* THEN add *a few* labourers"..[2-2]

One of the other advantages of using the fuzzy expert rule is that there does not need to be sharp boundaries that determine whether a rule fires or not. If the traditional expert rule was used and the productivity was 10.01 m^3 / hr (slightly over the threshold), the system would not have recommended adding any labour. Moreover, only one labourer would be added whether productivity was 1 m^3 / hr or 9.9 m^3 / hr. Clearly, this inflexibility makes a rule of this type unable to handle real-life situations on its own.

It is possible to create an expert system with traditional rules that has coverage of a wide range of scenarios. The difficulty that rapidly becomes apparent is that an extremely large number of rules are required to ensure each and every situation is accounted for. A single fuzzy rule can take the place of several traditional rules within an expert system. Also, the overall output of a traditional expert system can be erratic as small changes in the input data can trigger rules with significantly different output to fire. It takes considerable work on behalf of the system designer to iron out these types of inconsistencies. In contrast, a fuzzy rule is able to modify its recommendation incrementally depending on the input provided.

A requirement of using fuzzy rules in an expert system is that membership functions for the descriptors used in each rule must be defined. Membership functions represent numerically the concept introduced by the linguistic descriptor of the variable. The shape of a membership function is determined by the degree a concept is considered valid over a range of values.

There are different ways to define membership functions for descriptors of variables. Sun (2000) performs a comprehensive review of the various methods proposed in the literature to develop membership functions. However, without historical data it is not possible to use many of the techniques proposed such as fuzzy clustering, parametric optimization, or inferring membership functions from probability density functions. Therefore, experts are commonly surveyed to determine the shape of membership functions.

There are three typical approaches for defining membership functions that are based on expert surveys. Pedrycz and Gomide (1998) describe in detail the horizontal, vertical, and pairwise comparison methods, respectively. The horizontal method surveys the membership value of a concept (from no match = 0 to full match = 1) over the universe of discourse for the variable. Conversely, the vertical method surveys the range of values that a concept is valid for a certain degree of membership. A range at a particular membership values is called an "alpha-cut". Alpha-cuts for the full range of membership (0 to 1) are assembled into the membership function for the concept. A pairwise comparison exercise requires the expert to declare a level of preference for a concept at a certain value compared to a different concept at the same value. Membership functions for descriptors of a variable can then be mapped over the universe of discourse.

Sample membership functions for the linguistic descriptors of variables used in Equation 2-2 are illustrated in Figures 2-1 and 2-2.

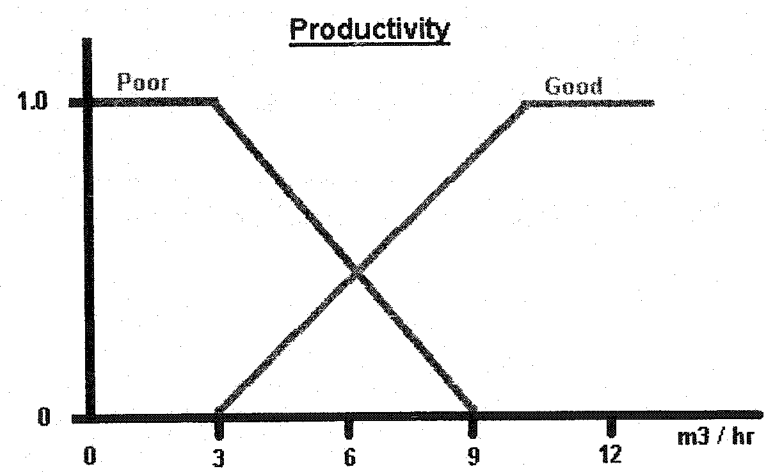

Figure 2-1: Membership Functions for Descriptors of Productivity

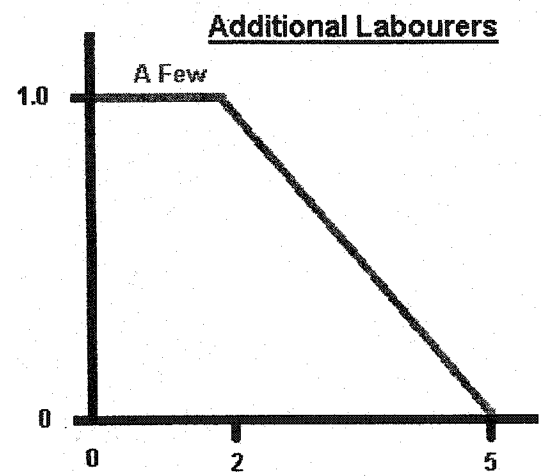

Figure 2-2: Membership Function for "A Few" Labourers

There are two methods for using the rules within a fuzzy expert system. One method is to provide crisp values for input variables. Crisp input is fuzzified by mapping it to the corresponding membership values of the input membership functions. Rules fire with strengths corresponding to the membership values of the descriptors of variables in their antecedents. Continuing the example defined in Equation 2-2, if productivity in the field is measured, a rating of the degree to which the productivity matches the concept of "poor" can be determined by the shape of the membership function. This rating is between 0 and 1 and is then used as the firing strength of the rule.

An alternate method of calculating the consequence of each individual rule is allowing the user to specify a linguistic descriptor that corresponds to a defined membership function. Any rule that includes this descriptor as its antecedent fires with full strength. Other rules fire at varying degrees depending on the amount their antecedents overlap with the specified descriptor. In the previous example, if a user had specified "poor" productivity the rule would have fired with full strength (1.0). In addition, any rule that had an antecedent of "good" productivity would fire with a strength of 0.45 because the two concepts have membership functions that overlap at that membership value (refer to Figure 2-1).

When rated using linguistics, membership functions can be modified using qualifying terms to more accurately describe them. The common qualifying terms used are "very" and "somewhat". For example, when using the fuzzy expert rule defined in Equation 2-2 the user could more explicitly rate the productivity as being "very poor" or "somewhat poor". The qualifying terms adjust the firing strength of the rules to better reflect the user's understanding of the value of the input variables. Given the membership function A(x) for the descriptor "poor", the qualifying term "very" modifies the function as shown in Equation 2-3 and the term "somewhat" modifies the function as shown in Equation 2-4 (Nguyen, 1985).

$$\textit{poor} = A(x) = a_{x1}, a_{x2} \ldots a_{xn}, \textit{very poor} = A^2(x) = a_{x1}^{2}, a_{x2}^{2} \ldots a_{xn}^{2} \quad \text{[2-3]}$$

$$\textit{poor} = A(x) = a_{x1}, a_{x2} \ldots a_{xn}, \textit{somewhat poor} = A^{1/2}(x) = a_{x1}^{1/2}, a_{x2}^{1/2} \ldots a_{xn}^{1/2} \quad \text{[2-4]}$$

Any number of variables can be contained within the antecedent of an expert rule and are combined with either the AND (intersection) or OR (union) operator when determining the firing strength of the rule. The AND operator on fuzzy sets is defined as a t-norm (Pedrycz and Gomide, 1998) and is typically implemented by calculating the minimum of the membership values for the descriptors of the variables. Conversely, the OR operator is a s-norm and is typically the maximum value of the input descriptors.

Output of a rule is determined by applying the rule's firing strength to the descriptors of the variables in the consequent of the rule. This process is referred to as implication. The output membership functions are either scaled or truncated by the rule's firing strength. A MIN operator is to truncate output membership functions and the PRODUCT operator is used if scaling the output is desired.

When more than one rule contains the same variable as a consequent, the output of multiple rules is aggregated into a single function over the universe of discourse for that variable. The universe of discourse is defined in fuzzy set theory as the range of values over which there is a possibility that a variable may be defined. Normally a MAX operator is used to aggregate the membership functions; however, other methods are also available including averaging and compensatory operators.

There are options for interpreting the output of a fuzzy expert system. Crisp output is required for certain applications. This can be accomplished though the defuzzification process. The most common method of defuzzification is the Centre of Area (COA) method, which is calculated by determining the centroid of the output membership function and mapping this point to the appropriate point on the x-axis. Other methods of defuzzification concentrate on the range of the maximum value of the membership function. Middle of Maxima (MOM), Largest of Maxima (LOM), and Smallest of

Maxima (SOM) methods use the middle, largest, and smallest values in the range as crisp output from the function, respectively.

Figure 2-3 illustrates the fuzzification, implication, and defuzzification (COA) techniques using the rule defined in Equation 2-2. Given the input of field productivity equal to 5 m3 / hr, the rule indicates that there should be 2 or 3 additional labourers added to the activity.

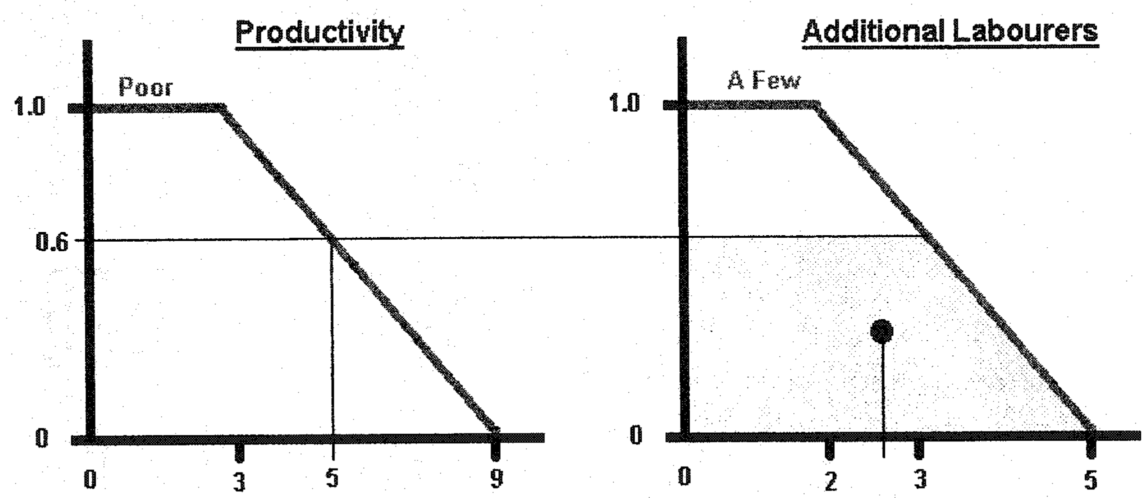

Figure 2-3: Method of Determining the Consequence of a Fuzzy Rule

It is not always necessary to calculate a crisp output value from the recommendations of the rules that form the knowledge base of the expert system. Instead, it is often enough to match the output with a linguistic descriptor that accurately describes it. Different measures are used to calculate the degree of matching of the output membership function to the membership function of each of the linguistic terms that describe the output variable. The term that has the smallest distance to the calculated output is the most accurate descriptor. A common distance measure used is the Euclidean distance (Pedrycz and Gomide, 1998), as defined in Equation 2-5.

$$d(A, B) = [\mathrm{Sum}[A(x)-B(x)]^2]^{1/2}, \qquad [2\text{-}5]$$

for all values of x over the universe of discourse

This alternate method of determining the output of an expert system is often appropriate if the user has described the input variables linguistically. In this situation, if the system was to give a crisp output there would be a distrust of the output because it would be too precise. A user would have a difficult time with the concept of providing loose descriptions of the input variables and receiving an exact numerical recommendation in return. It is much more natural to be presented with a linguistic descriptor similar to the ones provided as input.

A fuzzy expert system can provide an effective method of capturing expert knowledge for future use within a reasonably sized rule base. If designed properly, the system will react in a smooth, predictable manner that is more closely aligned with the behavior of natural systems. In addition, the information contained within a fuzzy expert system can be accessed through linguistic descriptors of the variables under consideration. This is an enormous advantage for applications relating to construction, where many conditions are understood empirically and described using natural language.

3. CONSTRUCTION-RELATED APPLICATIONS OF FUZZY SET THEORY AND AUTOMATED SCHEDULING TECHNIQUES

Fuzzy set theory has been used fairly extensively in the construction research community to build tools that attempt to model human decision-making. It was recognized soon after the establishment of fuzzy set theory as a legitimate analytical technique that it provided a framework that could be used to model many construction processes. Since the early 1980s, techniques incorporating fuzzy set theory have been used in research involving such varied topics as tender evaluation, cost estimating, risk analysis and others. This chapter describes previous research that has used fuzzy set theory to solve construction-related problems.

3.1. Fuzzy Set Theory Applied to Construction Problems

3.1.1. Estimating

In a paper published in 1997, Mason and Kahn describe a system designed to assist in the estimation of construction costs. They outline a fuzzy expert system that is comprised of cost drivers, construction process cost, and the relationships between the cost drivers and the process cost. Membership functions are defined for the cost drivers, as well as the process cost. Rules are contained within a knowledge base that describe the effects of the cost drivers on construction cost. The authors call these impacts of cost drivers on process cost "cost estimating relationships (CER)". The resultant CER for the overall construction process cost is a multi-dimensional plot that relates how the multiple cost drivers interact to influence the cost of construction.

Mason and Kahn provide the user flexibility by allowing input variables to be assessed using either crisp numbers or natural language. Similarly, the output of the fuzzy expert system can be defuzzified to obtain a crisp number, if desired by the user. This will often be the case in this application because the final output of a construction cost estimate is usually a crisp value that will be written on a tender form. However, the estimator can obtain valuable information by studying the resultant CER that is defuzzified to obtain the final, crisp output. The shape of the fuzzy number coveys the degree of certainty that is associated with the output, and can influence decisions made regarding issues such as the allocation of contingency, determining fee, and whether or not to submit a bid.

Fayek (1998) demonstrates a different application of fuzzy set theory for the tender phase of construction. The decision of what size of margin to apply to a bid is often quickly done in an empirical or heuristic manner by those in the construction industry. Fayek analyzes the decision-making process and suggests three categories of information are required to model the process. The first category is the bidding objective of the firm – whether it is to gain experience, win the project, or to maximize profit. Factors affecting margin size are also required for the model. Ninety-three factors are identified in the research. Finally, the range of margin acceptable to the bidder is the other category of information required to model the process.

Fuzzy set theory is able to provide a strategy that allows the interrelating objectives and factors that are present in the determination of margin size to be weighed together in accordance to the users experience. The user decides how applicable each bidding objective is for a project and the factors that will affect margin size. The degree of influence that each factor has on margin size is also set by the user. Then, for each factor, the user selects the most suitable margin to meet each objective.

Fuzzy binary relations are used in the model to calculate two matrices, which are in turn manipulated using fuzzy composition to calculate a matrix that relates objectives to margin size. The author compares a traditional max-min operator for fuzzy composition to an alternate cum-min operation. Output of the model takes the form of recommendations for using varying margin sizes on a project. These recommendations can also be defuzzified to arrive a crisp value that is the single value that is most able to achieve the different objectives of the bidder, given the factors affecting margin size that are present on the project.

3.1.2. Tender Processes

The prequalification of bidders is common in the preliminary stages of a tender process. However, direct comparisons or statistical analysis of the results of a contractor prequalification can not incorporate the non-random uncertainty present when rating certain qualities of companies. Elton et al. (1993) developed a model for prequalifying contractors using the concepts of fuzzy set theory to capture this type of uncertainty. The model allows linguistic terms to be used to describe how each contractor meets a certain criterion and also to combine the influence of multiple criteria into a single rating.

The research categorizes the factors that are used in the prequalification of bidders into nine classes. The authors suggest the relative weighting of the importance of these factors, which are provided as fuzzy numbers with bell-shaped membership functions. The user's linguistic rating of each category is translated into a fuzzy number grade with a predetermined, bell shape. An equation is then solved using Monte-Carlo simulation to obtain a fuzzy number as output that represents the overall rating of the company. This number can be defuzzified using standard techniques to be compared to other firms in the prequalification process.

A sensitivity analysis was completed by Elton et al. to help evaluate the results of their research. They found that large changes in the parameter that controls the shape of the bell-shaped membership function did not produce significant variation in the overall rating of a company. This suggests that the influence of the shape of a fuzzy membership function on a model is very small, as long as the range of values over which it is defined is accurate.

Another process that occurs during the tender period is the evaluation of bids. Nguyen (1985) demonstrated how fuzzy set theory can be used to incorporate subjective ratings of factors from multiple judges to select the most appropriate bidder for a contract. It is proposed that all common factors that may influence the awarding of a tender can be grouped into three independent categories – cost, experience and performance potential. Rating contractors according to these factors is best accomplished through subjective means that can be effectively modeled using fuzzy methods. Binary relations of the bids under consideration and the factors used to evaluate them are utilized to perform the required calculations.

The paper describes two ways of combining subjective ratings from multiple judges. The pessimistic aggregation takes into account the lowest score given by one of many decision-makers, which corresponds to the AND operator in fuzzy set theory. Alternately, using the OR operator results in an optimistic aggregation by selecting the highest rating of a factor by the judges. A modified pessimistic aggregation method is recommended as the preferred technique. If ratings of subcategories are used, they must be aggregated prior to this operation due to the interactivity of the subcategories within each of the three main categories of factors.

In order to obtain a final, overall rating of each tender, the pessimistic aggregation method is used again to combine the ratings of each of the three categories into a single value. Prior to this calculation, the binary relations for a category may be scaled to ensure the range for each category of factors is similar, and one does not consistently dominate the process of pessimistic aggregation.

Nguyen also demonstrates the use of linguistic qualifying terms such as "very" to modify the importance rating attributed to each category of factors, and to consequently adjust the binary relation matrix prior to calculating the overall rating of a tender. In this manner, the emphasis placed on each category of factors can be altered to accurately reflect the values of the users completing the evaluation.

3.1.3. Risk Management

As opposed to more traditional numeric methods, Kangari and Riggs (1989) proposed a risk analysis model that is based on fuzzy-set theory in order to utilize linguistics when assessing levels of risk. Popularized methods of the evaluation of risks use probabilistic measures to assess the likelihood of the occurrence of an event. The authors explain that these statistical techniques are often not valid for construction-related applications because there is not enough data available to validate the developed models. Moreover, the uncertainty of the information in construction is of a different nature than the random variations of values that statistical analysis can capture. Instead, uncertainty arises when a qualitative, linguistic term is assigned a crisp numeric value. Fuzzy-set theory is able to model this type of uncertainty, and is therefore a natural modeling technique for construction-related processes.

The model presented by Kangari and Riggs is a categorized structure of different types of risk for a project, which is further refined into subcategories of each type of risk. Each sub-category is assigned two variables, "Severity of Loss" and the "Probability of Occurrence", and a linguistic descriptor is assigned by the user that describes the value of each variable for a particular project. Predefined membership functions for descriptors of risk correspond to the linguistic ratings of the variables. A fuzzy set mathematical model based on the extension principle is then used to combine the ratings of risk for all of the sub-categories within a certain category to determine the severity of loss for the overall category. The same technique is used to determine the severity of loss for the entire project, given the linguistic ratings of the sub-categories of risk. The output is a fuzzy membership function that can be assessed linguistically by calculating the Euclidean distance from the output function to each of the predefined membership functions of the ratings of risk. The rating with the smallest distance to the output function is that which best describes the severity of loss for the project, given the known risks.

A concluding note made by the authors is that considerable effort is required to define the membership functions of the ratings of risk. They state that this is an area where research efforts must be concentrated in order to develop a valid model. This concern is one that is often noted in literature describing the use of fuzzy models for construction-related applications.

In similar research to that completed by Kangari and Riggs (1989), fuzzy set theory was utilized by Tah et al. (1992) to provide a framework for risk assessment on construction projects. They suggest that risk factors were divided into two different categories – internal and external. External risks related to a project, such as weather conditions, were deemed uncontrollable. Conversely, internal risks are defined as those that can be managed through the project. In order to obtain a true estimate of the cost of a project, the work should be estimated initially without consideration of any risk factors. Subsequently, the cost of all potential effects of risk should be summed and added to the estimate as a contingency amount.

The research uses the extension principle to calculate a weighted average value of the severity of loss for overall project risk from the severity of loss for several individual risk events, which are rated using subjective, linguistic terms defined by fuzzy sets. The overall project risk is also output as a fuzzy set that can be defined using linguistics, if desired.

The authors state that subjective, linguistic methods are used to rate the factors because they are the best way of describing uncertain parameters when completing an assessment of risk on a project. Probabilistic methods of risk assessment are dismissed as unworkable because precise, numeric ratings, a requirement for statistical analysis, are not effective as a technique for rating risk factors on construction projects.

Paek et al. (1993) add that probabilistic methods can only be effective for determining the impact of risk on a construction project if a historical database is available that explicitly holds the past impacts of similar risk events, under similar conditions. This type of database is difficult to develop due to the unique nature of construction projects. They expand their investigation to include interval analysis, which is also dismissed because ranges are not easily defined for the input variables that are then used to estimate results.

Accounting for the cost impact of risk during the tender stage of a project is the focus of the research conducted by Peak et al. They introduce a method of accounting for risk through the analysis of fuzzy numbers. Two ranges of values are defined for the consequences of a risk event – the most likely interval and the largest likely interval. The two ranges are then combined into a trapezoidal membership function by joining the endpoints. Summing the individual risk event consequences at each membership value will provide a total consequence of the occurrence of all risks on the project. The fuzzy number representing the total consequence can be defuzzified using any of a number of techniques. The authors recommend a ranking method that produces a number between the average most likely value and the average largest likely value. A risk-adjusted tender can then be prepared using Equation 3-1.

$$BP = AC + PF + RC, \qquad [3\text{-}1]$$

where BP = Bid Price, AC = Actual Costs, PF = Profit, and RC = Risk Contingency

Risk management is addressed by Paek et al. through the provision of a method for adjusting the fuzzy numbers that are used to define the consequences of risk events. They demonstrate their method for pricing construction risk through a case study, in which the proposed algorithm calculates the risk contingency to cover potential loss on a large civil construction project.

Kangari and Boyer (1987) developed a knowledge-based system that incorporates fuzzy set theory to allow the assessment of risk in natural language. The resulting automated risk management system queries a user to determine the conditions surrounding a project. The system can clarify questions and explain to the user the logic behind the line of questioning. Risk, and the user's policy for managing risk, are identified for a project through this line of questioning.

The system allows the identified risk factors to be described by the user by using linguistic terms that are defined by fuzzy membership functions. The user provides both the severity of loss and the relative weight of each risk factor. Then the extension principle is used by the system to infer the severity of loss of the total risk surrounding the project. An appropriate linguistic descriptor of the overall severity of loss is then selected by calculating the minimum Euclidean distance from the output fuzzy set to various fuzzy sets representing natural language expressions.

The system developed by Kangari and Boyer has several other features that are useful for completing an analysis of risk for a project. The knowledge base includes recommendations for mitigating the identified risks for a project. In addition, databases are utilized to maintain cost estimate and control data. This information is used to prioritize the activities within a construction project for analysis. Activities with a high standard deviation of cost or opportunity to produce a profit are identified as priorities for risk management.

3.1.4. Construction Methods

Chao and Skibniewski (1998) propose an application of fuzzy set theory that evaluates alternative construction methods. They investigate several other analytical techniques including Monte-Carlo simulation, utility theory, and the analytical hierarchy process and determine that an application of fuzzy set theory is desirable because it allows the decision-maker to influence the outcome of the analysis based on his or her attitude toward risk.

A set of conditional rules is defined by the user that defines their attitude toward risk based on three variables: the probability of profit, the expected profit in favourable conditions, and the expected loss in unfavourable conditions. Each variable is described in a linguistic term with an associated fuzzy set or membership function. Compiling all combinations of the three variables results in a rulebase consisting of twenty-seven rules, with the consequence of each rule defined by the user using a linguistic descriptor.

Each construction method alternative is defined by what is termed a probability-profit-loss vector. This distribution determines the average profit likely under profit conditions and the average loss likely under loss conditions, in addition to the probability of a profit. These three crisp variables for each construction method are fuzzified and fed through the developed rulebase. Each rule's firing strength depends on where the three input variables map to the membership functions of the inputs of the rule. The output membership functions of all of the rules aggregate into an overall output membership function for the construction method through the union operation of the fuzzy sets. The output membership function is then defuzzified to produce a rating between 0 and 100 for that construction method. The ratings of alternative construction methods can then be compared, based on the decision-maker's attitude toward risk.

During construction, it is imperative for project control that site information is properly interpreted so problems can be identified and corrective action taken. Russell and Fayek (1994) theorized that activity attributes, problem sources, problems, and corrective actions are similar for most projects. These variables can be stored within a knowledge base and linked using fuzzy set theory. The knowledge base can then be utilized on future projects to suggest corrective action, given a set of particular problem sources. Problem sources are identified in the research and categorized into ten general classifications. Corrective actions are also determined that are not specific to individual problem sources, but to the problem sources as a whole.

The system combines the output of two schema to rate corrective actions, given a set of problem sources. The first schema relates problem sources to corrective actions by utilizing the fuzzy composition operation. The strength of the relationship between a problem source and an attribute for an activity is determined through user-provided ratings. In addition, expert rules provide ratings of corrective actions for activity attributes. The composition operation is then used to calculate from the two matrices of fuzzy binary relations the relationships between problem sources and corrective actions.

The second schema also relates problem sources to corrective actions, however, in this schema the calculation is based on the type of problem instead of activity attributes. Problem sources are related to the four identified types of problems using expert rules. Corrective actions are also rated for each of the different problem types – time, cost, quality, and no problem. Again, the composition operation is used to determine the relationship between problem sources and corrective actions.

For each schema, two different composition methods are compared. A traditional max-min composition is used, as well as a cum-min method. The authors illustrate that the feature of the cum-min operation is that it takes into account all data, as opposed to the max-min technique that eliminates weaker data from consideration.

An intersection operation is performed on the output matrices from the two schemas to produce a rating of each corrective action. This operation was chosen for its conservative nature. The resulting output recommends corrective action given a set of problem sources, and is calculated from: (1) Activity attributes through Schema A, and (2) Types of problems through Schema B. This method models the decision-making process of a construction professional when faced with a number of problem sources on site.

3.1.5. General Tools

A useful general purpose tool for creating fuzzy expert systems has been developed by Leung and Lam (1998). Although this system is not specifically tailored for construction-related applications, its generality allows the user to create a fuzzy expert system to model decision-making processes, including those in the construction industry.

The fuzzy expert system development tool is based on three subsystems. The first is a knowledge acquisition subsystem that is comprised of several modules to obtain the knowledge required to build a fuzzy expert system. For example, modules for fuzzy terms management and rules management acquire the information necessary to create those components of the fuzzy expert system. A feature of the system is that rules can be defined using either crisp or fuzzy variables, and that rules themselves can be assigned a degree of truth to account for uncertainty.

The second subsystem is the fuzzy knowledge base that stores all the information acquired through the knowledge acquisition process. The final subsystem that completes the overall system is the consultation driver. It either infers values for the input variables in the expert rules by referring to other rules or it queries the user for input. Firing strengths for fuzzy rules are then calculated by fuzzifying the input and carrying out the appropriate operations on the fuzzy input variables defined in the conditional rules. Normal rules with crisp input variables only fire if the antecedent is true. The conclusion made for each rule is then mapped to fuzzy sets representing linguistic descriptors of the output variable. The result is a series of output variables with values described in natural language. If two or more rules have the same consequent, the output fuzzy sets for each rule are combined using the fuzzy intersection operation prior to determining the linguistic descriptor of the variable.

3.2. Scheduling Systems That Use Fuzzy Set Theory

There are few examples in the literature of using fuzzy set theory for scheduling applications. However, the limited number of papers that have been published indicate that fuzzy sets are a robust method for accounting for uncertainty when compiling a project schedule. The research indicates a diverse number of applications for fuzzy sets to be implemented when developing scheduling techniques.

In order to capture non-random uncertainty associated with estimating the effects on certain factors on activity duration, Ayyub and Haldar (1984) used fuzzy set theory to estimate activity durations in a schedule. The results could then be implemented within a deterministic (such as CPM) or probabilistic (such as PERT) scheduling method to arrive at an overall project schedule.

Factors that affect activity duration are defined according to the variables "frequency of occurrence" and "consequences of occurrence". The variables, and an activity's duration, are described using natural language descriptors that can be adjusted using qualifying terms to more accurately assign values. A fuzzy relation, or the cartesian-product, is then defined for the values that all combinations of values that the two variables can assume. A matrix of the total effect of the consequence of all factors based on the frequency of occurrence is then calculated through the union operation on all the fuzzy relations. Similarly, a fuzzy relation is defined for the fuzzy sets of consequences and activity duration. The union of these fuzzy relations then represents the total effect of all consequences on activity duration.

The fuzzy composition of the two fuzzy relations [frequency-consequence] and [consequence-duration] results in a matrix relating the frequency of occurrence of factors to activity duration. The authors provide a method for estimating the duration of the activity and standard deviation of the estimate from the fuzzy composition matrix. The maximum row summation for each value of activity duration corresponds to the highest frequency of occurrence. The probability mass function can be calculated for that row's values as they correspond to the possible activity durations. The result is an activity duration that takes into account non-random uncertainties, which can be used in one of the traditional network scheduling techniques.

Smith and Hancher (1989) use the methods proposed by Ayyub and Haldar to estimate the impact of precipitation on activity duration. The fuzzy composition matrix that results from their study relates the frequency potential of factors that determine the susceptibility of an activity to poor weather to delays in activity duration.

The anticipated weather pattern for a project is determined by using the Markov process and Monte-Carlo simulation. Prediction of precipitation events is accomplished through an analysis of historical weather data and the Markov process. Monte-Carlo simulation generates a random prediction of the weather pattern over the project life. After each predicted precipitation event, the fuzzy analysis is performed for activities in progress on that day. The predicted overall duration for the project can be determined by following this process until the final activity is completed.

An aspect of scheduling that is often overlooked is resource allocation and leveling. Chang et al. (1990) utilized a fuzzy expert system to assist in prioritizing activities within a schedule that are competing for resources. The authors assert that only internal factors such as total float and downstream resource usage are typically accounted for when allocating resources. Their use of a fuzzy expert system is an attempt to also take into account external factors such as weather and change orders.

The proposed method assesses a priority ranking for each activity competing for resources by using the fuzzy expert system to determine the effect of external, project related factors. An algorithm is proposed that uses the priority ranking to assess the effect of internal factors. Consequently, both internal and external factors are considered during the process of allocating resources.

The fuzzy expert system developed incorporates the following concepts. A typical fuzzy expert system with embedded expert knowledge is used to determine the susceptibility of each activity to a set of criteria, when the user inputs project characteristics. The set of criteria is determined through the use of fuzzy propositions, which consist of fuzzy production rules and probabilistic fuzzy propositions. These relationships relate criteria for resource allocation to the likelihood they are applicable in a certain situation. The priority ranking of activities is then calculated using a simple formula based on the defuzzified output of the fuzzy expert system. In order to account for internal factors to accomplish things like resource leveling and optimizing overall project duration, the priority ranking is then used in an algorithm that allows internal factors to be evaluated. The result is an integrated system for resource allocation that takes into account external factors that were traditionally dismissed when completing the exercise.

An alternate network scheduling technique to CPM or PERT has been proposed by Lorterapong and Moselhi (1996) to account for subjective assessments of activity duration. They identify fuzzy set theory as an ideal structure from which to build the schedule analysis technique because it models the uncertainty associated with subjective judgements.

Similar to CPM, a network of activities that a project is comprised of must be defined. However, trapezoidal fuzzy numbers are used for activity durations instead of crisp numbers. Different shapes for the fuzzy numbers are defined by specifying the bounds and spread of full membership for each number.

A forward pass calculation is carried out on the schedule to start the network analysis. Fuzzy early start for any activity is equal to the maximum of the fuzzy early finishes of all its predecessors. The fuzzy early finish for an activity is the fuzzy early start combined with its fuzzy duration. The fuzzy number addition operation is used to calculate the fuzzy early finish. Total project duration is the fuzzy early finish of the final activity in the project schedule.

The backward pass calculations are more complex than in CPM analysis. The fuzzy number subtraction operation is deemed not workable because of the large uncertainties it outputs for fuzzy late times. Therefore, an algorithm has been developed that calculates the fuzzy late start based on the shape of the fuzzy number representing activity duration.

The likelihood of activity durations violating project constraints is analyzed by determining the possibility measure and agreement index. In addition, the critical path is determined through calculating these measures for each individual path within the network.

Ordonez (2002) incorporates the methods proposed by Ayyub and Haldar (1984), Lorterapong and Moselhi (1996), and others into a model that predicts the effects of an activity delay on project schedule. This application combines the various techniques that have been developed for utilizing fuzzy set theory in construction into a comprehensive system for maintaining project control.

When a delay is experienced by a construction activity, linguistic descriptors are used to determine the values of delay-sensitive attributes of the activity, the relationship of each attribute to a frequency of occurrence, and the relationship between the frequency of occurrence and any adverse consequences. Fuzzy membership functions are defined for the linguistic descriptors used and the method proposed by Ayyub and Haldar (1984) is utilized to determine the new activity duration based on the activity and delay information. The probability density function that represents the new activity duration is then converted into a fuzzy membership function.

Ordonez then utilizes the forward and backward pass calculations developed by Lorterapong and Moselhi (1996) to schedule a project in which activity durations are expressed using fuzzy membership functions. The resulting schedule incorporates activity susceptibility to experienced conditions, reassesses activity durations, and determines the impact of delays on overall schedule.

The described research over the past twenty years of fuzzy set theory applied to scheduling is limited in volume. However, fuzzy set theory has been shown to be applicable to a variety of scheduling problems and has characteristics that address many of the shortcomings of other scheduling techniques. The main advantage is that it is able to quantify non-random uncertainty for use in calculations. In addition, it is not a theory based on probabilities that require large amounts of data and calculations to be valid. As such, it is very attractive for construction-related applications where it is difficult to obtain repeatable data in large quantities, and where variables are defined in uncertain, natural language descriptors.

3.3. Automation of Scheduling by Other Means

Other methods have been developed to account for the uncertainty associated with activity durations in schedules. The most widely used is Monte-Carlo simulation. This method has become firmly established with the development of the microcomputer. Its extensive computational requirements required a certain level of computing power to be accessible before applications could become widespread.

The theory behind Monte-Carlo simulation of schedules is that probabilistic functions can be defined to represent activity durations within a network schedule. It can be extremely difficult in the construction industry to obtain enough historical data to calculate the probabilistic functions; therefore, methods have been developed where the functions are defined through subjective assessments.

To carry out a Monte-Carlo simulation, random numbers between 0 and 1 are generated and mapped to the activity duration probability functions. This results in a crisp duration for each activity. A CPM network analysis is then completed to determine the overall schedule duration. This process is repeated enough times to perform a statistical analysis on the resulting project duration. The critical path can be determined by calculating the number of times each individual path within the schedule dictates the overall schedule duration relative to the other paths.

As part of their previously discussed research, Lorterapong and Moselhi (1996) compared their fuzzy network analysis methods to traditional Monte-Carlo network analysis. They identify several advantages that fuzzy set theory provides. No historical data, other than expert opinion, is required to create the network. This is in contrast to probabilistic methods that can require a wealth of historical data to create the probability functions for variables. In addition, the number of calculations required to complete the network analysis is greatly reduced. Finally, they noted that the fuzzy approach is much more transparent to the user than Monte-Carlo simulation. The results of their case studies showed little difference in the actual output of the network analysis when comparing the two systems.

Another promising development in the automation of project schedule control during construction comes from the endeavors of researchers to implement Fully Integrated and Automated Project Processes (FIAPP) as proposed by the Construction Industry Institute (CII). For example, Chang et al. (2001) are testing with case studies their "N-dimensional construction management information system". Many aspects of project control can be integrated and/or automated by assigning various attributes to components within a 3-D model of a project. When one of the attributes is time, the project life can be simulated and evaluated prior to actual construction, based on the visual, 3-D model.

As the construction of a project progresses, "as-built" conditions can be assigned to the attributes of components. This allows the project schedule to be reassessed at any point during construction. The model is updated and the remaining work is simulated to determine if any changes to the overall project schedule are caused by the as-built conditions. If undesirable delays or accelerations in activity duration are experienced or forecast, the time attribute for various components can be adjusted by implementing different construction strategies or resource loading. The completion of remaining construction can again be simulated through the model to determine if the changes had the desired effect on project delivery. The result is an ongoing evaluation of project schedule and, if desired, other component attributes such as cost. One of the major advantages of the N-D system is it provides the opportunity to truly visualize the project and its components as they are projected to occur without the risk of actual construction. Any number of simulation techniques can be used in the N-D model to forecast the values of component attributes, such as activity duration.

3.4. Potential for Further Research of Scheduling Methods

There is an opportunity to develop innovative automated scheduling techniques because of the limited efforts applied to date. It appears that the current trend is moving toward integrating scheduling within an overall project delivery and control system. Future research will likely focus on a more integrated approach than what has been accomplished in the past. Sophisticated modeling and simulation techniques will likely allow the products that result from future research to be widely distributed throughout industry.

This research project builds on concepts and techniques previously developed and described throughout the various sections of Chapter 3. There have been very few applications of fuzzy set theory to construction scheduling, which is the area where this research contributes most to the existing body of knowledge. In addition, one of the most significant deficiencies observed in other applications of fuzzy set theory to solve construction problems is that proposed methods are not fully developed and tested. This work is structured in such a way that components of the proposed model can be developed and tested using data collected from the construction industry. An extensive effort has been made to collect the required data to fully complete development and testing of the model.

Finally, the proposed scheduling system was developed with the intent that it could be integrated within an overall project delivery system. This provides opportunity for further research and development of the concepts proposed in this work. The flexibility of the model allows the system to be utilized within the framework of other systems.

4. STRUCTURE OF THE SCHEDULING SYSTEM

There are three main components of the scheduling system that has been developed to accomplish the goals of this research project. Each performs a specific function. The first component determines important project parameters from very general user requirements for a new building. A developer of a parking structure may only know the number of cars that need to be accommodated and the size of the parcel of land on which the building is to be constructed. The intention was to be able to automatically schedule the required construction project based on a minimum of these two pieces of information. This portion of the system allows a significant advantage to be realized when planning a project. The effects on the construction schedule of various design scenarios can be quickly determined to help evaluate each scenario.

The second element of the overall scheduling package converts the project parameters into a summary-level project schedule. Although the activity durations in the schedule are simply based on production achieved during past projects, it provides a starting point from which to base a risk analysis.

Finally, the third component of the scheduling system performs a risk analysis on the summary-level project schedule by utilizing a fuzzy expert system. The outputs of the fuzzy expert system are the variations in activity durations that can be expected when the impacts risk factors on the project schedule are considered.

When all three components are integrated, the result is a seamless scheduling system that can produce a risk-adjusted, summary-level project schedule based on very minimal user input. This type of system would be invaluable for any member of a project team when planning a construction project. An owner could easily determine the effects on construction duration when considering building requirements. Consultants and construction managers would be able to ascertain the effects of managing risk in different ways. Even the eventual builder could use the summary-level schedule as a starting point to develop the work breakdown structure.

The components of the scheduling system are explained in detail throughout the remaining sections of this chapter. Methods used to develop these components are discussed further in Chapter 5. A diagram illustrating the components of the system, as well as the function of the overall scheduling system, is shown in Figure 4-1.

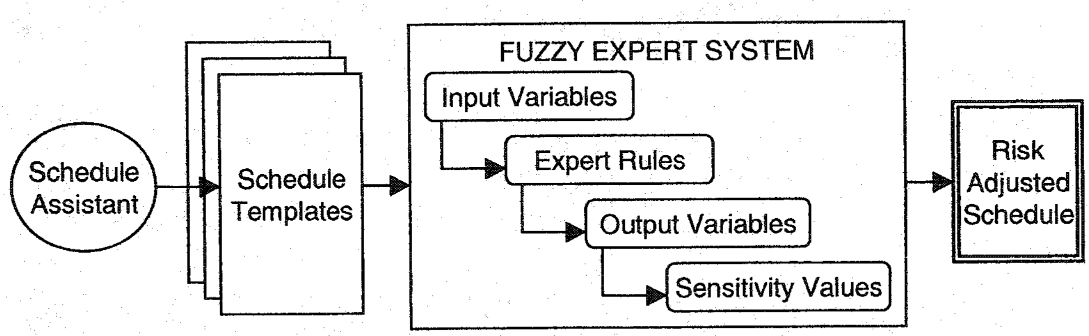

Figure 4-1: Components of the Scheduling System

4.1. Schedule Assistant

A small application, named *Schedule Assistant*, was programmed in Visual Basic to package the first component of the scheduling system with a user-friendly interface. This portion of the system is that which determines required project parameters from limited user input. A series of ratios are used to extend the few parameters given by the user into a series of parameters that together form a meaningful description of the construction project. A screen capture of *Schedule Assistant* is shown in Figure 4-2.

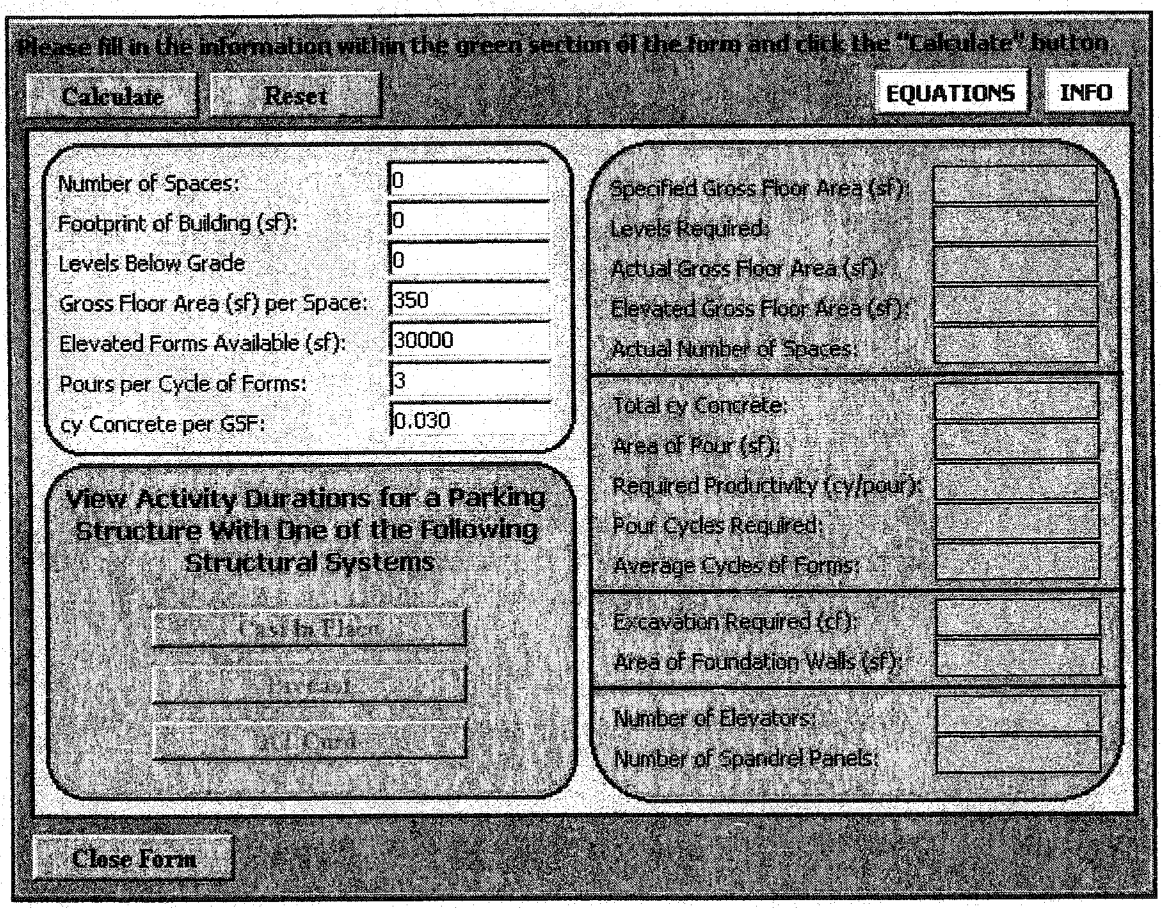

Figure 4-2: Schedule Assistant

In Figure 4-2, the button identified as "AT Curd" refers to the precast column/cast-in-place deck structural system that corresponds to one of the three schedule templates in the system.

The only two parameters that a user must have prior knowledge of are "Number of Spaces" and "Footprint of Building". Other input parameters ("Levels Below Grade", "Gross Floor Area per Space", "Elevated Forms Available", "Pours per Cycle of Forms", "cy Concrete per GSF") have default values suggested by the system. This allows a person to use the system in the preliminary stages of planning when there is very limited knowledge of the details of a proposed project. As more information becomes available, the user can modify the default input parameters to capture a more accurate representation of the project.

The key parameter used by the application is "cy of concrete per GSF". This value is used to translate the area measures given by the user into the volume of concrete that a building of the size required will be comprised of. With the quantity of concrete established, several other project parameters can then be determined. A complete list of the calculations performed by *Schedule Assistant* is included in Appendix A.

Schedule Assistant also provides additional output not required by the subsequent functions of the scheduling system, but useful for other analyses that a project manager may wish to carry out during a planning exercise. For example, productivity values for the placement of concrete are given, in addition to information regarding the cycling of formwork.

4.2. Schedule Templates

The series of schedule templates included in the system were created to automate the generation of a summary-level project schedules. Using a portion of the output of *Schedule Assistant*, the templates perform the function of the second component of the overall scheduling system – to create a project schedule given certain project parameters.

A schedule template specific to each combination of structure type and construction method was developed. This is required to ensure that all activities that occur when using a particular construction method to build a structure of a certain type are considered. There are three different schedule templates for parking structures that have been included in the system. One is applicable to cast in place concrete structures, one to precast structures, and one was created for a hybrid system of precast columns and beams with cast in place decks. All three schedules have several common activities, however, each also has activities that are unique to it alone. The schedule templates are included in Appendix B.

A standard format was required for the templates as a starting point from which to automate the scheduling process. The appropriate level of activity summarization has been determined to ensure that the flow of work is accurately represented. However, the level of detail remains at a summary level because the overall scheduling system is meant as a planning tool, not as an instrument for detailed project control. When creating a more detailed project schedule, the user can drill down into these higher level hierarchical activities to break them into their component tasks.

Productivity values for the activities within the schedule templates are expressed in units that match the project size output variables of *Schedule Assistant*. Because of this feature, the two components can be integrated to work together to produce baseline schedules with very little input from the user.

4.3. Fuzzy Expert System

A description of fuzzy expert systems has been provided already in Chapter 3. However, it is useful to review the properties of these systems that played a role in influencing the decision to build the scheduling system around a fuzzy expert system.

Most importantly, fuzzy set theory provides a framework with which uncertain, linguistic descriptors of real-life conditions can be translated into numbers that can be subsequently used in calculations. This feature has the potential to be very powerful for the construction research community because historical data from industry is often extremely limited. Therefore, researchers are often required to depend on data collection tools such as surveys and interviews to gather the information required to advance their projects. In addition, those working within the construction industry are very much oriented toward using natural language descriptors to explain their environment. Crisp, numeric representations of many processes are very difficult to make in an accurate fashion. Fuzzy set theory provides a method that allows data to be collected for modeling purposes when situations are best described using meaningful, natural language terms.

The benefit of using an expert system to model the decision-making process of assessing the effects of risk on schedule is that the described advantages of fuzzy set theory can be incorporated by expert systems. An expert system is fundamentally a series of calculations that have been defined by expert knowledge. The numbers that are translated from linguistic descriptors of a situation by fuzzy set theory can be used as input by the expert system in the calculations defined by the rules in its knowledge base. Moreover, the numbers that are given as output by the expert system can be translated back into linguistic descriptors, once again by using fuzzy set theory. Membership functions defined by fuzzy set theory can be seamlessly integrated with an expert system, creating a powerful and flexible fuzzy expert system that is applicable to a wide range of situations. In addition, scheduling of construction projects relies heavily on heuristic knowledge, therefore, the structure of rules contained within the fuzzy expert system naturally mirrors the actual scheduling process.

4.3.1. A Fuzzy Expert System for Creating Risk-Adjusted Schedules

The logic relationships and activity durations included in each schedule template described in Section 4.2 are calculated from those realized on previously completed projects. These components are based on average historical production of activities that were completed under standard conditions. Therefore, a schedule produced from one of the templates alone is accurate only if standard conditions are again expected on the project under consideration. To account for non-standard conditions, a fuzzy expert system has been developed that adjusts activity durations according to project-specific risk factors.

The fuzzy expert system that is utilized in this application follows the generally accepted method for performing a risk analysis, which is to combine the likelihood of occurrence with the impact of occurrence for each risk factor. In this application, the likelihood of occurrence is always considered 100% due to the structure of the fuzzy expert system and is therefore not formally included in the framework of the system. This will be explained further in the discussion of input variables in section 4.3.2. The impact of occurrence is determined by the various components of the fuzzy expert system.

Certain components are a part of any fuzzy expert system including membership functions for descriptions of variables, input and output variables, and expert rules that calculate the effect on the output variables given a particular set of input values. However, the system developed in this research project contains a few unique characteristics that were developed to meet various requirements specifically related to the scheduling application. The structure of the fuzzy expert system used for this application is shown in Figure 4-3, and each component is described in the sections that follow.

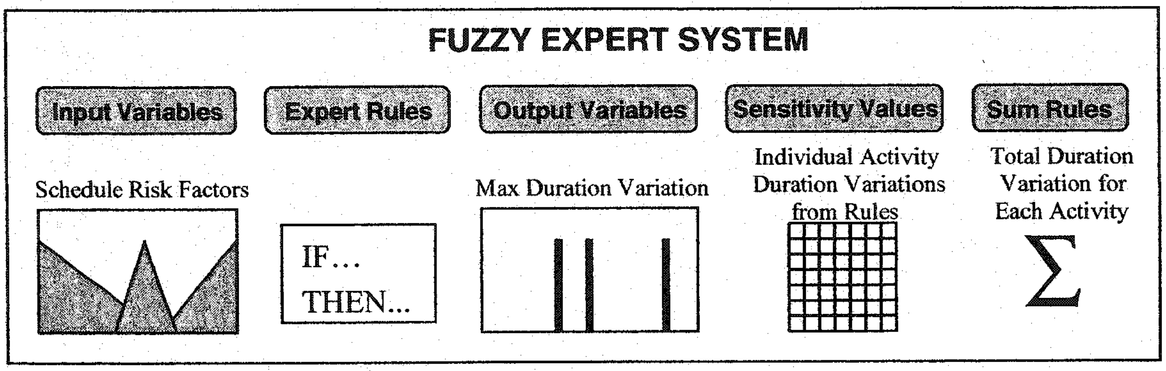

Figure 4-3: Structure of the Fuzzy Expert System

4.3.2. Input Variables

The input variables of the fuzzy expert system are defined as risk factors that may occur on a construction project, and that have an effect on schedule. Only factors that may impact the construction schedule alone or in concert with other events are included in the system as input variables. Risk factors that affect construction systems other than the schedule are not included in the system because, even if they had been included, none of the rules in the system would include those risks in their antecedent. For example, a risk factor such as "Quality of Formwork Materials" only affects the quality of a finished concrete surface, not the frequency of the pour cycle, and would therefore not be considered a risk factor to be included in this model.

Forty-four risk factors that affect schedule were compiled during this research, however, a subset of fifteen risk factors were used as input variables for the system. This reduction was necessary because of the amount of data available to develop the model and is described in more detail in Chapter 5. The factors not part of the subset explicitly included in the system can be considered as causing a normal effect on all projects that are scheduled using the developed system. Therefore, they have no impact on the activity durations included in the schedule templates, which were calculated using historical data from projects with standard conditions. A chart listing the risk factors identified as potentially impacting a construction schedule and the subset of risks used as input variables is shown in Figure 4-4.

Comprehensive List of Schedule Risk Factors	Subset of Risk Factors Used in the Model
Physical 1. Precipitation 2. Temperature 3. Humidity 4. Wind 5. Freeze-thaw cycles 6. Ground Conditions 7. Natural Disaster **Regulatory** 8. Timeliness of Permitting Process 9. Timeliness of Inspections **Contractual** 10. Delay in Award of Contract 11. Disputes in Contract Interpretation 12. Timeliness of Payments 13. Financial Uncertainty of Parties to the Contract **Owner/Consultants** 14. Speed of Owner's Decisions 15. Interference by Owner 16. Quality Demanded by Owner 17. Timely Production of Design Documents 18. Design Errors/Completeness of Design 19. Changes to Design (Change Orders) **Construction** 20. Quality of Initial Schedule Plan 21. Access to Site 22. Interference with Utilities (Existing/Unexpected) 23. Quality of Field Management 24. Work Done Out of Sequence 25. Skill of Workforce (Quality of Subcontractors) 26. Shift Length 27. Labour Disputes 28. Availability of Materials 29. Timeliness of Materials Delivery 30. Quality of Materials 31. Materials Handling Procedures 32. Material Quantity Variation 33. Shop Drawings Procedures 34. Effectiveness of Equipment Used 35. Congestion of Trades 36. Accidents/Safety 37. Cleanliness of Site **Performance** 38. Changes in Production Rate 39. Construction Errors 40. Fabrication Errors 41. Quality of Workmanship **Other** 42. Theft/Vandalism 43. Government Policy Changes 44. Public Disorder	**Physical** 1. Precipitation 2. Temperature / Humidity 3. Ground Conditions **Regulatory** 4. Timeliness of Permitting and Inspections **Contractual** 5. Disputes in Contract Interpretation **Owner/Consultants** 6. Speed of Owner's Decisions 7. Interference by Owner 8. Design Errors/Completeness of Design 9. Changes to Design (Change Orders) **Construction** 10. Quality of Initial Schedule Plan 11. Quality of Field Management 12. Skill of Workforce (Quality of Subcontractors) 13. Shift Length **Performance** 14. Changes in Production Rate 15. Quality of Workmanship

Figure 4-4: Input Variables – Risk Factors Affecting Schedule

Values that can be used to describe the presence of many of the input variables on a construction project are limited and standardized to three natural language descriptors: "unfavourable", "normal", and "favourable". These descriptions are well understood by most people and are often used in standard practice when explain the effects of various factors on a construction project. Therefore, they are a natural way to describe many of the input factors in the system. When a user of the scheduling system assesses a risk factor using one of the natural language descriptors, the system considers the likelihood of occurrence for that descriptor of the factor to be 100%. This is the first step in the risk analysis performed by the fuzzy expert system.

In order to be able to use such "fuzzy" descriptions of the input variables, membership functions are defined for each descriptor of each variable. The membership functions are not random distributions of values that the descriptor might mean in a particular instance. Instead, they are a distribution of values that indicate the degree of matching that a certain value has with a descriptor of the variable. Unfortunately, this subtle but critical differentiation is often not well understood because a random distribution used in statistical analysis may have an identical shape to that of a membership function used in fuzzy set theory. A sample of one of the input variables used in the system and the associated membership functions is shown in Figure 4-5.

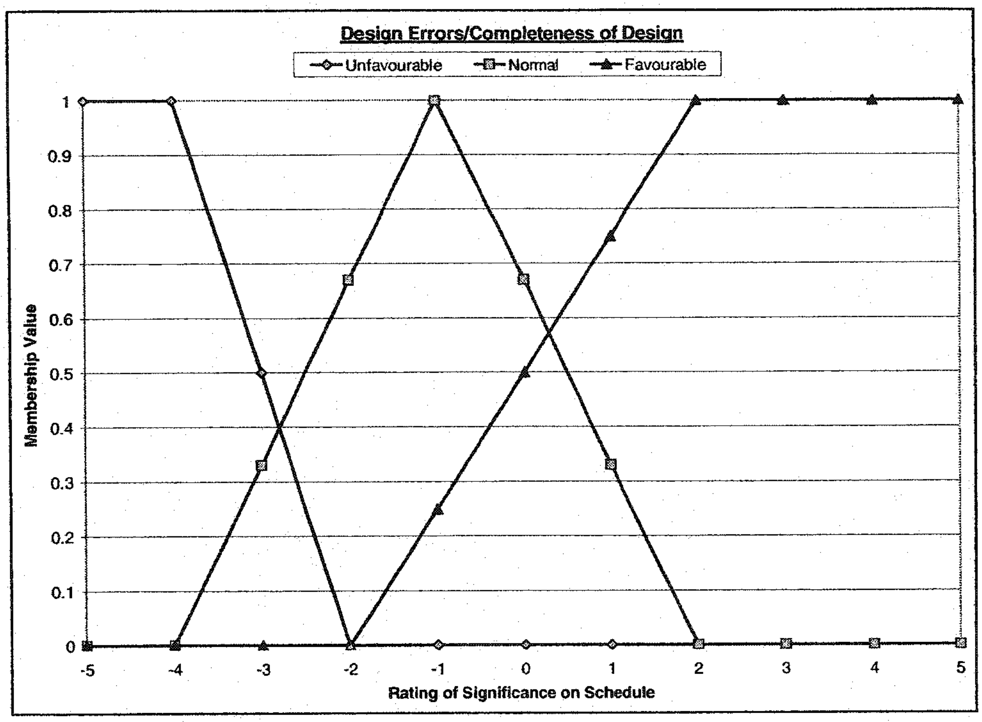

Figure 4-5: Membership Functions for Risk Factor "Design Errors/Completeness"

The easiest way to identify a fuzzy membership function is to integrate the function. If the integration results in a value of 1.0, the function is most likely a random distribution, however, if the function integrates to a value other than 1.0, and the range of values on the y-axis is from 0 to 1.0, it could be used as a fuzzy membership function. Appendix C diagrams the membership functions for the input variables used by fuzzy rules within expert system.

It was decided that four of the risk factors in the scheduling system are variables that are best described crisply using numeric measures. The risk factors that are crisply defined are "Precipitation", "Temperature/Humidity", "Shift Length", and "Changes in Production". In order to illustrate the flexibility of fuzzy expert systems, crisp input for the rules based on these factors is required by the system. This is further described in the section on expert rules, section 4.3.3. Appendix D includes the direct relationships modeled by these four rules.

4.3.3. Expert Rules

In most expert systems, the majority of the data collection required to build the system is undertaken to develop the knowledge base, which is represented by expert rules. However, in this scheduling application the rules that have been defined are simple and direct. One rule is defined for each of the descriptors of the input variables, which describes how the variable affects activity durations in the schedule when that particular descriptor expresses the variable best. As will be described in more detail in Chapter 5, very little data analysis was required to create the rules. Instead, the expert knowledge within the system is stored in the membership functions of the descriptors of the input and output variables, as well as the sensitivity values for each activity in the schedule templates.

The flexibility of fuzzy expert systems allows different types of rules to be utilized by the scheduling system. When applicable, rules that contain variables that are best described numerically in a crisp manner can be used. Also, different methods of calculating the output of rules can be used and later combined with the output of the fuzzy rules. Four of the fifteen risk factors cause output to vary directly as input changes. Therefore, rules were developed that have variables that must be crisply defined by the user. These crisp rules are seamlessly integrated with the fuzzy rules within the fuzzy expert system. A typical fuzzy rule from the system is shown in Equation 4-1, and Equation 4-2 is one of the crisply defined rules.

IF [Interference by Owner] is *Unfavourable* THEN the [Maximum Activity Duration Variation Due to Risk Factor "Interference by Owner"] is *Unfavourable*......................[4-1]

IF [Shift Length] is *7 Hours* THEN the [Maximum Activity Duration Variation Due to Risk Factor "Shift Length"] equals *(Shift Length – 8) / 8*..[4-2]

The rules relate the effect of each risk factor to the activity durations within a schedule template. Each descriptor or measure of a risk factor has a predetermined impact on the schedule. When a fuzzy rule fires to the degree appropriate for a given input, the output of the rule is scaled according to the firing strength of the rule. The crisp rules calculate an impact on schedule that is determined by the equation that defines the relationship between input and output.

A chart of all the rules defined for the scheduling system is shown in Table 4-1. The crisp rules are identified in the table with the description "Varies Directly". The output of the rules is a multiplier of activity duration and therefore no units of measure are defined.

Input Risk Factor	Favourable Output	Normal Output	Unfavourable Output
Precipitation	Varies Directly	0.00	Varies Directly
Temperature/Humidity	Varies Directly	0.00	Varies Directly
Ground Condititons	-0.20	0.00	3.00
Regulatory Timeliness	-0.50	0.00	2.00
Contract Interpretation	-0.10	0.00	2.51
Speed of Owner's Decisions	-0.25	0.00	2.10
Interference by Owner	-0.10	0.00	0.95
Design Errors/Completeness	-0.25	0.00	0.80
Changes to Design	-0.20	0.00	2.05
Quality of Initial Schedule	0.00	0.05	0.25
Quality of Field Management	-0.25	0.00	2.00
Skill of Workforce	-0.21	0.00	1.74
Shift Length	Varies Directly	0.00	Varies Directly
Changes in Production	Varies Directly	0.00	Varies Directly
Quality of Workmanship	-0.10	0.00	1.44

Table 4-1: Expert Rules of the Scheduling System

Equations 4-1 and 4-2 can be used in conjunction with Table 4-1 to clarify the structure of the rules in the fuzzy expert system. Each of the input risk factors using causes either three fuzzy expert rules (one for each of the favourable, normal, and unfavourable conditions) or any number of crisply defined rules to be defined in the expert system.

The risk factor "Quality of Initial Schedule" is an anomaly due to the fact that the output of the rule based on normal input is equal to 0.05. As described previously, all of the other rules based on normal input result in activity duration variations of zero. The decision to arbitrarily adjust this single rule was made after completing the data collection for this research project. The project managers interviewed expressed that they use caution when interpreting schedule plans because of the level of accuracy that is present during the early planning stage. Therefore, it was decided to introduce an uncertainty factor of five percent to all activities that are normally scheduled. This acknowledges that the schedule plans are summary-level plans that would be developed early on in the planning phase and can be expected to lack a certain level of accuracy. In order to eliminate this uncertainty factor, the "Quality of Initial Schedule" can be rated as "Favourable", which results in activity variations of 0.00. This rating technique matches conceptually the opinions expressed by the members of industry that contributed to this research.

In each of the rules, there is only one condition in the antecedent and also only one consequence. The effects of different combinations of input within each rule were not considered because the input variables were deemed to be independent. It was believed that none of the risk factors used as input for the fuzzy expert system had any effect in causing the other risk factors identified to occur. However, due to a lack of available data, the assumption could not be tested adequately.

Independent input variables make it possible to sum the output of the individual rules when calculating the overall impact of all the identified risk factors on a project schedule. This allows assessments of different combinations of risk factors to be calculated despite the simple rules contained within the knowledge base. The assumption of independence of variables is discussed further in the conclusions of the research made in Chapter 7.

As mentioned, expert knowledge is stored within the membership functions of the variables expressed in the rules and the sensitivity values for each activity, which will be described in the following section. This is one of the unique aspects of this scheduling system – traditionally, expert knowledge is stored within the rule base of an expert system, however, this application shifts the bulk of this knowledge to other components of the system. Significant advantages were realized during the development of the system due to this feature.

4.3.4. Output Variables

The consequent of each fuzzy rule in the system is a descriptor of an output variable, which describes the effect of the input variable in the antecedent of the same rule on the activity durations in the project schedule. Similarly to the descriptors of the input variables, the descriptors of the output variables are also the natural language descriptors "unfavourable", "normal", and "favourable". In this case, these descriptors were applied to activity duration variations caused by the risk factor. A sample output variable, and its corresponding membership functions, is shown in Figure 4-6.

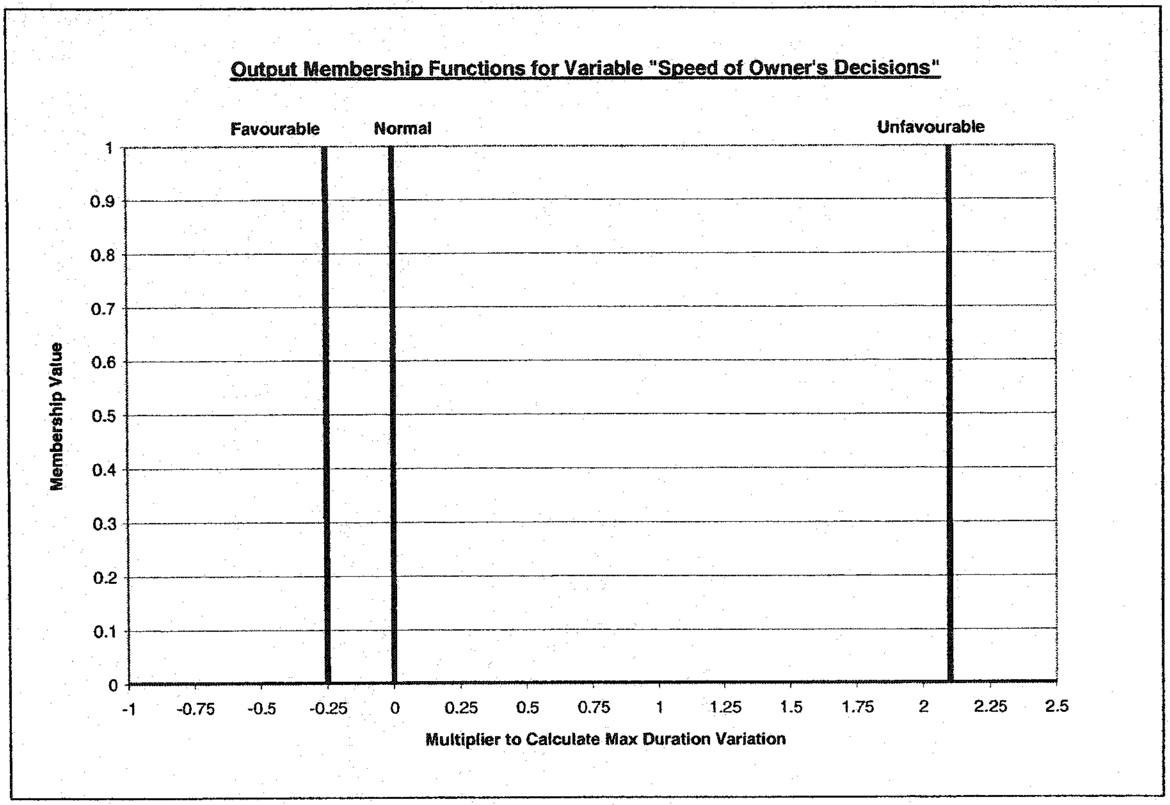

Figure 4-6: Output Variable "Speed of Owner's Decisions"

The membership functions for the descriptors of the output variables are of a different type than those that were defined for the input variables. Each membership function is a single-value spike that represents a crisp value. Only a single value of output matches a descriptor with a full membership value of 1.0 and all other values of output correspond to a membership value of 0 for the descriptor. When a rule fires at less than full strength, the appropriate membership functions are truncated or scaled in the same manner as the previously-described fuzzy membership function. However, a much simpler calculation is used to determine the final output. The single output value spike is scaled down according to the firing strength of the rule. This method has been utilized based on the technique incorporated by the Matlab Fuzzy Logic Toolbox (1994), in which Sugeno-type inferencing is used. An example of this calculation is shown in Figure 4-7.

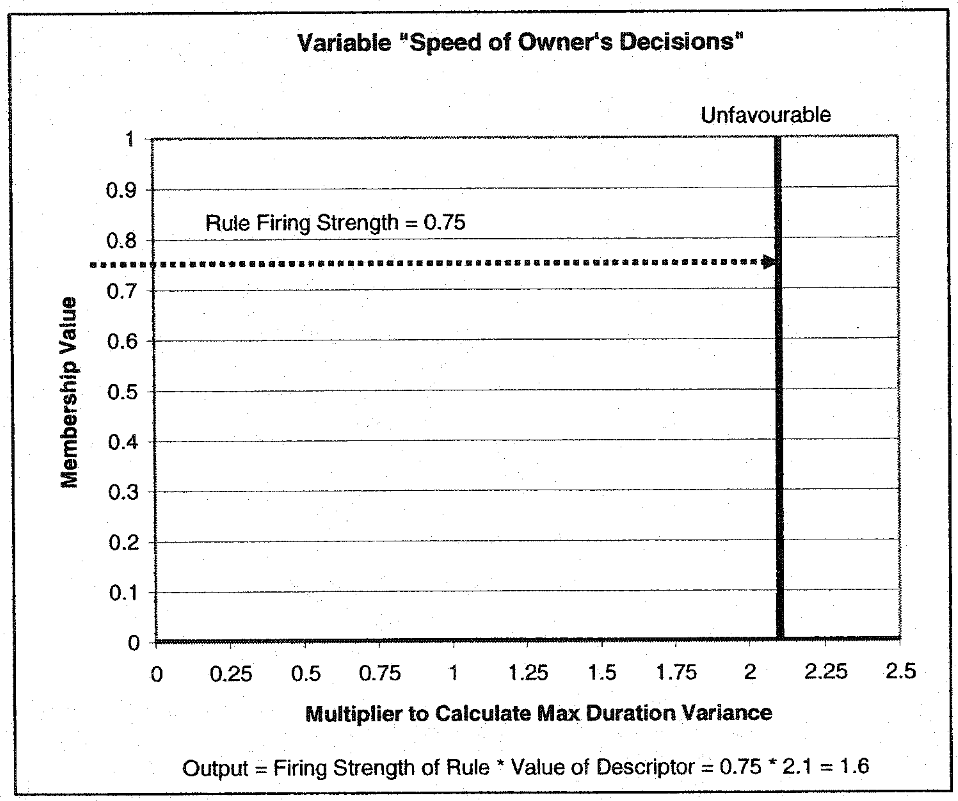

Figure 4-7: Modifying Output Based on the Firing Strength of a Rule

This type of output membership function was chosen for the scheduling system because of the research objective to develop components of the system as fully as possible using a case study approach. The single-value output membership functions could be calculated from data collected from analysis of schedules from completed projects, as will be explained in Chapter 5. Therefore, the consequence of the rules in the system did not need to be based in entirety on expert opinion obtained through surveys. Diagrams of the membership functions for each of the output variables are included in Appendix E.

4.4. Sensitivity Values

Sensitivity values are included in the scheduling system because the output of the fuzzy expert system requires further refinement prior to being useful in any meaningful kind of analysis. Taken on its own, the output of any rule should never be used as an indicator of activity duration variations because the output is an intermediate calculation within the overall framework of the scheduling system. By definition, the output of a rule is the maximum duration variation possible for any of the activities within the schedule, for a particular descriptor of the input variable under consideration. The sensitivity values determine the duration variation for each individual activity in the schedule given this output.

The sensitivity values represent the degree an activity is vulnerable to a descriptor of one of the input variables. Therefore, one is defined for each combination of activity within a schedule and descriptor of an input variable risk factor. The sensitivity values within the system are presented in Appendix F.

4.5. Summation of Duration Variations

Every rule that fires when presented with a set of input causes a duration variation to be calculated for each activity within the schedule template. Some variations may be tabulated as zero effect. In fact, every input risk factor except "Quality of Initial Schedule" rated as "normal" will cause a duration variation of zero for every activity in the schedule. This is because the schedule template was developed considering only "normal" conditions, which will be discussed at greater length in Chapter 5.

The final component of the scheduling system is the summation of all the duration variations predicted for an activity. As mentioned before, this calculation is possible because the input variables were assumed to be independent. The result is a multiplier that represents the variation from the predicted activity duration in the schedule template for each activity in the schedule. This completes the assessment of the impact of occurrence for the risk analysis performed by the fuzzy expert system.

The resulting risk-adjusted schedule has considered the unique conditions of risk surrounding a project and is a better representation of the likely project schedule than the template it is based on. It can be used with confidence for communication purposes and can be expanded on to create a schedule used for project control.

4.6. Use of the Scheduling System

The structure of the scheduling system is best illustrated by working through a sample application. The following example provides an overview of the function of the system:

- An above-grade parking structure is planned to hold 1000 vehicles. 50 000 sf of land is available and the designer has chosen a precast structural system.

- *Schedule Assistant* calculates the project attributes shown in Figure 4-8 using the equations listed in Appendix A.

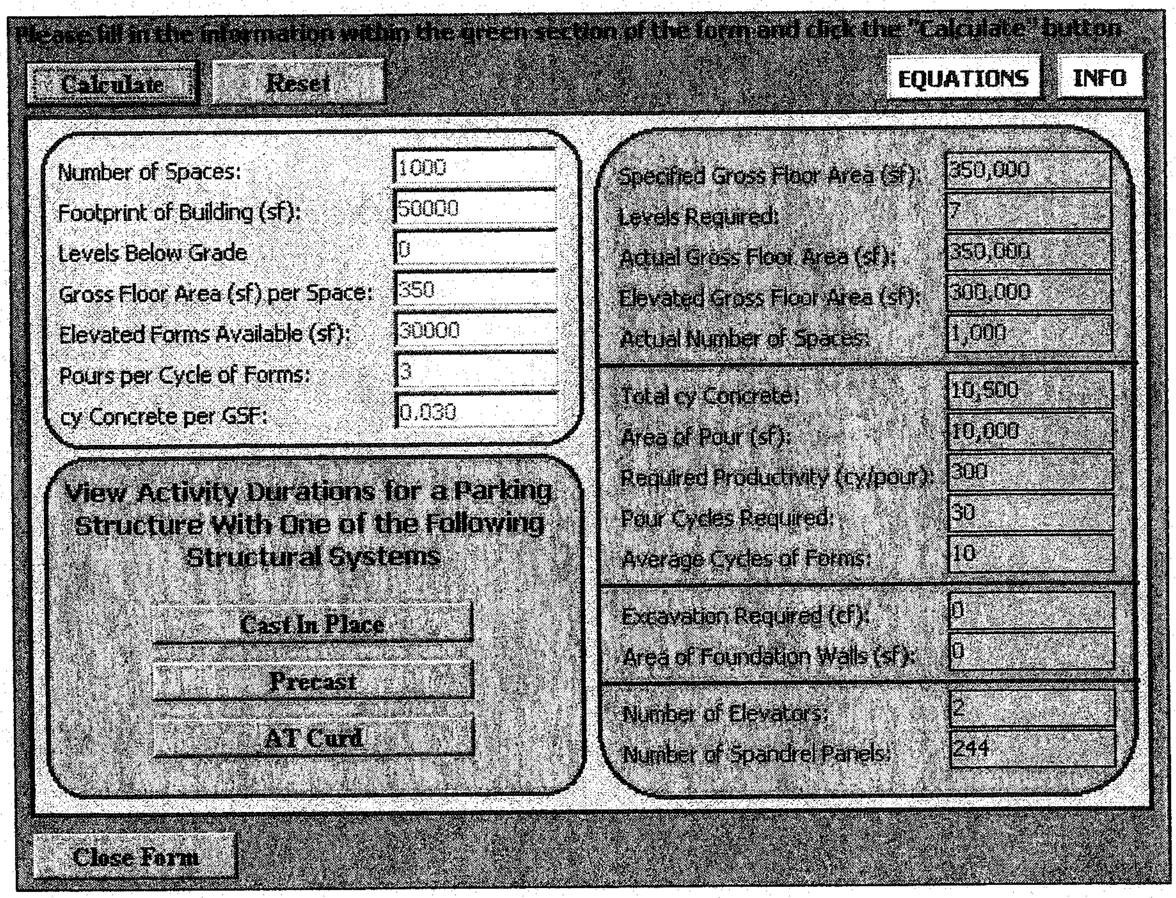

Figure 4-8: Sample Project Attributes

- The precast structure schedule template is adjusted according to the project attributes. Figure 4-9 contains the schedule plan based on the precast template.

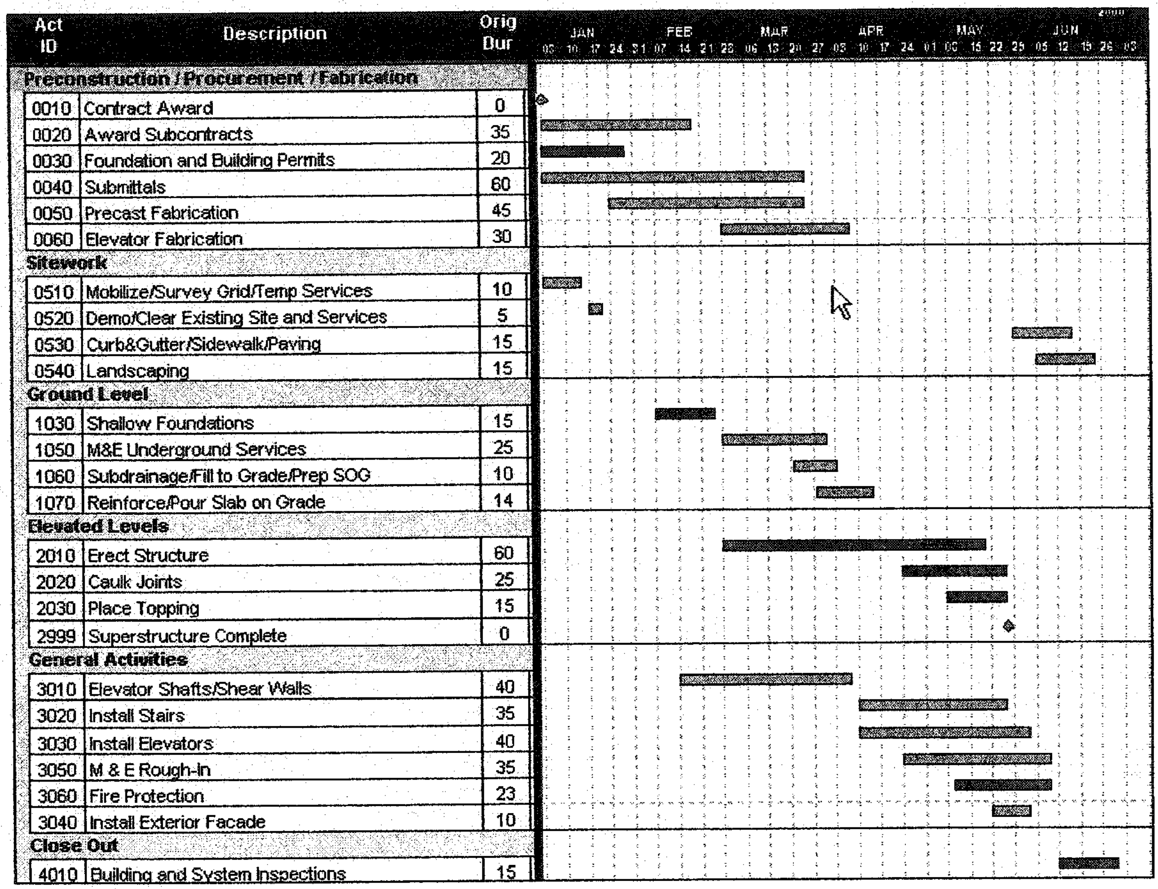

Figure 4-9: Sample Project Schedule Plan

- There are three risk factors that are anticipated as having values other than normal. The impact of design changes is predicted to be *unfavourable* and interference by owner is predicted to be *unfavourable*. Quality of initial schedule is considered *favourable*, which eliminates it from consideration (see explanation in section 4.3.3).

- The ratings of factors are given linguistically, therefore, the risk factors rated as *unfavourable* cause four of the fuzzy rules in the expert system to fire due to overlap of the *unfavourable* and *normal* membership functions. To simplify this example, the four crisp rules are given input values that do not cause any activity duration variations and are therefore not considered. The rules in the system that fire are included in Equations 4-3 through 4-6.

If [Changes to Design] is *Unfavourable* THEN the [Maximum Activity Duration Variation Due to Risk Factor "Changes to Design"] is *2.05*..........[4-3]

If [Changes to Design] is *Normal* THEN the [Maximum Activity Duration Variation Due to Risk Factor "Changes to Design"] is *0*..........[4-4]

If [Interference by Owner] is *Unfavourable* THEN the [Maximum Activity Duration Variation Due to Risk Factor "Interference by Owner"] is *0.95*..........[4-5]

If [Interference by Owner] is *Normal* THEN the [Maximum Activity Duration Variation Due to Risk Factor "Interference by Owner"] is *0*..........[4-6]

- The effects of a risk factor on schedule are calculated through a weighted average of the output all the rules that fire with that particular factor in their antecedents. This method is used for the Sugeno-type output membership functions and corresponds to the Centre of Area defuzzification technique for fuzzy membership functions. The weighting for rules that implicitly fired due to overlap with a descriptor in their antecedent and the descriptor that was explicitly used as to rate the factor is calculated by measuring the membership value at the overlap point of the two functions. For the changes to design factor, this overlap occurs at a membership value of 0.67 and for interference by owner the overlap is at 0.40 (reference Appendix C). The rule that contains the term given by the user to describe the variable is given a weight of 1.0. If crisp ratings had been given, the respective weights would equal the membership value at the intersection of the rating given and the membership function of each descriptor. Equation 4-7 calculates the weighted average of output for the changes to design factor and Equation 4-8 does the same for the interference by owner factor.

Max variation due to [Changes to Design] = (1.0*2.05+0.67*0.0)/(1.0+0.67)..............[4-7]

= 1.23

Max variation due to [Interference by Owner] = (1.0*0.95+0.40*0.0)/(1.0+0.40)........[4-8]

= 0.68

- Sensitivity values are then used to translate the maximum activity duration variation given as output from the rules into duration variations for each activity in the schedule. The calculations based on the sensitivity values for the two risk factors that affect the sample project are included Tables 4-2 and 4-3.

Activity Duration Variations from Changes in Design

[A]	[B]	[C]	[D]	[E]
		Changes in Design		
Activity	Initial Schedule	Output	Sensitivity	Activity Variation (C*D)
Award Subcontracts	35	1.23	1.00	1.23
Permits	20	1.23	1.00	1.23
Submittals	60	1.23	1.00	1.23
Precast Fab (PRE,ATC)	45	1.23	1.00	1.23
Elevator Fab	60	1.23	1.00	1.23
Mobilize	10	1.23	0.00	0.00
Demo	5	1.23	1.00	1.23
Curb&Gutter/Sidewalk	15	1.23	0.50	0.62
Landscaping	15	1.23	0.50	0.62
Shallow Foundations	15	1.23	0.50	0.62
M&E UG	25	1.23	0.25	0.31
Prep SOG	10	1.23	0.25	0.31
Pour SOG	14	1.23	0.31	0.38
Erect Precast Structure (PRE)	60	1.23	0.50	0.62
Caulk Joints (PRE)	25	1.23	0.25	0.31
Place Topping (PRE)	15	1.23	0.10	0.12
Elevator Shafts	40	1.23	0.64	0.79
Install Stairs	35	1.23	0.50	0.62
Install Elevators	40	1.23	0.25	0.31
Install Exterior Façade	33	1.23	0.75	0.92
M&E R-in	35	1.23	0.25	0.31
Fire Protection	23	1.23	0.24	0.30
Inspections	15	1.23	0.00	0.00

Table 4-2: Sensitivity Values for Changes in Design

Activity Duration Variations from Owner Interference

[A]	[B]	[C]	[D]	[E]
		Owner Interference		
Activity	Initial Schedule	Output	Sensitivity	Activity Variation (C*D)
Award Subcontracts	35	0.68	1.00	0.68
Permits	20	0.68	0.00	0.00
Submittals	60	0.68	1.00	0.68
Precast Fab (PRE,ATC)	45	0.68	1.00	0.68
Elevator Fab	60	0.68	1.00	0.68
Mobilize	10	0.68	1.00	0.68
Demo	5	0.68	1.00	0.68
Curb&Gutter/Sidewalk	15	0.68	1.00	0.68
Landscaping	15	0.68	1.00	0.68
Shallow Foundations	15	0.68	1.00	0.68
M&E UG	25	0.68	1.00	0.68
Prep SOG	10	0.68	1.00	0.68
Pour SOG	14	0.68	1.00	0.68
Erect Precast Structure (PRE)	60	0.68	1.00	0.68
Caulk Joints (PRE)	25	0.68	1.00	0.68
Place Topping (PRE)	15	0.68	1.00	0.68
Elevator Shafts	40	0.68	1.00	0.68
Install Stairs	35	0.68	1.00	0.68
Install Elevators	40	0.68	1.00	0.68
Install Exterior Façade	33	0.68	1.00	0.68
M&E R-in	35	0.68	1.00	0.68
Fire Protection	23	0.68	1.00	0.68
Inspections	15	0.68	1.00	0.68

Table 4-3: Sensitivity Values for Owner Interference

- The duration variations for each activity due to each factor are then summed to obtain overall activity duration variation due to the risks surrounding the project. Table 4-4 shows this calculation for the sample project.

Total Activity Duration Variations

[A] Activity	[B] Initial Schedule	[C] Total Duration Variation (Design + Owner)	[D] Final Schedule (B*[1+C])
Award Subcontracts	35	1.91	102
Permits	20	1.23	45
Submittals	60	1.91	175
Precast Fab (PRE,ATC)	45	1.91	131
Elevator Fab	60	1.91	175
Mobilize	10	0.68	17
Demo	5	1.91	15
Curb&Gutter/Sidewalk	15	1.30	34
Landscaping	15	1.30	34
Shallow Foundations	15	1.30	34
M&E UG	25	0.99	50
Prep SOG	10	0.99	20
Pour SOG	14	1.06	29
Erect Precast Structure (PRE)	60	1.30	138
Caulk Joints (PRE)	25	0.99	50
Place Topping (PRE)	15	0.80	27
Elevator Shafts	40	1.47	99
Install Stairs	35	1.30	80
Install Elevators	40	0.99	80
Install Exterior Façade	33	1.60	86
M&E R-in	35	0.99	70
Fire Protection	23	0.98	45
Inspections	15	0.68	25

Table 4-4: Total Activity Duration Variations

- The output of the system is a risk-adjusted, summary-level schedule containing activity durations that account for the risks identified by the user. Figure 4-10 shows the risk-adjusted schedule for the sample project.

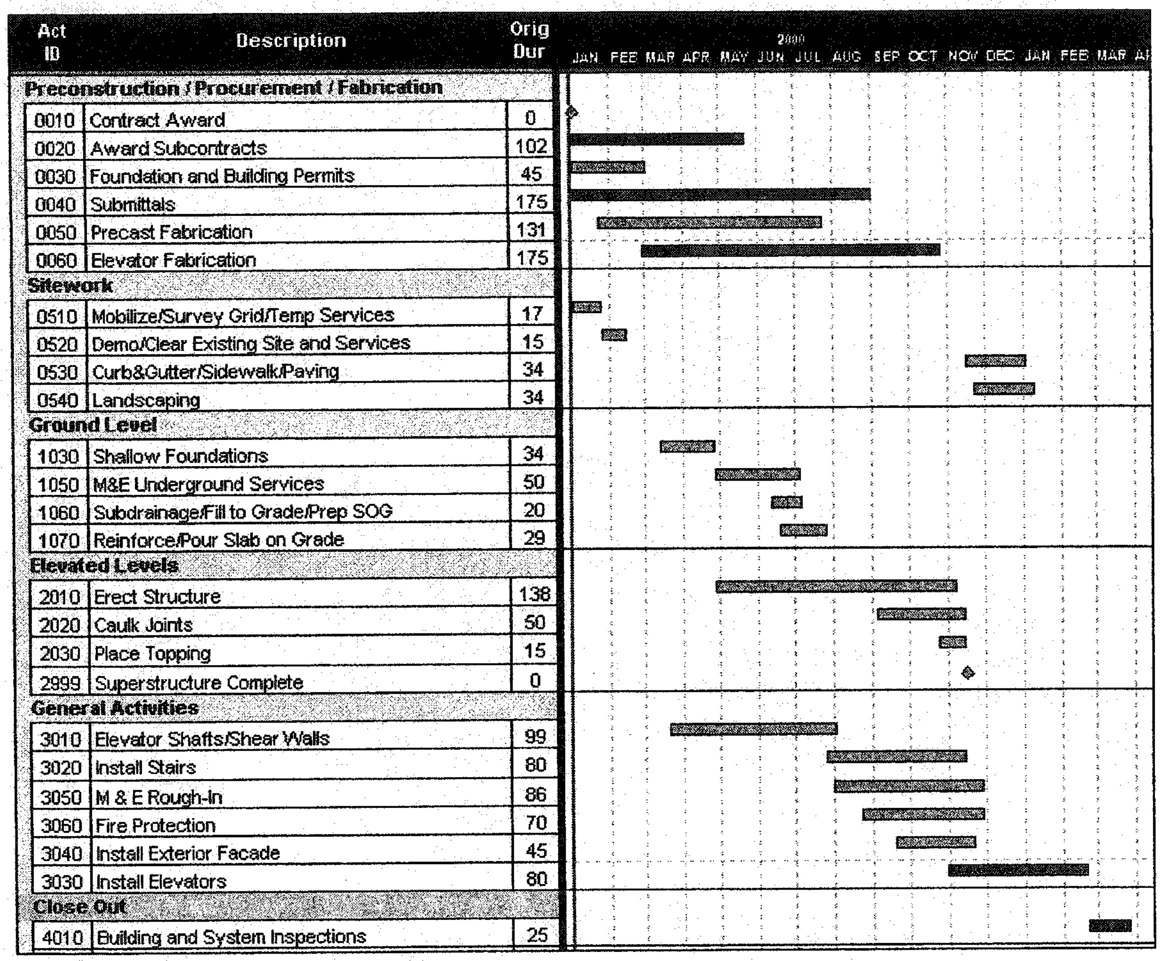

Figure 4-10: Risk-Adjusted Schedule for Sample Project

5. DEVELOPING THE SCHEDULING SYSTEM

A multi-phase strategy of data collection was used to develop and test the scheduling system. Information collected through case studies, interviews with project personnel, and a literature review was compiled during the project. This information was then used to shape the various components of the scheduling system.

The very fact that a concerted effort was made to collect the data required to develop and test the system makes this project fairly unique amongst other construction research that has implemented fuzzy set theory. Often in the literature, a model of a system is proposed, however, the membership functions and other components required to actually implement the system are not fully developed. This is largely due to the difficulties inherent in the process of collecting data from the construction industry.

The data collection phase of this research had a five-month duration and was completed with the cooperation of PCL Constructors Inc., one of the largest general contractors in North America. Branch offices in four major North American cities took part in the study and a full month of travel between the centres was required to compile the information into a useful form and to conduct interviews. Despite this depth of study, very real deficiencies in the quantity of the data collected remain, which are discussed in Chapter 7.

5.1. A Model Based on Case Studies

One of the intentions for the development of the scheduling system was to base as many components of the system on data that was collected from actual events, as opposed to expert opinion. This direction was established because of the belief that the system would be more accurate if it modeled the actual cause-effect relationships on historical construction projects than if it modeled expert opinion of the effects those relationships had on projects. It was felt that expert opinion is more effective in interpreting the meaning of the effects of risk on projects instead of the actual effects themselves. The nature of the scheduling system being created was not one that produced recommendations for corrective action and thus the expert knowledge required to develop it was reduced substantially.

The scheduling system was therefore created in such a way that expert knowledge was used in a very limited fashion during the development stage. Expert opinion was required to create the input membership functions required for the fuzzy expert system, as well as to identify risk factors that had an effect on project schedules. However, all the other components of the system were developed through the study of completed projects. Expert opinion was also utilized to occasionally confirm assumptions that were made about the collected project data.

When a project is undertaken in the manner described, the main difficulty is collecting enough hard data to be able to develop the components of the system. It is relatively easy to collect expert knowledge, but historical project data are often very difficult to find and interpret. Also, the information stored on past projects may not include data that are required for development. Even if the information is of a useful nature, it will likely require reformatting to meet the parameters of the research project. Despite these challenges, it was felt that it was important to build an accurate model of the scheduling process and to demonstrate a robust method of developing the components of the model.

5.2. Literature Review

A literature review was conducted with two main objectives when this research commenced. One was to study similar research that had been conducted by the construction research community. As was discussed in Chapter 3, there have been limited applications of fuzzy set theory to solve problems within the construction industry. Much of the research that has been undertaken takes the familiar structures of fuzzy set theory and expert systems and uses them directly to model a specific decision making process. A few applications to scheduling have been made by researchers such as Ayyub and Haldar (1984), Smith and Hancher (1989), Chang et al. (1990), Lorterapong and Moselhi (1996), and Ordonez (2002). However, none were found of a similar nature to this research project.

The other objective of the literature review was to develop the list of input variables that could be used in the fuzzy expert system. The input variables are risk factors that affect schedule. It was found that other attempts to determine this type of risk factors had been make previously by other researchers. Kangari and Boyer (1987) developed an extensive set of construction risk factors, not limited to those that impact schedule, when building a fuzzy expert system to assist in risk management. In a different study, Tah, et al. (1993) broke the construction risks that affect the contractor into those under the control of the contractor (internal) and those that are controlled by outside forces (external). This categorization was created as part of a research project that produced a method of accounting for risk in an estimate by using fuzzy set theory. In the process of developing a model to assist in corrective action selection, Russell and Fayek (1994) also produced an extensive list of construction-related risks.

There are certainly many other researchers that have compiled lists of risks that affect construction projects. Those identified were analyzed and reduced to only the risks that affect schedule. Also, risks that were dependent on others were adjusted or eliminated to attempt to build an inventory of risk factors that were independent of each other. This was done to ensure the integrity of the model being used to represent the process of scheduling projects. Forty-four risk factors were compiled during this operation, which are listed in Figure 4-4.

During the literature review, the crisp rules were also developed. Two of the crisp rules related to the effects of weather and were developed in part by using data from Environment Canada (2000). The other two described the effects of shift length and changes in productivity on schedule, which were refined throughout the project during the interviews with project personnel.

5.3. Case Studies I

Several components of the scheduling system were developed entirely, or in part, by studying historical data from completed projects. In order to mirror the format of the data collection process, these components will be divided into two groups – Case Studies I (Section 5.3) and Case Studies II (Section 5.5). The components independent from the interview process, or that the interviews later further developed, will be discussed in Section 5.3. Section 5.5 follows the section on interviews with project personnel and will then examine portions of the system developed through case studies but dependant on information collected through the interview process.

The schedule templates for cast-in-place concrete, precast concrete, and the hybrid cast-in-place/precast construction system were all developed through case studies. Activities, logic relationships, and productivities that imply activity durations were all calculated by examining data that were collected and stored on previously completed construction projects. All the projects under consideration were completed by firms that operated within the PCL group of companies.

The initial investigation of historical project data revealed a total of nineteen stand-alone parking structures that had been completed by PCL over the past ten years. Many other structures were identified that included integral parking garages, however, these projects were not considered in this research. It was determined that construction methods and design strategies were significantly different when building a parking garage under a hotel or office tower compared to building a stand-alone parking structure. Therefore, projects included in the study were limited to stand-alone structures.

The next stage after identifying completed projects was to examine project files to determine if a schedule plan was archived for the project. This was done in several ways including having project personnel fax hard copies or email electronic files of the project schedule plan. If files had already been archived or could not be located on the computer network, a physical search of the project file archives was made. The result of this rigorous search resulted in only ten projects being identified that had recorded and archived a schedule plan. Appendix G lists the projects completed by PCL and indicates those that had enough data stored to be included in this study.

The fuzzy expert system included as part of the overall schedule system modifies standard activity durations in a schedule template to account for the effects of risk anticipated for a project. Therefore, only schedule plans that were created accounting for "normal" conditions were taken into consideration when developing the templates. Interviews with the schedulers of the projects were used to confirm that the schedule plans were based on normal conditions. This restriction was initiated to limit the activities, relationships, and productivities in the templates to those that had not been affected by project-specific risk events. If an as-built schedule had been included when developing the templates, it would be likely that activity durations would be skewed according to unusual conditions that actually were present on that individual project. Of course, if an abundance of data had been available, as-built schedules could have been used because an accurate average could be calculated from the historical data for activity durations. However, with such limited data available for this research, it was critical that no effects from unusual events were included in the data set used to develop the templates.

Another consideration that became immediately apparent was that the schedules obtained from each completed project were built at extremely variable levels of detail. Some of the more detailed schedule plans included hundreds of activities, while others had much less detail represented by a few dozen activities. A process of determining the ideal number of activities within a summary schedule was carried out to resolve these discrepancies. This was done by grouping activities into common categories and eliminating activities that were unique to a specific project. In this systematic way, each schedule was converted into a common list of activities. The process was complicated by projects that had overlapping activities in multiple phases, as well as activities with shared resources. At times, a subjective judgement was required to allocate an original activity into one of the schedule template summary activities.

In addition to the schedule information that was collected from the identified projects, project attributes were also determined so that activity durations could be stored as productivities within the schedule templates. The project attributes were also used to develop the *Schedule Assistant* application, which relies on ratios calculated from historical data to output measures of project size. Both these portions of the system were intentionally developed using the same measures of productivity so that the output of

Schedule Assistant could be directly used to create a summary-level schedule from the appropriate template. The productivity calculations based on historical data are included in Appendix H. During this process, default values for the input parameters required by Schedule Assistant were also calculated from the project attributes.

Repetitive activities, such as pouring a concrete deck, were included in the schedule templates by showing an ideal cycle time. In the case of pouring concrete, a weekly cycle was used. However, the overall scheduling system does end up reflecting the information contained within the case studies because the productivities stored in *Schedule Assistant* are based on it. For example, if a schedule plan allowed 9 days to pour 900 m3, the productivity in *Schedule Assistant* would be stored as [900 m3 / 9 days * 5 days per week] = 500 m3/wk and the cycle time stored the template would be 1 week. This is opposed to showing the activity of 9 days with a productivity of 900 m3 per 9 days. This technique may introduce a error into the productivity value due to a change in the number of times associated activities, such as stripping forms, would be need to be cycled. However, this error is negligible because the method that the case study schedules would have likely been developed. An overall productivity for pouring concrete and a desired area of pour would be used to calculate each pour's duration. By dividing the quantity by duration, the original productivity value is uncovered. This is the value used in the scheduling system.

In order to assist in the data collection process, a series of forms was developed to standardize each portion of the process for every project included in the study. The portion of the form used for collecting productivity information is shown in Appendix I.

Only schedule plans were used to develop the schedule templates, however both schedule plans and as-built schedules were required to develop output membership functions and sensitivity values for activities. As shown in Appendix G, five of the nineteen projects identified for study had archived both schedules. This resulted in an extremely limited data set available for model development. Fortunately, projects of all three structural types were represented in the five complete data sets.

Each of the five projects that had archived both required schedules were analyzed to determine variations from planned activity durations during actual construction. Appendix J displays the form used to manually tabulate the activity duration variations. The duration variation for each activity in the planned and as-built schedules, modified to the format of the appropriate schedule template, was tabulated for the case study projects. Appendix K shows the planned and as-built schedules from the case studies, modified to fit the schedule templates.

The duration variations were normalized during model development by calculating them as percentages of the original activity duration. This was done to allow the variations observed from parking structures with different project attribute values (i.e. size) to be averaged in meaningful way when developing the model. When the units of the variations are left as 'time', the impact of the variation varies substantially depending on the overall schedule duration. A ten-day delay is likely a larger concern for a four-week activity than a similar activity with a duration of eight weeks on a larger project. When normalized, the ten-day delay results in an activity duration variation of 0.50 on the smaller project, but only 0.25 on the larger. In the developed scheduling system, normalized values are used in calculations to ensure the model is applicable to projects of a wide variety of attributes and the impact of risk events on a project are captured accurately.

5.4. Interviews with Project Personnel

There are several reasons why interviews with project management staff that worked on the projects studied were required. The overall scheduling system could not have been developed as outlined without some kind of interview process to provide critical information for certain components of the system, particularly the fuzzy expert system. Also, the interviews provided a means of collecting 'soft' data from the projects. For example, a list of factors was produced that contained construction tips that the project personnel considered important when building a parking structure and is shown in Appendix L. This kind of information is important to be captured when sharing best practices within a company. The sample worksheets used to guide the interviews are included in Appendix M.

For each project included in the study, the project manager was asked to confirm various attributes of the planned and as-built schedules archived from their completed project. Activities and relationships were verified and the planned schedule was confirmed as being scheduled according to "normal" conditions - for the reasons explained in Section 5.3. In addition, the forty-four input variables (risk factors) were reviewed for completeness. The opportunity was given to add to the list throughout the interview.

The key information required from the interviews was the risk factors that caused the observed activity duration variations in the case studies. The input and output membership functions, as well as the sensitivity factors, required this information for development. For each observed activity duration variation from the planned to as-built schedule, project personnel were asked to identify the various risk factors that caused the change in duration. The list of risks identified through the literature review was used as an aid to this process. They were then asked to determine proportionally the impact that each risk factor had on the activity. In this manner, the activity's duration variation was assigned to the various risk factors that caused it.

Data required to develop the input membership functions for the risk factors chosen by the interviewee were then collected. To begin, the numerical measure that is most commonly used to assess each risk factor was identified. A simple rating of on a scale of 1 to 10 was the most common measure suggested, however, an attempt was made to determine a scale that was less subjective and had more significance for each risk factor. For example, instead of a scale of 1 to 10 for a variable such as "Experience", a measure of the actual years of experience is less subjective and may provide a more meaningful representation of the risk factor. Any risk factor that did end up with a scale defined for its numerical measure was later converted to a scale with a range of –5 to +5 in order to provide consistent, meaningful numerical measures for the input variables.

Values of the numerical measure that each variable was defined over were subsequently associated with the descriptors "Unfavourable", "Normal", and "Unfavourable". A value, or range of values, that represented normal conditions for each risk factor was provided by the interviewee. All values below that range were taken as unfavourable and all those above the normal range were favourable. Frequency graphs of all the responses for each risk factor were then developed and are shown in Appendix N.

Research conducted by Ayyub and Haldar (1984) and Elton et al. (1993) has shown that the shape of a membership function is not nearly as important as the range of values that it spans. Therefore it was decided to use simple trapezoidal membership functions to represent the descriptors of the input variables in this model. This shape is easy to represent mathematically, and can be modified somewhat by refining the descriptors with qualifying terms, if desired. Triangular membership functions were mapped to fit the frequency diagrams for the descriptors of risk factors, which are also shown in Appendix N.

There were limits imposed for the membership functions of the descriptors "unfavourable" and "favourable" for each risk factor. The functions were forced to a value of 0.0 at their intersection point if they overlapped. This actually is quite intuitive, as normally one would not consider an occurrence favourable at the same value for which it was unfavourable. This adjustment was a requirement based on the method of determining output membership functions and sensitivity values, which is described in Chapter 5.

It was decided to limit the data collected for input membership functions to only those risk events that the project staff experienced when constructing the case studies. Consideration was given to asking for information relating to all the risk factors identified through the literature review, however, the interviewees most likely would not have experienced many of the factors on the list. Therefore, much of the data collected would have been educated guesses and provided a false sense of confidence in the results. The result of limiting the interview to those risk factors identified on the case studies was the creation of a subset of risk factors that membership functions could be defined with some measure of confidence and then be used to develop the overall system. The subset was supplemented by risk factors that were considered important by the developer. The data used to develop the additional risk factors was decided on by utilizing the experience of the research team. The risk factors developed based on expert opinion are those included in Appendix N and the complete list of risk factors included in the schedule system is shown in Diagram 4-4.

The final information obtained through the interview process was a numeric measure of each risk factor identified as causing a duration variation on the project. This information was required to develop the output membership functions and sensitivity values. The project staff assigned values for risk factors on the project using the range of numeric measures previously determined for each risk factor.

5.5. Case Studies II

By utilizing the data collected through the literature review and interviews, the output membership functions and sensitivity values for the scheduling system could be developed. These were the final two components required to complete the overall scheduling system and were calculated in conjunction with each other.

The first step was to use the results of the case studies and interviews to determine how the activities in a schedule template would be affected if the descriptors of each input variable (risk factor) had fired at full strength. For each case study, the risk factors that had been identified as impacting the project were examined. The value of a risk factor for the project was used to scale the observed duration variation for each activity to its maximum value by utilizing the developed input membership functions.

For example, assume that one of the project managers determined that the risk factor "Design Errors/Completeness of Design" was rated –3 for its significance on schedule on his or her project. This corresponds to a membership value of 0.5 for the descriptor *unfavourable* and a membership value of 0.33 for the descriptor *normal*. The project manager also judged that the same factor caused 0.75 of the delay in completing foundations of the parking structure. Through the comparison of the planned and as-built schedules, it was observed that a total duration variation of 0.8 was experienced for the foundations activity. With this information, the effect of the rule for the descriptor *unfavourable* of the factor alone on the foundations activity can then be calculated. Equation 5-1 illustrates this calculation, which simply rearranges the weighted average calculation introduced in section 4-6 to solve for output.

Unfavourable Effect of Factor on Activity

= Activity Delay Due to Factor * ((Rated Value of Input Mapped to *Unfavourable* MF + Rated Value of Input Mapped to *Normal* MF) – (Rated Value of Input Mapped to *Normal* MF * Output MF for *Normal* Effect of Factor)) / Rated Value of Input Mapped to *Unfavourable* MF ....[5-1]

The output membership function for the *Normal* descriptor of any risk factor is defined as being equal to 0.0, therefore Equation 5-1 can be simplified and solved for the sample problem as shown in Equation 5-2.

Unfavourable Effect of Factor on Activity

= Activity Delay Due to Factor * (Rated Value of Input Mapped to *Unfavourable* MF + Rated Value of Input Mapped to *Normal* MF) / Rated Value of Input Mapped to *Unfavourable* MF

= 0.75*0.8 * (0.5 + 0.33) / 0.5 = 0.6 * 0.83 / 0.5 = 0.996 ....[5-2]

After the activity duration variations were scaled for all projects, any that occurred on multiple projects to the same risk factor were averaged. Ideally, enough values would have been available to obtain a statistically valid sample size, however, due to the limited data available this was not possible.

The output membership functions for each risk factor were determined by selecting the largest activity duration variation for both "Unfavourable" and "Favourable" descriptors. The shapes of these membership functions were single value spikes. As previously described, the output value for the descriptor "Normal" is set to 0.0 to allow the duration from the schedule template to stand unchanged if the risk factors are rated normal. These output membership functions represent the largest activity duration variation in the schedule that would be caused by each descriptor of the risk factor. A chart showing the development of the output membership functions is shown in Appendix O.

Sensitivity values to the risk factors were then developed for each activity in the schedule templates. These values convert the output of the rules (largest activity duration variation) into duration variations for each activity in the schedule template. The development of the sensitivity values was accomplished by dividing the scaled activity variation for each activity due to a certain risk factor (calculated using Equation 5-2) by the output membership functions for the same factor. In this way, the activities most affected by a risk factor are given a sensitivity value to that factor close to 1.0 and those unaffected by the factor receive a value of 0.0. The sensitivities to "Unfavourable" and

"Favourable" conditions were averaged to obtain the final sensitivity value for each activity. The development of sensitivity values is also shown in Appendix O.

5.6. Development Issues

The main development issue that arose during this research project is the lack of data available. This is a common phenomenon when researching construction processes and made the development of the model difficult at times. Even though the research incorporated project information stored by a modern construction company that has some of the best business practices in the industry, in many cases the data required for this project was not available.

The most common deficiency in the data available was the updated, as-built project schedule. It seemed that a schedule plan was usually developed prior to construction, however, it was mainly used as a communication tool for the owner. The schedules were not used for project control and therefore rarely updated. Of course, this may have been due to only parking structures being included in the study. These projects were generally completed in less than six months at a cost of less than $10 000 000. For these relatively small projects, the project management may decide that the advantages that updating the project schedule afford are not significant enough to pursue. In any case, the amount of data available severely limited the number of projects that could be included in the study. The issue of data availability is further discussed in Chapter 7.

Another issue that arose during development of the scheduling system was the accuracy of information obtained through the interview process. Several factors were noted during the interviews for this research. Most importantly, any project that had been completed more than one year ago was not fresh in the minds of the project managers any more. They had difficulty remembering cause and effect relationships for activity duration variations that had occurred on older projects. This gives a very limited window of opportunity for obtaining meaningful data through the interview process.

When interviewees were asked to rate anything on a scale, there was immediate confusion over what the scale represented. For instance, the scale of 1 to 10 was often used to rate the descriptors of a factor, as well as the effect on schedule that factors had during a project. This scale was confusing because people had problems with the abstraction required to place a concept on a rating scale. They weren't sure if the rating scale referred to the amount of significance ("less" or "more") or the type of significance ("unfavourable" or "favourable"). Even after being told the latter definition was correct, people had difficulty rating the factors. In retrospect, a scale of –5 to +5, with 0 being "no effect", -5 being "unfavourable", and +5 being "favourable" may have been more understandable.

Those people being interviewed also had difficulty with the concept that a "favourable" descriptor of a factor may happen to be rated in the "unfavourable" end of the scale presented. This can often occur if the norm is for the factor to have a very unfavourable effect on a project. A less unfavourable effect would be considered relatively favourable.

Also, when rating the presence of a risk factor during a project, some people were not sure if they were rating the effect on the overall schedule or the effect on a single activity in the schedule. In this case, they should have been rating the way the factor affected the individual activity that had a measured duration variation.

All of the above issues that arose during the interviews create a certain level of uncertainty regarding the quality of responses. However, the development of membership functions for a fuzzy expert system relies on gathering data from the common body of knowledge, which can only be done through the interview process. Therefore, all responses were included when developing the system.

6. RESULTS FROM THE SYSTEM

As the data collection phase of this research project came to a close, it became clear that a working prototype of the type scheduling system would not be able to be as fully tested as originally planned. The lack of available data made it difficult to establish a sound testing strategy. However, testing and calibration of the developed system were still desired to allow analysis and enhancement of the system's performance. A method was developed where output from the system was compared to expert opinion. In this way, an indication of how well the scheduling system mirrored the decision-making process of experts could be determined.

6.1. Testing the Scheduling System

Testing of the scheduling system was accomplished by presenting a series of scenarios to the system. The risk-adjusted schedules that were output from the system were compared to schedule templates that were modified by experts to account for risk in each scenario. This approach was used because the lack of completed projects that were found to have complete scheduling data recorded. It was not possible to separate complete data sets for testing from the data sets used to develop the system because of the few case studies that were used in development. The method and testing results are described in detail in the sections that follow.

Five project scenarios were created for the purpose of testing the scheduling system. Project characteristics were defined for each scenario that allowed a schedule template to be selected and activity durations to be calculated. Two cast in place, one precast, and two precast column/cast in place deck scenarios were created. The project characteristics of the five scenarios are listed in Table 6-1.

Scenario 1 714 Spaces Hybrid Cast-in-Place Deck / Precast Column Structure 250 000 GSF 50 000 sf Footprint 5 Parking Levels Above Grade Shallow Foundations 2 Elevator Banks 20 Elevated Slab Pours 10 000 sf per Slab Pour	**Scenario 2** 686 Spaces Cast-in-Place Structure 240 000 GSF 80 000 sf Footprint 3 Parking Levels 1 Level Below Grade 32 600 cy Excavation Pile Foundations 1 Elevator Bank 16 Elevated Slab Pours 10 000 sf per Slab Pour	**Scenario 3** 5143 spaces Precast Structure 1 800 000 GSF 225 000 sf Footprint 8 Parking Levels 2 Levels Below Grade 91 667 cy Excavation Pile Foundation 3 Elevator Banks Field-topped Double-Tees
Scenario 4 10 000 Spaces Hybrid Cast-in-Place Deck / Precast Column Structure 3 500 000 GSF 500 000 sf Footprint 7 Parking Levels Above Grade Pile Foundations 3 Elevator Banks 120 Elevated Slab Pours 25 000 sf per Slab Pour	**Scenario 5** 1286 Spaces Cast-in-Place Structure 450 000 GSF 90 000 sf Footprint 5 Parking Levels Above Grade Shallow Foundations 1 Elevator Bank 36 Elevated Slab Pours 10 000 sf per Slab Pour	

Table 6-1: Project Characteristics of the Scenarios Used for Testing

The construction methods of the scenarios were chosen while keeping with the expertise of the four participating project managers in mind. This was done to ensure each participant would be able to respond accurately to the scenarios under consideration. Also, at least one project scenario for each type of construction included in the schedule templates was included in the testing.

Risk factors that took values other than normal were chosen for each scenario. The number of risk factors chosen varied from three to five. Less than five factors was felt to be the range within which a user of the system would select the number of factors. However, it was decided that one or two factors would not result in very complex decision-making on the part of the people taking part in the testing of the system. Therefore, three to five factors were defined for each scenario.

For each scenario, the values for risk factors were rated both linguistically and crisply in an attempt to determine whether the system was able to perform more robustly for one of the two methods. The intent was to choose the same risk factors for the linguistic and crisp analysis, however, an error was made for Scenario 1 when defining the linguistically rated risk factors. For that scenario only, there are different factors identified for the crisply rated and linguistically rated situations. This did not have a significant impact on the results. Table 6-2 lists the ratings of risk factors for each scenario.

Risk Factor	Rating
Scenario 1a: Crisp (1 Response)	
Interference by Owner	-4
Quality of Initial Schedule Plan	+4
Quality of Field Management	+3
Scenario 1b: Linguistic (1 Response)	
Ground Conditions	Unfavourable
Interference by Owner	Unfavourable
Quality of Field Management	Favourable
Scenario 3: Crisp (2 Responses)	
Timeliness of Permitting/Inspections	-5
Interference by Owner	+4
Changes to Design	-3
Quality of Workmanship	-3
Scenario 3: Linguistic (1 Response)	
Timeliness of Permitting/Inspections	Unfavourable
Interference by Owner	Favourable
Changes to Design	Unfavourable
Quality of Workmanship	Unfavourable
Scenario 5: Crisp (1 Response)	
Ground Conditions	+3
Disputes in Contract Interpretation	-4
Design Errors/Completeness	-3
Quality of Initial Schedule Plan	-2
Quality of Workmanship	+2
Scenario 5: Linguistic (1 Response)	
Ground Conditions	Favourable
Disputes in Contract Interpretation	Unfavourable
Design Errors/Completeness	Unfavourable
Quality of Initial Schedule Plan	Unfavourable
Quality of Workmanship	Favourable

Risk Factor	Rating
Scenario 2: Crisp (1 Response)	
Ground Conditions	-2
Speed of Owner's Decisions	-2
Changes to Design	-3
Skill of Workforce	2
Scenario 2: Linguistic (2 Responses)	
Ground Conditions	Unfavourable
Speed of Owner's Decisions	Unfavourable
Changes to Design	Unfavourable
Skill of Workforce	Favourable
Scenario 4: Crisp (1 Response)	
Speed of Owner's Decisions	-2
Quality of Field Management	-3
Quality of Workforce	-2
Scenario 4: Linguistic (1 Response)	
Speed of Owner's Decisions	Unfavourable
Quality of Field Management	Unfavourable
Quality of Workforce	Unfavourable

Table 6-2: Ratings of Risk Factors Defined for the Testing Scenarios

A package of information was sent by fax to the four project managers that had agreed to take part in the testing of the system. Included in the package were instructions, project descriptions of the scenarios, ratings of the risk factors for each scenario, and schedule templates. Each person was asked to complete an analysis of the schedule impacts of the described risk factors for three scenarios. In this way, a response would be obtained for each risk scenario originally defined. Two responses would be obtained for Scenario 2 with linguistically rated risks, and Scenario 3 with crisply rated risks. The testing scenarios, and instructions sent to the experts, are included in Appendix P.

The calculations of the scheduling system were completed by using a spreadsheet, as they have not been hardcoded into a computer application to date. The risk-adjusted schedule for each scenario was determined through the process described in Section 4.6. In addition, the comparison of the results of the scheduling system to expert decision-making was completed in the same spreadsheet. Appendix Q includes the results from all of the testing scenarios.

A typical error measure of each predicted activity duration in the schedules was determined by using Equation 6-1.

Error = actual – estimated / actual = $\Delta_X - \Delta_{FES} / \Delta_X$,..[6-1]

where Δ_X = estimate of change in activity duration from expert (actual), Δ_{FES} = estimate of change in activity duration from scheduling system (estimated)

It became apparent that the scheduling system was overpredicting variation in activity duration for a vast majority of activities. This was occurring because the experts chose to assign zero variation for a large number of activity durations within the schedules. A possible reason for this trend is that, when presented with multiple risk factors, the ratings tended to balance out in the minds of the experts. Alternatively, the sensitivity values in the system may have overemphasized the importance of the risk factors on the duration of certain activities.

Another cause of overprediction was the occasional determination by an expert that an activity duration would decrease due to the combination of risk factors for a scenario. They determined that the combination of risks actually presented an opportunity to improve schedule. This invariably would cause a large error because the system did not predict any activity durations to decrease, given the various combinations of risk factors presented to it.

In any case, it was decided to eliminate from the analysis any activity that was rated by the expert as either have no duration variation or decreasing in duration. This ensured that only the activities that the user and system agreed had extended durations due to the risk factors would be taken into account. The uncertainty surrounding the zero-variation and negative-variation judgments prevented them from being confidently used to test and calibrate the system. By eliminating the uncertain data, the number of activity duration variations available for analysis was reduced from one hundred and thirty-two to one hundred and seven.

The results of the testing scenarios were also sorted according to two variables. The first was the number of risk factors that took a value other than "normal" for the projects. This allows an analysis of whether the number of risk factors selected affects the ability of the scheduling system to perform. Results from scenarios that had risk factors rated linguistically were also calculated separately from those rated crisply to determine if the system performed differently for the two methods. The average errors are represented in

Table 6-3. Included in the chart are the calculated errors if all data are taken into account and if only those activity durations that the experts lengthened are included.

Abs Error

# Var	Average Error	Error Linguistic	Error Crisp
3	22.20	17.50	36.20
4	7.20	8.40	6.50
5	32.30	14.20	43.20

Overpridiction Only

# Var	Average Error	Error Linguistic	Error Crisp
3	-25.00	-20.42	-36.23
4	-5.88	-4.60	-6.48
5	-35.34	-15.48	-55.20

Error measure = delta actual - delta predicted / delta actual
delta actual = delay given by human tester
delta predicted = delay given by FES

Table 6-3: Analysis of Errors

Many outlying data were observed from two scenarios in particular. Scenario #4 was created as a large, ten thousand parking space structure to test the limits of the scheduling system. Scenario #3 contained over five thousand parking spaces and was two levels below grade. There are only a few parking structures of these sizes in North America, and only one included in the case studies with which the fuzzy expert system was developed. The results from the testing of the scenario were likely skewed because of two reasons: (1) very few project managers have experience building such structures, and (2) the fuzzy expert system did not have sufficient data to make sound recommendations for a project of such a scale. When the testing data from Scenario #3 and #4 are dropped from the analysis, the average error drops significantly. This is illustrated in Table 6-4.

No Large Projects (eliminate scenarios 3 and 4)

Abs Error

# Var	Average Error	Error Linguistic	Error Crisp
3	3.18	3.18	N/A
4	8.09	9.45	5.24
5	32.30	14.18	43.17

Overpridiction Only

# Var	Average Error	Error Linguistic	Error Crisp
3	-1.38	-1.38	N/A
4	-4.38	-4.58	-3.85
5	-35.34	-15.48	-55.20

Error measure = delta actual - delta predicted / delta actual
delta actual = delay given by human tester
delta predicted = delay given by FES

Table 6-4: Results Excluding Scenario #3 and #4

A significant performance error was observed for the scheduling system. The error will be discussed to a further extent in Chapter 7. However, despite the error, a calibration of the system was completed in an attempt to improve the system's performance and to determine if there was a pattern to the errors observed.

6.2. Calibration of the System

An equation to represent the error in performance was required to calibrate the scheduling system. After dropping the outlying Scenario #4 from the analysis, the error was observed to pattern itself according to the number of risk factors rated other than normal for a project. Therefore, the number of factors was chosen as the variable on which to base the calibration equation.

One data set was removed from the error calculation for later testing purposes. The error was recalculated without one of the crisp ratings of Scenario #3. Scenario #4 was not included in the analysis, and only activity durations predicted by the experts as being extended were used in the error calculation. Table 6-5 shows the results of the recalculation of the error generated by the scheduling system.

Abs Error				**Overpridiction Only**				
# Var	Average Error	Error Linguistic	Error Crisp	# Var	Average Error	Error Linguistic	Error Crisp	Fitted Line
3	2.57	2.57	0.33	3	-1.32	-1.38	-0.90	-1.03
4	7.76	8.38	7.15	4	-6.03	-4.60	-7.26	-6.06
5	32.30	14.18	43.17	5	-35.34	-15.48	-55.20	-35.53

Error measure = delta actual - delta predicted / delta actual
delta actual = delay given by human tester
delta predicted = delay given by FES

Equation for Fitted Line to Overprediction Error = 3^(1.61*(NUM VAR)-4.8)

Table 6-5: Recalculated Error Without Testing Data Set

An equation was fit to the three calculated error values corresponding to the variable number of risk factors. This was accomplished through a trial and error method and is also included in Table 6.5. A graphical representation is shown in Appendix R. As can be observed, the calibration equation represents the calculated error values remarkably well.

The testing data set not used in the calculation of error was then used to determine the ability of the error equation to dampen the overprediction of the scheduling system and produce more accurate results. Appendix S includes the complete results of this analysis. Scenario #3 had four risk factors rated other than normal, which were crisply defined. The resulting average value of the overprediction errors produced by the system was 1.18 when using the dampening equation. This compares to an average value of 6.03 when the system predicted activity duration variations without the dampening equation. Table 6-6 shows the complete testing results of the calibration equation.

Number of Variables = 4

Scaling Factor = 6.0601

Activity	Initial Duration	FES	Jim	Scaled FES	Scaled Err $\Delta_J - \Delta_{SFES}/\Delta_J$	Abs Err	Overpred. Only
Award Subcontracts	35	55	35	38	Infinity	N/A	N/A
Permits	20	74	40	29	0.5572	0.5572	N/A
Submittals	60	95	60	66	Infinity	N/A	N/A
Precast Fab	237	717	237	316	Infinity	N/A	N/A
Elevator Fab	90	175	90	104	Infinity	N/A	N/A
Mobilize	10	9	10	10	Infinity	N/A	N/A
Demo	5	10	5	6	Infinity	N/A	N/A
Curb&Gutter/Sidewalk	15	29	20	17	0.5239	0.5239	N/A
Landscaping	15	29	20	17	0.5239	0.5239	N/A
Bulk Excavation	69	134	90	80	0.4885	0.4885	N/A
Deep Foundations	62	98	90	68	0.7854	0.7854	N/A
Shallow Foundations	47	75	60	52	0.6411	0.6411	N/A
Foundation Walls	167	228	180	177	0.2316	0.2316	N/A
M&E UG	25	45	30	28	0.3475	0.3475	N/A
Prep SOG	32	46	35	34	0.2417	0.2417	N/A
Pour SOG	65	96	70	70	-0.0122	0.0122	0.0122
Erect Precast Structure	315	845	330	402	-4.8275	4.8275	4.8275
Place Topping	141	238	155	157	-0.1440	0.1440	0.1440
Elevator Shafts	286	485	300	319	-1.3507	1.3507	1.3507
Install Stairs	40	107	60	51	0.4450	0.4450	N/A
Install Elevators	60	151	60	75	Infinity	N/A	N/A
Install Exterior Façade	58	165	80	76	0.1941	0.1941	N/A
M&E R-in	180	322	200	203	-0.1745	0.1745	0.1745
Fire Protection	120	214	130	136	-0.5525	0.5525	0.5525
Inspections	15	44	30	20	0.6865	0.6865	N/A
Average						0.7071	1.1769

Table 6-6: Testing the Calibration Equation

The results of the calibration of the system are successful; however, this calibration is purely mathematical and does not account for the actual causes of the error produced by the scheduling system. The possible causes of the errors and opportunities for future development are discussed in further detail in Chapter 7.

7. CONCLUSIONS

This research has produced an innovative technique for automating the process of creating summary-level schedules for construction projects. Building on the foundation of established theory and modeling techniques, the developed scheduling system has a unique structure. Many components of this system, including the embedded fuzzy expert system, are either used or have been developed in a manner not found elsewhere in the literature. At the same time, none of the concepts that the system is based on are new or unproven. The components have been assembled in a new way that is especially effective for research in the construction industry. Previous research using fuzzy set theory for construction-related applications, including scheduling, was thoroughly reviewed to ensure this new direction is legitimate and does not overlap with previously completed work.

The results of the research raised two major issues that have yet to be overcome. The first is the lack of data available with which to build components of the system. This difficulty was compounded by the fact that many components of the system were developed using case studies of completed projects in order to avoid a dependence on expert surveys. The other major problem experienced relates to the interdependence of risk factors. It appears that the assumption made when developing the scheduling system that these variables are entirely independent is not supported by the observed results of the system.

The problem of obtaining data for research in the construction industry is not new. Many published studies propose a model or theory but do not attempt to obtain the data required to either fully develop the proposed system or to complete an adequate test of the system if it was developed. It is left up to future studies to validate the proposed method. This research project was conducted from the initial stages with the goal of able to fully develop and test the methods proposed.

Unfortunately, despite an intensive data collection phase, the project information required to develop the components of the system was not as readily available as anticipated. As much data as possible were collected, however, gaps in the information required many components to be created arbitrarily. This problem mirrors those that have been documented by other researchers focusing on modeling construction processes. Lack of data is one of the major issues the construction research community is faced with.

Several reasons can be cited for the lack of data available for this research project. Much of the data required to develop the system was project schedule information. Only large projects are generally scheduled and tracked in a level of detail that is useful for future research. The resources required to maintain a schedule are simply not available on projects of lesser scope. Even on larger projects, tracking schedule is often one of the activities that are not kept up to date as the project comes to a close. Often, a very complete schedule plan can be found; however, there is no as-built schedule available for a project.

Also, prior to the mid-1990s, very few construction project schedules were continuously updated and tracked formally as many are now. The change has been brought on by the popularization of computerized scheduling, which provides easy creation and updating of schedules, in addition to sophisticated tools such as resource leveling. It also allows long-term data storage, which should make this type of research much more feasible in the future.

The other issue relating to the results of this research project is the definition of the relationships between risk factors in the scheduling system. The original assumption that the risk factors were independent was made through simple logic. For example, the risk factor "Amount of Precipitation" obviously has no effect on "Experience of Supervisor". However, no allowance was made to account for the combined effect of "Experience" and "Precipitation", which might be different than the adding of the effects of each to arrive at a total effect. The assumption that risk factors were independent was originally made in an attempt to limit the amount of data required to develop components of the fuzzy expert system and reduce the complexity of the overall scheduling system.

The testing and calibration of the model exposed the relationships between risk factors as a concern because the error of the model increased exponentially according to the number of factors in a testing scenario. A dampening equation was calculated that compensated for the generated error, but it did not address the cause of the error.

Despite the remaining issues, the overall research was successful in many ways. It contributes to the body of knowledge relating to the use of fuzzy set theory and expert systems as tools for researchers creating decision-support applications for the construction industry. The application to project scheduling is unique and can be further refined with possible future development.

7.1. Contributions of Research

There have been several contributions made by this research to advance the state of the art practice in scheduling and the use of fuzzy expert systems. The main objective of the research was to create a scheduling system to transfer expert knowledge within the construction industry. This was accomplished through the modeling of the scheduling process using a fuzzy expert system to adjust schedule templates to account for project risk. The use of fuzzy set theory adds to the existing body of knowledge relating to the scheduling of construction projects and applications of fuzzy set theory to solve construction-related problems.

The structure of the scheduling system is innovative and contains components that were developed and assembled using methods not previously recorded in the literature. Specifically, the use of output from a fuzzy expert system combined with sensitivity factors to obtain individual activity duration variations based on project risk is a new scheduling technique. Also, the way that the output membership functions and sensitivity values were developed through case studies, not surveys of expert knowledge, was a unique process. It allowed another objective of the research to be met, which was to reduce the dependency on data collected from expert surveys when completing research in the construction industry. Although case studies of projects constructed by only one company were completed, through a process of standardization the results have been made fully transferable and applicable to other members of the construction industry.

It has been shown that this scheduling system provides a structured method for risk to be considered when creating a project schedule. The user can assess risk using linguistic terms and can easily follow the calculations performed by the system to arrive at the risk-adjusted schedule. These features of the system contribute to the research community a philosophy that transparent systems and models that allow users to express themselves in a natural manner will have a much greater opportunity for acceptance.

The developed scheduling system is structured in such a way that it can be integrated with other automated processes. The input and output of the system is a series of activities, their durations, and their relationships with each other. The input can be obtained from other sources and the output can be formatted in a manner that is available for other uses. This contributes by opening avenues for future research that can build on what has already been accomplished.

Any member of a project team could use this scheduling system during the planning phase of a construction project. Developers, owners, and contractors can quickly perform schedule risk analyses to determine how different combinations of risk will affect a project schedule. Users can assess risk using natural language, which increases the likelihood of acceptance within the construction industry. The summary-level schedule templates included in the system automatically create schedule plans and require very little input from the user. This application has the potential to be a valuable tool for the planning of construction projects.

7.2. Future Development

There are many opportunities for future development to enhance the results of this research project. The user interface must be developed in its entirety, in addition to potential integration with software that manages other project processes. Refinement of the system components and improving their function could be accomplished during this future development. However, the problems encountered during the development and testing of the scheduling system must be satisfactorily resolved prior to improving the interface between the scheduling system, the user, and other systems.

One possible way to obtain more complete data for creating system components is to conduct an ongoing data collection project from projects currently underway. Researchers could coordinate the updating and tracking of project schedules and ensure that the data required for future research are collected and stored. In addition, researchers would be involved throughout the project life so the risk factors encountered would be properly identified and accounted for. Contractors would likely be open to this type of project because they receive manpower to update the schedule in exchange for access to project information. If this type of research was conducted with the cooperation of several contractors, within a few years many project schedules could be obtained and analyzed.

The problem of determining the combined effects of risk factors is difficult to solve but must be addressed prior to additional work being completed on the scheduling system. One possible method is to include multiple conditions in the antecedent portion of the rules, which would expand the number of rules in the system by a significant factor. The number of rules in the system grows exponentially as the number of conditions in the rules increases. It would be possible to counteract a portion of this expansion by limiting the number of risk factors in the system to those most likely to be encountered. Five or six factors common on projects could be identified and used as the input to the fuzzy expert system.

The risk analysis performed by the fuzzy expert system could also be adjusted to allow users to assess the likelihood of occurrence as they rate input variables. For example, when a risk factor is rated "unfavourable", a rating of the likelihood of the risk factor taking that value could also be chosen. When this uncertainty factor is combined with the output of the associated rule, a more complete risk analysis would be accomplished than the system is currently able to perform. The effects of risk factors may be modeled more accurately with this enhancement.

Another potential method of accounting for interrelation of risk factors is to adjust the sensitivity values so that they are scaled according to the number, or different combinations, of factors that are predicted to occur for a project. If the dampening equation used to calibrate this system is verified with further testing as controlling the effects of multiple factors, it could be used to scale the sensitivity factors. Otherwise, further analysis is required to determine how the sensitivity values could be adjusted to account for different combinations of risk factors.

After the above-mentioned issues are resolved, it is necessary to hardcode the components of this scheduling system into a computer application. This would not be a difficult task as the components are relatively simple. A graphical user interface is necessary for easy use of the system. In the current format, the system is only useful as a research tool.

When the system is developed into a user application, there are features that could be added as enhancements. For example, a method of allowing the user to adjust the shape of input and output membership functions could be easily incorporated. In addition, rules and sensitivity values should be available for inspection and adjustment by the user. One of the features of fuzzy expert systems is their transparency, and every component of this scheduling application could be presented for analysis and optimization by the user. Theoretically, the shape of the membership functions should always match the perceptions held by the user regarding the concepts modeled using the functions.

Otherwise, the factors will not be rated correctly and the firing strengths of the rules will not be accurate.

The relationships between activities in a schedule could also be investigated to determine if they are affected by certain risk factors and if the effects can be modeled within the system. If so, this additional feature would increase the accuracy of the risk analyses performed on the schedule plans. It would also allow a user flexibility to take into account float within a schedule when allocating risk.

A final enhancement to the scheduling system would be to integrate it with another software package to further automate the scheduling component of project delivery. It is a natural extension of cost estimating, and all the project characteristics required by the system could be obtained from the output of an estimating package. In this idealized scenario, the user would complete a quantity survey using either a traditional 2-D take-off or by assigning components to a 3-D model. Cost information would be determined for each component and the risk factors for the project predicted. The output would be a complete estimate and a risk-adjusted schedule plan. By incorporating methods suggested in the literature, other features such as an analysis of alternative construction methods or optimization of mark-up set for the project could also be completed through various applications of fuzzy set theory. In this manner, a robust project-planning tool could be developed for practical use within the construction industry.

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APPENDIX A – CALCULATIONS PERFORMED BY *SCHEDULE ASSISTANT*

Equations

The following equations are used to caculate the outputs on this form:

Specified Gross Floor Area (GFA) = Number of Spaces * GFA per Space

Levels Required = ROUNDUP(Specified GFA / Footprint of Building)

Actual GFA = Levels Required * Footprint of Building

Elevated GFA = Actual GFA - Footprint of Building

Actual Number of Spaces = Actual GFA / GFA per Space

Total cy Concrete = Actual GFA * cy Concrete per GSF

Area of Pour = Elevated Forms Available / Pours per Cycle of Forms

Required Productivity = Area of Pour * cy Concrete per GSF

Pour Cycles Required = ROUNDUP[(Actual GFA / Levels) * (Levels - 1) / Area of Pour]

Average Cycles of Forms = (Actual GFA / Levels) * (Levels - 1) / Elevated Forms Available

Excavation Required = 11 * Footprint of Building * Below Grade Levels

Area of Fdn Walls = 4 * sqrt(Footprint of Building) * 11* Below Grade Levels

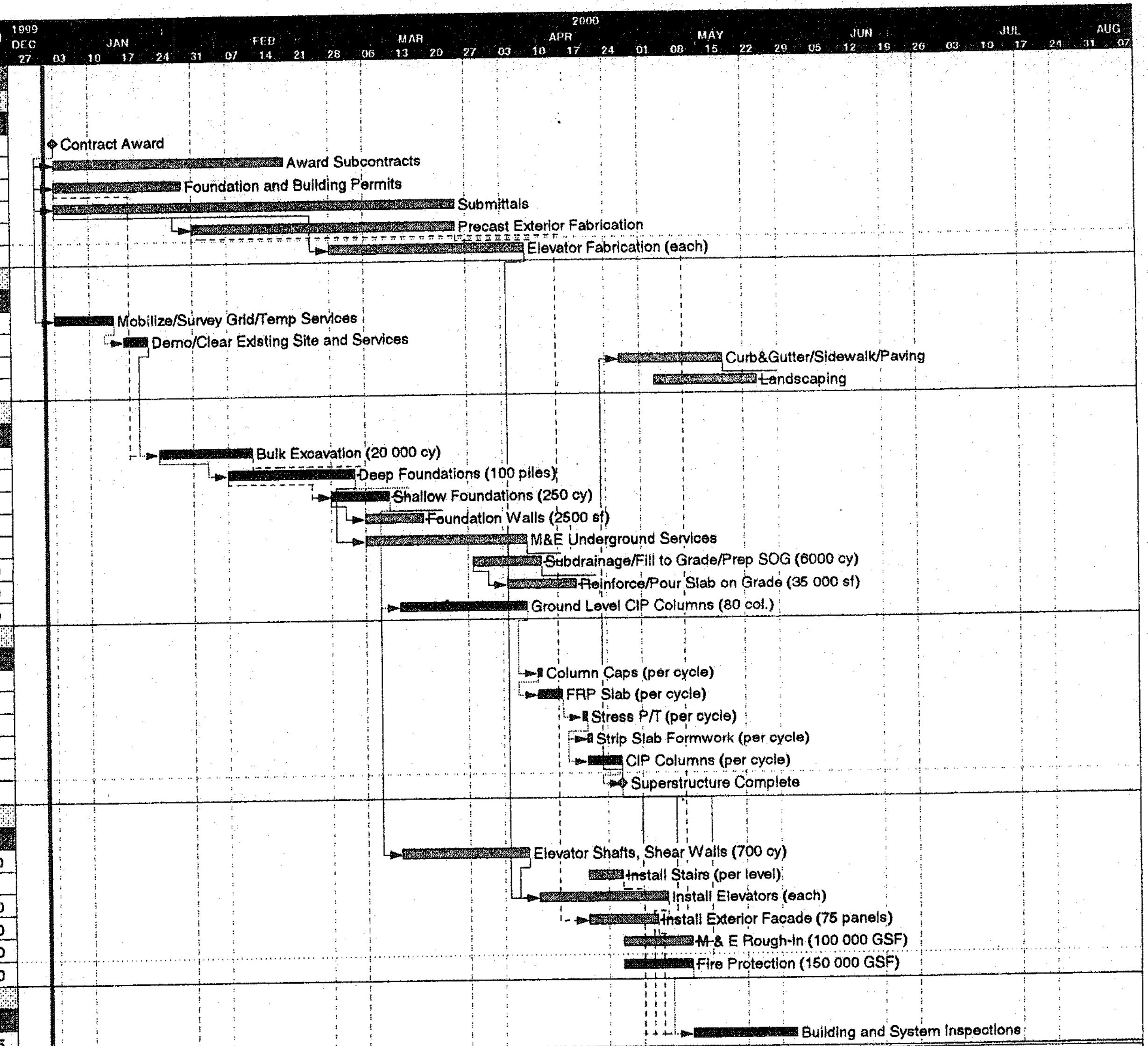
Number of Elevators = Elevated GFA / 220 000 sf

Number of Spandrel Panels = 4 * sqrt(Footprint of Bujilding) * (Levels Above Grade)

OK

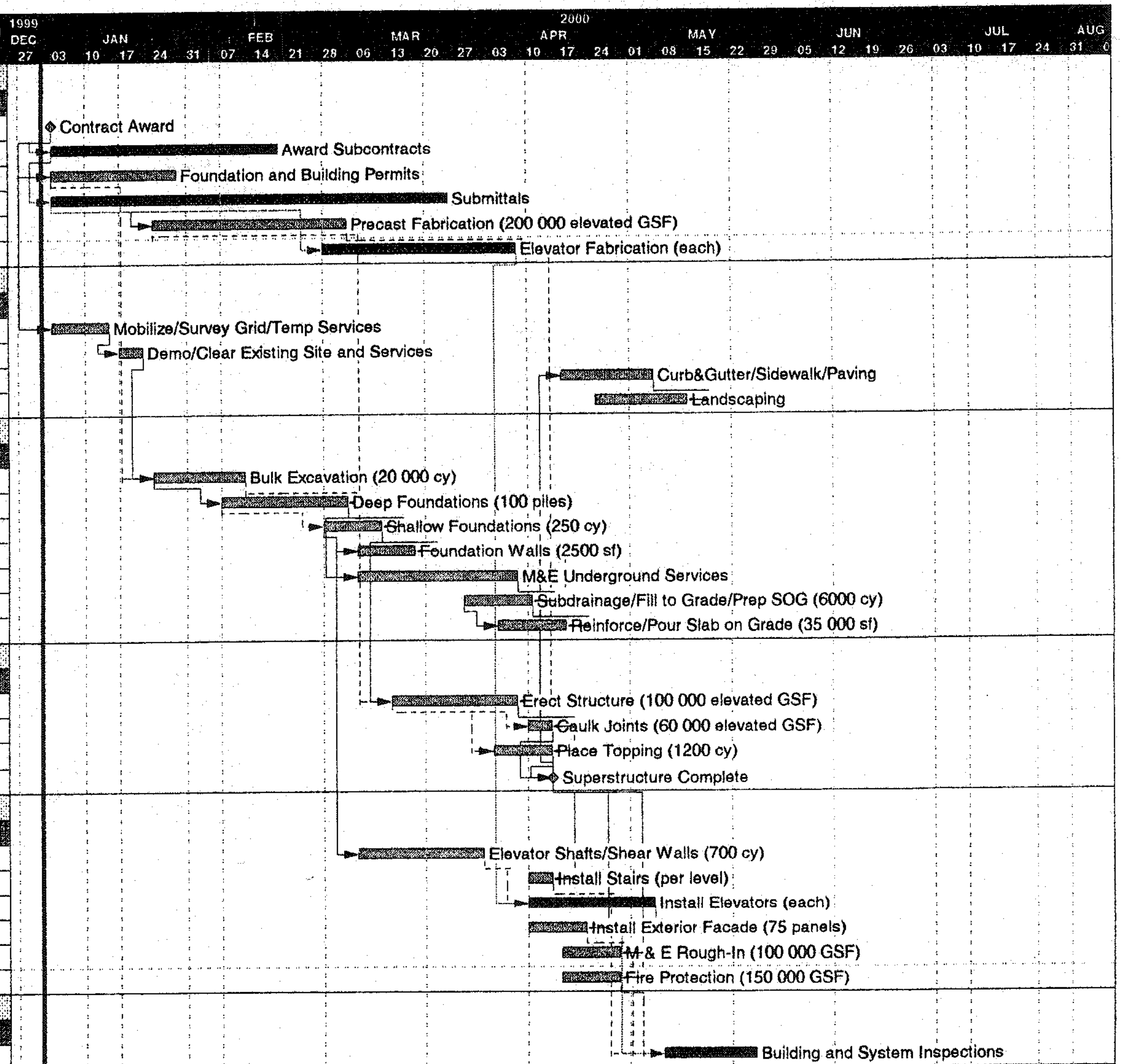
APPENDIX B – SCHEDULE TEMPLATES

Act ID	Description	Orig Dur
All Phases		
Preconstruction / Procurement / Fabrication		
All Levels		
0010	Contract Award	0
0020	Award Subcontracts	35
0030	Foundation and Building Permits	20
0040	Submittals	60
0060	Precast Exterior Fabrication	40
0070	Elevator Fabrication (each)	30
Sitework		
All Levels		
0510	Mobilize/Survey Grid/Temp Services	10
0520	Demo/Clear Existing Site and Services	5
0530	Curb&Gutter/Sidewalk/Paving	15
0540	Landscaping	15
Ground Level		
Ground Level		
1010	Bulk Excavation (20 000 cy)	15
1020	Deep Foundations (100 piles)	20
1030	Shallow Foundations (250 cy)	10
1040	Foundation Walls (2500 sf)	10
1050	M&E Underground Services	25
1060	Subdrainage/Fill to Grade/Prep SOG (6000 cy)	10
1070	Reinforce/Pour Slab on Grade (35 000 sf)	10
1080	Ground Level CIP Columns (80 col.)	20
Typical Level		
All Levels		
2010	Column Caps (per cycle)	1
2020	FRP Slab (per cycle)	5
2030	Stress P/T (per cycle)	1
2040	Strip Slab Formwork (per cycle)	1
2050	CIP Columns (per cycle)	5
2999	Superstructure Complete	0
General Activities		
All Levels		
3010	Elevator Shafts, Shear Walls (700 cy)	20
3020	Install Stairs (per level)	5
3030	Install Elevators (each)	20
3040	Install Exterior Facade (75 panels)	10
3050	M & E Rough-In (100 000 GSF)	10
3060	Fire Protection (150 000 GSF)	10
Close Out		
All Levels		
4010	Building and System Inspections	15



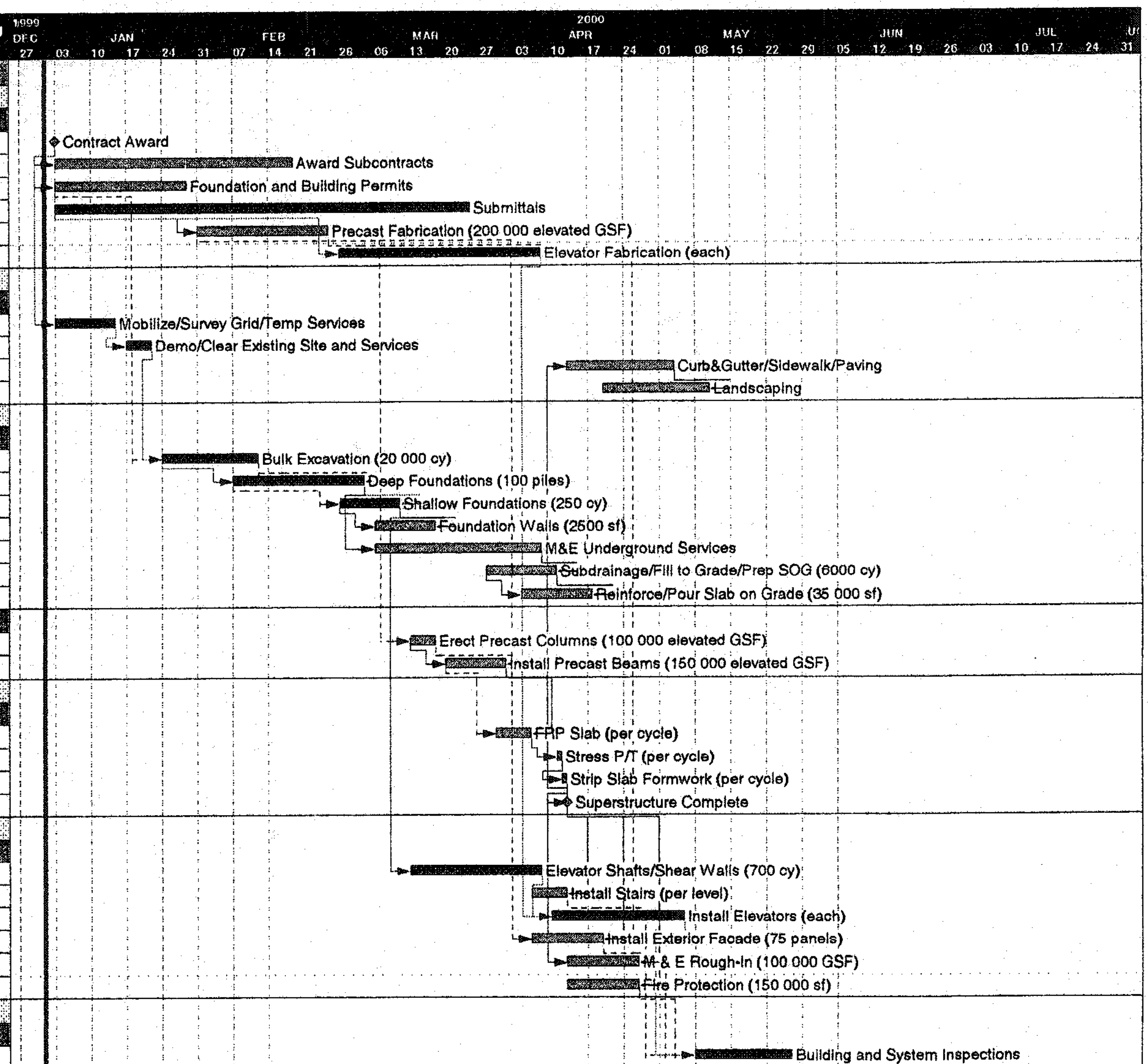
CIP System - Parking Structures: Template

Act ID	Description	Orig Dur
	Preconstruction / Procurement / Fabrication	
	All Levels	
0010	Contract Award	0
0020	Award Subcontracts	35
0030	Foundation and Building Permits	20
0040	Submittals	60
0050	Precast Fabrication (200 000 elevated GSF)	30
0060	Elevator Fabrication (each)	30
	Sitework	
	All Levels	
0510	Mobilize/Survey Grid/Temp Services	10
0520	Demo/Clear Existing Site and Services	5
0530	Curb&Gutter/Sidewalk/Paving	15
0540	Landscaping	15
	Ground Level	
	Ground Level	
1010	Bulk Excavation (20 000 cy)	15
1020	Deep Foundations (100 piles)	20
1030	Shallow Foundations (250 cy)	10
1040	Foundation Walls (2500 sf)	10
1050	M&E Underground Services	25
1060	Subdrainage/Fill to Grade/Prep SOG (6000 cy)	10
1070	Reinforce/Pour Slab on Grade (35 000 sf)	10
	Elevated Levels	
	All Levels	
2010	Erect Structure (100 000 elevated GSF)	20
2020	Caulk Joints (60 000 elevated GSF)	5
2030	Place Topping (1200 cy)	10
2999	Superstructure Complete	0
	General Activities	
	All Levels	
3010	Elevator Shafts/Shear Walls (700 cy)	20
3020	Install Stairs (per level)	5
3030	Install Elevators (each)	20
3040	Install Exterior Facade (75 panels)	10
3050	M & E Rough-In (100 000 GSF)	10
3060	Fire Protection (150 000 GSF)	10
	Close Out	
	All Levels	
4010	Building and System Inspections	15



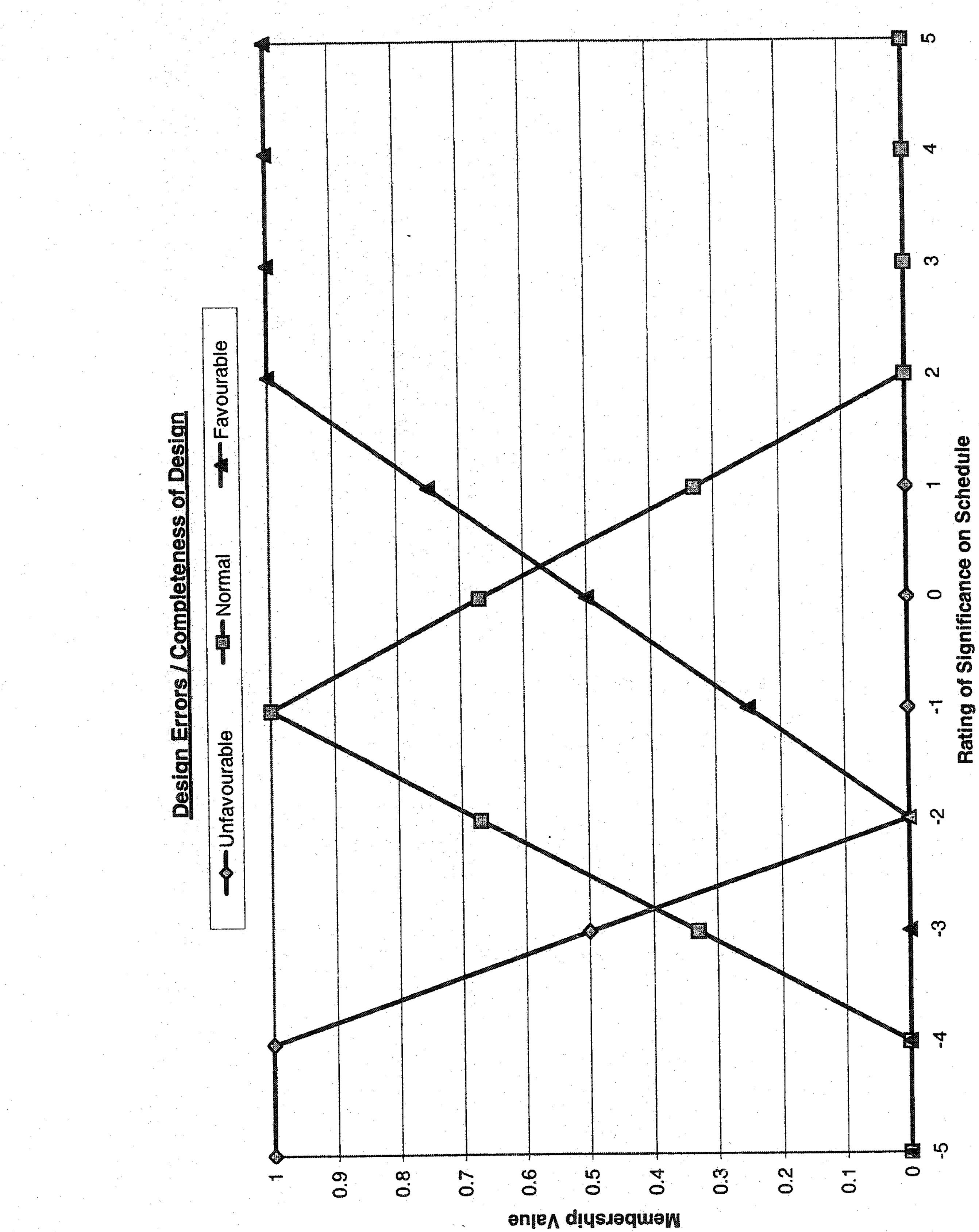
Precast System - Parking Structures: Template

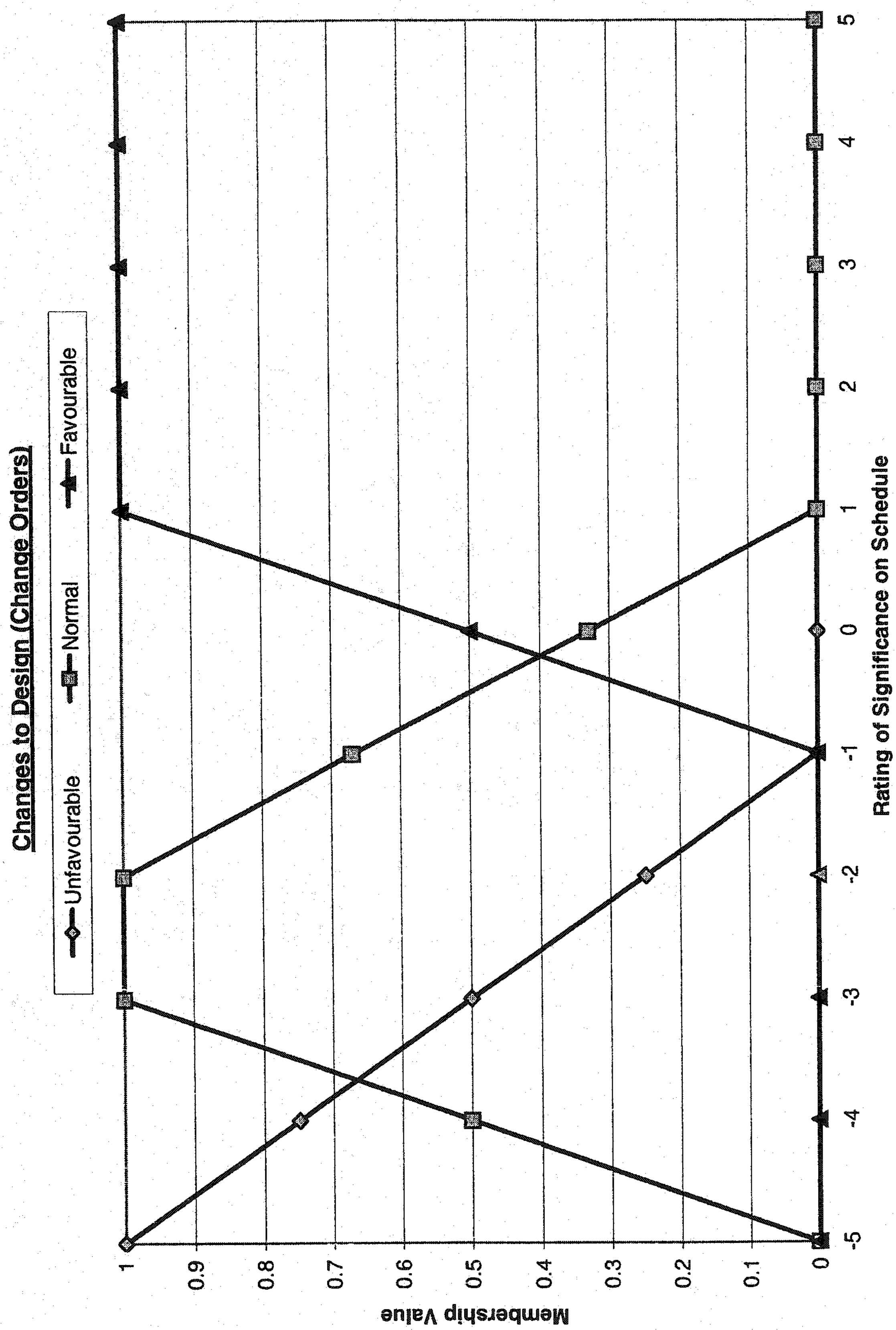
Act ID	Description	Orig Dur
All Phases		
Preconstruction / Procurement / Fabrication		
All Levels		
0010	Contract Award	0
0020	Award Subcontracts	35
0030	Foundation and Building Permits	20
0040	Submittals	60
0050	Precast Fabrication (200 000 elevated GSF)	20
0060	Elevator Fabrication (each)	30
Sitework		
All Levels		
0510	Mobilize/Survey Grid/Temp Services	10
0520	Demo/Clear Existing Site and Services	5
0530	Curb&Gutter/Sidewalk/Paving	15
0540	Landscaping	15
Ground Level		
Ground Level		
1010	Bulk Excavation (20 000 cy)	15
1020	Deep Foundations (100 piles)	20
1030	Shallow Foundations (250 cy)	10
1040	Foundation Walls (2500 sf)	10
1050	M&E Underground Services	25
1060	Subdrainage/Fill to Grade/Prep SOG (6000 cy)	10
1070	Reinforce/Pour Slab on Grade (35 000 sf)	10
All Levels		
1100	Erect Precast Columns (100 000 elevated GSF)	5
1110	Install Precast Beams (150 000 elevated GSF)	10
Typical Level		
All Levels		
2020	FRP Slab (per cycle)	5
2030	Stress P/T (per cycle)	1
2040	Strip Slab Formwork (per cycle)	1
2999	Superstructure Complete	0
General Activities		
All Levels		
3010	Elevator Shafts/Shear Walls (700 cy)	20
3020	Install Stairs (per level)	5
3030	Install Elevators (each)	20
3040	Install Exterior Facade (75 panels)	10
3050	M & E Rough-In (100 000 GSF)	10
3060	Fire Protection (150 000 sf)	10
Close Out		
All Levels		
4010	Building and System Inspections	15



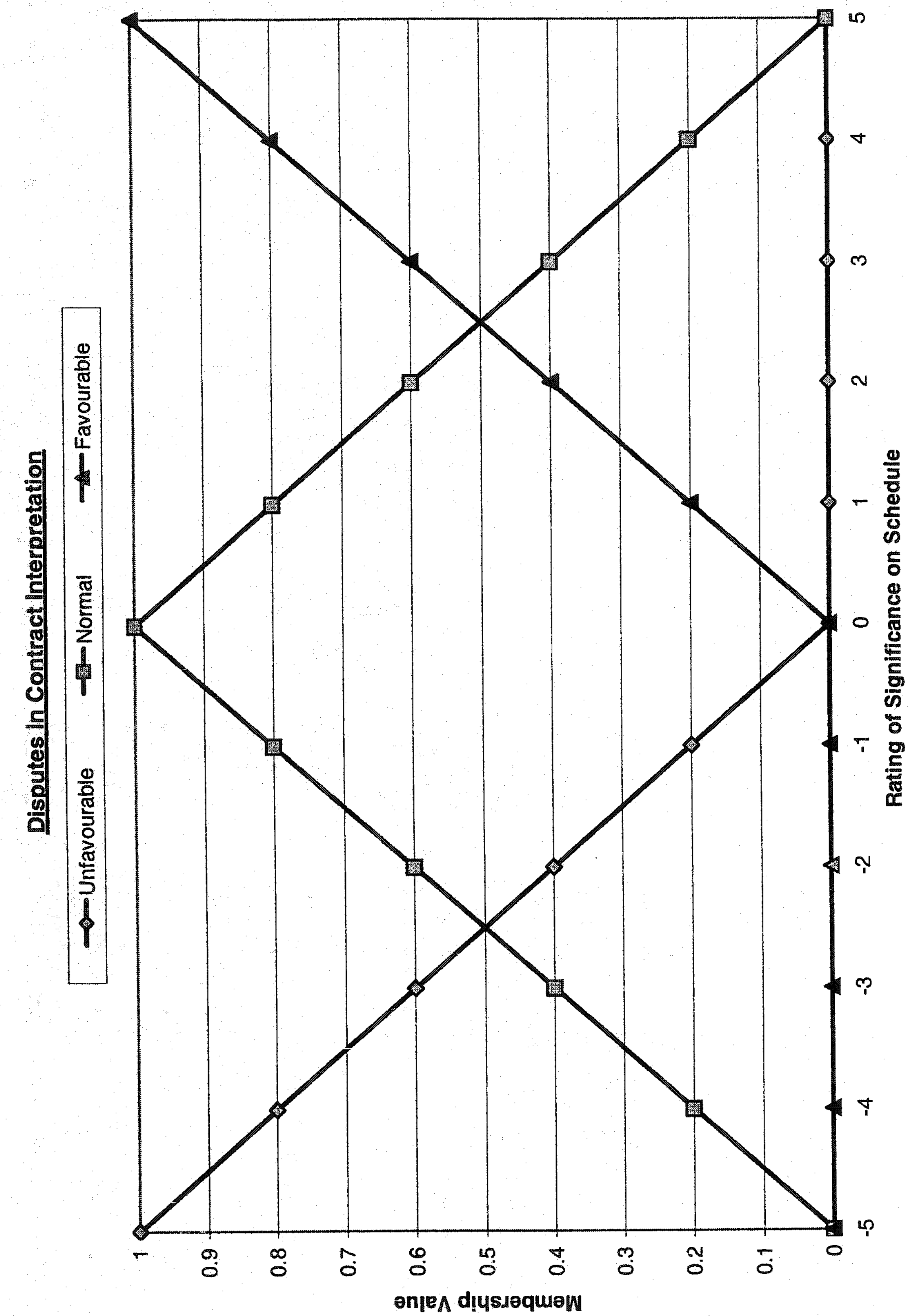
Hybrid System - Parking Structures: Template

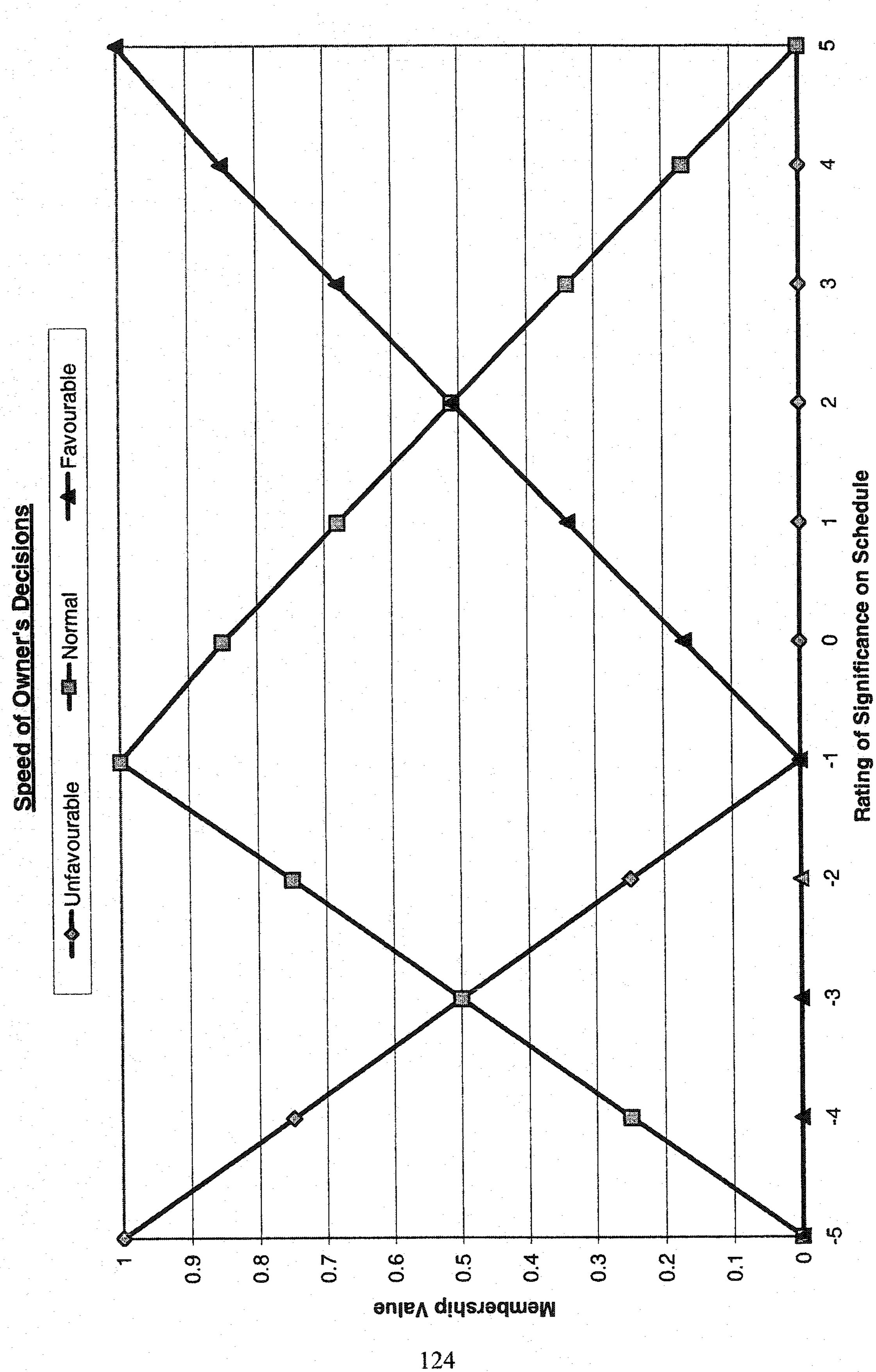
APPENDIX C – MEMBERSHIP FUNCTIONS FOR INPUT VARIABLES


Design Errors / Completeness of Design
Unfavourable
Normal
Favourable
Membership Value
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
Rating of Significance on Schedule

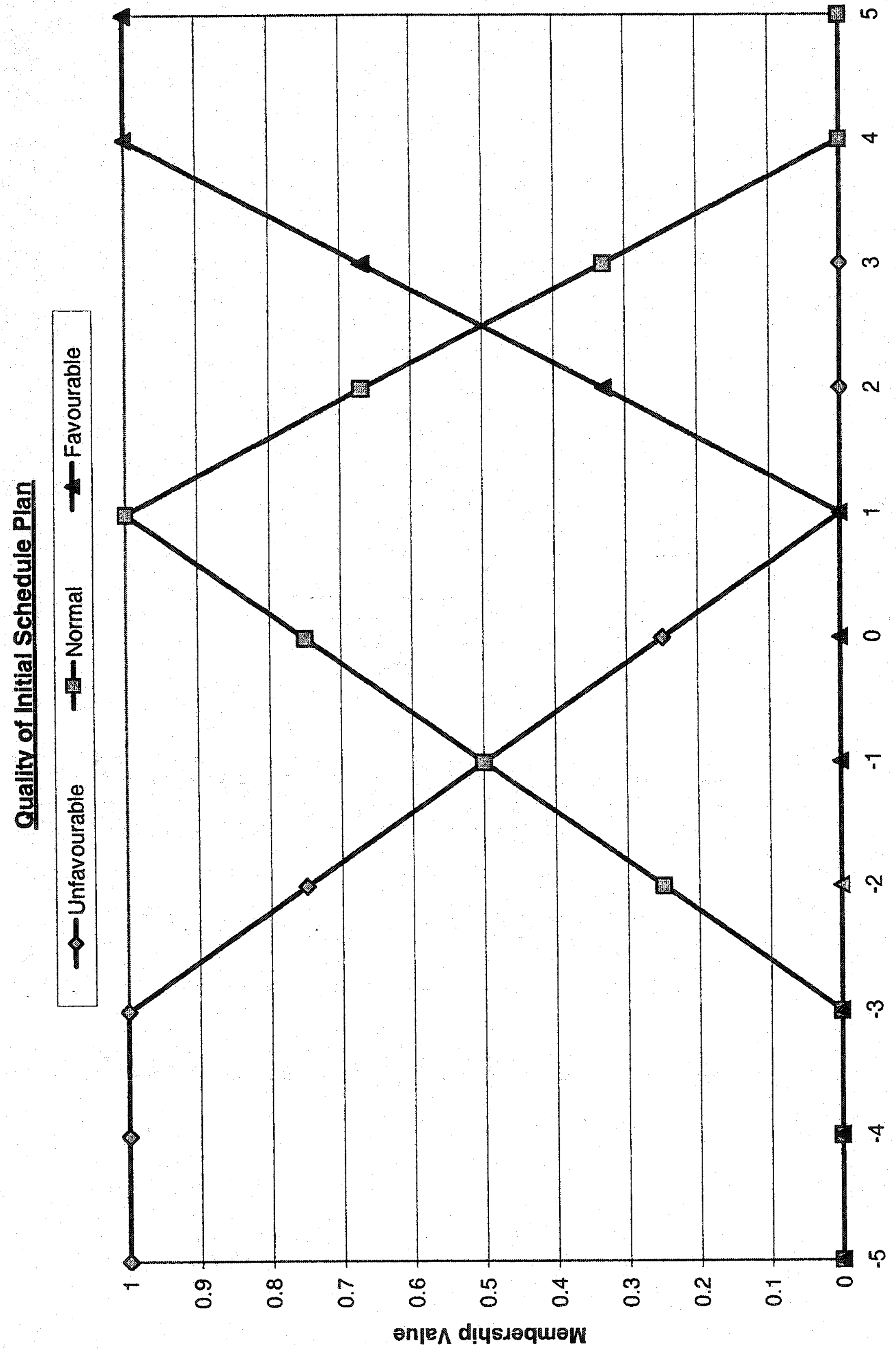


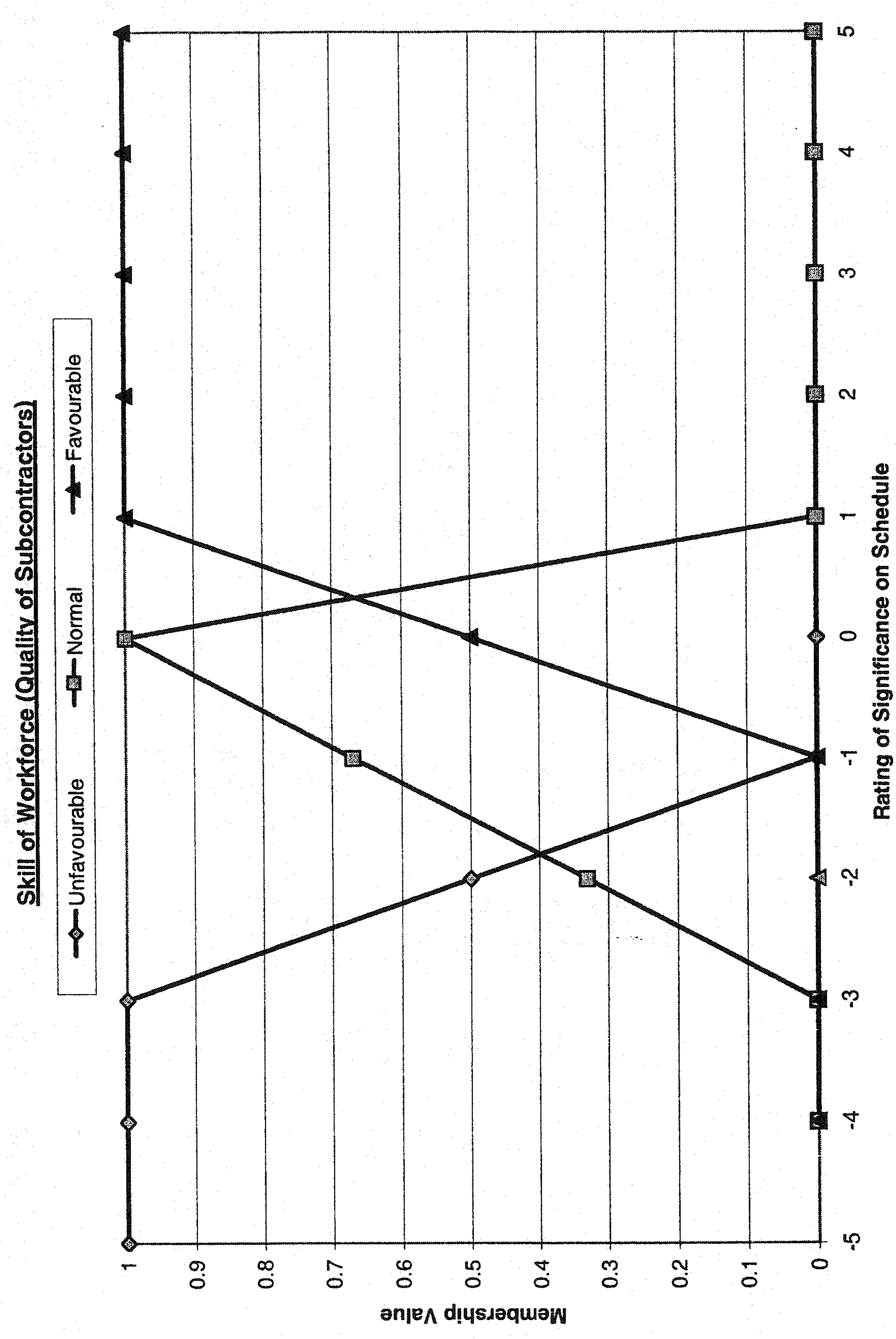
Changes to Design (Change Orders)
Unfavourable
Normal
Favourable
Membership Value
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
Rating of Significance on Schedule

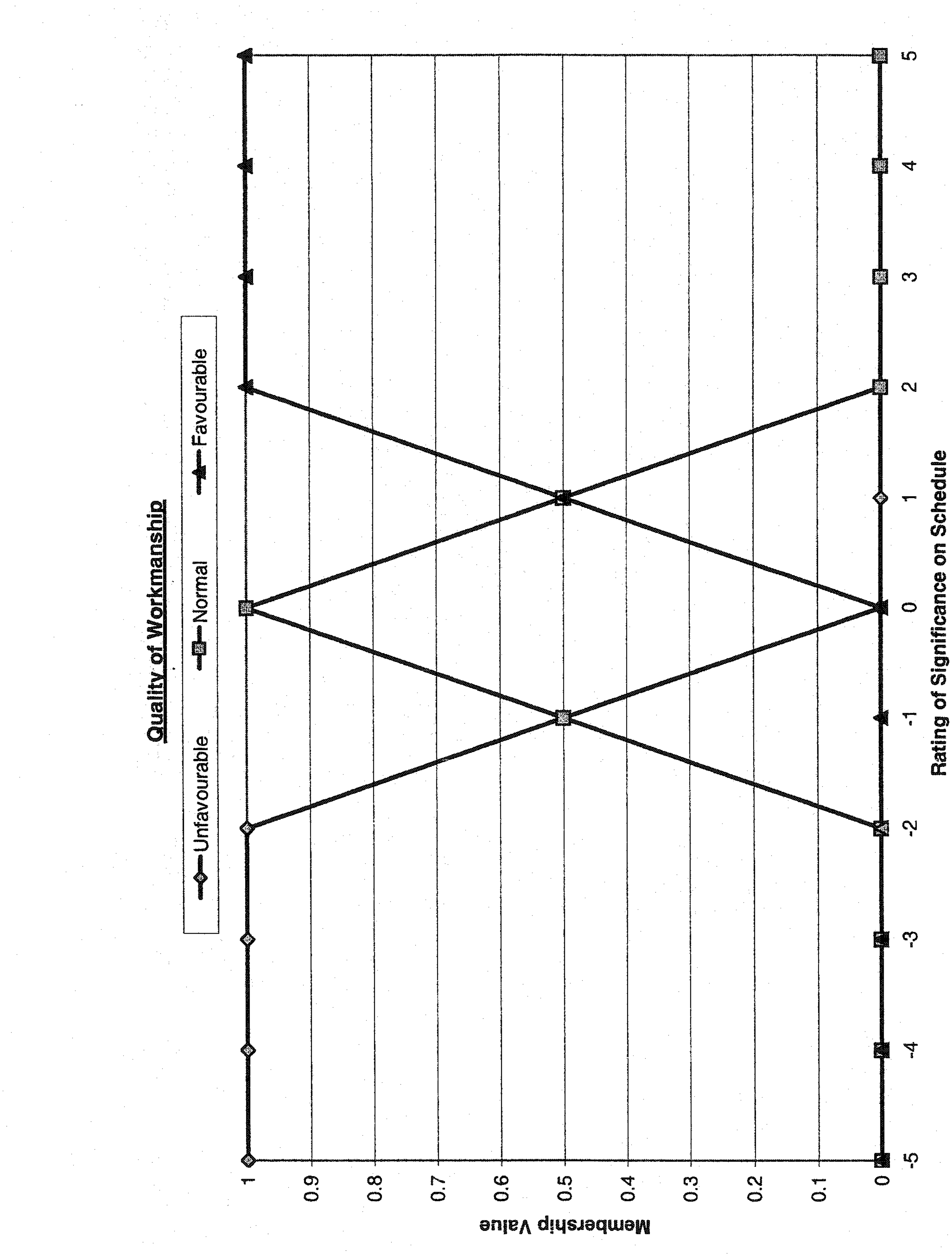

Disputes In Contract Interpretation
Unfavourable
Normal
Favourable
Membership Value
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
Rating of Significance on Schedule



Speed of Owner's Decisions
Unfavourable
Normal
Favourable
Membership Value
Rating of Significance on Schedule
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-5
-4
-3
-2
-1
0
1
2
3
4
5


Quality of Initial Schedule Plan
Unfavourable
Normal
Favourable
Membership Value
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
Rating of Significance on Schedule


Skill of Workforce (Quality of Subcontractors)
Unfavourable
Normal
Favourable
Membership Value
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
Rating of Significance on Schedule


Quality of Workmanship
Unfavourable
Normal
Favourable
Membership Value
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
Rating of Significance on Schedule

Membership Functions for Input Variables Developed Without Data

Ground Conditions

	Unfavourable	Normal	Favourable
-5	1	0	0
-4	0.8	0.25	0
-3	0.6	0.5	0
-2	0.4	0.74	0
-1	0.2	1	0
0	0	1	0
1	0	0.75	0.2
2	0	0.5	0.4
3	0	0.25	0.6
4	0	0	0.8
5	0	0	1

Timeliness of Permitting and Inspections

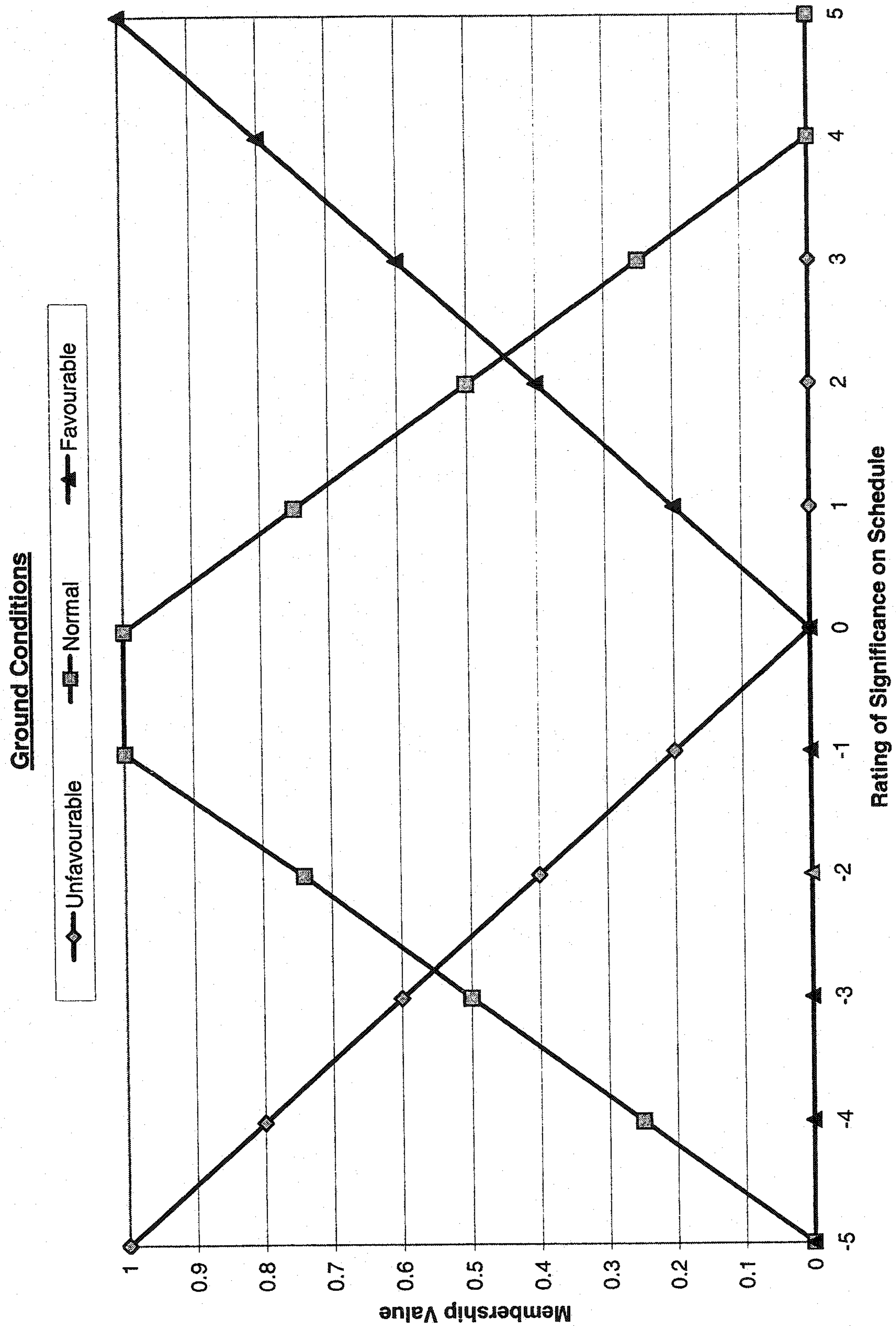
	Unfavourable	Normal	Favourable
-5	1	0	0
-4	1	0	0
-3	0.75	0	0
-2	0.5	0.33	0
-1	0.25	0.67	0
0	0	1	0
1	0	0.67	0.25
2	0	0.33	0.5
3	0	0	0.75
4	0	0	1
5	0	0	1

Interference by Owner

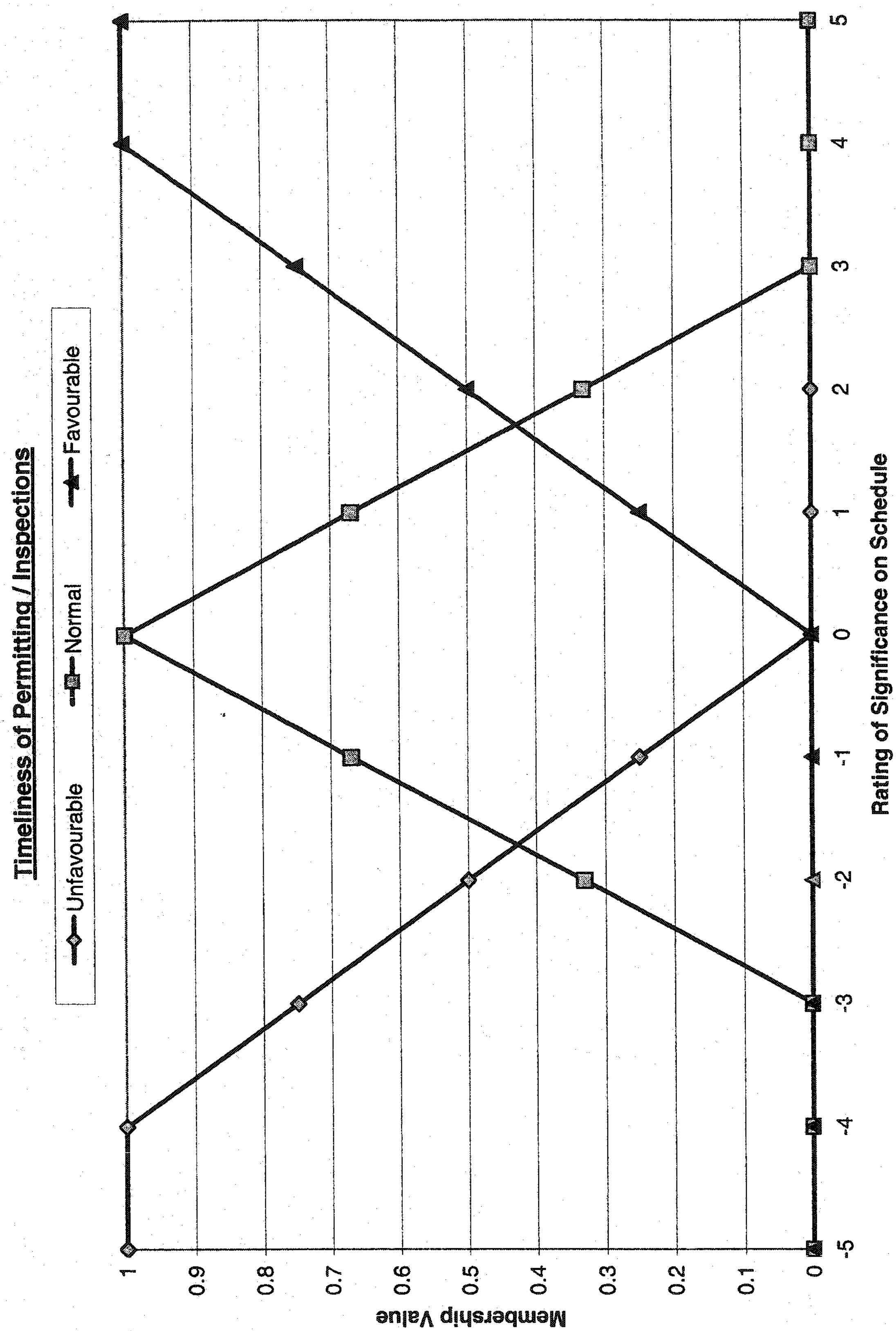
	Unfavourable	Normal	Favourable
-5	1	0	0
-4	1	0	0
-3	1	0	0
-2	0.67	0	0
-1	0.33	0.5	0
0	0	1	0
1	0	0.5	0.33
2	0	0	0.67
3	0	0	1
4	0	0	1
5	0	0	1

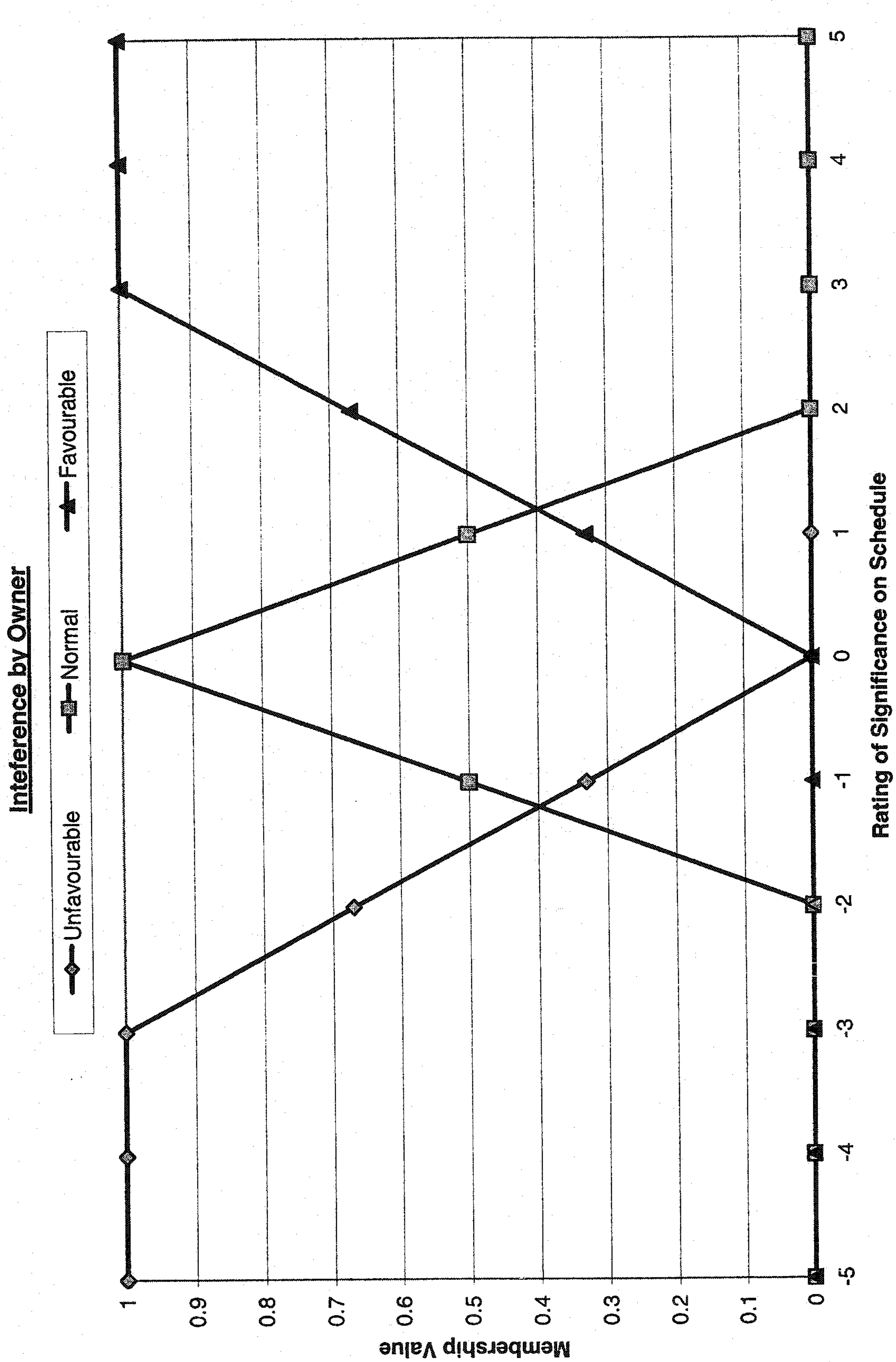
Quality of Field Management

	Unfavourable	Normal	Favourable
-5	1	0	0
-4	1	0	0
-3	0.75	0	0
-2	0.5	0.33	0
-1	0.25	0.67	0
0	0	1	0
1	0	1	0
2	0	1	0.25
3	0	0.67	0.5
4	0	0.33	0.75
5	0	0	1

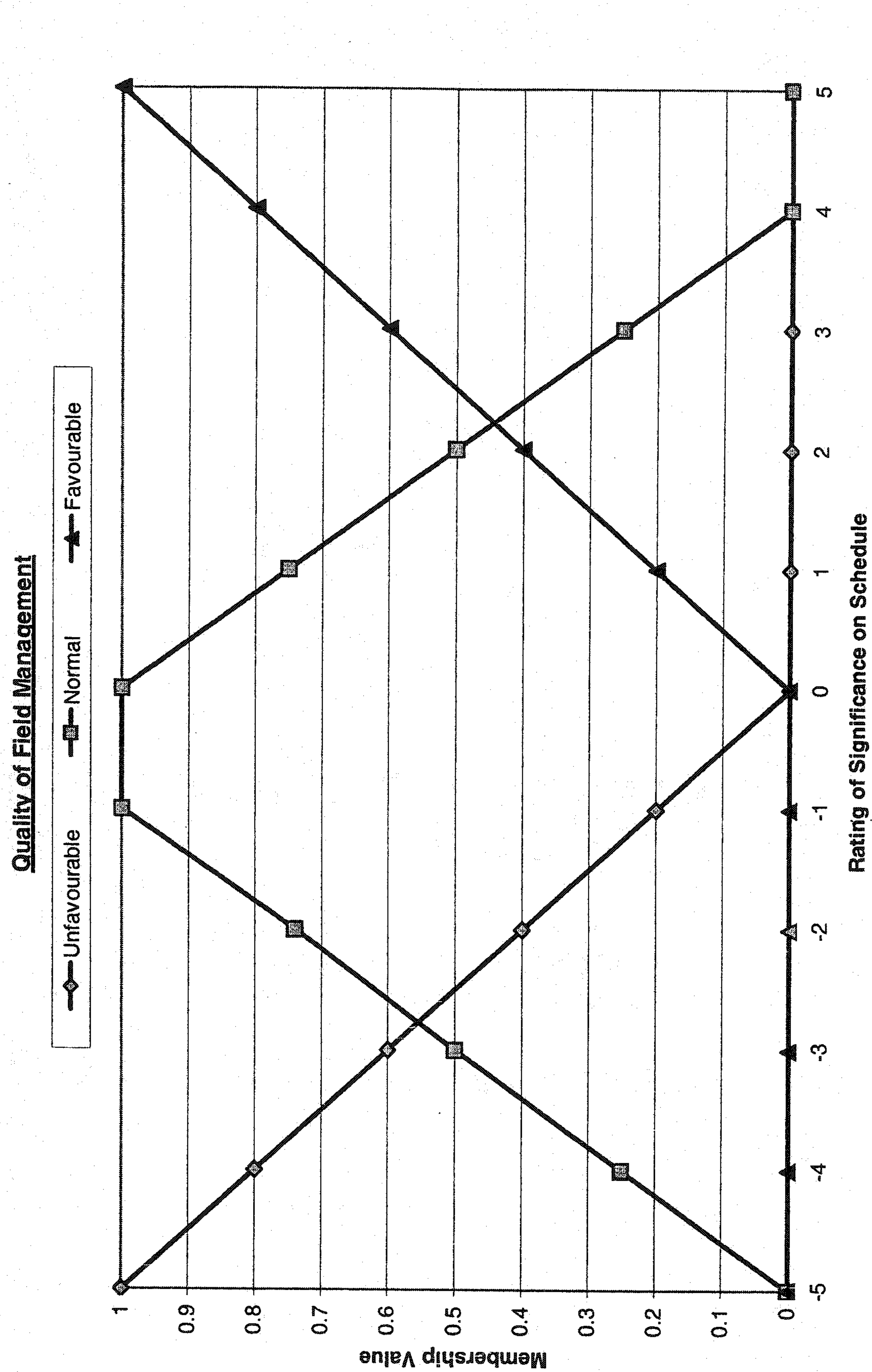


Ground Conditions
Unfavourable
Normal
Favourable
Membership Value
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
-5
-4
-3
-2
-1
0
1
2
3
4
5
Rating of Significance on Schedule


Timeliness of Permitting / Inspections
Unfavourable
Normal
Favourable
Membership Value
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
Rating of Significance on Schedule



Inteference by Owner
Unfavourable
Normal
Favourable
Membership Value
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
Rating of Significance on Schedule


Quality of Field Management
Unfavourable
Normal
Favourable
Membership Value
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
Rating of Significance on Schedule

APPENDIX D – FACTORS WITH DIRECT RELATIONSHIPS TO OUTPUT

Variables with Crisp Input and Direct Relationships to Output

Shift Length

Shift Length	Duration Variation
0	-1
4	-0.5
6	-0.25
8	0
10	0.25
12	0.5
16	1
20.	1.5
24	2

Variation = (Length-8)/8

Change in Planned Production

% Change	Duration Variation
-100	-1
-80	-0.8
-60	-0.6
-40	-0.4
-20	-0.2
0	0
20	0.2
40	0.4
60	0.6
80	0.8
100	1

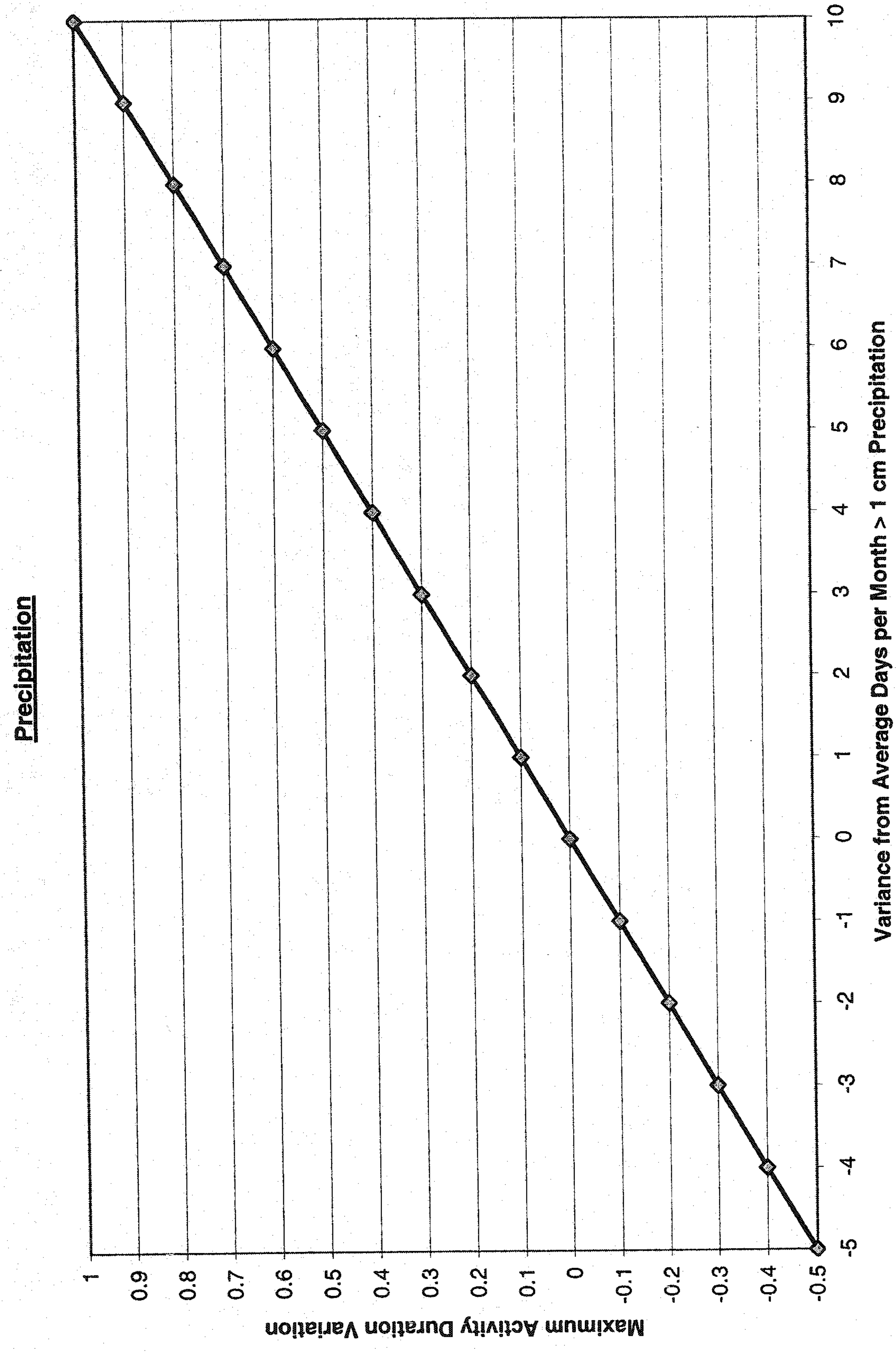
Variation = %Change/100

Precipitation

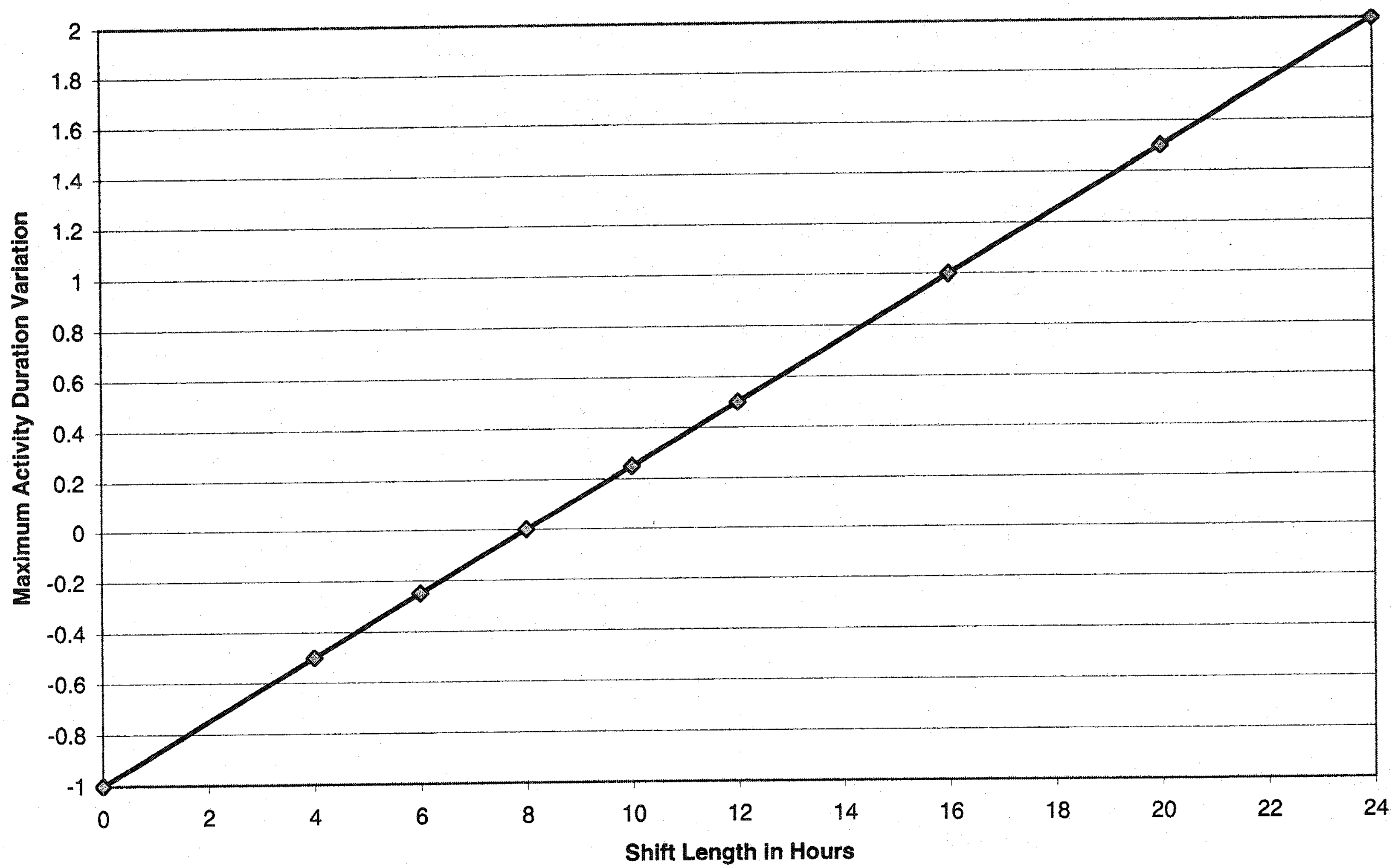
Change from Ave.	Duration Variation
-5	-0.5
-4	-0.4
-3	-0.3
-2	-0.2
-1	-0.1
0	0
1	0.1
2	0.2
3	0.3
4	0.4
5	0.5
6	0.6
7	0.7
8	0.8
9	0.9
10	1

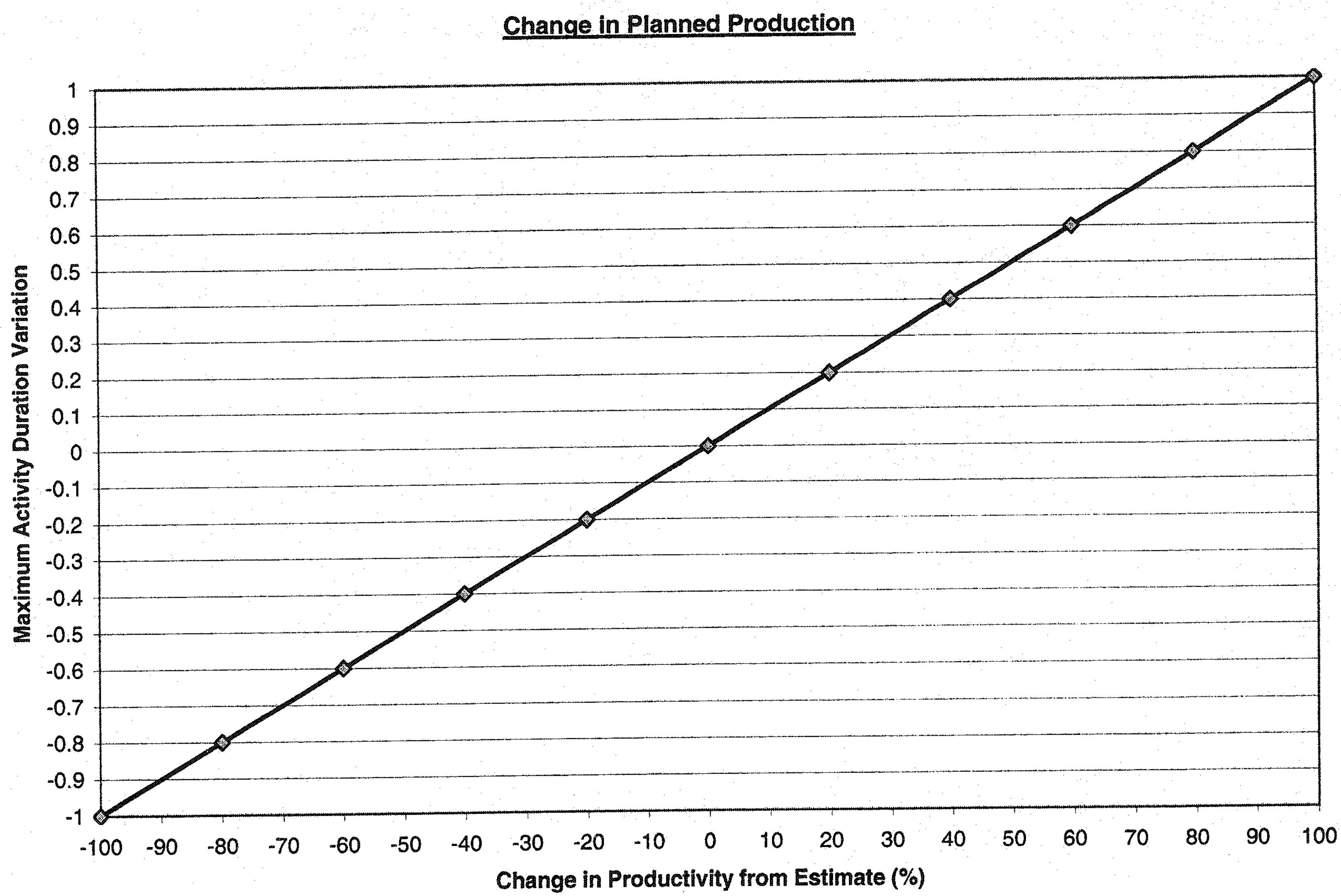
Variation = (Change from Average Days Rain) * 0.1

Based on 20 working days per month
and 2 days delay per rain event


Precipitation
Maximum Activity Duration Variation
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
Variance from Average Days per Month > 1 cm Precipitation

Shift Length




Change in Planned Production
Maximum Activity Duration Variation
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1
-100 -90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100
Change in Productivity from Estimate (%)

Temperature / Humidity Effects on Productivity

- units of Production are "% of Planned Production"
- units of Temp are "Degrees Celsius"

90% Relative Humidity

Temp	Production
-23	56
-18	71
-12	82
-7	89
-1	93
4	96
10	98
16	98
21	96
27	93
32	84
38	57
43	0

80% Relative Humidity

Temp	Production
-23	57
-18	73
-12	84
-7	91
-1	95
4	98
10	100
16	100
21	98
27	95
32	87
38	68
43	15

70% Relative Humidity

Temp	Production
-23	59
-18	75
-12	86
-7	93
-1	97
4	99
10	100
16	100
21	99
27	97
32	90
38	76
43	50

60% Relative Humidity

Temp	Production
-23	60
-18	76
-12	87
-7	94
-1	98
4	100
10	100
16	100
21	100
27	98
32	93
38	80
43	57

50% Relative Humidity

Temp	Production
-23	61
-18	77
-12	88
-7	94
-1	98
4	100
10	100
16	100
21	100
27	99
32	94
38	82
43	60

40% Relative Humidity

Temp	Production
-23	62
-18	78
-12	88
-7	94
-1	98
4	100
10	100
16	100
21	100
27	99
32	94
38	84
43	63

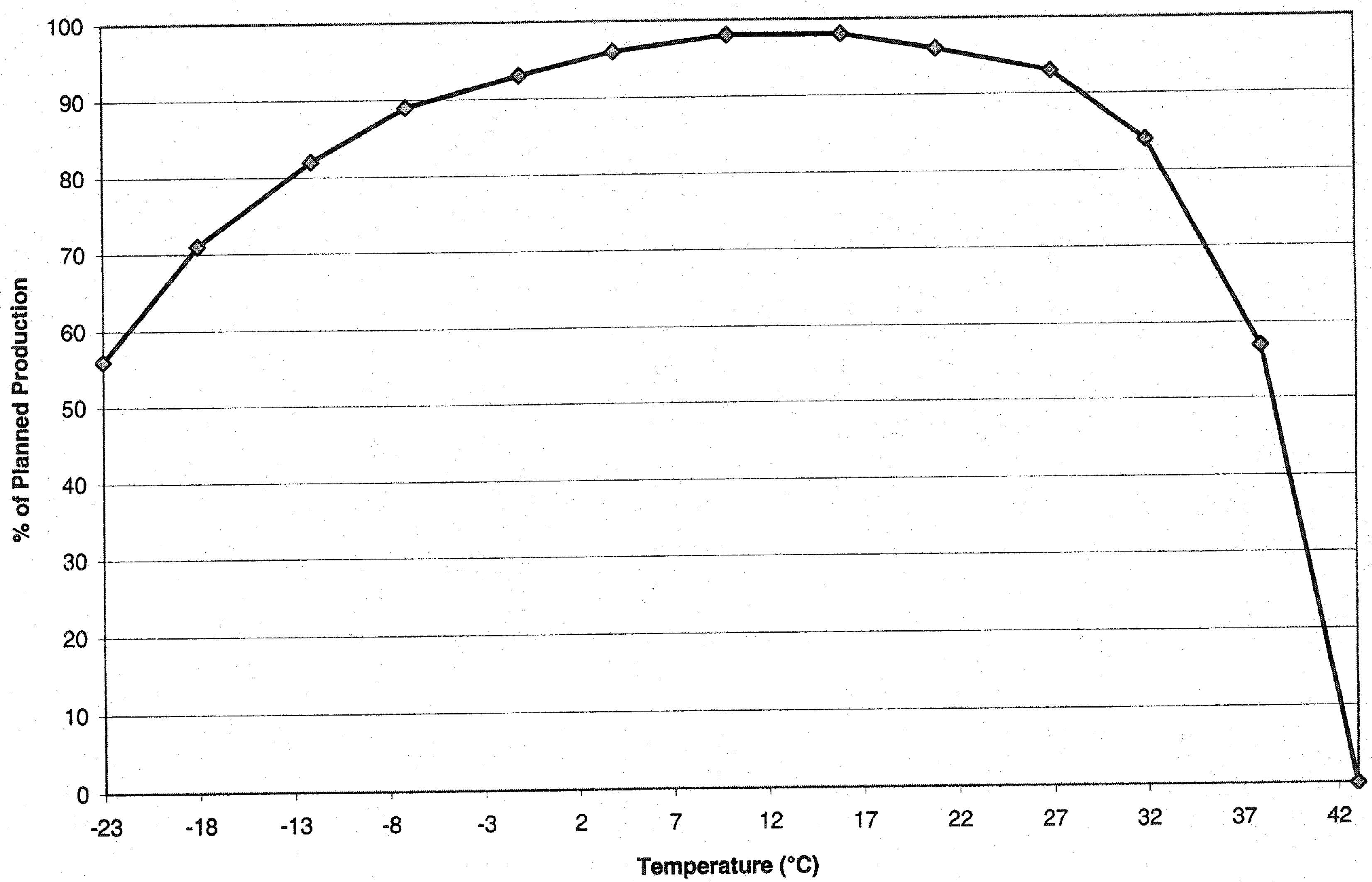
30% Relative Humidity

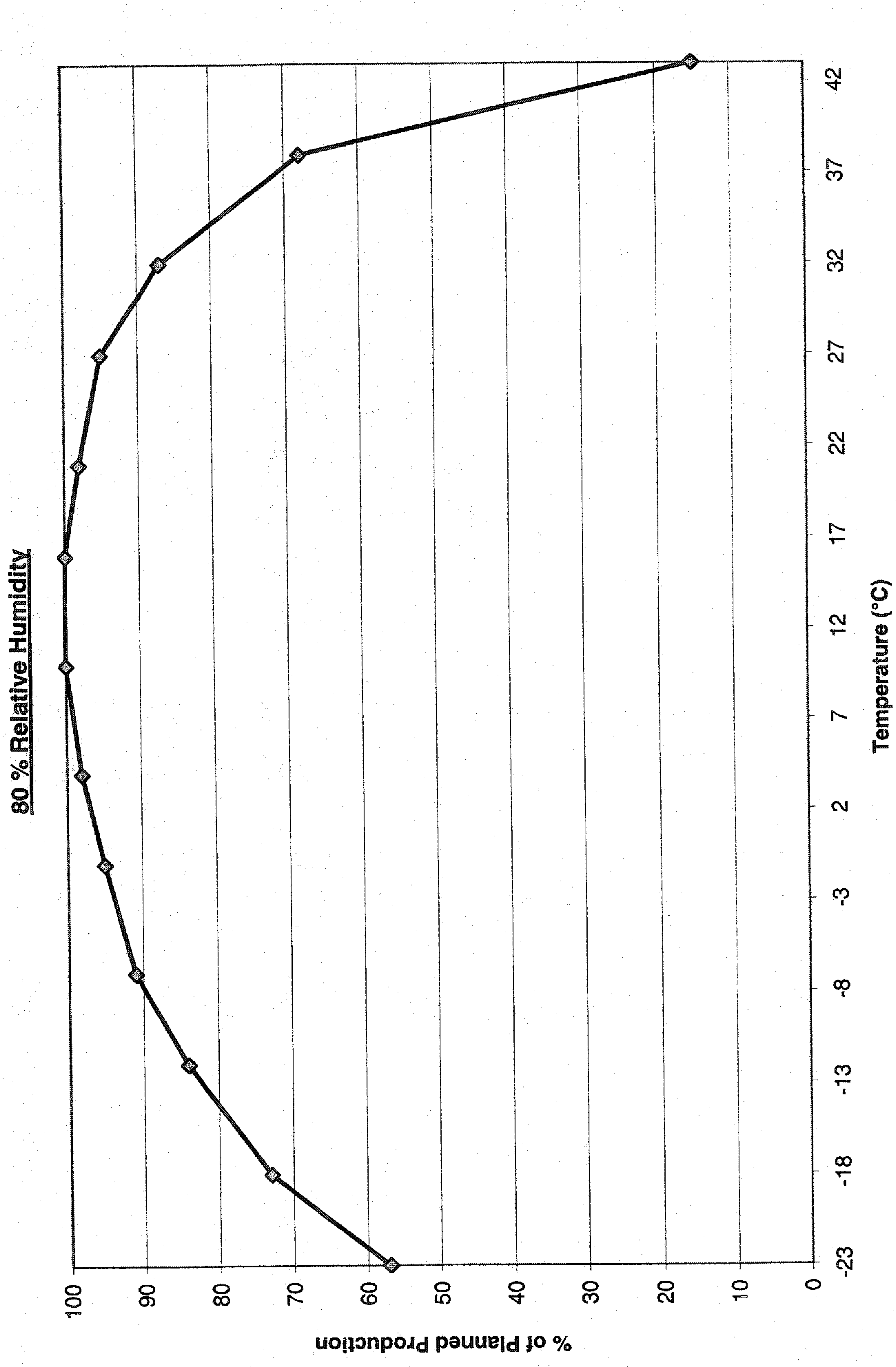
Temp	Production
-23	62
-18	78
-12	88
-7	94
-1	98
4	100
10	100
16	100
21	100
27	99
32	93
38	83
43	62

20% Relative Humidity

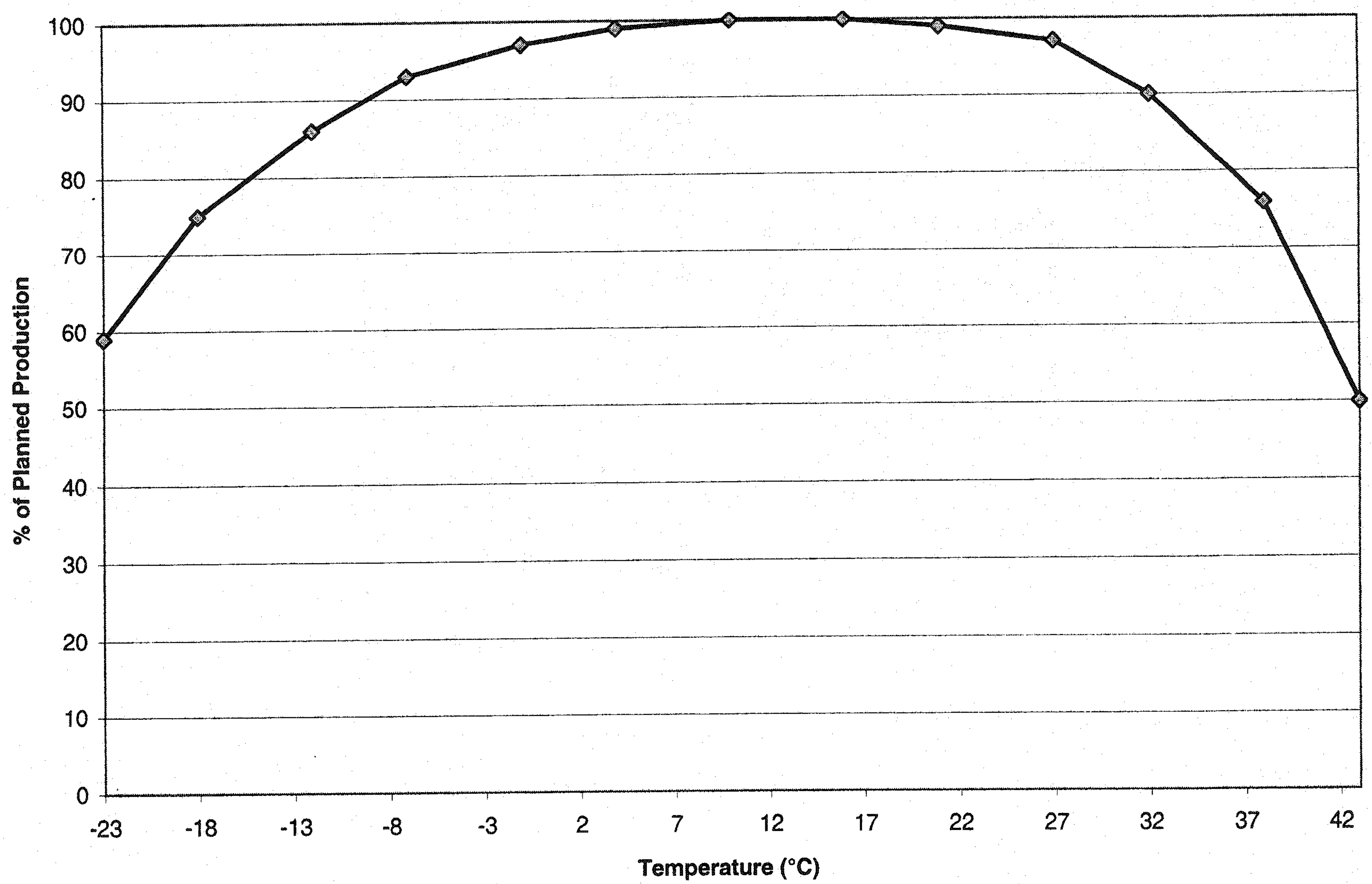
Temp	Production
-23	62
-18	78
-12	88
-7	94
-1	98
4	100
10	100
16	100
21	100
27	99
32	93
38	82
43	61

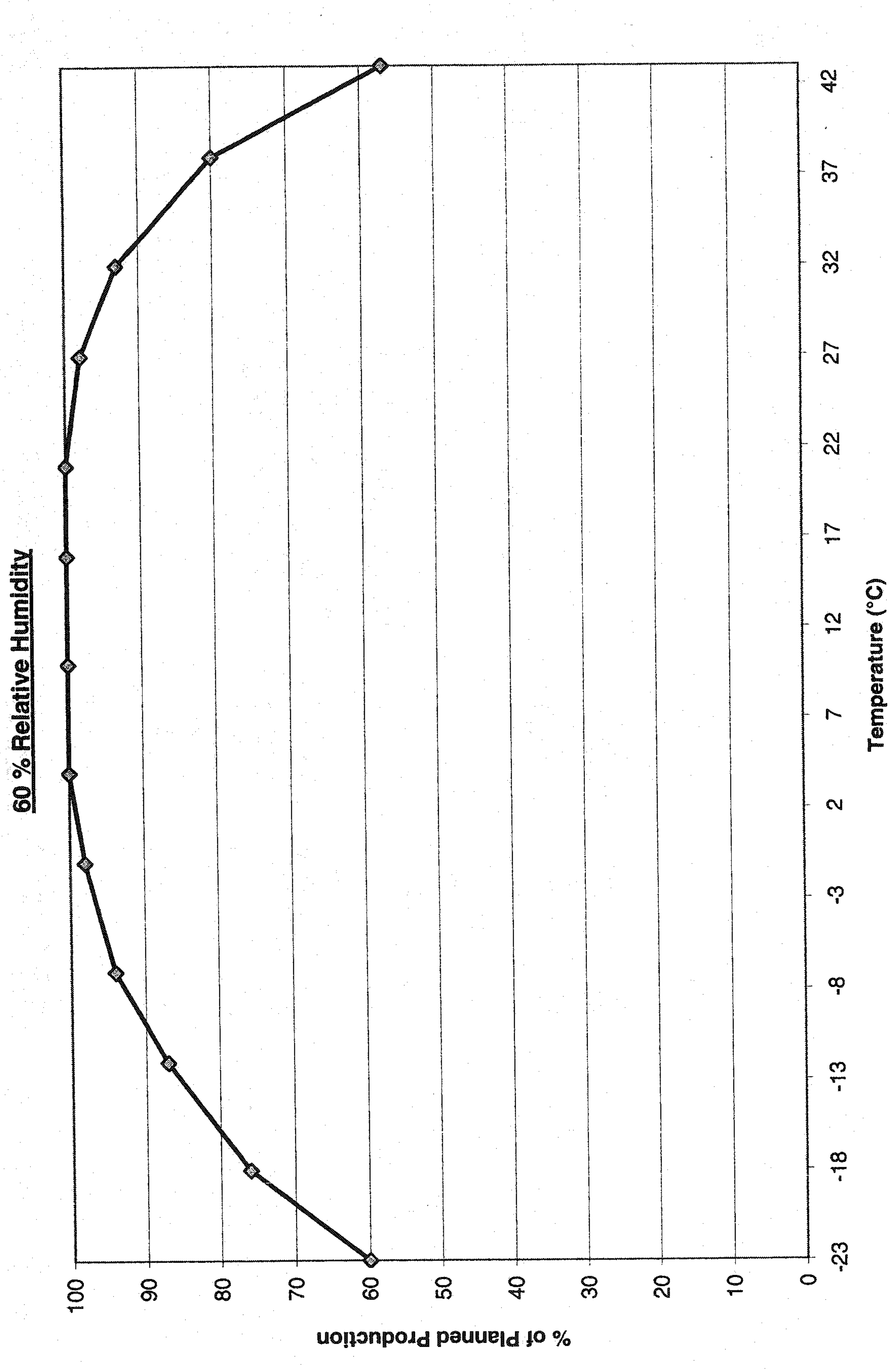
90 % Relative Humidity



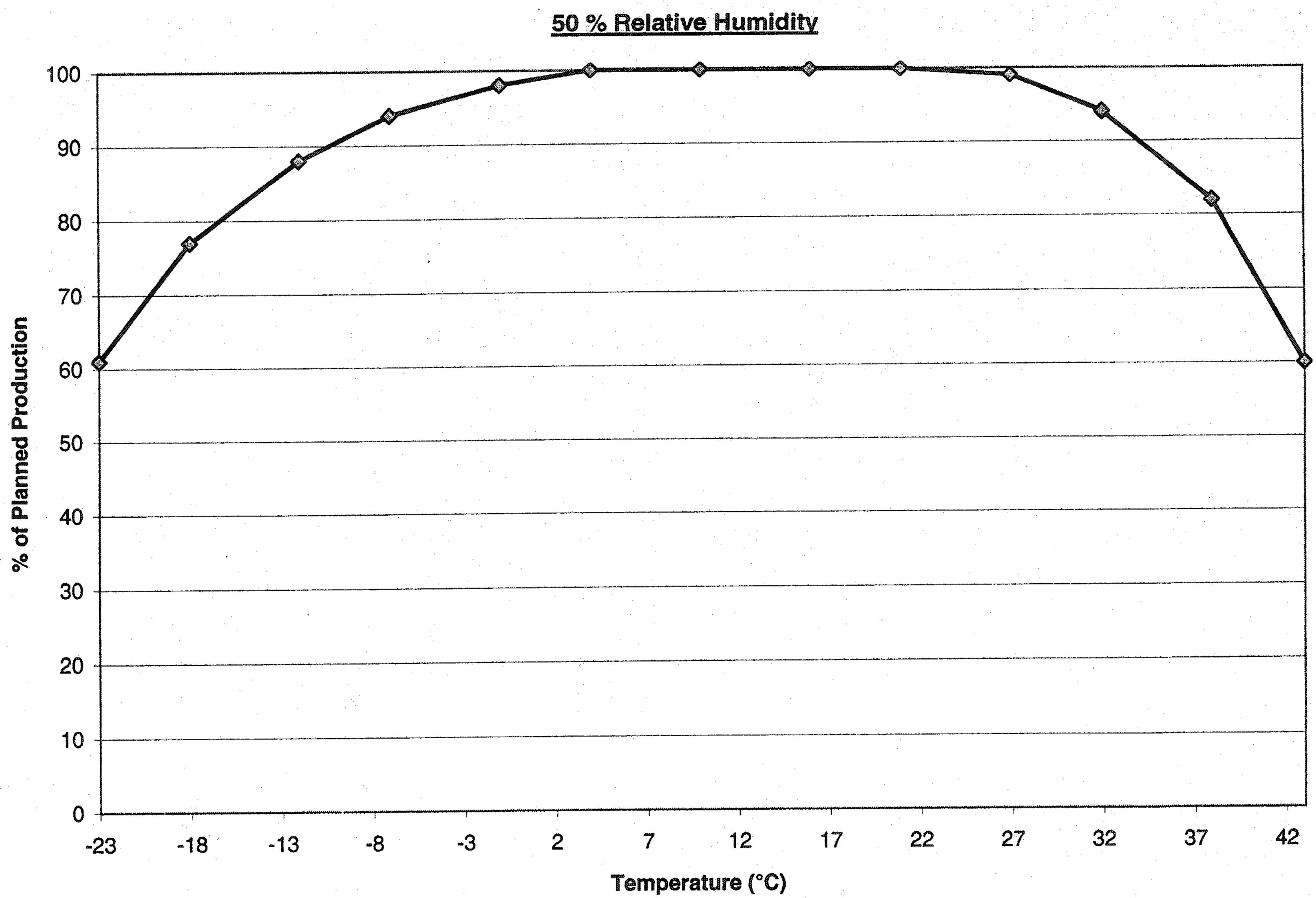

80 % Relative Humidity
% of Planned Production
100
90
80
70
60
50
40
30
20
10
0
-23
-18
-13
-8
-3
2
7
12
17
22
27
32
37
42
Temperature (°C)

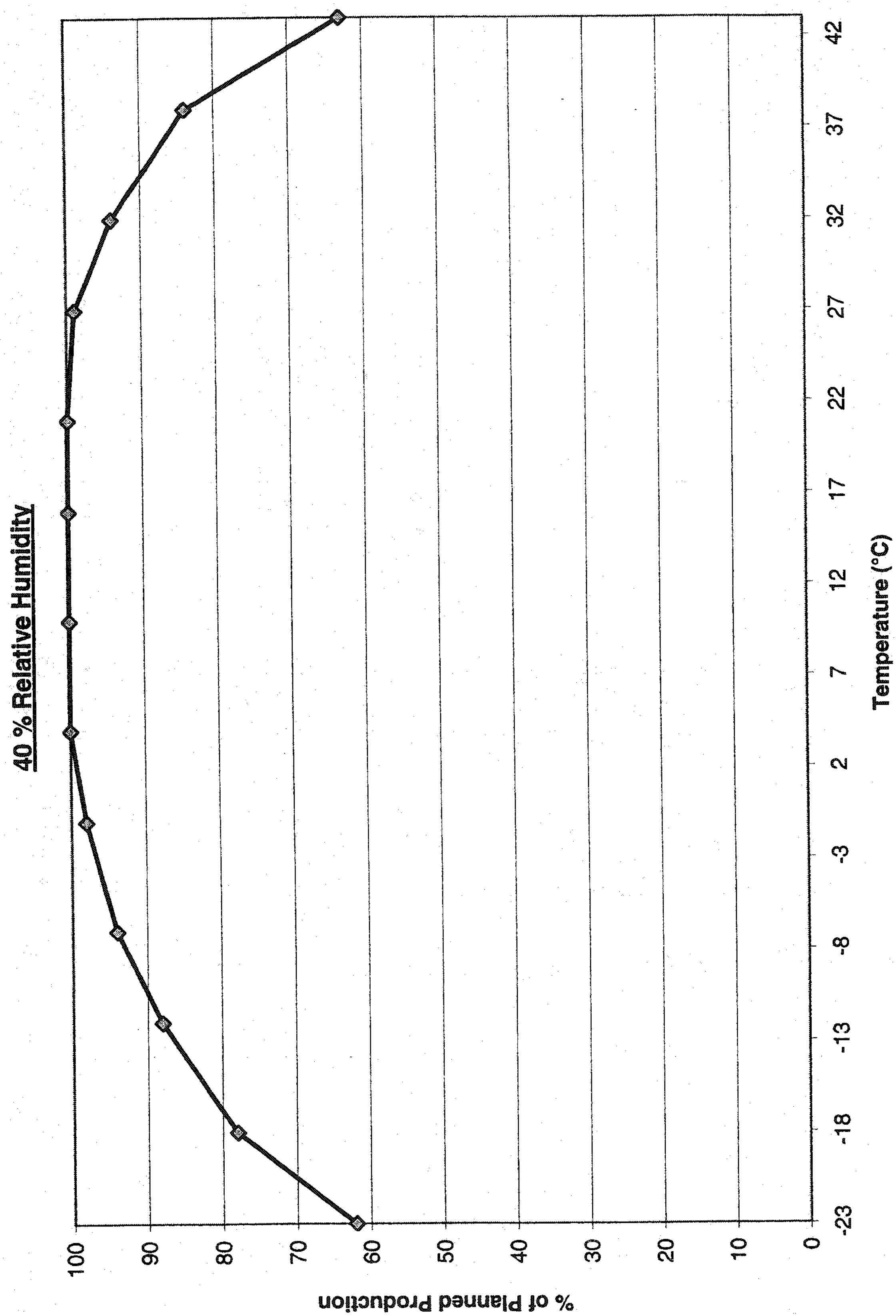
70 % Relative Humidity

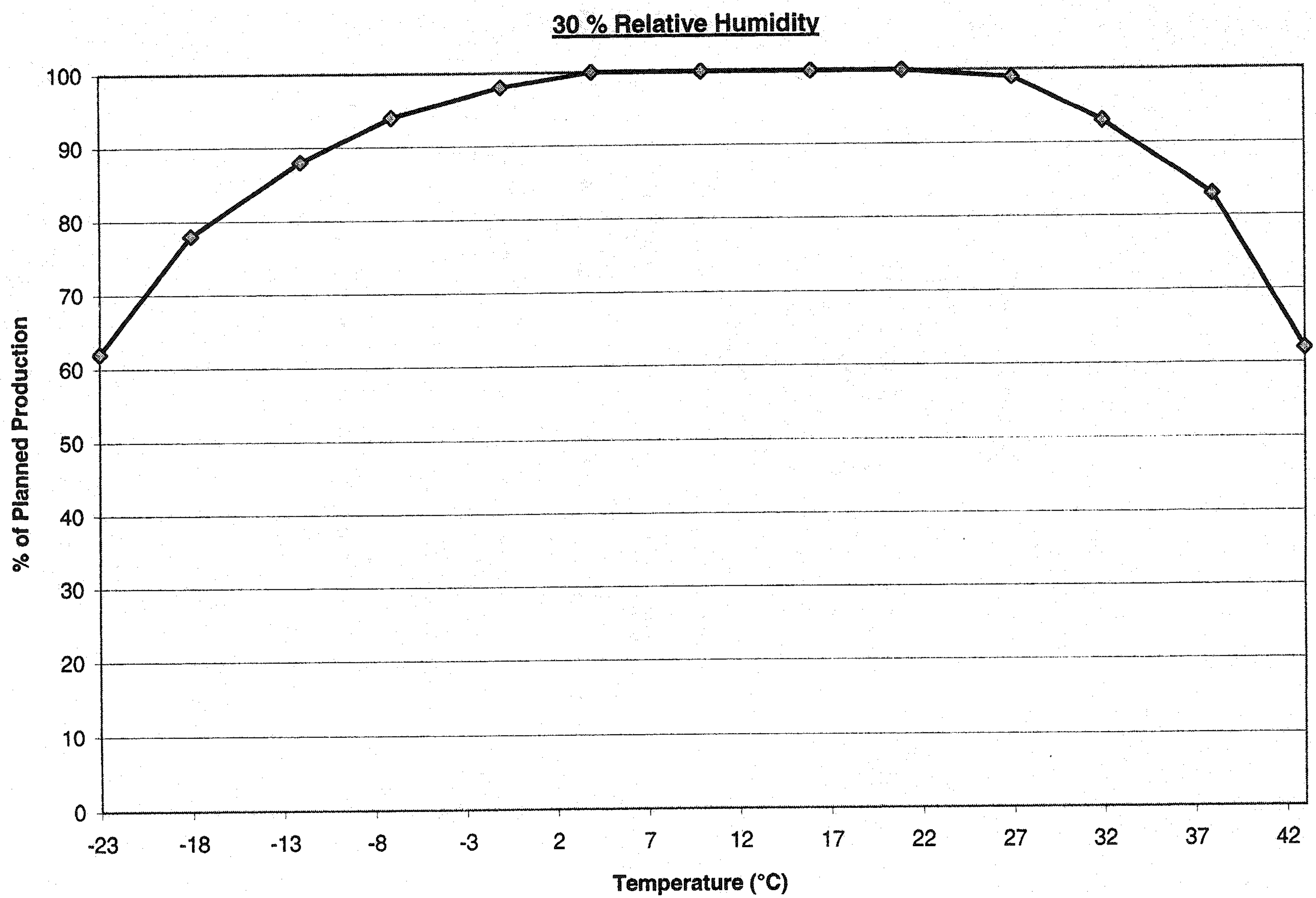


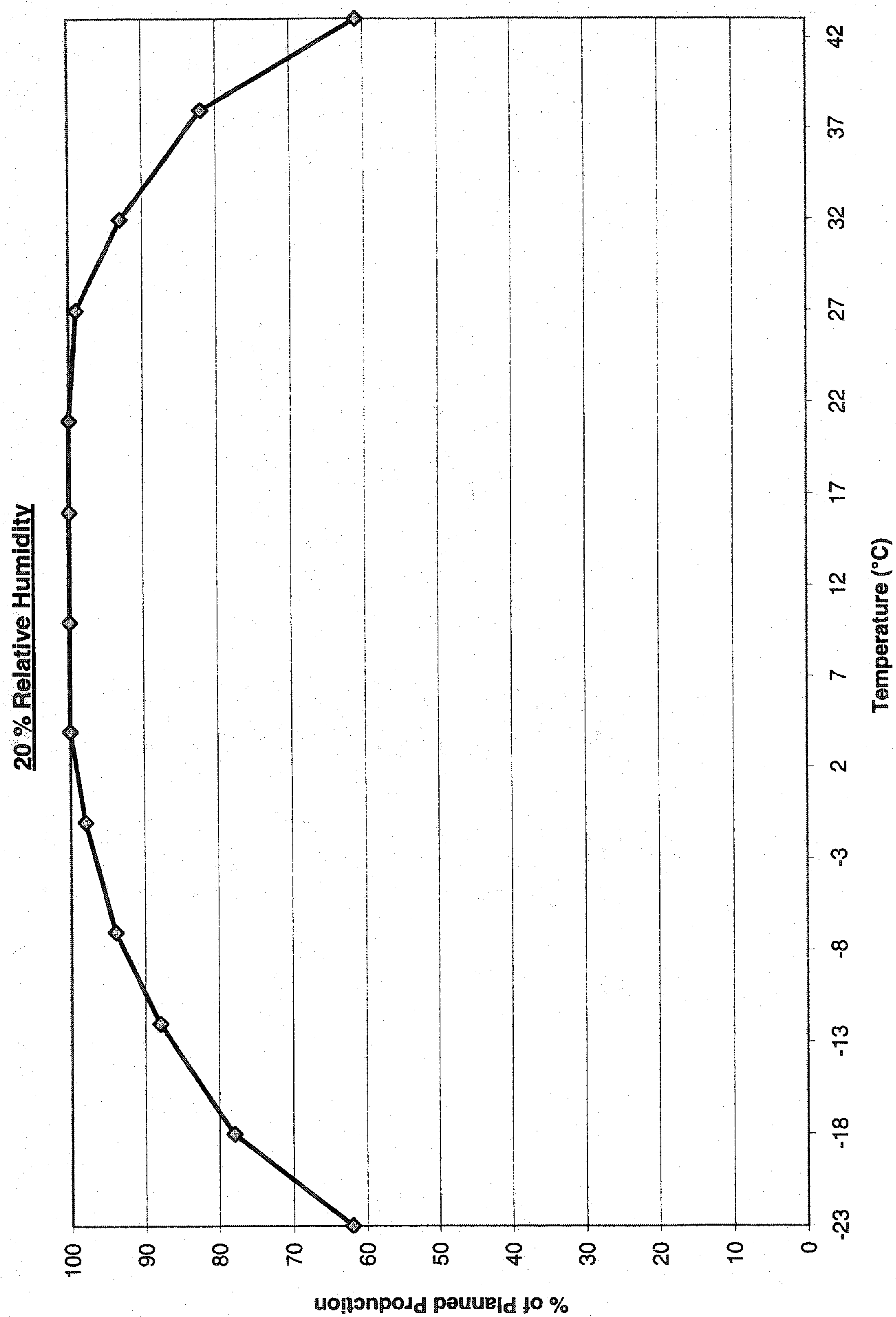


60 % Relative Humidity
% of Planned Production
100
90
80
70
60
50
40
30
20
10
0
-23
-18
-13
-8
-3
2
7
12
17
22
27
32
37
42
Temperature (°C)


50 % Relative Humidity
% of Planned Production
100
90
80
70
60
50
40
30
20
10
0
-23
-18
-13
-8
-3
2
7
12
17
22
27
32
37
42
Temperature (°C)

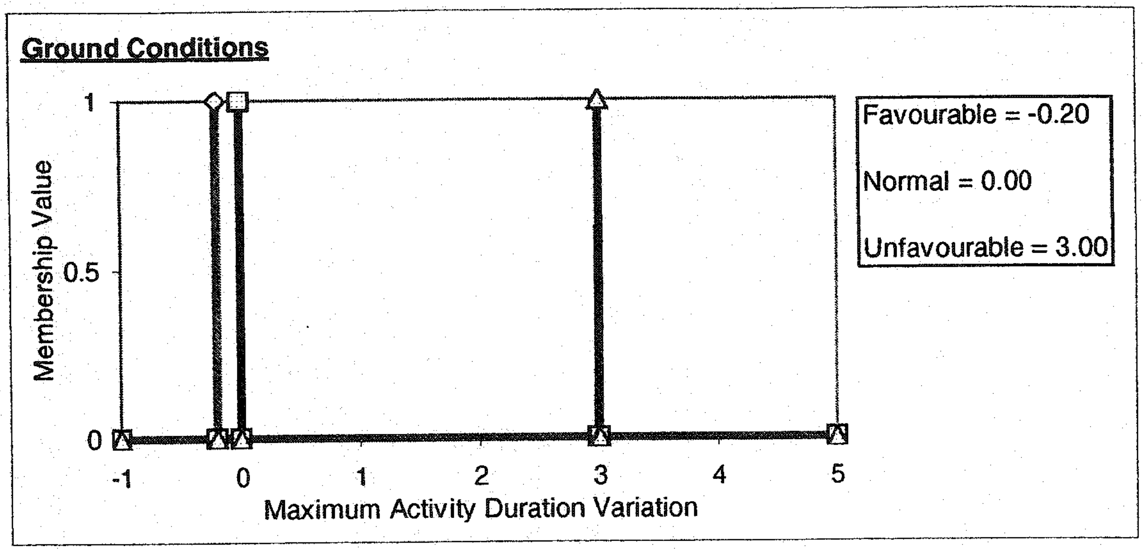

40 % Relative Humidity
% of Planned Production
100
90
80
70
60
50
40
30
20
10
0
-23
-18
-13
-8
-3
2
7
12
17
22
27
32
37
42
Temperature (°C)

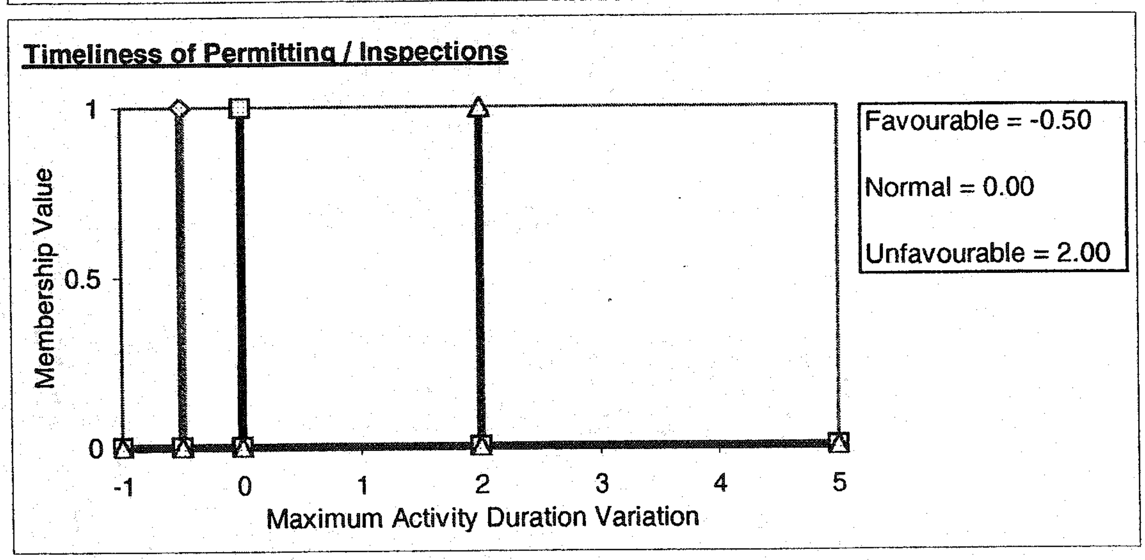

30 % Relative Humidity
% of Planned Production
100
90
80
70
60
50
40
30
20
10
0
-23
-18
-13
-8
-3
2
7
12
17
22
27
32
37
42
Temperature (°C)

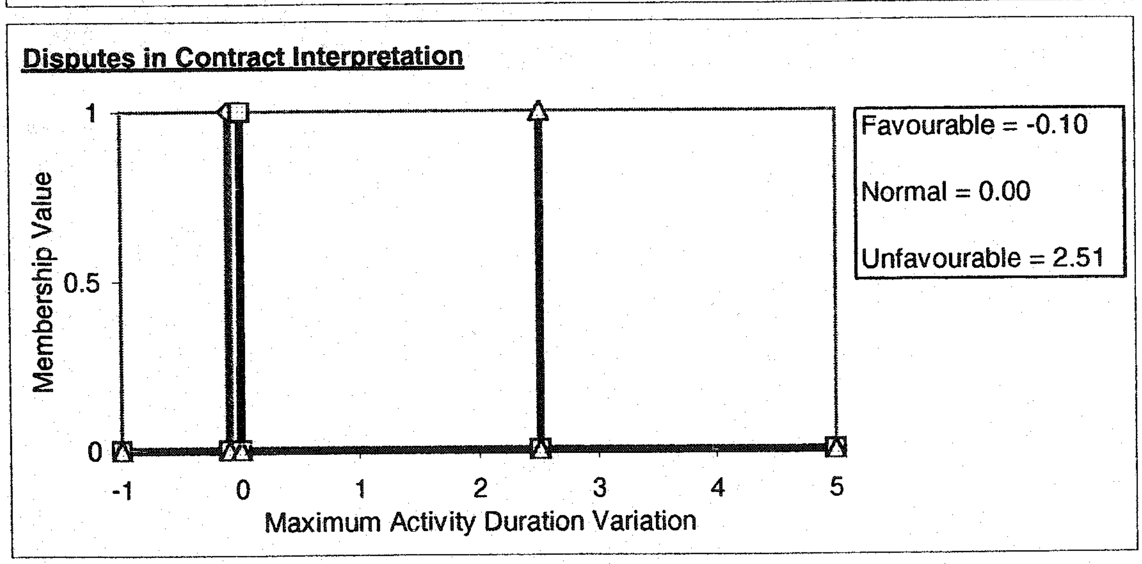


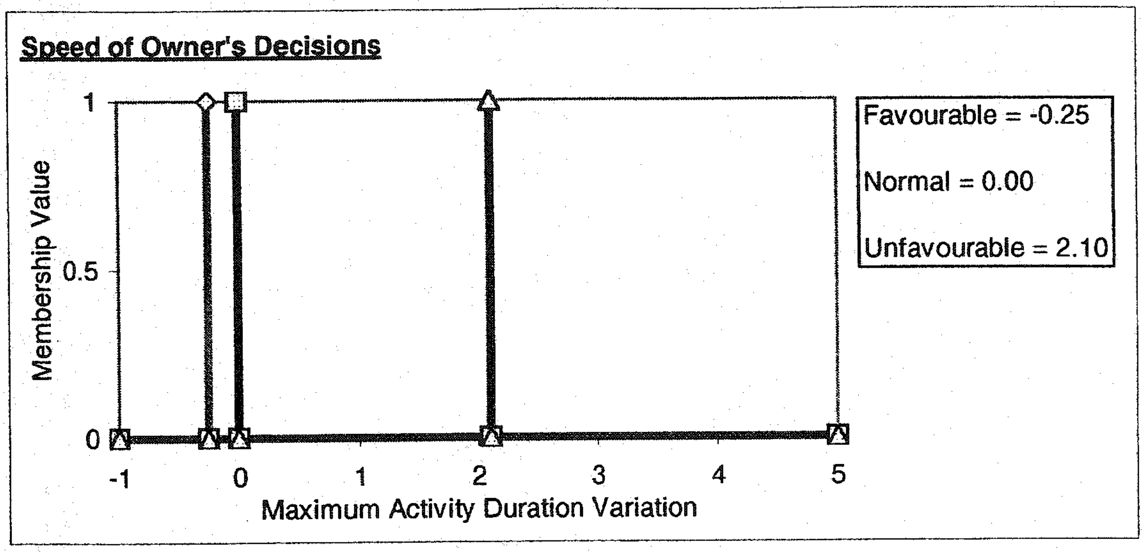
20 % Relative Humidity
% of Planned Production
100
90
80
70
60
50
40
30
20
10
0
-23
-18
-13
-8
-3
2
7
12
17
22
27
32
37
42
Temperature (°C)

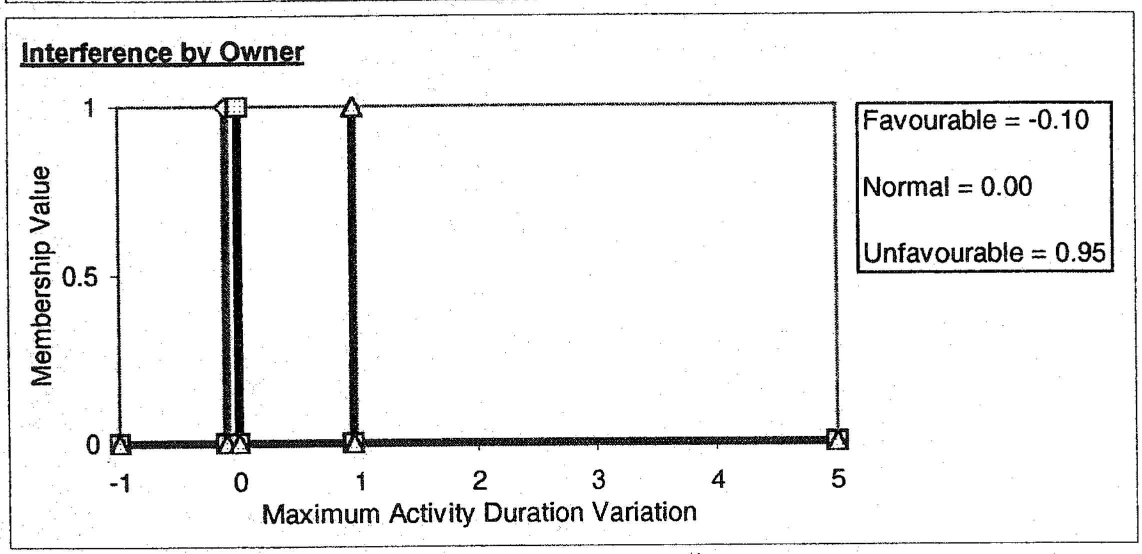
APPENDIX E – MEMBERSHIP FUNCTIONS FOR OUTPUT VARIABLES

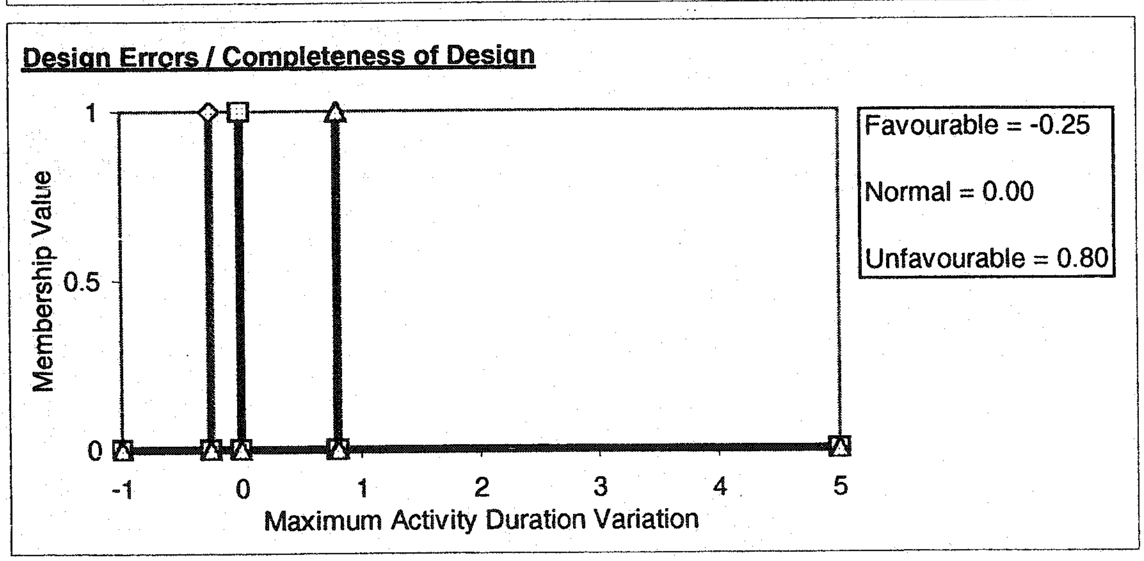

Ground Conditions
1
0.5
0
Membership Value
-1
0
1
2
3
4
5
Maximum Activity Duration Variation
Favourable = -0.20
Normal = 0.00
Unfavourable = 3.00

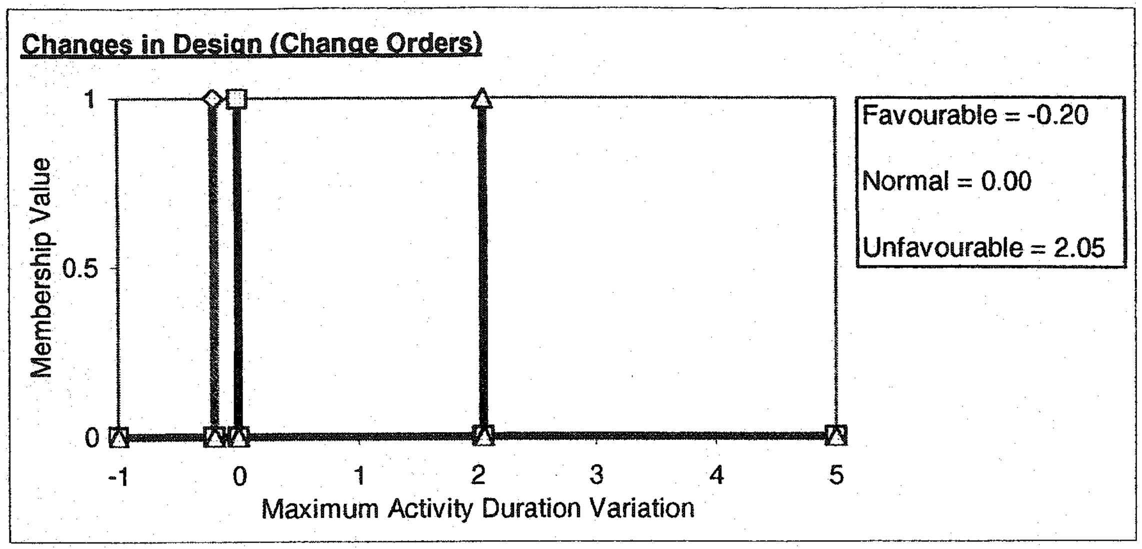

Timeliness of Permitting / Inspections
1
0.5
0
Membership Value
-1
0
1
2
3
4
5
Maximum Activity Duration Variation
Favourable = -0.50
Normal = 0.00
Unfavourable = 2.00

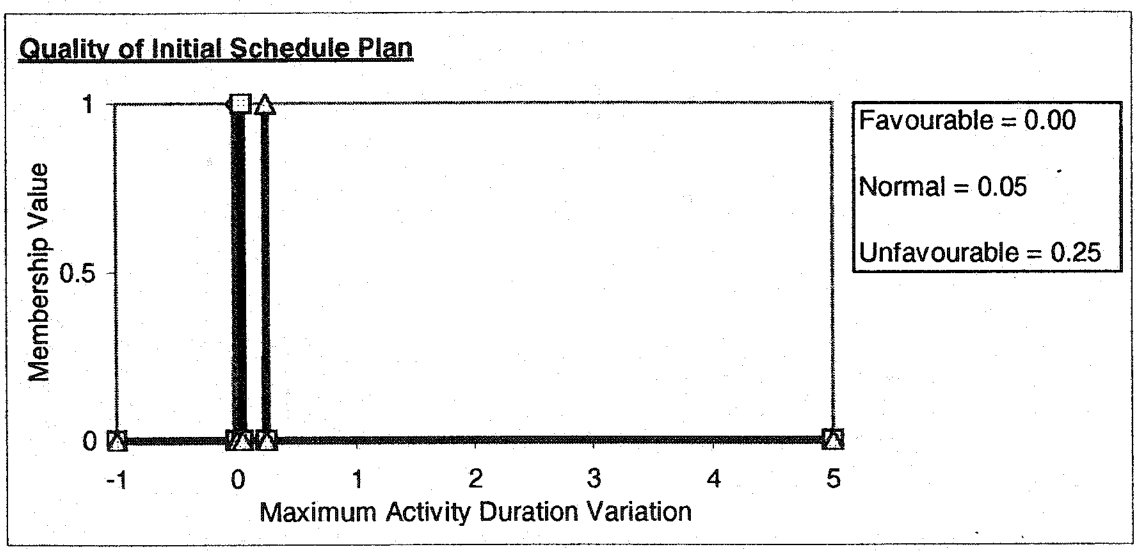

Disputes in Contract Interpretation
1
0.5
0
Membership Value
-1
0
1
2
3
4
5
Maximum Activity Duration Variation
Favourable = -0.10
Normal = 0.00
Unfavourable = 2.51

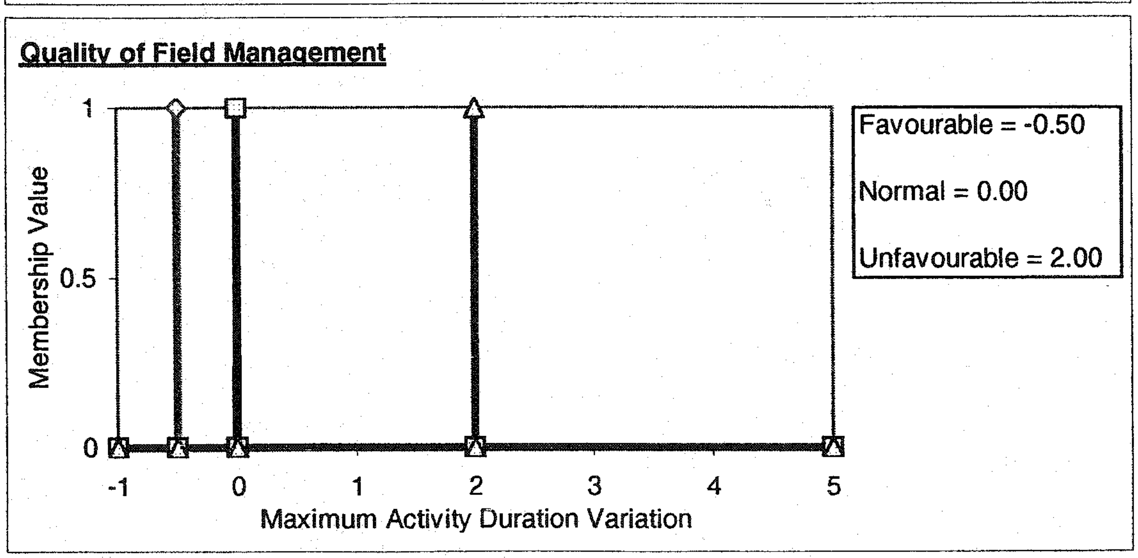

Speed of Owner's Decisions
Membership Value
1
0.5
0
-1
0
1
2
3
4
5
Maximum Activity Duration Variation
Favourable = -0.25
Normal = 0.00
Unfavourable = 2.10

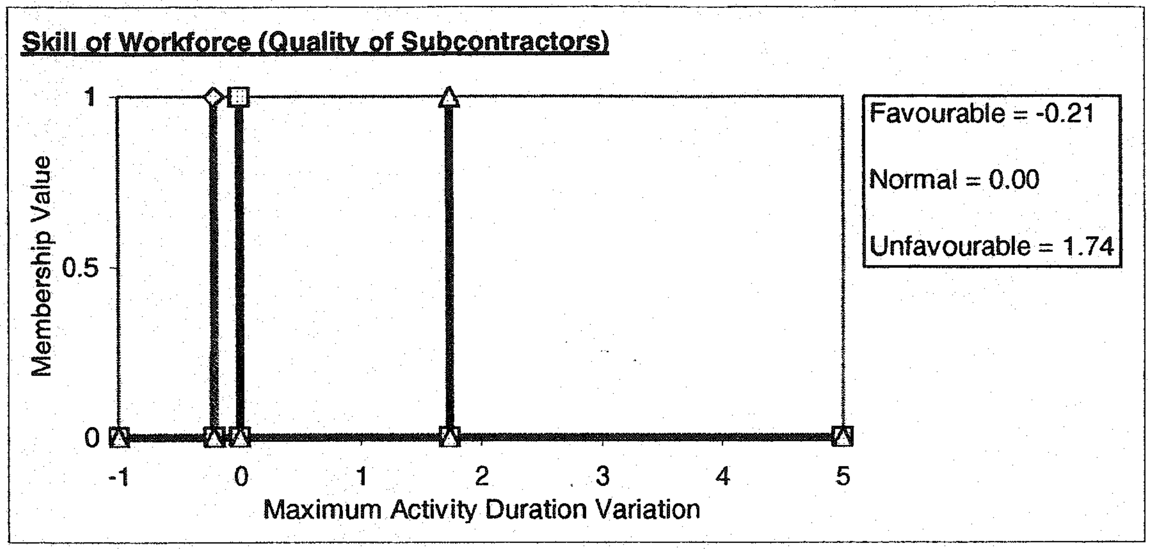

Interference by Owner
Membership Value
1
0.5
0
-1
0
1
2
3
4
5
Maximum Activity Duration Variation
Favourable = -0.10
Normal = 0.00
Unfavourable = 0.95

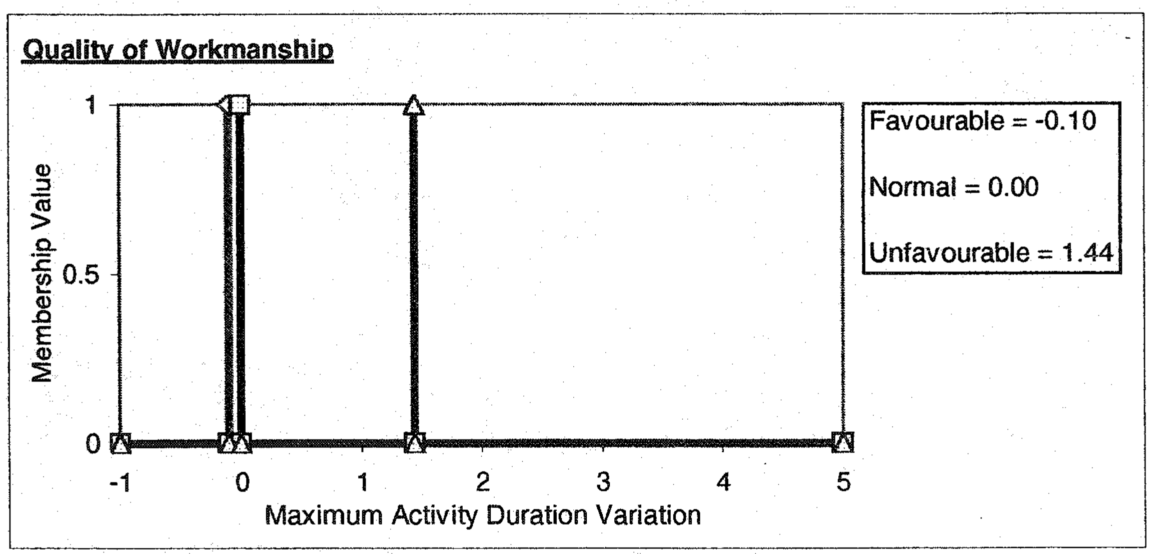

Design Errors / Completeness of Design
Membership Value
1
0.5
0
-1
0
1
2
3
4
5
Maximum Activity Duration Variation
Favourable = -0.25
Normal = 0.00
Unfavourable = 0.80


Changes in Design (Change Orders)
Membership Value
1
0.5
0
-1
0
1
2
3
4
5
Maximum Activity Duration Variation
Favourable = -0.20
Normal = 0.00
Unfavourable = 2.05


Quality of Initial Schedule Plan
Membership Value
1
0.5
0
-1
0
1
2
3
4
5
Maximum Activity Duration Variation
Favourable = 0.00
Normal = 0.05
Unfavourable = 0.25


Quality of Field Management
Membership Value
1
0.5
0
-1
0
1
2
3
4
5
Maximum Activity Duration Variation
Favourable = -0.50
Normal = 0.00
Unfavourable = 2.00


Skill of Workforce (Quality of Subcontractors)
Membership Value
1
0.5
0
-1
0
1
2
3
4
5
Maximum Activity Duration Variation
Favourable = -0.21
Normal = 0.00
Unfavourable = 1.74


Quality of Workmanship
Membership Value
1
0.5
0
-1
0
1
2
3
4
5
Maximum Activity Duration Variation
Favourable = -0.10
Normal = 0.00
Unfavourable = 1.44

APPENDIX F – SENSITIVITY VALUES

Those Developed from Collected Data in Black	Precipitation	Temp/ Humidity	Ground Conditions	Regulatory Timeliness	Contract Interpretation	Owner's Decisions	Interference by Owner
Award Subcontracts	0.00	0.00	0.00	0.00	1.00	0.00	1.00
Permits	0.00	0.00	0.00	1.00	0.00	0.00	0.00
Submittals	0.00	0.00	0.00	0.00	1.00	1.00	1.00
Precast Exterior Fab (CIP)	0.00	0.00	0.00	0.00	1.00	1.00	1.00
Precast Fab (PRE,ATC)	0.00	0.00	0.00	0.00	1.00	1.00	1.00
Elevator Fab	0.00	0.00	0.00	0.00	1.00	1.00	1.00
Mobilize	0.50	0.00	0.00	0.00	1.00	1.00	1.00
Demo	0.75	0.25	0.50	0.00	1.00	1.00	1.00
Curb&Gutter/Sidewalk	0.75	0.50	0.50	0.00	1.00	1.00	1.00
Landscaping	0.75	0.75	0.50	0.00	1.00	1.00	1.00
Bulk Excavation	1.00	0.25	1.00	0.00	1.00	1.00	1.00
Deep Foundations	0.90	0.25	1.00	0.00	1.00	1.00	1.00
Shallow Foundations	0.90	0.50	0.75	0.00	1.00	1.00	1.00
Foundation Walls	0.75	0.75	0.50	0.00	1.00	1.00	1.00
M&E UG	0.90	0.50	1.00	0.00	1.00	1.00	1.00
Prep SOG	1.00	0.50	0.50	0.00	1.00	1.00	1.00
Pour SOG	0.50	0.75	0.00	0.00	1.00	1.00	1.00
Erect Precast Columns (ATC)	0.25	0.25	0.00	0.00	1.00	1.00	1.00
Install Precast Beams (ATC)	0.25	0.25	0.00	0.00	1.00	1.00	1.00
Erect Precast Structure (PRE)	0.25	0.25	0.00	0.00	1.00	1.00	1.00
Caulk Joints (PRE)	0.25	1.00	0.00	0.00	1.00	1.00	1.00
Place Topping (PRE)	0.25	0.75	0.00	0.00	1.00	1.00	1.00
Ground Level Columns (CIP)	0.35	0.75	0.00	0.00	1.00	1.00	1.00
Column Caps (CIP)	0.25	0.75	0.00	0.00	1.00	1.00	1.00
FRP Slab (CIP,ATC)	0.25	0.75	0.00	0.00	1.00	1.00	1.00
Stress P/T (CIP,ATC)	0.25	0.50	0.00	0.00	1.00	1.00	1.00
Strip Slab Formwork (CIP,ATC)	0.25	1.00	0.00	0.00	1.00	1.00	1.00
CIP Columns (CIP)	0.25	0.75	0.00	0.00	1.00	1.00	1.00
Elevator Shafts	0.25	0.75	0.00	0.00	1.00	1.00	1.00
Install Stairs	0.20	0.50	0.00	0.00	1.00	1.00	1.00
Install Elevators	0.20	0.50	0.00	0.00	1.00	1.00	1.00
Install Exterior Façade	0.30	0.25	0.00	0.00	1.00	1.00	1.00
M&E R-in	0.20	1.00	0.00	0.00	1.00	1.00	1.00
Fire Protection	0.20	1.00	0.00	0.00	1.00	1.00	1.00
Inspections	0.00	0.00	0.00	1.00	0.00	0.00	1.00

Those Developed from Collected Data in Black	Design Errors/ Completeness	Changes to Design	Initial Schedule	Field Management	Skill of Workforce	Shift Length	Changes in Production	Quality of Workmanship
Award Subcontracts	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Permits	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Submittals	1.00	1.00	1.00	0.00	1.00	0.00	0.00	0.00
Precast Exterior Fab (CIP)	0.25	1.00	1.00	0.00	0.57	1.00	1.00	1.00
Precast Fab (PRE,ATC)	0.25	1.00	1.00	0.00	0.50	1.00	1.00	1.00
Elevator Fab	0.25	1.00	1.00	0.00	0.50	1.00	1.00	0.25
Mobilize	0.00	0.00	1.00	1.00	0.25	1.00	1.00	0.00
Demo	0.50	1.00	1.00	1.00	1.00	1.00	1.00	0.25
Curb&Gutter/Sidewalk	0.25	0.50	1.00	1.00	0.50	1.00	1.00	0.50
Landscaping	0.25	0.50	1.00	1.00	0.50	1.00	1.00	0.50
Bulk Excavation	1.00	1.00	1.00	1.00	0.50	1.00	1.00	0.25
Deep Foundations	0.50	0.50	1.00	1.00	1.00	1.00	1.00	0.24
Shallow Foundations	0.50	0.50	1.00	1.00	1.00	1.00	1.00	0.25
Foundation Walls	0.50	0.15	1.00	1.00	0.29	1.00	1.00	0.25
M&E UG	1.00	0.25	1.00	1.00	1.00	1.00	1.00	0.50
Prep SOG	0.50	0.25	1.00	1.00	0.75	1.00	1.00	0.25
Pour SOG	0.50	0.31	1.00	1.00	0.75	1.00	1.00	0.25
Erect Precast Columns (ATC)	1.00	0.50	1.00	1.00	1.00	1.00	1.00	1.00
Install Precast Beams (ATC)	1.00	0.50	1.00	1.00	1.00	1.00	1.00	1.00
Erect Precast Structure (PRE)	1.00	0.50	1.00	1.00	1.00	1.00	1.00	1.00
Caulk Joints (PRE)	0.38	0.25	1.00	1.00	0.50	1.00	1.00	1.00
Place Topping (PRE)	0.50	0.10	1.00	1.00	0.75	1.00	1.00	0.50
Ground Level Columns (CIP)	0.50	0.25	1.00	1.00	0.75	1.00	1.00	0.25
Column Caps (CIP)	0.50	0.25	1.00	1.00	0.75	1.00	1.00	0.25
FRP Slab (CIP,ATC)	0.50	0.25	1.00	1.00	1.00	1.00	1.00	0.25
Stress P/T (CIP,ATC)	0.25	0.10	1.00	1.00	0.19	1.00	1.00	1.00
Strip Slab Formwork (CIP,ATC)	0.25	0.25	1.00	1.00	0.25	1.00	1.00	0.10
CIP Columns (CIP)	0.50	0.16	1.00	1.00	0.75	1.00	1.00	0.25
Elevator Shafts	0.75	0.64	1.00	1.00	1.00	1.00	1.00	0.25
Install Stairs	0.50	0.50	1.00	1.00	1.00	1.00	1.00	1.00
Install Elevators	0.50	0.25	1.00	1.00	1.00	1.00	1.00	1.00
Install Exterior Façade	0.67	0.75	1.00	1.00	1.00	1.00	1.00	1.00
M&E R-in	1.00	0.25	1.00	1.00	1.00	1.00	1.00	0.50
Fire Protection	1.00	0.24	1.00	1.00	1.00	1.00	1.00	0.50
Inspections	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00

APPENDIX G – PROJECTS USED TO DEVELOP SCHEDULE TEMPLATES

This appendix contains information that is confidential.

To request a copy of this appendix, contact:

Dev Fraser,
PCL Constructors, Inc.

APPENDIX H – PRODUCTIVITY CALCULATIONS FOR SCHEDULE TEMPLATES AND *SCHEDULE ASSISTANT*

Durations

Award Subcontracts
Based on 2 observations
Average = 35
Duration Used = 35 days

Permits
Based on 8 observations
Average = 20
Duration Used = 20 days

Submittals
Based on 4 observations
Average = 57.5
Duration Used = 60 days

Elevator Fabrication (each)
Based on 3 observations
Average = 33.3
Duration Used = 30 days

Mobilize
Based on 7 observations
Average = 10.9
Duration Used = 10 days

Clear and Demo Exisiting
Based on 8 observations
Average = 6.9
Duration Used = 5 days

Paving/Sidewalk
Based on 8 observations
Average = 15.3
Duration Used = 15 days

Prep SOG
Based on 7 observations
Average = 606 cy per day
Duration Used = 10 days per 6000 cy

Reinforce/Pour SOG
Based on 9 observations
Average = 3727 sf per day
Duration Used = 10 days per 35 000 sf

Elevator Shafts/Shear Walls (CIP)
Based on 3 observations
Average = 35.2 cy per day
Duration Used = 20 days per 700 cy

Install Stairs
Based on 0 observations
Average =
Duration Used = 5 days per level

Install Elevators
Based on 6 observations
Average = 22.1 days per elevator
Duration Used = 20 days per elevator

Install Exterior Façade
Based on 3 observations
Average = 7.5 panels per day
Duration Used = 10 days per 75 panels

M & E Rough-In
Based on 9 observations
Average = 8841 GSF per day
Duration Used = 10 days per 100 000 GSF

Landscaping
Based on 9 observations
Average = 15.8
Duration Used = 15 days

Precast Fabrication (ATC - no Dtees)
Based on 3 observations
Average = 10 233 elevated GSF per day
Duration Used = 20 days per elevated 200 000 sf

Precast Fabrication (incl. Dtees)
Based on 1 observations
Average = 788 elevated GSF per day (this is low)
Duration Used = 30 days per elevated 200 000 sf

Exterior Precast Fabrication only (for CIP)
Based on 0 observations
Average =
Duration Used = 40 days

Bulk Excavation
Based on 2 observations
Average = 1371.5 cy per day
Duration Used = 15 days per 20 000 cy

Deep Foundations
Based on 4 observations
Average = 5.2 per day
Duration Used = 20 days per 100 piles

Shallow Foundations
Based on 6 observations
Average = 355 sf per day
Duration Used = 10 days per 250 cy

Fire Protection
Based on 6 observations
Average = 13 859 GSF per day
Duration Used = 10 days per 150 000 GSF

Building and System Inspections
Based on 8 observations
Average = 15.3
Duration Used = 15 days

Erect Precast (Precast System)
Based on 3 observations
Average = 5035 elevated GSF per day
Duration Used = 20 days per 100 000 elevated GSF

Caulk Joints (Precast System)
Based on 1 observations
Average = 11 923 elevated GSF per day
Duration Used = 5 days per 60 000 elevated GSF

Place Topping (Precast System)
Based on 2 observations
Average = 122.4 cy per day
Duration Used = 10 days per 1200 cy

Erect Columns (ATC System)
Based on 4 observations
Average = 19 394 elevated GSF per day
Duration Used = 5 days per 100 000 elevated GSF

Install Beams (ATC System)
Based on 4 observations
Average = 14 823 elevated GSF per day
Duration Used = 10 days per 150 000 elevated GSF

<u>Foundation Walls</u>
Based on 3 observations
Average =
Duration Used = 10 days per 2500 sf

<u>M & E UG Services</u>
Based on 9 observations
Average = 25.6
Duration Used = 25 days

<u>Ground Level CIP Columns</u>
Based on 3 observations
Average = 3.9 per day
Duration Used = 20 days per 80 columns

APPENDIX I – PRODUCTIVITY DATA COLLECTION FORM

Cast in Place Structural System

Name:
Job Number:
District:
Year Completed:
Value:
Contact:

Specifications

Number of Stalls =
Gross Floor Area =
GFA per Stall = GFA/Stalls =
Total Volume of Concrete Poured =
cy Concrete per GFA = Vol Conc/GFA =
Levels Below Grade =
Levels Above Grade =
Footprint of Building =
Excavation: Depth/Volume =
Piles: Number/Volume/Volume of Pile Caps =
Grade Beams: Length/Volume =
Foundation Walls: Length/Height/Volume =
Fill to Grade, Prep SOG: Volume =
Slab on Grade: Depth/Volume =
Stair/Elevator Shafts, Shear Walls: Number/Vol Conc =
Elevators: Number/Levels High =
Fire Protection: Levels =
Number of Precast Exterior Panels =
Columns: Number/Volume =
Beams: Length/Volume =
Formwork: Elevated Area Purchased =
Formwork: Pours per Cycle of Forms =

Other Project Data

Precast Structural System

Name:
Job Number:
District:
Year Completed:
Value:
Contact:

Specifications

Number of Stalls =
Gross Floor Area =
GFA per Stall = GFA/Stalls =
Levels Below Grade =
Levels Above Grade =
Footprint of Building =
Excavation: Depth/Volume =
Piles: Number/Volume/Volume of Pile Caps =
Grade Beams: Length/Volume =
Foundation Walls: Length/Height/Volume =
Fill to Grade, Prep SOG: Volume =
Slab on Grade: Depth/Volume =
Stair/Elevator Shafts, Shear Walls: Number/Vol Conc =
Elevators: Number/Levels High =
Fire Protection: Levels =
Precast Columns: Number/Height =
Precast Beams: Number/Length =
Number of Double Tees =
Depth of Topping =
Number of Precast Exterior Panels =

Other Project Data

Hybrid Precast/Cast in Place Deck Structural System

Name:
Job Number:
District:
Year Completed:
Value:
Contact:

Specifications

Number of Stalls =
Gross Floor Area =
GFA per Stall = GFA/Stalls =
Total Volume of Concrete Poured =
cy Concrete per GFA = Vol Conc/GFA =
Levels Below Grade =
Levels Above Grade =
Footprint of Building =
Excavation: Depth/Volume =
Piles: Number/Volume/Volume of Pile Caps =
Grade Beams: Length/Volume =
Foundation Walls: Length/Height/Volume =
Fill to Grade, Prep SOG: Volume =
Slab on Grade: Depth/Volume =
Stair/Elevator Shafts, Shear Walls: Number/Vol Conc =
Elevators: Number/Levels High =
Fire Protection: Levels =
Precast Columns: Number/Height =
Precast Beams: Number/Length =
Number of Precast Exterior Panels =
Slab Formwork: Area Purchased =
Slab Formwork: Pours per Cycle of Forms =

Other Project Data

APPENDIX J – FORM FOR TABULATING ACTIVITY DURATION VARIATIONS

CIP System Schedule Information - Overall Activities

Project Name:	
District:	

Activity Name	Planned Duration	Actual Duration
Preconstruction / Procurement / Manufacturing		
1) Award Subcontracts		
2) Foundation and Building Permits		
3) Submittals		
4) Door/Hardware Procurement		
5) Precast Exterior Fabrication		
6) Elevator Fabrication		
Sitework		
1) Mobilize / Survey Grid / Temporary Services		
2) Demo / Clear Existing Site and Services		
3) Curb & Gutter / Sidewalk / Aspalt Paving		
4) Landscaping		
General Activities		
1) Tower Crane Foundation		
2) Erect Tower Crane		
3) Stair and Elevator Shafts		
4) Install Elevators		
5) Install Exterior Façade		
6) M & E Rough-In		
7) Fire Protection		
8) Building and System Inspections		

Activity Name	Planned Duration	Actual Duration
Activities to be Added to Template		
1) Area of Work:		
2) Area of Work:		
3) Area of Work:		
4) Area of Work:		
5) Area of Work:		
6) Area of Work:		
7) Area of Work:		
8) Area of Work:		
9) Area of Work:		
10) Area of Work:		
11) Area of Work:		
12) Area of Work:		
13) Area of Work:		
14) Area of Work:		
15) Area of Work:		
16) Area of Work:		
17) Area of Work:		
18) Area of Work:		
19) Area of Work:		
20) Area of Work:		
21) Area of Work:		

CIP System Schedule Information - Ground Level

Project Name:

District:

Activity Name	Planned Duration	Actual Duration
Ground Level, Phase		
1) Piling Operation		
2) Bulk Excavation		
3) Shoring		
4) Pile Caps		
5) Grade Beams		
6) Foundation Walls		
7) M & E Underground Installation		
8) Subdrainage / Fill to Grade / Prep Slab on Grade		
9) Reinforce/Pour Slab on Grade		
10) Ground Level CIP Columns		
Ground Level, Phase		
1) Piling Operation		
2) Bulk Excavation		
3) Shoring		
4) Pile Caps		
5) Grade Beams		
6) Foundation Walls		
7) M & E Underground Installation		
8) Subdrainage / Fill to Grade / Prep Slab on Grade		
9) Reinforce/Pour Slab on Grade		
10) Ground Level CIP Columns		

Activity Name	Planned Duration	Actual Duration
Ground Level, Phase		
1) Piling Operation		
2) Bulk Excavation		
3) Shoring		
4) Pile Caps		
5) Grade Beams		
6) Foundation Walls		
7) M & E Underground Installation		
8) Subdrainage / Fill to Grade / Prep Slab on Grade		
9) Reinforce/Pour Slab on Grade		
10) Ground Level CIP Columns		
Ground Level, Phase		
1) Piling Operation		
2) Bulk Excavation		
3) Shoring		
4) Pile Caps		
5) Grade Beams		
6) Foundation Walls		
7) M & E Underground Installation		
8) Subdrainage / Fill to Grade / Prep Slab on Grade		
9) Reinforce/Pour Slab on Grade		
10) Ground Level CIP Columns		

CIP System Schedule Information - Typical Level

Project Name:
District:

Activity Name	Planned Duration	Actual Duration
Level ____, Phase ____		
1) Column Caps		
2) FRP Slab		
3) Stress Post-Tensioning		
4) Strip Slab		
5) CIP Columns		
Level ____, Phase ____		
1) Column Caps		
2) FRP Slab		
3) Stress Post-Tensioning		
4) Strip Slab		
5) CIP Columns		
Level ____, Phase ____		
1) Column Caps		
2) FRP Slab		
3) Stress Post-Tensioning		
4) Strip Slab		
5) CIP Columns		
Level ____, Phase ____		
1) Column Caps		
2) FRP Slab		
3) Stress Post-Tensioning		
4) Strip Slab		
5) CIP Columns		

Activity Name	Planned Duration	Actual Duration
Level ____, Phase ____		
1) Column Caps		
2) FRP Slab		
3) Stress Post-Tensioning		
4) Strip Slab		
5) CIP Columns		
Level ____, Phase ____		
1) Column Caps		
2) FRP Slab		
3) Stress Post-Tensioning		
4) Strip Slab		
5) CIP Columns		
Level ____, Phase ____		
1) Column Caps		
2) FRP Slab		
3) Stress Post-Tensioning		
4) Strip Slab		
5) CIP Columns		
Level ____, Phase ____		
1) Column Caps		
2) FRP Slab		
3) Stress Post-Tensioning		
4) Strip Slab		
5) CIP Columns		

Precast System Schedule Information - Overall Activities

Project Name:	
District:	

Activity Name	Planned Duration	Actual Duration
Preconstruction / Procurement / Manufacturing		
1) Award Subcontracts		
2) Foundation and Building Permits		
3) Submittals		
4) Door/Hardware Procurement		
5) Precast Beam/Column Fabrication		
6) Precast Double-Tee Fabrication		
7) Precast Exterior Fabrication		
8) Elevator Fabrication		
Sitework		
1) Mobilize / Survey Grid / Temporary Services		
2) Demo / Clear Existing Site and Services		
3) Curb & Gutter / Sidewalk / Aspalt Paving		
4) Landscaping		
General Activities		
1) Tower Crane Foundation		
2) Erect Tower Crane		
3) Stair and Elevator Shafts		
4) Install Elevators		
5) Install Exterior Façade		
6) M & E Rough-In		
7) Fire Protection		
8) Building and System Inspections		

Activity Name	Planned Duration	Actual Duration
Activities to be Added to Template		
1) Area of Work:		
2) Area of Work:		
3) Area of Work:		
4) Area of Work:		
5) Area of Work:		
6) Area of Work:		
7) Area of Work:		
8) Area of Work:		
9) Area of Work:		
10) Area of Work:		
11) Area of Work:		
12) Area of Work:		
13) Area of Work:		
14) Area of Work:		
15) Area of Work:		
16) Area of Work:		
17) Area of Work:		
18) Area of Work:		
19) Area of Work:		
20) Area of Work:		
21) Area of Work:		

Precast System Schedule Information - Ground Level

Project Name:	
District:	

Activity Name	Planned Duration	Actual Duration
Ground Level, Phase		
1) Piling Operation		
2) Bulk Excavation		
3) Shoring		
4) Pile Caps		
5) Grade Beams		
6) Foundation Walls		
7) M & E Underground Installation		
8) Subdrainage / Fill to Grade / Prep Slab on Grade		
9) Reinforce/Pour Slab on Grade		
Ground Level, Phase		
1) Piling Operation		
2) Bulk Excavation		
3) Shoring		
4) Pile Caps		
5) Grade Beams		
6) Foundation Walls		
7) M & E Underground Installation		
8) Subdrainage / Fill to Grade / Prep Slab on Grade		
9) Reinforce/Pour Slab on Grade		

Activity Name	Planned Duration	Actual Duration
Ground Level, Phase		
1) Piling Operation		
2) Bulk Excavation		
3) Shoring		
4) Pile Caps		
5) Grade Beams		
6) Foundation Walls		
7) M & E Underground Installation		
8) Subdrainage / Fill to Grade / Prep Slab on Grade		
9) Reinforce/Pour Slab on Grade		
Ground Level, Phase		
1) Piling Operation		
2) Bulk Excavation		
3) Shoring		
4) Pile Caps		
5) Grade Beams		
6) Foundation Walls		
7) M & E Underground Installation		
8) Subdrainage / Fill to Grade / Prep Slab on Grade		
9) Reinforce/Pour Slab on Grade		

Precast System Schedule Information - Typical Level

Project Name:	
District:	

Activity Name	Planned Duration	Actual Duration
Level ___, Phase ___		
1) Install Beams and Columns		
2) Install Double-Tee Elements		
3) Expansion Joints / Caulking to Joints		
4) Pour Topping		
Level ___, Phase ___		
1) Install Beams and Columns		
2) Install Double-Tee Elements		
3) Expansion Joints / Caulking to Joints		
4) Pour Topping		
Level ___, Phase ___		
1) Install Beams and Columns		
2) Install Double-Tee Elements		
3) Expansion Joints / Caulking to Joints		
4) Pour Topping		
Level ___, Phase ___		
1) Install Beams and Columns		
2) Install Double-Tee Elements		
3) Expansion Joints / Caulking to Joints		
4) Pour Topping		
Level ___, Phase ___		
1) Install Beams and Columns		
2) Install Double-Tee Elements		
3) Expansion Joints / Caulking to Joints		
4) Pour Topping		

Activity Name	Planned Duration	Actual Duration
Level ___, Phase ___		
1) Install Beams and Columns		
2) Install Double-Tee Elements		
3) Expansion Joints / Caulking to Joints		
4) Pour Topping		
Level ___, Phase ___		
1) Install Beams and Columns		
2) Install Double-Tee Elements		
3) Expansion Joints / Caulking to Joints		
4) Pour Topping		
Level ___, Phase ___		
1) Install Beams and Columns		
2) Install Double-Tee Elements		
3) Expansion Joints / Caulking to Joints		
4) Pour Topping		
Level ___, Phase ___		
1) Install Beams and Columns		
2) Install Double-Tee Elements		
3) Expansion Joints / Caulking to Joints		
4) Pour Topping		
Level ___, Phase ___		
1) Install Beams and Columns		
2) Install Double-Tee Elements		
3) Expansion Joints / Caulking to Joints		
4) Pour Topping		

Hybrid System Schedule Information - Overall Activities

Project Name:	
District:	

Activity Name	Planned Duration	Actual Duration
Preconstruction / Procurement / Manufacturing		
1) Award Subcontracts		
2) Foundation and Building Permits		
3) Submittals		
4) Door/Hardware Procurement		
5) Precast Column Fabrication		
6) Precast Beam Fabrication		
7) Precast Exterior Fabrication		
8) Elevator Fabrication		
Sitework		
1) Mobilize / Survey Grid / Temporary Services		
2) Demo / Clear Existing Site and Services		
3) Curb & Gutter / Sidewalk / Aspalt Paving		
4) Landscaping		
General Activities		
1) Tower Crane Foundation		
2) Erect Tower Crane		
3) Stair and Elevator Shafts		
4) Install Elevators		
5) Install Exterior Façade		
6) M & E Rough-In		
7) Fire Protection		
8) Building and System Inspections		

Activity Name	Planned Duration	Actual Duration
Activities to be Added to Template		
1) Area of Work:		
2) Area of Work:		
3) Area of Work:		
4) Area of Work:		
5) Area of Work:		
6) Area of Work:		
7) Area of Work:		
8) Area of Work:		
9) Area of Work:		
10) Area of Work:		
11) Area of Work:		
12) Area of Work:		
13) Area of Work:		
14) Area of Work:		
15) Area of Work:		
16) Area of Work:		
17) Area of Work:		
18) Area of Work:		
19) Area of Work:		
20) Area of Work:		
21) Area of Work:		

Hybrid System Schedule Information - Ground Level

Project Name:	
District:	

Activity Name	Planned Duration	Actual Duration
Ground Level, Phase		
1) Piling Operation		
2) Bulk Excavation		
3) Shoring		
4) Pile Caps		
5) Grade Beams		
6) Foundation Walls		
7) M & E Underground Installation		
8) Subdrainage / Fill to Grade / Prep Slab on Grade		
9) Reinforce/Pour Slab on Grade		
10) Erect Columns to Full Height of Structure		
Ground Level, Phase		
1) Piling Operation		
2) Bulk Excavation		
3) Shoring		
4) Pile Caps		
5) Grade Beams		
6) Foundation Walls		
7) M & E Underground Installation		
8) Subdrainage / Fill to Grade / Prep Slab on Grade		
9) Reinforce/Pour Slab on Grade		
10) Erect Columns to Full Height of Structure		

Activity Name	Planned Duration	Actual Duration
Ground Level, Phase		
1) Piling Operation		
2) Bulk Excavation		
3) Shoring		
4) Pile Caps		
5) Grade Beams		
6) Foundation Walls		
7) M & E Underground Installation		
8) Subdrainage / Fill to Grade / Prep Slab on Grade		
9) Reinforce/Pour Slab on Grade		
10) Erect Columns to Full Height of Structure		
Ground Level, Phase		
1) Piling Operation		
2) Bulk Excavation		
3) Shoring		
4) Pile Caps		
5) Grade Beams		
6) Foundation Walls		
7) M & E Underground Installation		
8) Subdrainage / Fill to Grade / Prep Slab on Grade		
9) Reinforce/Pour Slab on Grade		
10) Erect Columns to Full Height of Structure		

Hybrid System Schedule Information - Typical Level

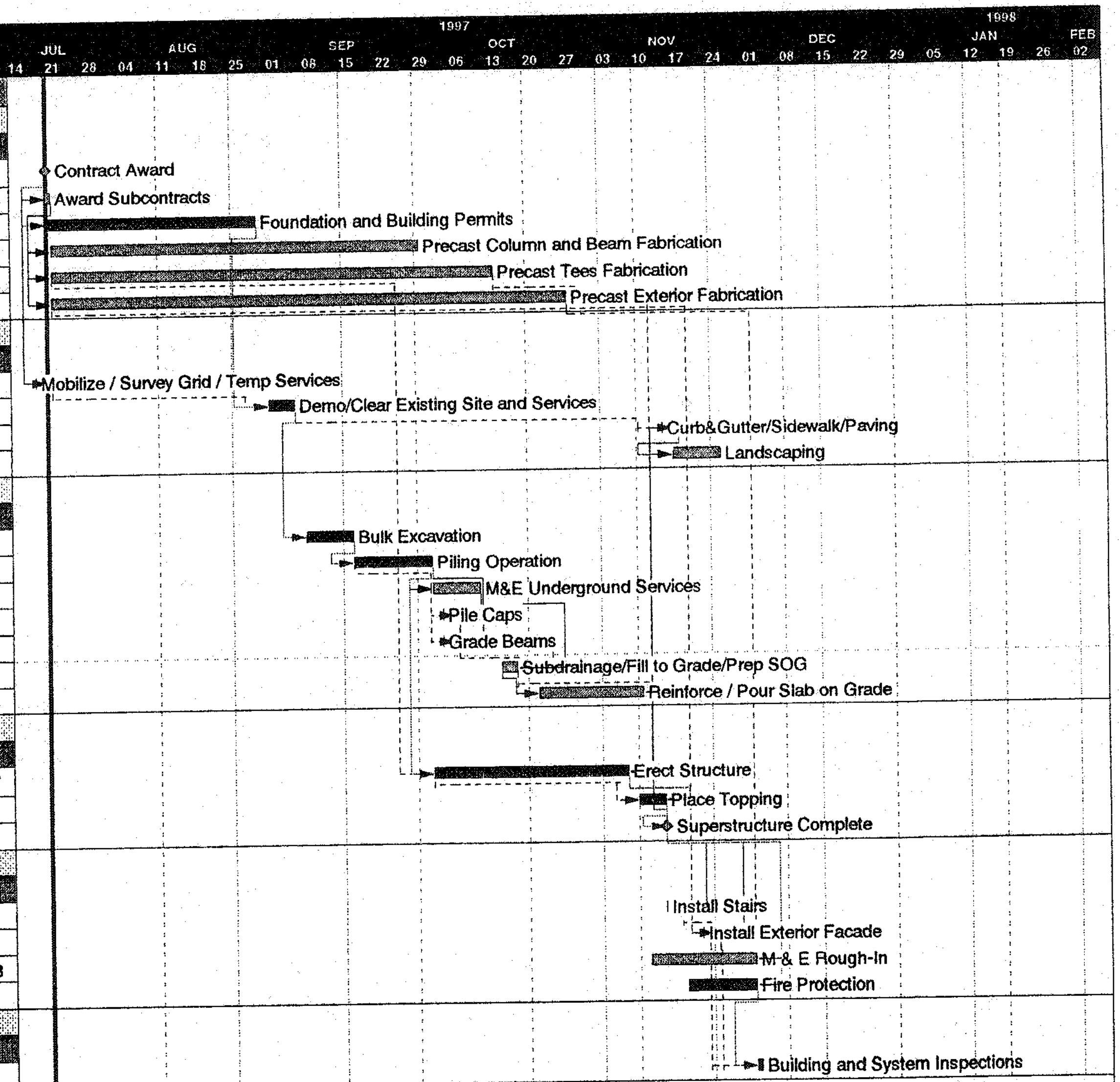
Project Name:	
District:	

Activity Name	Planned Duration	Actual Duration
Level ____, Phase ____		
1) Install Precast Beams		
2) FRP Slab		
3) Stress Post-Tensioning		
4) Strip Slab		
Level ____, Phase ____		
1) Install Precast Beams		
2) FRP Slab		
3) Stress Post-Tensioning		
4) Strip Slab		
Level ____, Phase ____		
1) Install Precast Beams		
2) FRP Slab		
3) Stress Post-Tensioning		
4) Strip Slab		
Level ____, Phase ____		
1) Install Precast Beams		
2) FRP Slab		
3) Stress Post-Tensioning		
4) Strip Slab		
Level ____, Phase ____		
1) Install Precast Beams		
2) FRP Slab		
3) Stress Post-Tensioning		
4) Strip Slab		

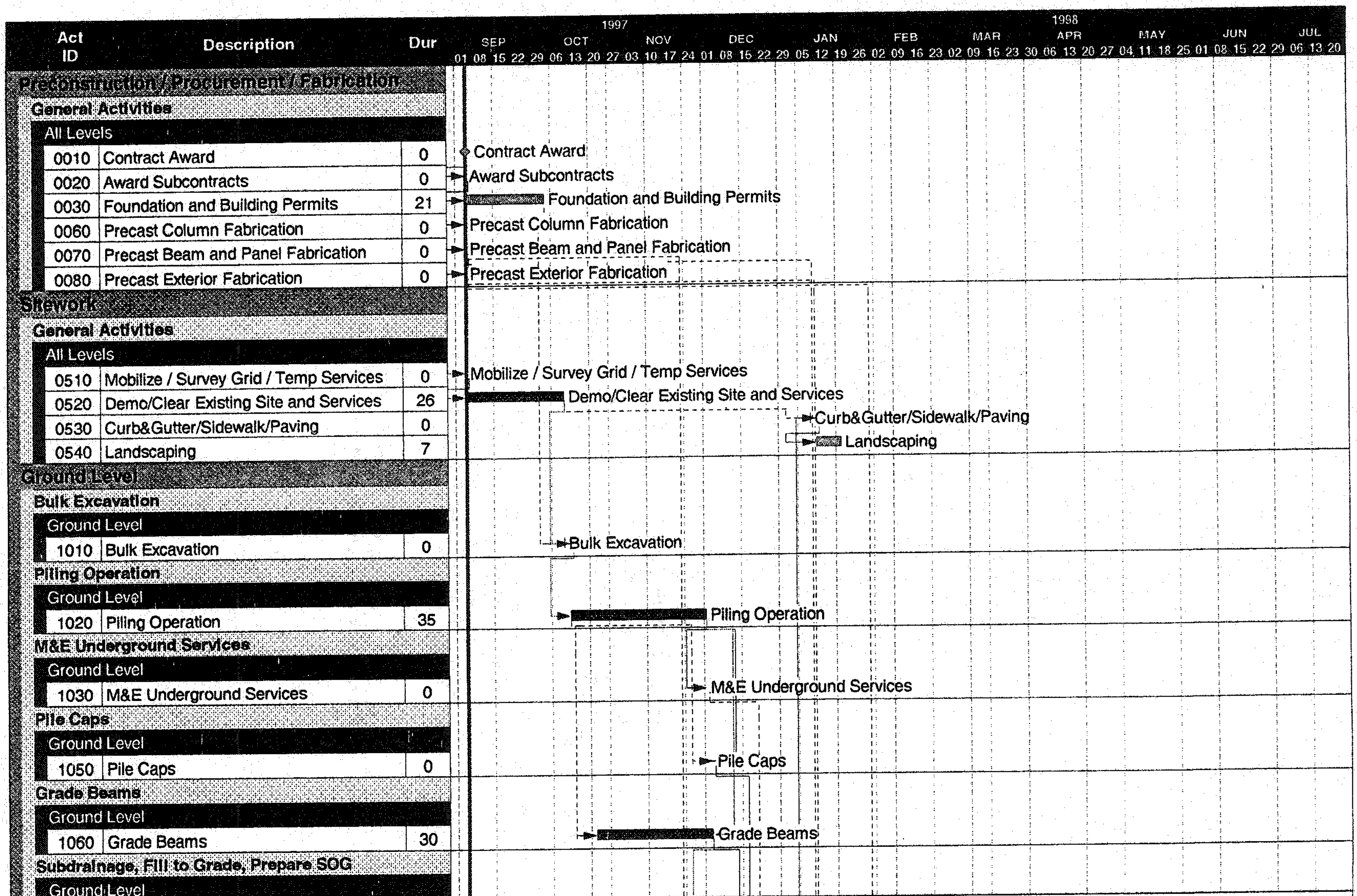
Activity Name	Planned Duration	Actual Duration
Level ____, Phase ____		
1) Install Precast Beams		
2) FRP Slab		
3) Stress Post-Tensioning		
4) Strip Slab		
Level ____, Phase ____		
1) Install Precast Beams		
2) FRP Slab		
3) Stress Post-Tensioning		
4) Strip Slab		
Level ____, Phase ____		
1) Install Precast Beams		
2) FRP Slab		
3) Stress Post-Tensioning		
4) Strip Slab		
Level ____, Phase ____		
1) Install Precast Beams		
2) FRP Slab		
3) Stress Post-Tensioning		
4) Strip Slab		
Level ____, Phase ____		
1) Install Precast Beams		
2) FRP Slab		
3) Stress Post-Tensioning		
4) Strip Slab		

APPENDIX K – PLANNED AND AS-BUILT CASE STUDY SCHEDULES

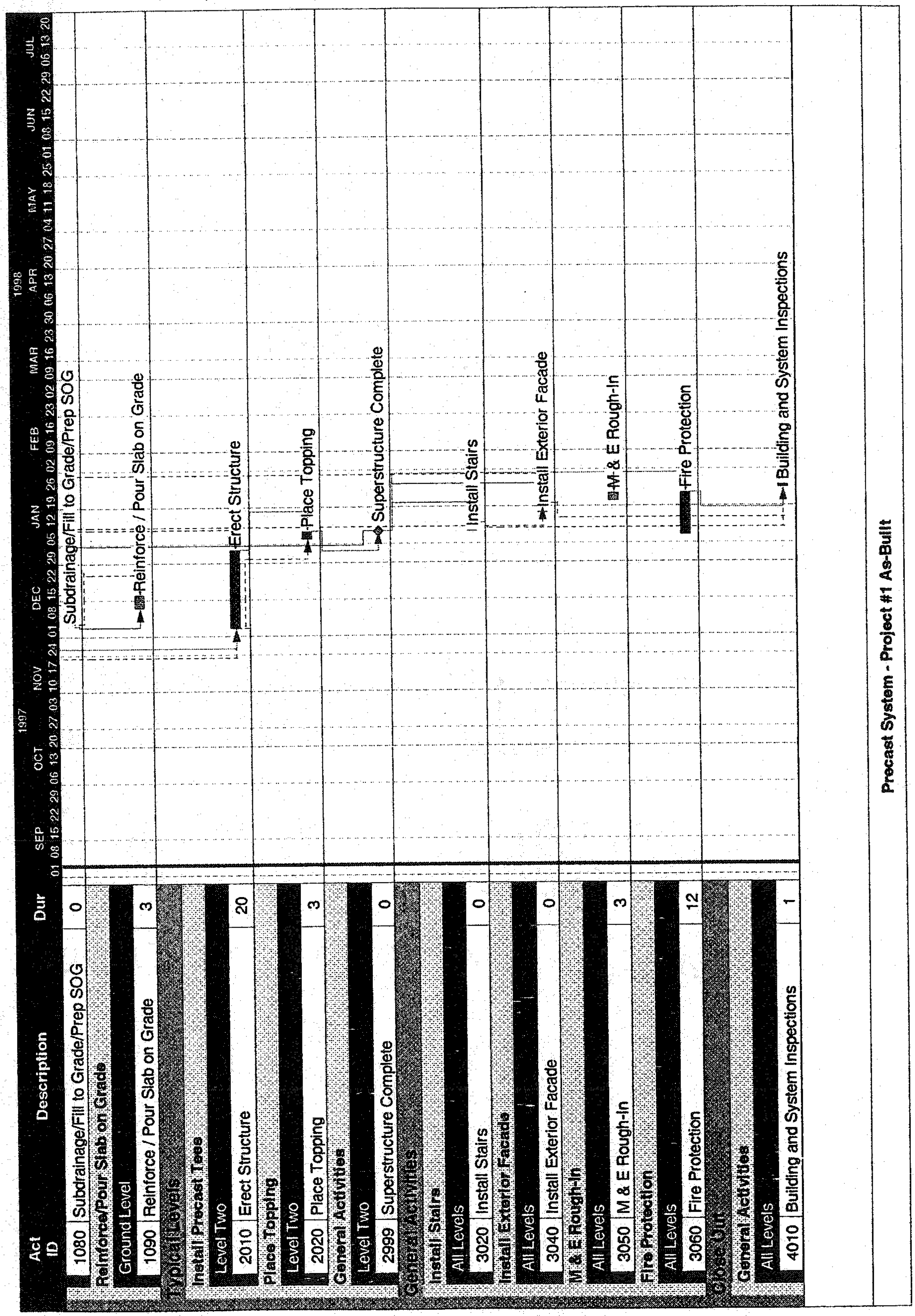
Act ID	Description	Orig Dur
All Phases		
Preconstruction / Procurement / Fabrication		
All Levels		
0010	Contract Award	0
0020	Award Subcontracts	1
0030	Foundation and Building Permits	30
0060	Precast Column and Beam Fabrication	50
0070	Precast Tees Fabrication	60
0080	Precast Exterior Fabrication	70
Sitework		
All Levels		
0510	Mobilize / Survey Grid / Temp Services	0
0520	Demo/Clear Existing Site and Services	5
0530	Curb&Gutter/Sidewalk/Paving	0
0540	Landscaping	7
Ground Level		
Ground Level		
1010	Bulk Excavation	7
1020	Piling Operation	11
1030	M&E Underground Services	7
1050	Pile Caps	0
1060	Grade Beams	0
1080	Subdrainage/Fill to Grade/Prep SOG	3
1090	Reinforce / Pour Slab on Grade	14
Typical Levels		
Level Two		
2010	Erect Structure	27
2020	Place Topping	5
2999	Superstructure Complete	0
General Activities		
All Levels		
3020	Install Stairs	0
3040	Install Exterior Facade	0
3050	M & E Rough-In	13
3060	Fire Protection	8
Close Out		
All Levels		
4010	Building and System Inspections	1



Precast System - Project #1 Plan

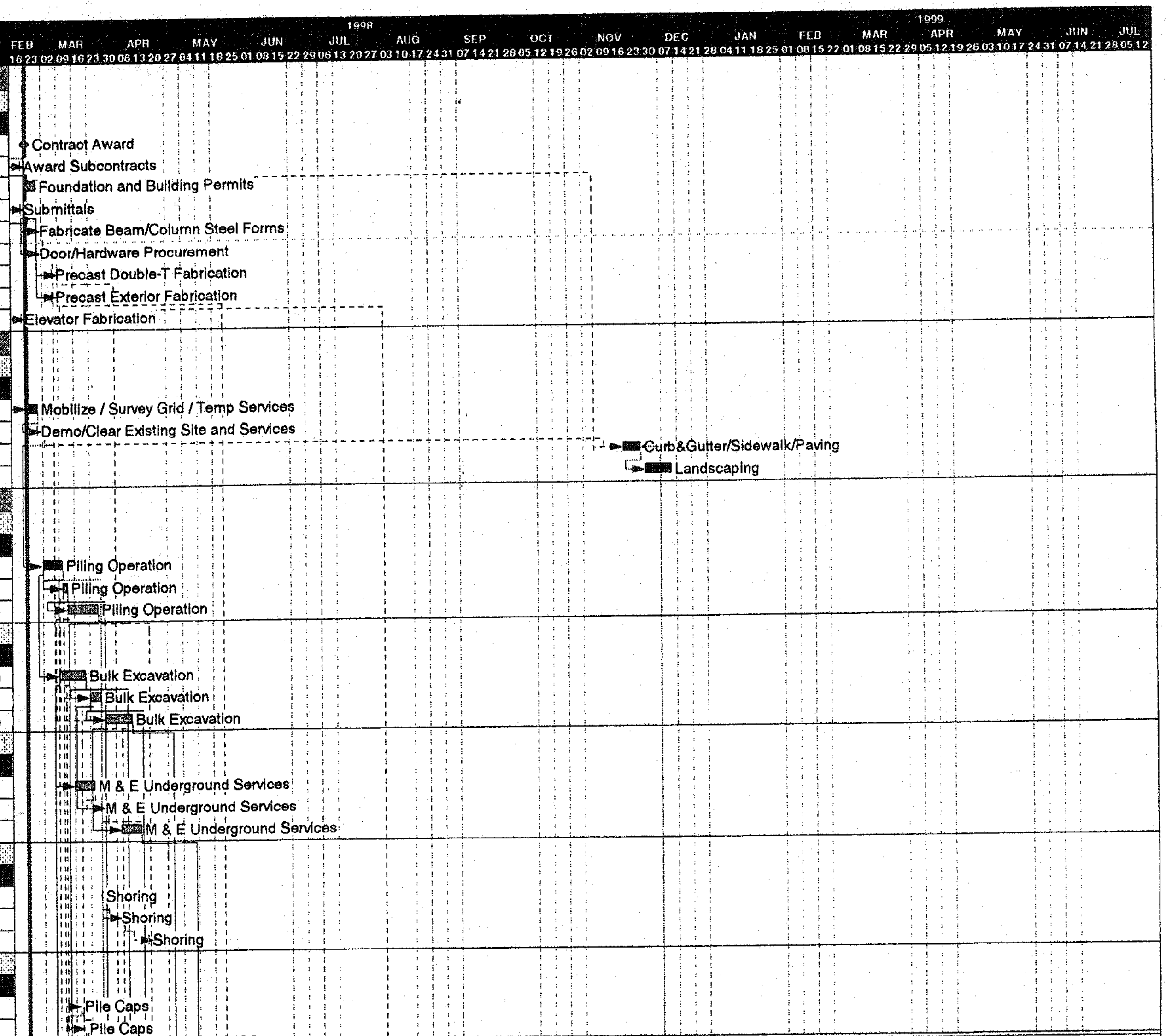


Precast System - Project #1 As-Built



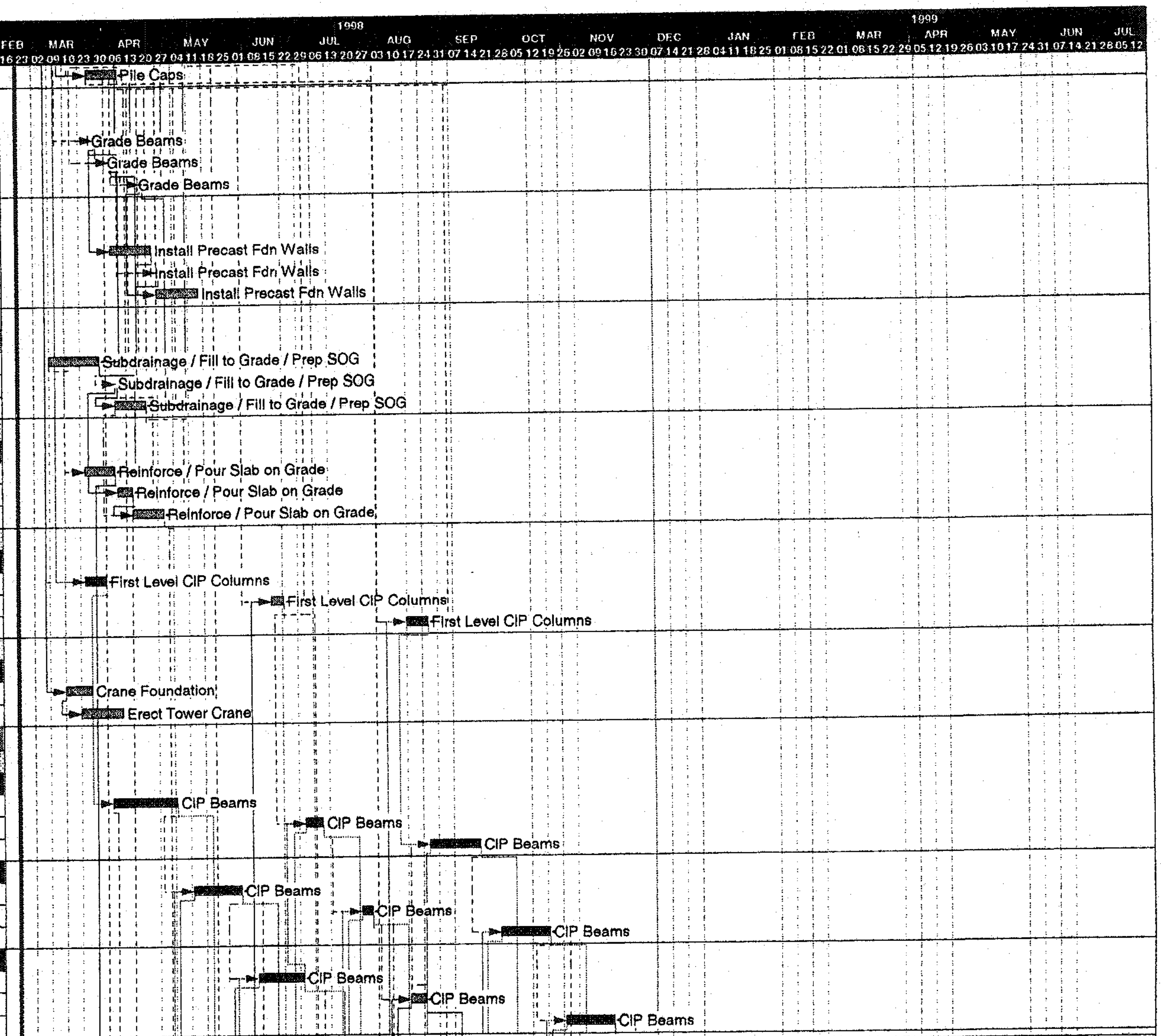
Precast System - Project #1 As-Built

Act ID	Description	Dur
Preconstruction / Procurement / Manufacturing		
General Activities		
All Levels		
0010	Contract Award	0
0020	Award Subcontracts	0
0030	Foundation and Building Permits	5
0040	Submittals	0
0050	Fabricate Beam/Column Steel Forms	0
0060	Door/Hardware Procurement	0
0070	Precast Double-T Fabrication	0
0080	Precast Exterior Fabrication	0
0090	Elevator Fabrication	0
Sitework		
General Activities		
All Levels		
0510	Mobilize / Survey Grid / Temp Services	5
0520	Demo/Clear Existing Site and Services	0
0530	Curb&Gutter/Sidewalk/Paving	5
0540	Landscaping	10
Ground Level		
Piling Operation		
Ground Level		
1010	Piling Operation	7
1110	Piling Operation	2
1210	Piling Operation	10
Bulk Excavation		
Ground Level		
1020	Bulk Excavation	10
1120	Bulk Excavation	5
1220	Bulk Excavation	10
M & E Underground Services		
Ground Level		
1030	M & E Underground Services	7
1130	M & E Underground Services	0
1230	M & E Underground Services	7
Shoring		
Ground Level		
1040	Shoring	0
1140	Shoring	0
1240	Shoring	0
Pile Caps		
Ground Level		
1050	Pile Caps	0
1150	Pile Caps	0



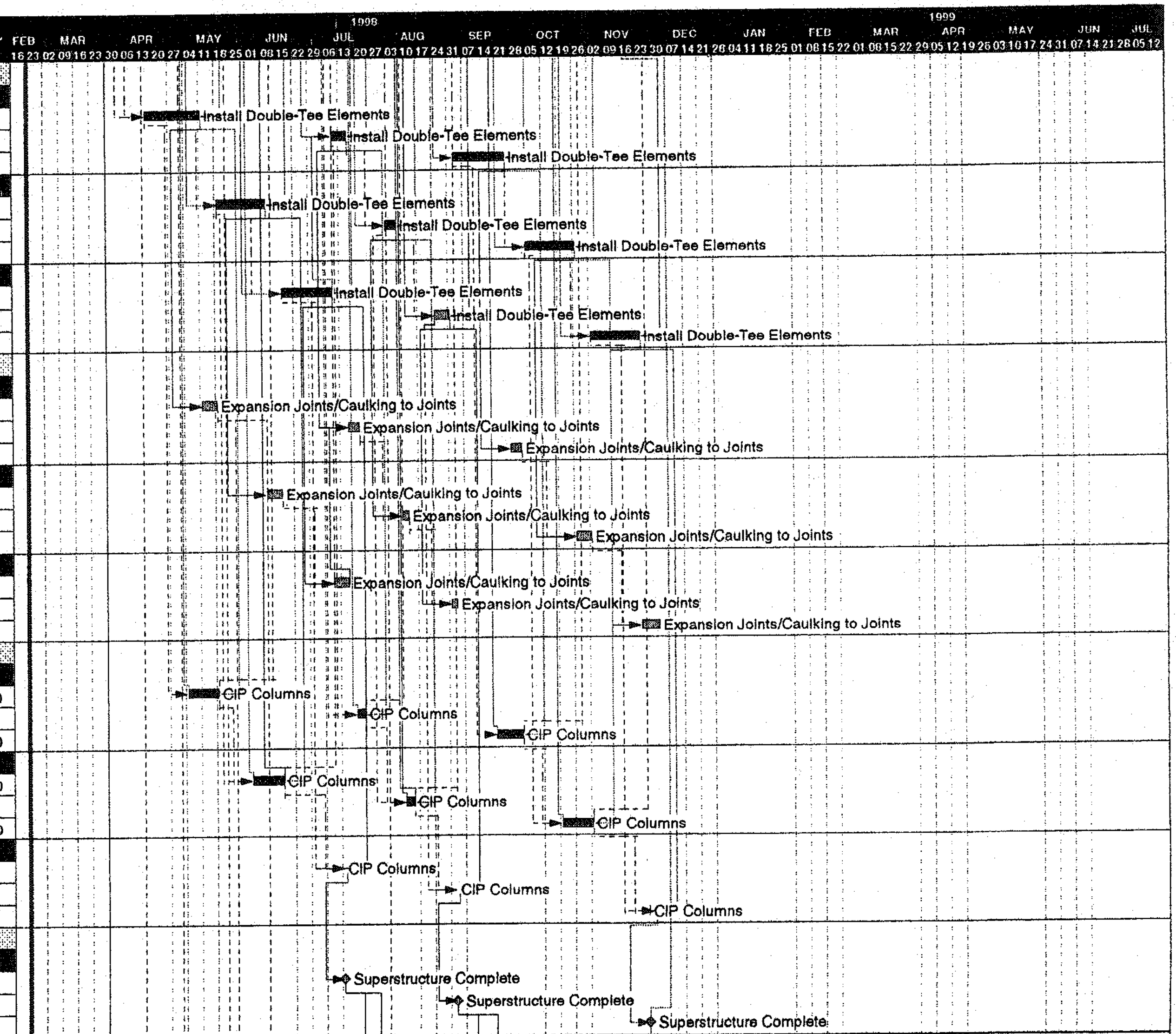
Reverse Hybrid - Project #2 Plan

Act ID	Description	Dur
1250	Pile Caps	10
Grade Beams		
Ground Level		
1060	Grade Beams	0
1160	Grade Beams	0
1260	Grade Beams	0
Foundation Walls		
Ground Level		
1080	Install Precast Fdn Walls	15
1180	Install Precast Fdn Walls	0
1280	Install Precast Fdn Walls	15
Subdrainage, Fill to Grade, Prepare SOG		
Ground Level		
1090	Subdrainage / Fill to Grade / Prep SOG	17
1190	Subdrainage / Fill to Grade / Prep SOG	0
1290	Subdrainage / Fill to Grade / Prep SOG	10
Reinforce/Pour Slab on Grade		
Ground Level		
1100	Reinforce / Pour Slab on Grade	10
1200	Reinforce / Pour Slab on Grade	5
1300	Reinforce / Pour Slab on Grade	10
Ground Level CIP Columns		
Ground Level		
1070	First Level CIP Columns	8
1170	First Level CIP Columns	4
1270	First Level CIP Columns	8
General Activities		
Ground Level		
0910	Crane Foundation	10
0920	Erect Tower Crane	15
Typical Levels		
CIP Beams		
Level Two		
2010	CIP Beams	21
2140	CIP Beams	5
2260	CIP Beams	16
Level Three		
2050	CIP Beams	15
2180	CIP Beams	5
2300	CIP Beams	16
Level Four		
2090	CIP Beams	15
2220	CIP Beams	5
2340	CIP Beams	16



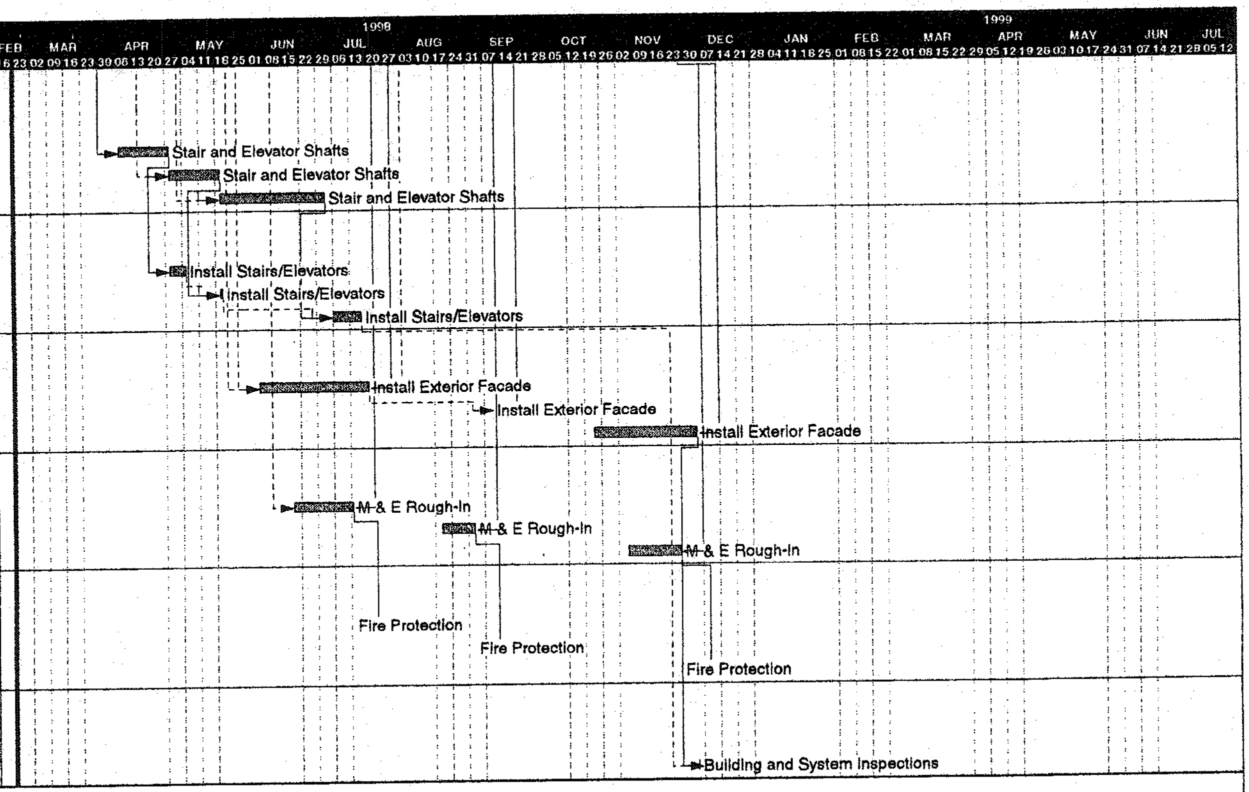
Reverse Hybrid - Project #2 Plan

Act ID	Description	Dur
Install Double-Tee Elements		
Level Two		
2020	Install Double-Tee Elements	17
2150	Install Double-Tee Elements	5
2270	Install Double-Tee Elements	16
Level Three		
2060	Install Double-Tee Elements	15
2190	Install Double-Tee Elements	5
2310	Install Double-Tee Elements	16
Level Four		
2100	Install Double-Tee Elements	15
2230	Install Double-Tee Elements	5
2350	Install Double-Tee Elements	16
Expansion Joints/Caulking to Joints		
Level Two		
2030	Expansion Joints/Caulking to Joints	5
2160	Expansion Joints/Caulking to Joints	3
2280	Expansion Joints/Caulking to Joints	5
Level Three		
2070	Expansion Joints/Caulking to Joints	5
2200	Expansion Joints/Caulking to Joints	3
2320	Expansion Joints/Caulking to Joints	5
Level Four		
2120	Expansion Joints/Caulking to Joints	5
2240	Expansion Joints/Caulking to Joints	3
2360	Expansion Joints/Caulking to Joints	5
Typical Level CIP Columns		
Level Two		
2040	CIP Columns	10
2170	CIP Columns	4
2290	CIP Columns	10
Level Three		
2080	CIP Columns	10
2210	CIP Columns	4
2330	CIP Columns	10
Level Four		
2130	CIP Columns	0
2250	CIP Columns	0
2370	CIP Columns	0
General Activities		
All Levels		
2995	Superstructure Complete	0
2996	Superstructure Complete	0
2997	Superstructure Complete	0



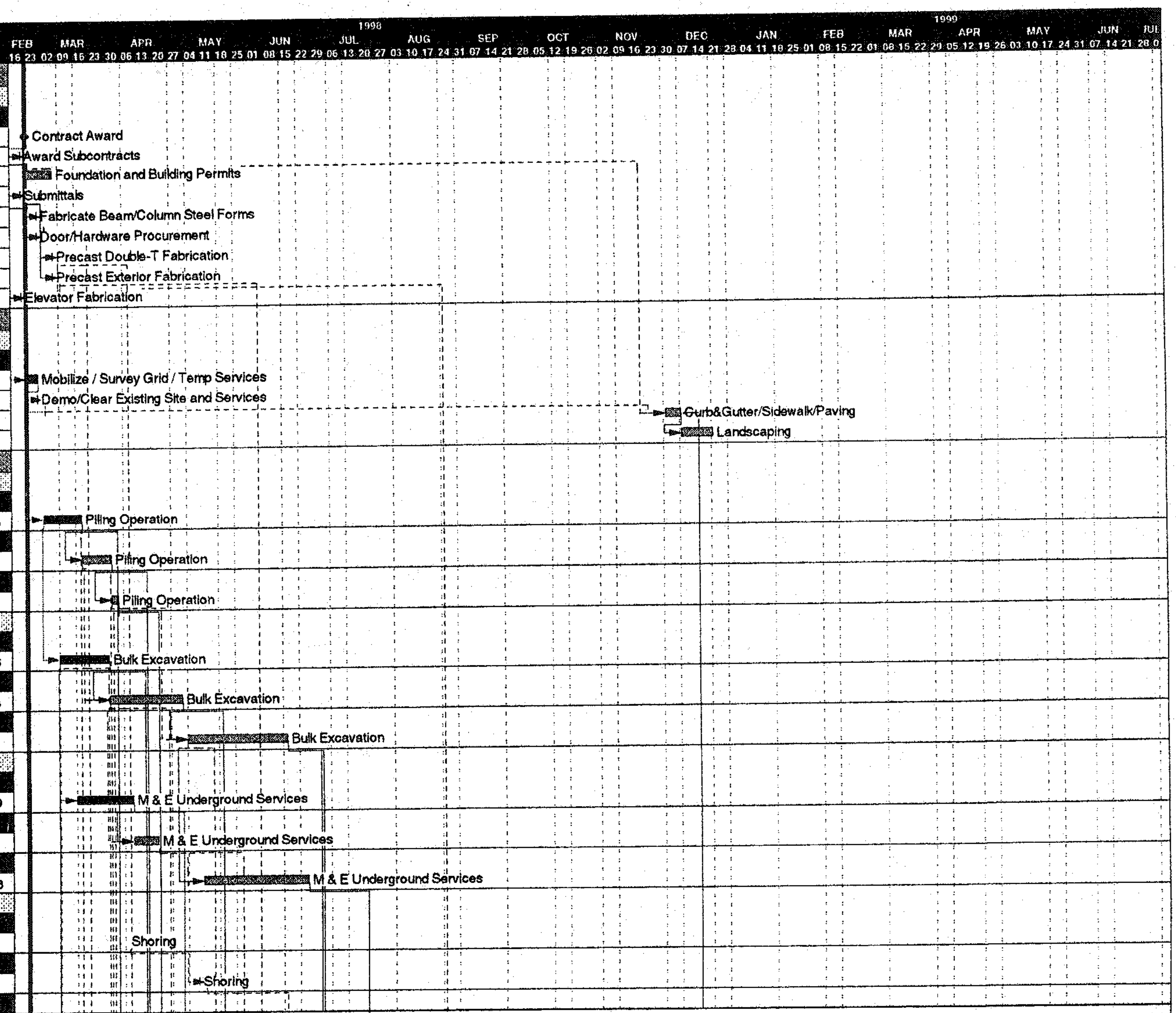
Reverse Hybrid - Project #2 Plan

Act ID	Description	Dur
General Activities		
Stair and Elevator Shafts		
All Levels		
3010	Stair and Elevator Shafts	15
3060	Stair and Elevator Shafts	15
3110	Stair and Elevator Shafts	30
Install Stairs and Elevators		
All Levels		
3020	Install Stairs/Elevators	5
3070	Install Stairs/Elevators	1
3120	Install Stairs/Elevators	10
Install Exterior Facade		
All Levels		
3030	Install Exterior Facade	30
3080	Install Exterior Facade	0
3130	Install Exterior Facade	30
M & E Rough-In		
All Levels		
3040	M & E Rough-In	15
3090	M & E Rough-In	10
3140	M & E Rough-In	15
Fire Protection		
All Levels		
3050	Fire Protection	0
3100	Fire Protection	0
3150	Fire Protection	0
Close Out		
General Activities		
All Levels		
4010	Building and System Inspections	0



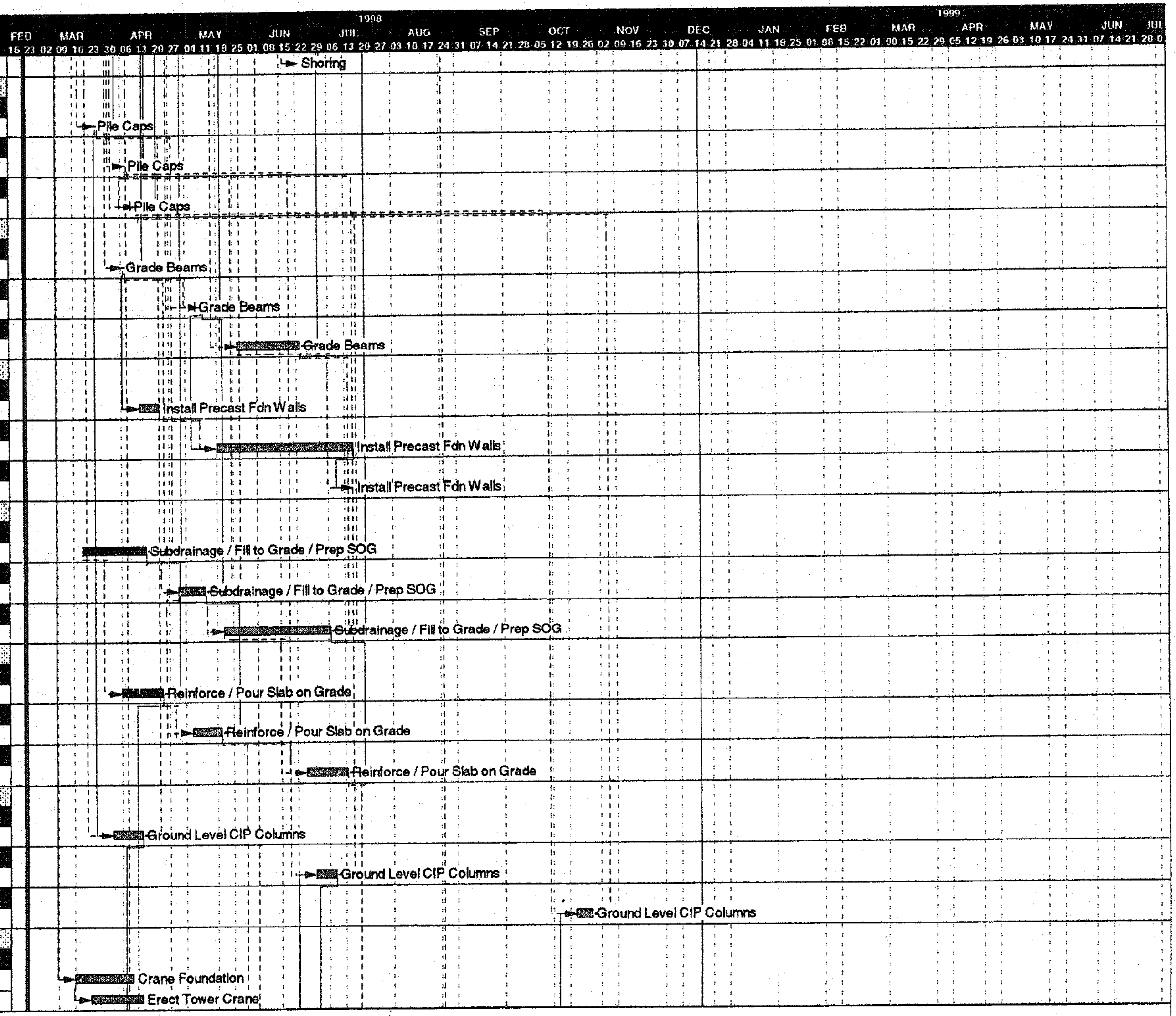
Reverse Hybrid - Project #2 Plan

Act ID	Description	Dur
Preconstruction / Procurement / Manufacturing		
General Activities		
All Phases		
0010	Contract Award	0
0020	Award Subcontracts	0
0030	Foundation and Building Permits	10
0040	Submittals	0
0050	Fabricate Beam/Column Steel Forms	0
0060	Door/Hardware Procurement	0
0070	Precast Double-T Fabrication	0
0080	Precast Exterior Fabrication	0
0090	Elevator Fabrication	0
Sitework		
General Activities		
All Phases		
0510	Mobilize / Survey Grid / Temp Services	5
0520	Demo/Clear Existing Site and Services	0
0530	Curb&Gutter/Sidewalk/Paving	5
0540	Landscaping	10
Ground Level		
Piling Operation		
North Phase		
1010	Piling Operation	13
South Phase		
1110	Piling Operation	9
Centre Phase		
1210	Piling Operation	3
Bulk Excavation		
North Phase		
1020	Bulk Excavation	16
South Phase		
1120	Bulk Excavation	24
Centre Phase		
1220	Bulk Excavation	31
M & E Underground Services		
North Phase		
1030	M & E Underground Services	19
South Phase		
1130	M & E Underground Services	7
Centre Phase		
1230	M & E Underground Services	33
Shoring		
North Phase		
1040	Shoring	0
South Phase		
1140	Shoring	0
Centre Phase		



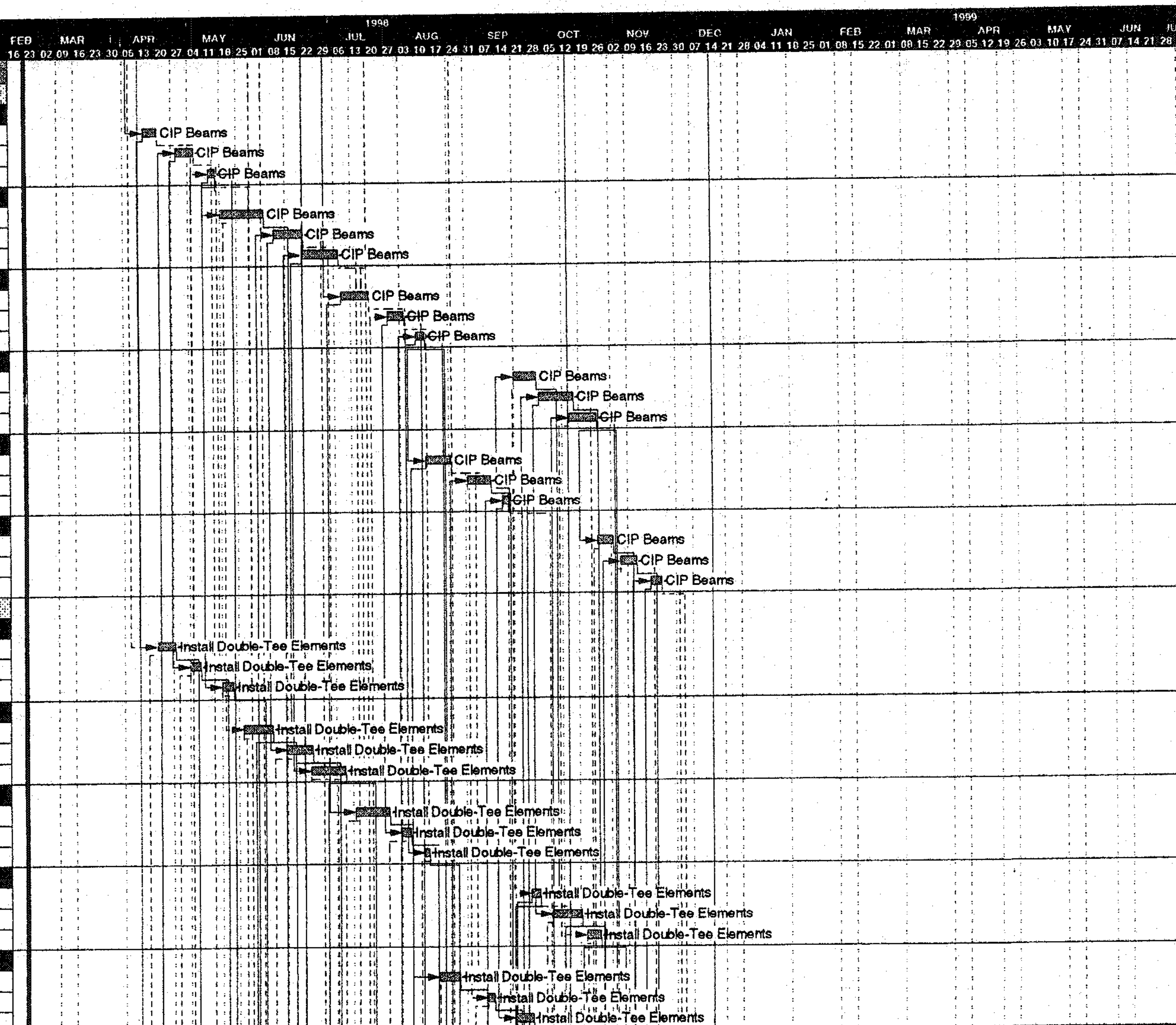
Reverse Hybrid - Project #2 As-Built

Act ID	Description	Dur
1240	Shoring	0
Pile Caps		
North Phase		
1050	Pile Caps	0
South Phase		
1150	Pile Caps	0
Centre Phase		
1250	Pile Caps	0
Grade Beams		
North Phase		
1060	Grade Beams	0
South Phase		
1160	Grade Beams	0
Centre Phase		
1260	Grade Beams	20
Foundation Walls		
North Phase		
1080	Install Precast Fdn Walls	7
South Phase		
1180	Install Precast Fdn Walls	41
Centre Phase		
1280	Install Precast Fdn Walls	0
Subdrainage, Fill to Grade, Prepare SOG		
North Phase		
1090	Subdrainage / Fill to Grade / Prep SOG	20
South Phase		
1190	Subdrainage / Fill to Grade / Prep SOG	8
Centre Phase		
1290	Subdrainage / Fill to Grade / Prep SOG	30
Reinforce/Pour Slab on Grade		
North Phase		
1100	Reinforce / Pour Slab on Grade	14
South Phase		
1200	Reinforce / Pour Slab on Grade	9
Centre Phase		
1300	Reinforce / Pour Slab on Grade	10
Ground Level CIP Columns		
North Phase		
1070	Ground Level CIP Columns	9
South Phase		
1170	Ground Level CIP Columns	5
Centre Phase		
1270	Ground Level CIP Columns	5
General Activities		
All Phases		
0910	Crane Foundation	20
0920	Erect Tower Crane	17



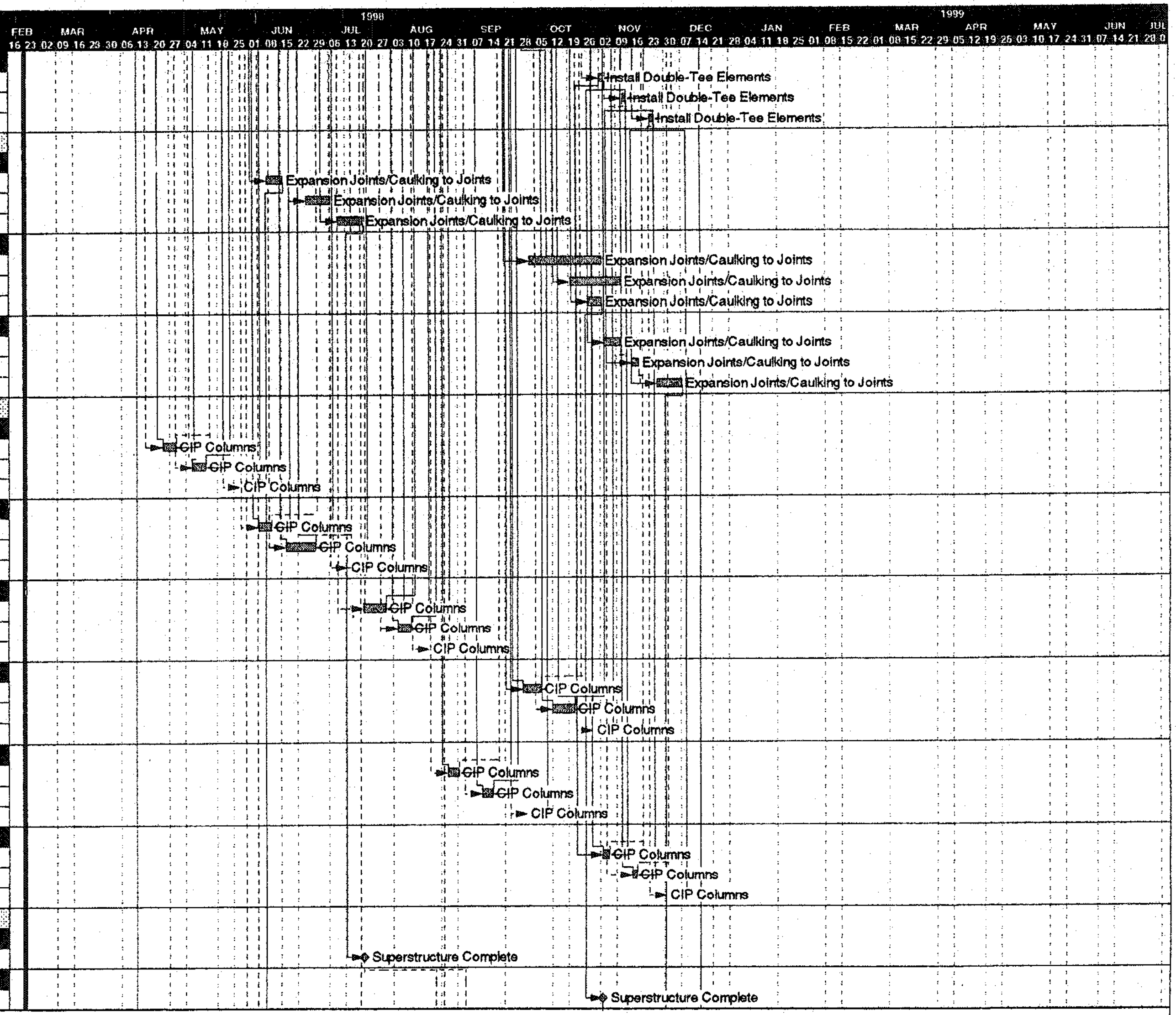
Reverse Hybrid - Project #2 As-Built

Act ID	Description	Dur
Typical Floor		
CIP Beams		
North-West Phase		
2010	CIP Beams	4
2050	CIP Beams	6
2090	CIP Beams	3
North-East Phase		
2015	CIP Beams	14
2055	CIP Beams	9
2095	CIP Beams	10
South-West Phase		
2140	CIP Beams	8
2180	CIP Beams	5
2220	CIP Beams	4
South-East Phase		
2145	CIP Beams	8
2185	CIP Beams	11
2225	CIP Beams	8
Centre-West Phase		
2260	CIP Beams	7
2300	CIP Beams	7
2340	CIP Beams	3
Centre-East Phase		
2265	CIP Beams	5
2305	CIP Beams	5
2345	CIP Beams	3
Install Double-Tee Elements		
North-West Phase		
2020	Install Double-Tee Elements	6
2060	Install Double-Tee Elements	5
2100	Install Double-Tee Elements	5
North-East Phase		
2025	Install Double-Tee Elements	9
2065	Install Double-Tee Elements	9
2105	Install Double-Tee Elements	9
South-West Phase		
2150	Install Double-Tee Elements	11
2190	Install Double-Tee Elements	4
2230	Install Double-Tee Elements	2
South-East Phase		
2155	Install Double-Tee Elements	4
2195	Install Double-Tee Elements	9
2235	Install Double-Tee Elements	4
Centre-West Phase		
2270	Install Double-Tee Elements	7
2310	Install Double-Tee Elements	3
2350	Install Double-Tee Elements	6



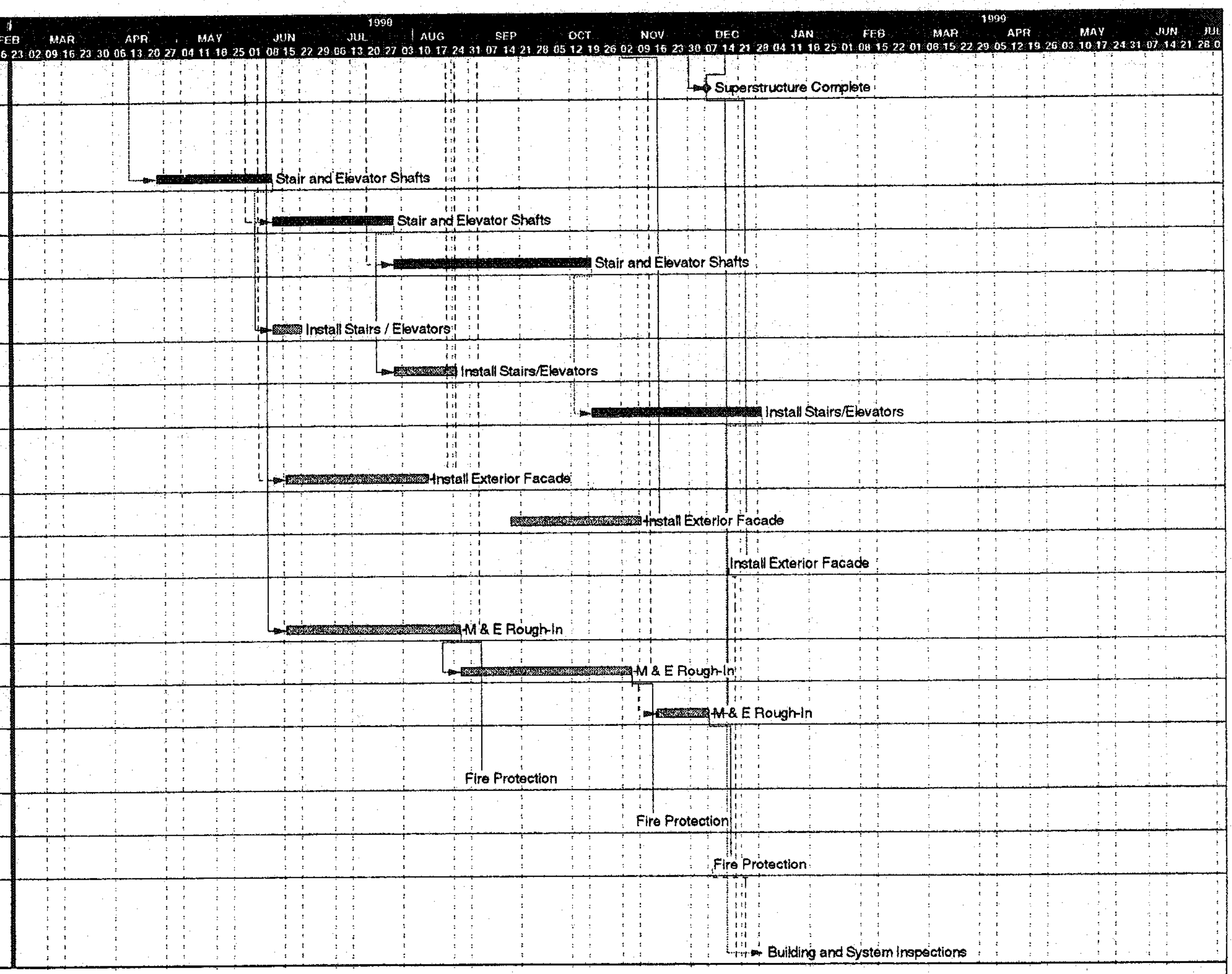
Reverse Hybrid - Project #2 As-Built

Act ID	Description	Dur
Centre-East Phase		
2275	Install Double-Tee Elements	2
2315	Install Double-Tee Elements	2
2355	Install Double-Tee Elements	2
Expansion Joints/Caulking to Joints		
North Phase		
2030	Expansion Joints/Caulking to Joints	5
2070	Expansion Joints/Caulking to Joints	5
2110	Expansion Joints/Caulking to Joints	7
South Phase		
2160	Expansion Joints/Caulking to Joints	22
2200	Expansion Joints/Caulking to Joints	16
2240	Expansion Joints/Caulking to Joints	4
Centre Phase		
2280	Expansion Joints/Caulking to Joints	5
2320	Expansion Joints/Caulking to Joints	3
2360	Expansion Joints/Caulking to Joints	7
Typical Level CIP Columns		
North-West Phase		
2040	CIP Columns	4
2080	CIP Columns	4
2120	CIP Columns	0
North-East Phase		
2045	CIP Columns	4
2085	CIP Columns	9
2125	CIP Columns	0
South-West Phase		
2170	CIP Columns	8
2210	CIP Columns	4
2250	CIP Columns	0
South-East Phase		
2175	CIP Columns	6
2215	CIP Columns	8
2255	CIP Columns	0
Centre-West Phase		
2290	CIP Columns	3
2330	CIP Columns	3
2370	CIP Columns	0
Centre-East Phase		
2295	CIP Columns	3
2335	CIP Columns	2
2375	CIP Columns	0
General Activities		
North Phase		
2995	Superstructure Complete	0
South Phase		
2996	Superstructure Complete	0



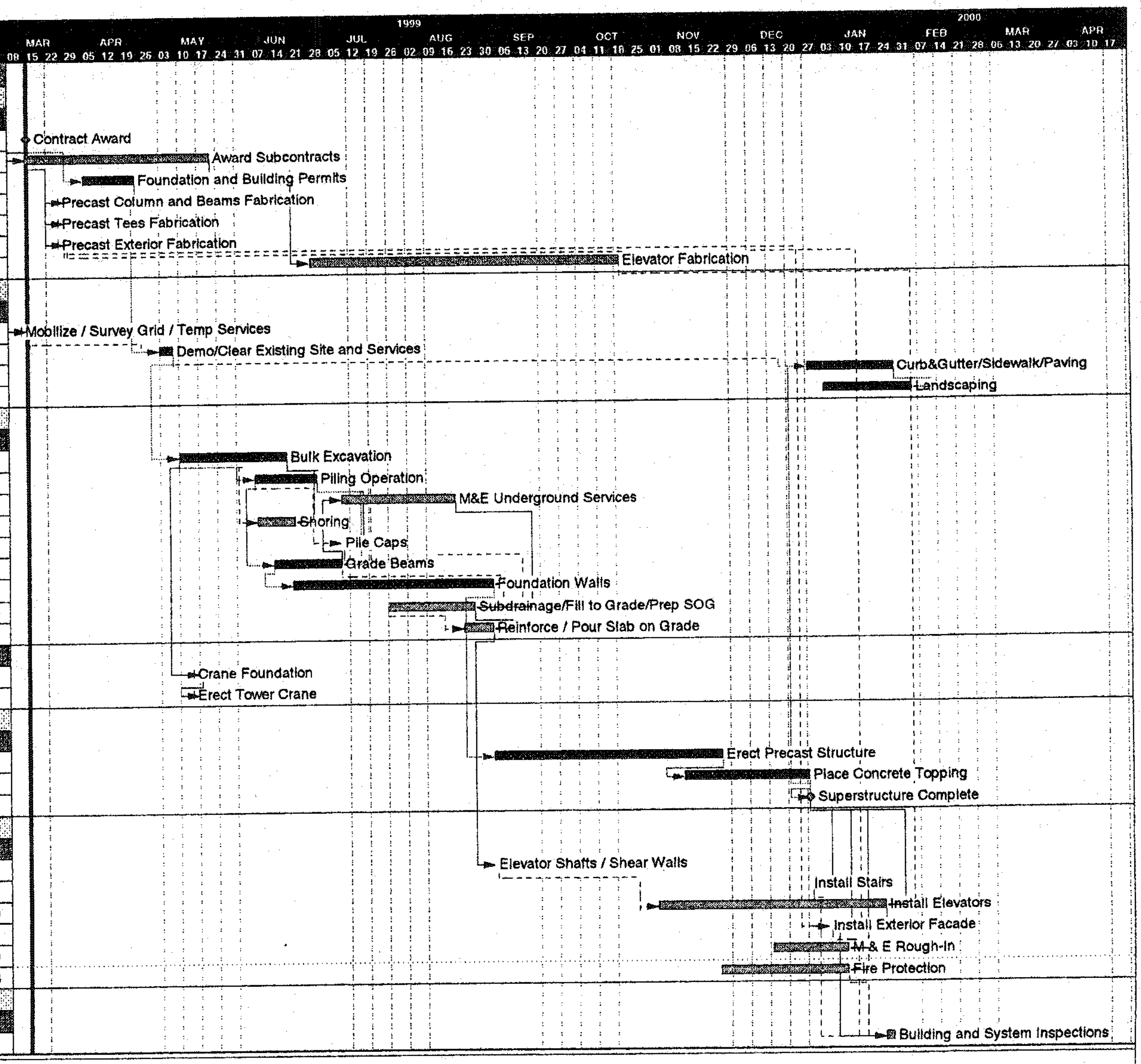
Reverse Hybrid - Project #2 As-Built

Act ID	Description	Dur
	General Activities	
	Stair and Elevator Shafts	
	North Phase	
3010	Stair and Elevator Shafts	33
	South Phase	
3060	Stair and Elevator Shafts	34
	Centre Phase	
3110	Stair and Elevator Shafts	57
	Install Stairs and Elevators	
	North Phase	
3020	Install Stairs / Elevators	8
	South Phase	
3070	Install Stairs/Elevators	18
	Centre Phase	
3120	Install Stairs/Elevators	48
	Install Exterior Facade	
	North Phase	
3030	Install Exterior Facade	41
	South Phase	
3080	Install Exterior Facade	38
	Centre Phase	
3130	Install Exterior Facade	0
	M & E Rough-In	
	North Phase	
3040	M & E Rough-In	50
	South Phase	
3090	M & E Rough-In	50
	Centre Phase	
3140	M & E Rough-In	15
	Fire Protection	
	North Phase	
3050	Fire Protection	0
	South Phase	
3100	Fire Protection	0
	Centre Phase	
3150	Fire Protection	0
	Close Out	
	General Activities	
	All Phases	
4010	Building and System Inspections	0



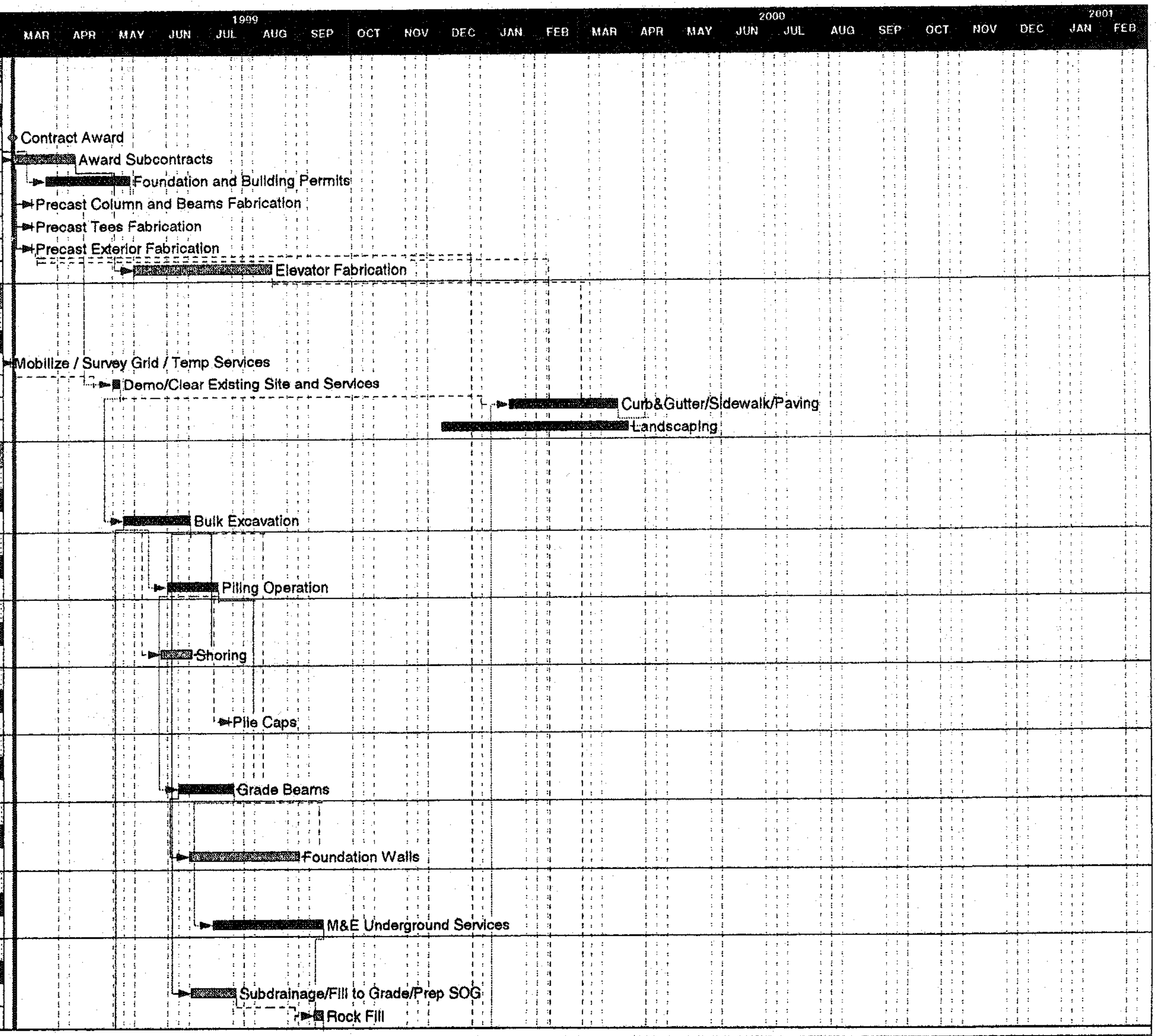
Reverse Hybrid - Project #2 As-Built

Act ID	Description	Orig Dur
All Phases		
Preconstruction / Procurement / Fabrication		
All Levels		
0010	Contract Award	0
0020	Award Subcontracts	50
0030	Foundation and Building Permits	15
0040	Precast Column and Beams Fabrication	0
0050	Precast Tees Fabrication	0
0060	Precast Exterior Fabrication	0
0070	Elevator Fabrication	80
Sitework		
All Levels		
0510	Mobilize / Survey Grid / Temp Services	0
0520	Demo/Clear Existing Site and Services	5
0530	Curb&Gutter/Sidewalk/Paving	24
0540	Landscaping	25
Ground Level		
Ground Level		
1010	Bulk Excavation	30
1020	Piling Operation	17
1030	M&E Underground Services	30
1040	Shoring	10
1050	Pile Caps	0
1060	Grade Beams	17
1070	Foundation Walls	52
1080	Subdrainage/Fill to Grade/Prep SOG	24
1090	Reinforce / Pour Slab on Grade	9
All Levels		
0910	Crane Foundation	0
0920	Erect Tower Crane	0
Typical Levels		
All Levels		
2010	Erect Precast Structure	60
2020	Place Concrete Topping	32
2999	Superstructure Complete	0
General Activities		
All Levels		
3010	Elevator Shafts / Shear Walls	0
3020	Install Stairs	0
3030	Install Elevators	60
3040	Install Exterior Facade	0
3050	M & E Rough-In	20
3060	Fire Protection	33
Close Out		
All Levels		
4010	Building and System Inspections	3



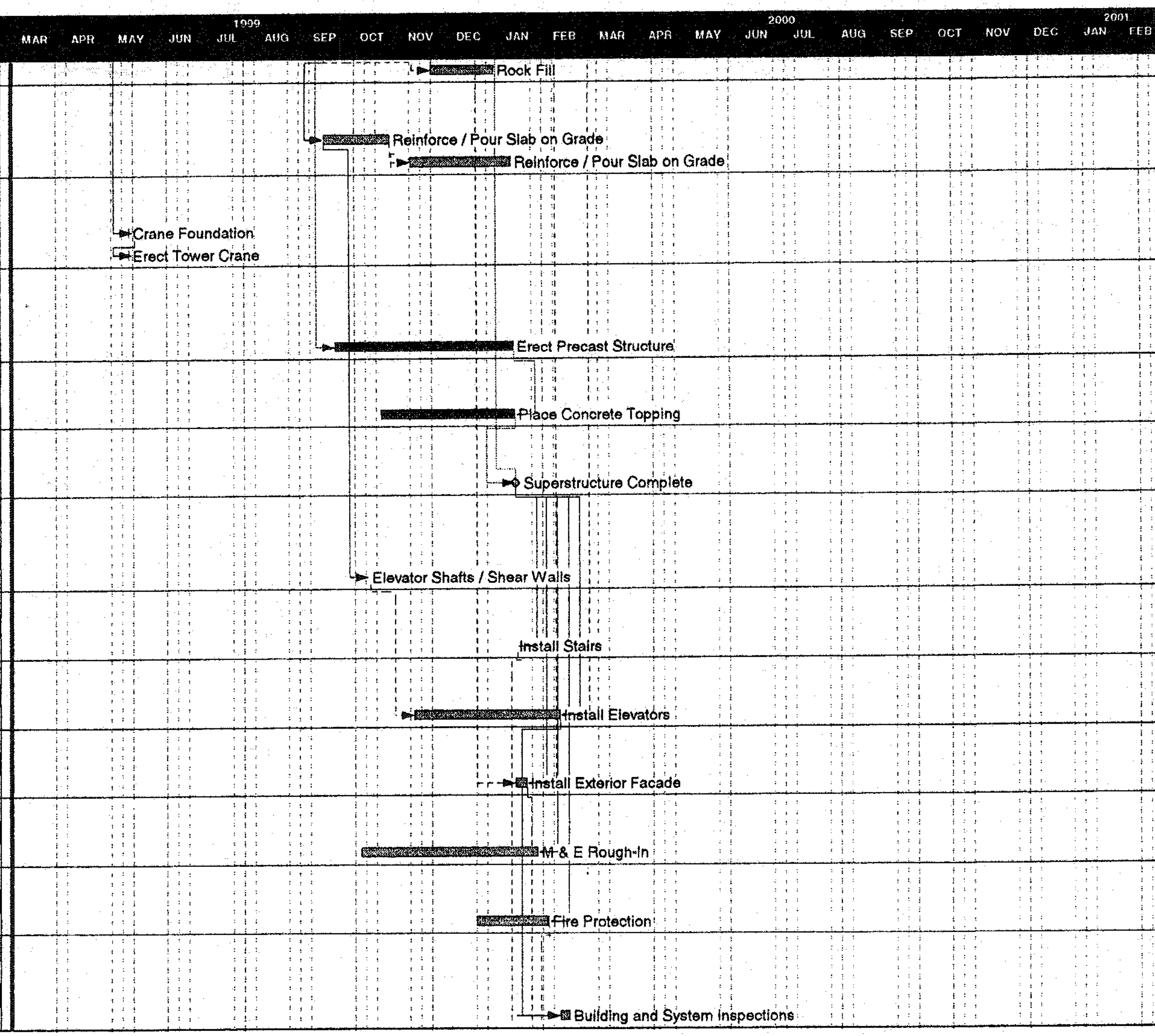
Precast/topping - Project #3 Plan

Act ID	Description	Dur
Preconstruction / Procurement / Fabrication		
General Activities		
All Levels		
0010	Contract Award	0
0020	Award Subcontracts	30
0030	Foundation and Building Permits	40
0040	Precast Column and Beams Fabrication	0
0050	Precast Tees Fabrication	0
0060	Precast Exterior Fabrication	0
0070	Elevator Fabrication	63
Sitework		
General Activities		
All Levels		
0510	Mobilize / Survey Grid / Temp Services	0
0520	Demo/Clear Existing Site and Services	5
0530	Curb&Gutter/Sidewalk/Paving	50
0540	Landscaping	87
Ground Level		
Bulk Excavation		
Ground Level		
1010	Bulk Excavation	31
Piling Operation		
Ground Level		
1020	Piling Operation	23
Shoring		
Ground Level		
1040	Shoring	14
Pile Caps		
Ground Level		
1050	Pile Caps	0
Grade Beams		
Ground Level		
1060	Grade Beams	24
Foundation Walls		
Ground Level		
1070	Foundation Walls	49
M&E Underground Services		
Ground Level		
1030	M&E Underground Services	51
Subdrainage, Fill to Grade, Prepare SOG		
Ground Level		
1080	Subdrainage/Fill to Grade/Prep SOG	19
1182	Rock Fill	4



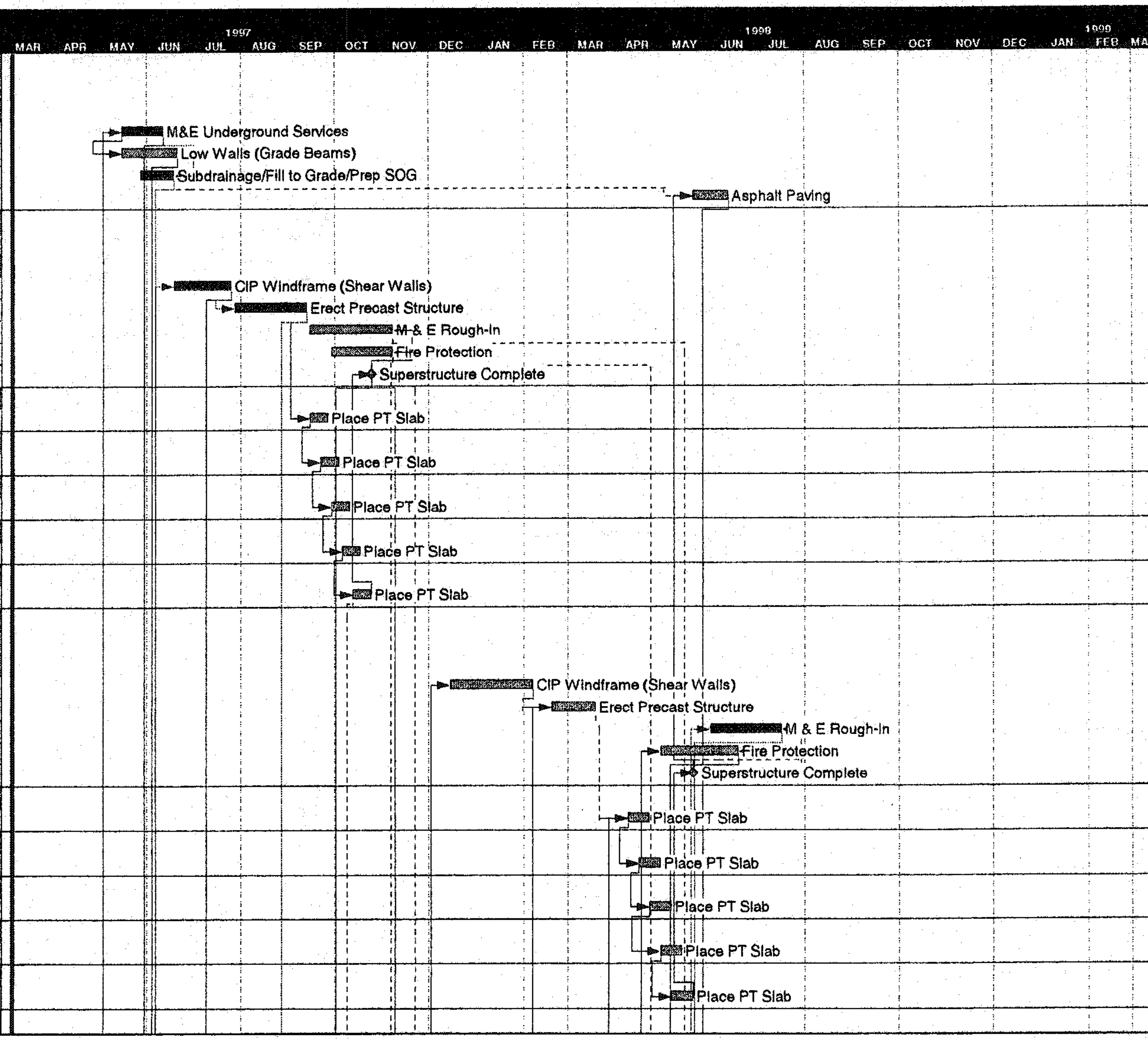
Precast/topping - Project #3 As-Built

Act ID	Description	Dur
1184	Rock Fill	30
Reinforce/Pour Slab on Grade		
Ground Level		
1090	Reinforce / Pour Slab on Grade	30
1092	Reinforce / Pour Slab on Grade	46
General Activities		
All Levels		
0910	Crane Foundation	0
0920	Erect Tower Crane	0
Typical Levels		
Erect Precast Structure		
All Levels		
2010	Erect Precast Structure	81
Place Concrete Topping		
All Levels		
2020	Place Concrete Topping	61
General Activities		
All Levels		
2999	Superstructure Complete	0
General Activities		
Elevator Shafts/Shear Walls		
All Levels		
3010	Elevator Shafts / Shear Walls	0
Install Stairs		
All Levels		
3020	Install Stairs	0
Install Elevators		
All Levels		
3030	Install Elevators	66
Install Exterior Facade		
All Levels		
3040	Install Exterior Facade	5
M & E Rough-In		
All Levels		
3050	M & E Rough-In	80
Fire Protection		
All Levels		
3060	Fire Protection	34
Close Out		
General Activities		
All Levels		
4010	Building and System Inspections	4



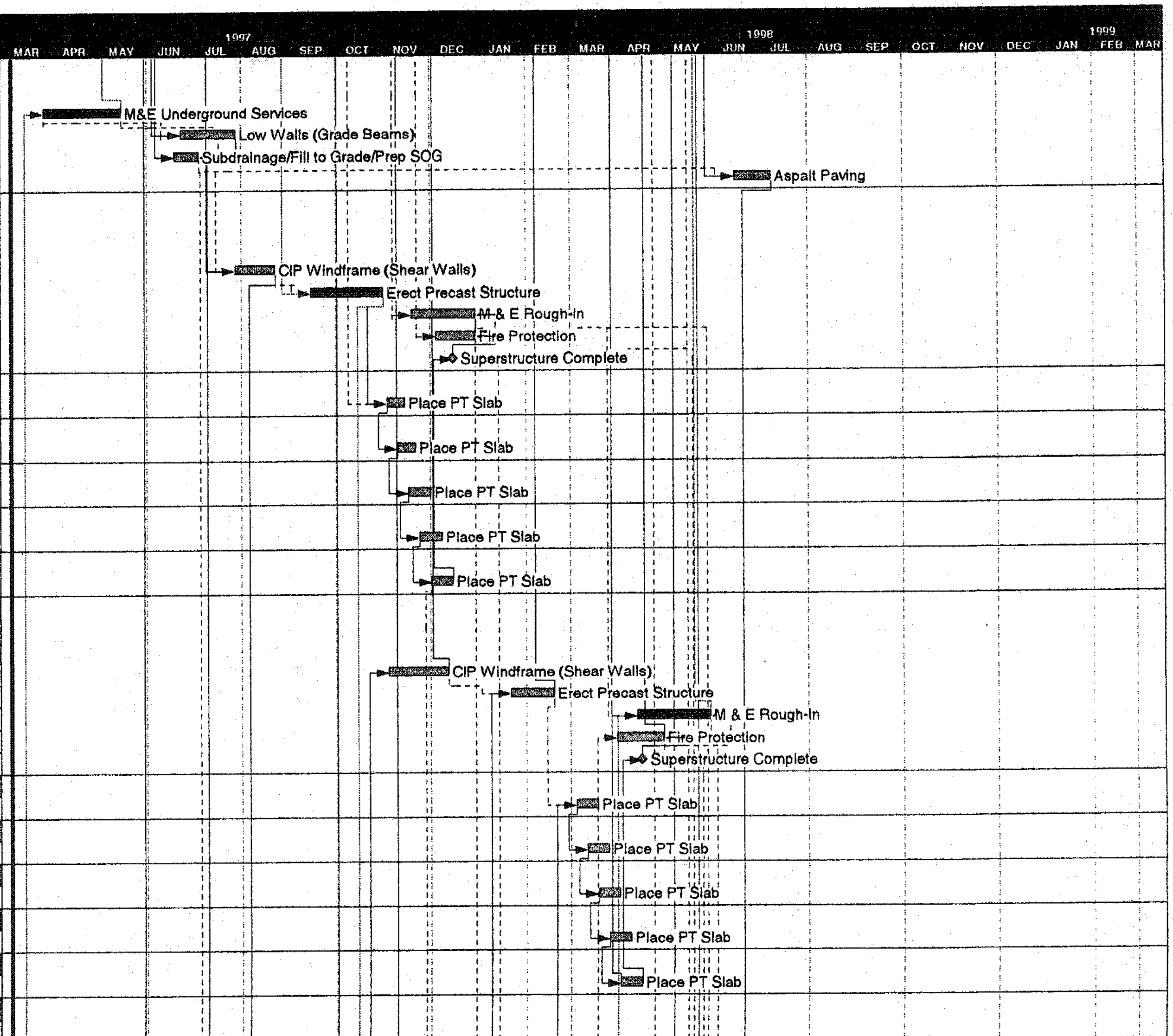
Precast/topping - Project #3 As-Built

Act ID	Description	Orig Dur
Phase B		
Ground Level		
Ground Level		
1010	M&E Underground Services	18
1020	Low Walls (Grade Beams)	25
1030	Subdrainage/Fill to Grade/Prep SOG	16
1040	Asphalt Paving	16
Phase B, Grid A-H		
Typical Levels		
All Levels		
2000	CIP Windframe (Shear Walls)	26
2002	Erect Precast Structure	35
2005	M & E Rough-In	40
2010	Fire Protection	30
2900	Superstructure Complete	0
Level Two		
2020	Place PT Slab	10
Level Three		
2025	Place PT Slab	10
Level Four		
2030	Place PT Slab	10
Level Five		
2035	Place PT Slab	10
Level Six		
2040	Place PT Slab	10
Phase B, Grid J-S		
Typical Levels		
All Levels		
2045	CIP Windframe (Shear Walls)	38
2047	Erect Precast Structure	20
2050	M & E Rough-In	32
2055	Fire Protection	35
2910	Superstructure Complete	0
Level Two		
2065	Place PT Slab	10
Level Three		
2070	Place PT Slab	10
Level Four		
2075	Place PT Slab	10
Level Five		
2080	Place PT Slab	10
Level Six		
2085	Place PT Slab	10
Phase C		



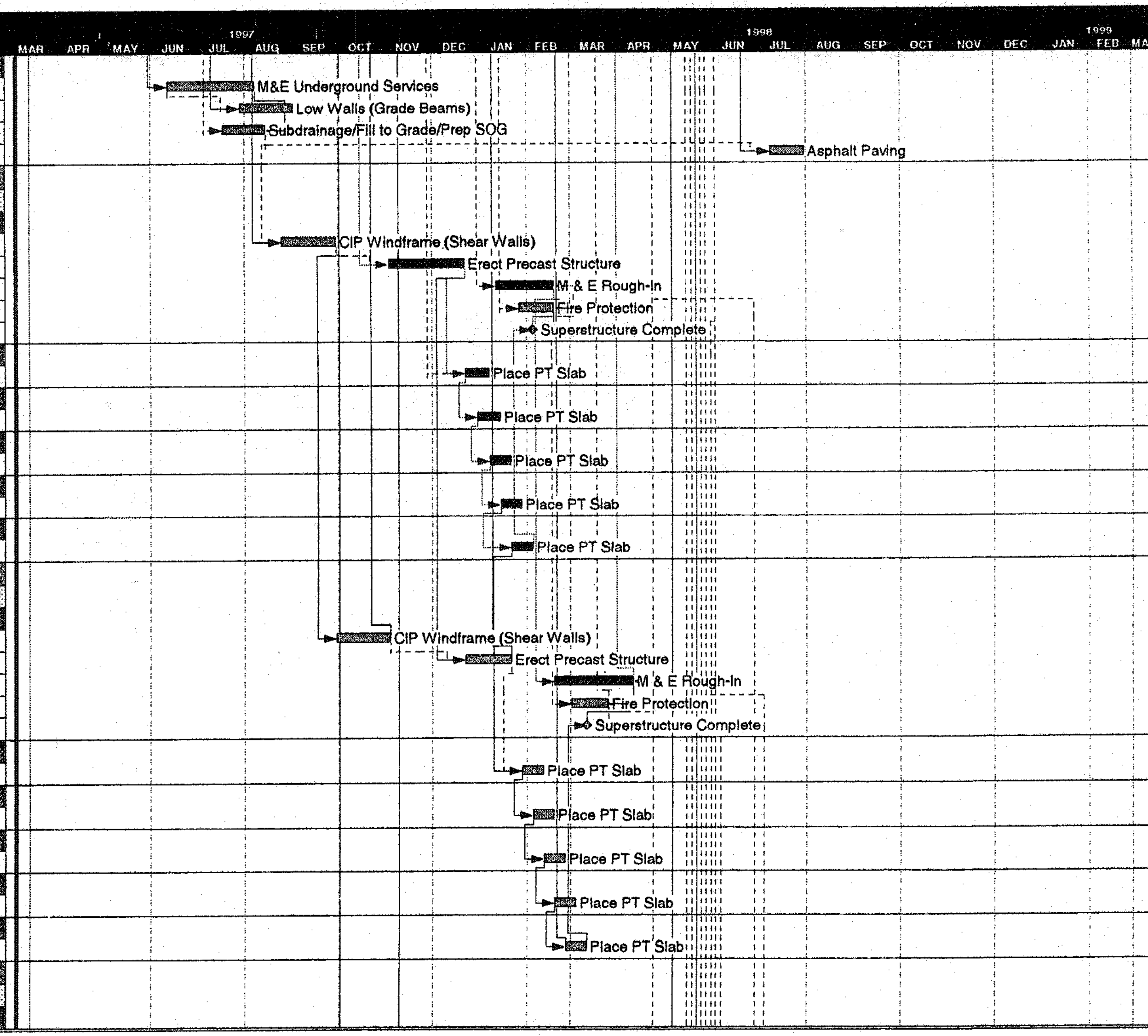
Precast/PT Slab - Project #4 Plan

Act ID	Description	Orig Dur
Ground Level		
Ground Level		
1050	M&E Underground Services	36
1060	Low Walls (Grade Beams)	25
1070	Subdrainage/Fill to Grade/Prep SOG	11
1080	Aspalt Paving	16
Phase C, Grid A-H		
Typical Levels		
All Levels		
2090	CIP Windframe (Shear Walls)	20
2092	Erect Precast Structure	35
2095	M & E Rough-In	28
2100	Fire Protection	17
2920	Superstructure Complete	0
Level Two		
2110	Place PT Slab	10
Level Three		
2115	Place PT Slab	10
Level Four		
2120	Place PT Slab	10
Level Five		
2125	Place PT Slab	10
Level Six		
2130	Place PT Slab	10
Phase C, Grid J-S		
Typical Levels		
All Levels		
2135	CIP Windframe (Shear Walls)	28
2137	Erect Precast Structure	20
2140	M & E Rough-In	34
2145	Fire Protection	22
2930	Superstructure Complete	0
Level Two		
2155	Place PT Slab	10
Level Three		
2160	Place PT Slab	10
Level Four		
2165	Place PT Slab	10
Level Five		
2170	Place PT Slab	10
Level Six		
2175	Place PT Slab	10
Phase D		
Ground Level		



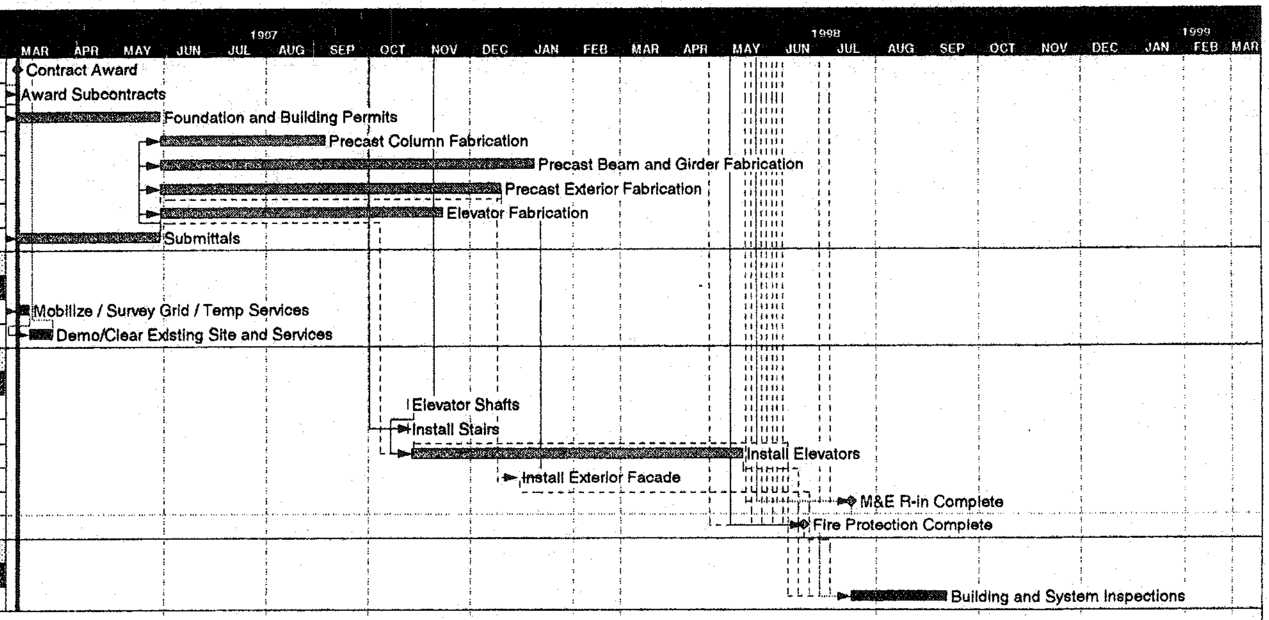
Precast/PT Slab - Project #4 Plan

Act ID	Description	Orig Dur
	Ground Level	
1090	M&E Underground Services	40
1100	Low Walls (Grade Beams)	25
1110	Subdrainage/Fill to Grade/Prep SOG	20
1120	Asphalt Paving	16
	Phase D, Grid A-H	
	Typical Levels	
	All Levels	
2180	CIP Windframe (Shear Walls)	26
2182	Erect Precast Structure	35
2185	M & E Rough-In	28
2190	Fire Protection	17
2940	Superstructure Complete	0
	Level Two	
2205	Place PT Slab	10
	Level Three	
2210	Place PT Slab	10
	Level Four	
2215	Place PT Slab	10
	Level Five	
2220	Place PT Slab	10
	Level Six	
2225	Place PT Slab	10
	Phase D, Grid J-S	
	Typical Levels	
	All Levels	
2230	CIP Windframe (Shear Walls)	25
2232	Erect Precast Structure	20
2235	M & E Rough-In	37
2240	Fire Protection	18
2950	Superstructure Complete	0
	Level Two	
2250	Place PT Slab	10
	Level Three	
2255	Place PT Slab	10
	Level Four	
2260	Place PT Slab	10
	Level Five	
2265	Place PT Slab	10
	Level Six	
2270	Place PT Slab	10
	All Phases	
	Preconstruction / Procurement / Fabrication	
	All Levels	



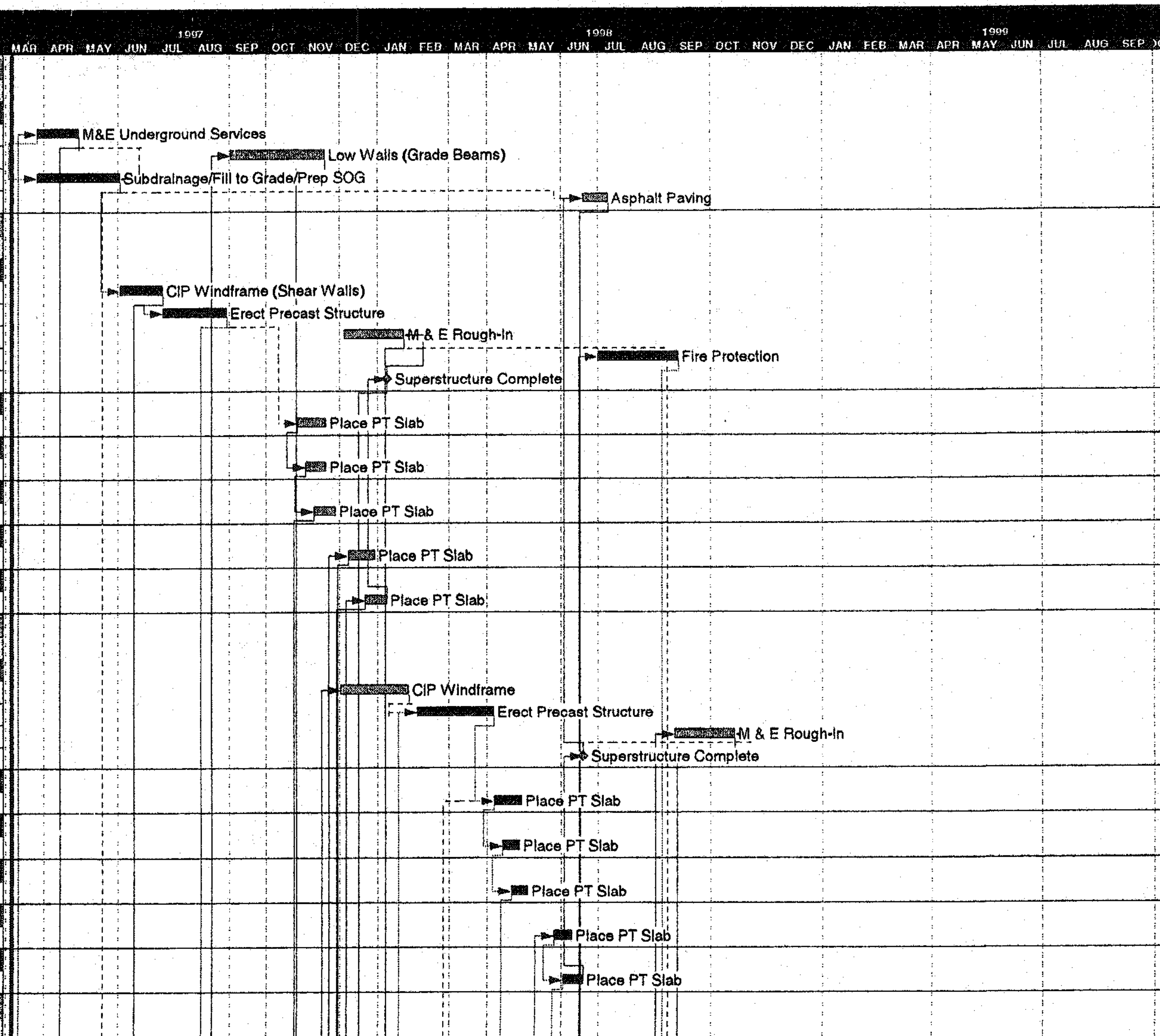
Precast/PT Slab - Project #4 Plan

Act ID	Description	Orig Dur
0010	Contract Award	0
0020	Award Subcontracts	0
0030	Foundation and Building Permits	60
0040	Precast Column Fabrication	70
0050	Precast Beam and Girder Fabrication	156
0060	Precast Exterior Fabrication	144
0070	Elevator Fabrication	120
0080	Submittals	60
Sitework		
All Levels		
0510	Mobilize / Survey Grid / Temp Services	5
0520	Demo/Clear Existing Site and Services	10
General Activities		
All Levels		
3010	Elevator Shafts	0
3020	Install Stairs	0
3030	Install Elevators	140
3040	Install Exterior Facade	0
3050	M&E R-in Complete	0
3060	Fire Protection Complete	0
Close Out		
All Levels		
4010	Building and System Inspections	40



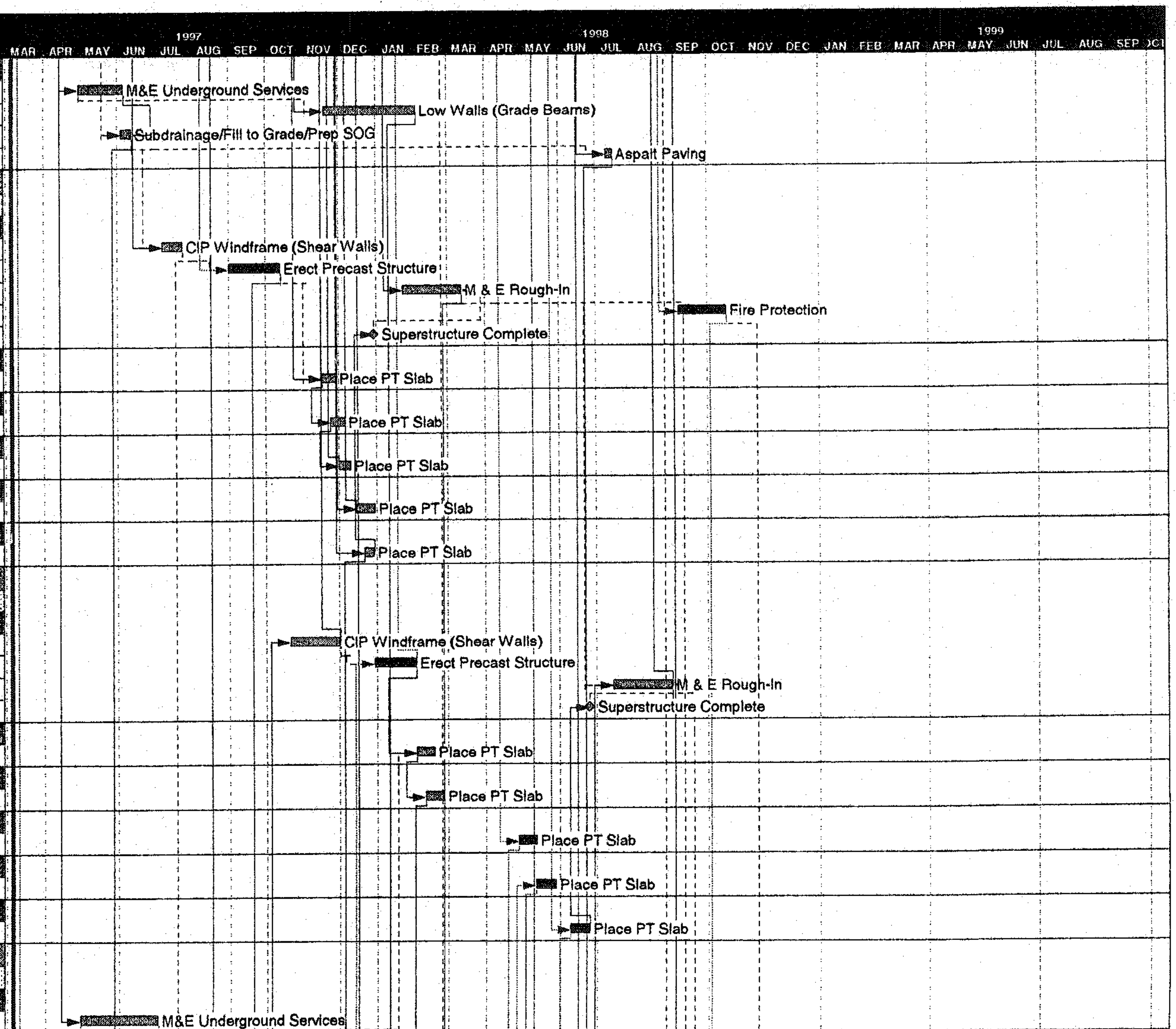
Precast/PT Slab - Project #4 Plan

Act ID	Description	Orig Dur
Phase B		
Ground Level		
Ground Level		
1010	M&E Underground Services	24
1020	Low Walls (Grade Beams)	56
1030	Subdrainage/Fill to Grade/Prep SOG	48
1040	Asphalt Paving	15
Phase B, Grid A-H		
Typical Levels		
All Levels		
2000	CIP Windframe (Shear Walls)	25
2002	Erect Precast Structure	39
2005	M & E Rough-In	35
2010	Fire Protection	48
2900	Superstructure Complete	0
Level Two		
2020	Place PT Slab	18
Level Three		
2025	Place PT Slab	13
Level Four		
2030	Place PT Slab	14
Level Five		
2035	Place PT Slab	16
Level Six		
2040	Place PT Slab	14
Phase B, Grid J-S		
Typical Levels		
All Levels		
2045	CIP Windframe	40
2047	Erect Precast Structure	45
2050	M & E Rough-In	35
2910	Superstructure Complete	0
Level Two		
2065	Place PT Slab	17
Level Three		
2070	Place PT Slab	10
Level Four		
2075	Place PT Slab	10
Level Five		
2080	Place PT Slab	11
Level Six		
2085	Place PT Slab	13
Phase C		
Ground Level		



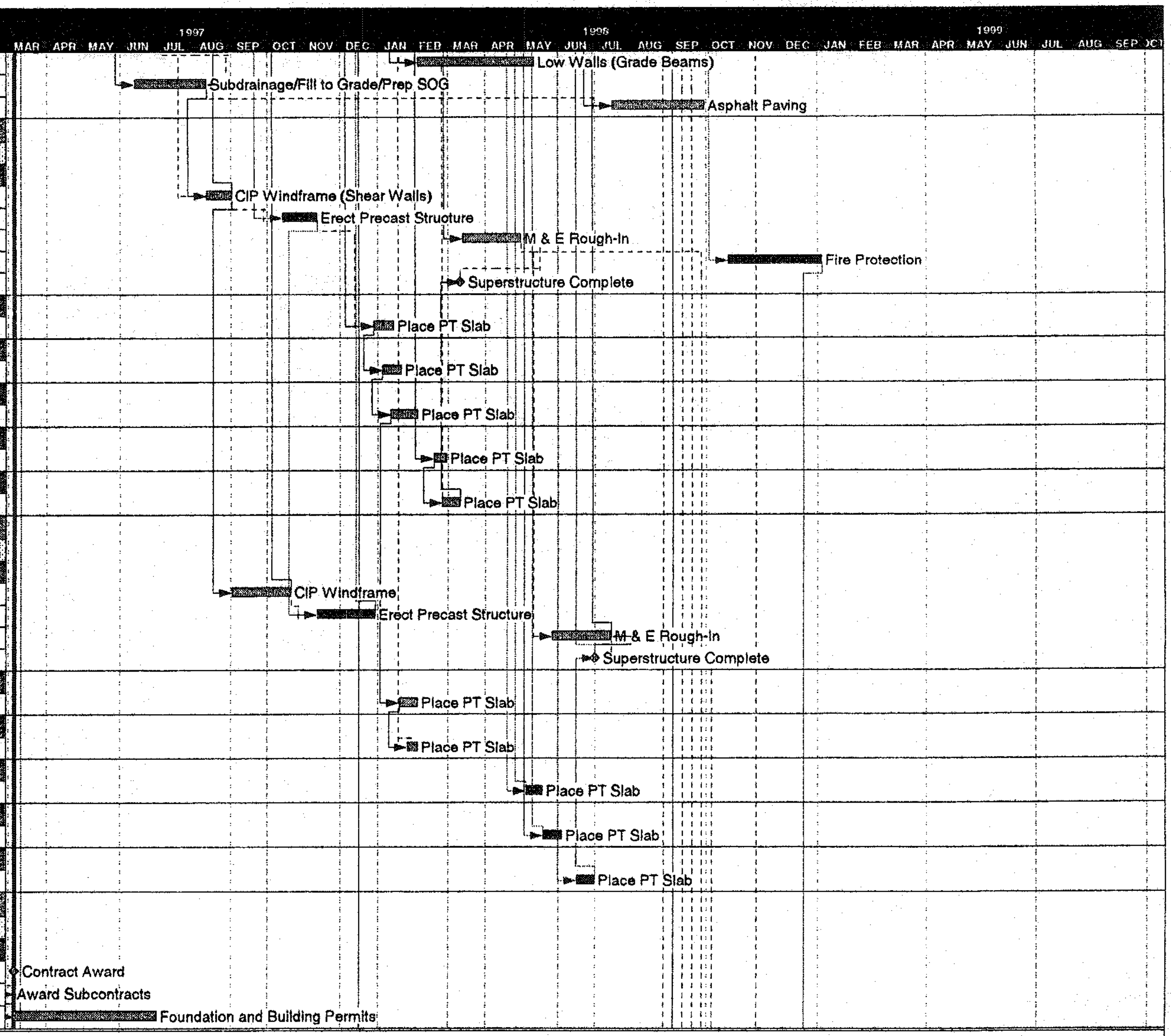
Precast/PT Slab - Project #4 As-Built

Act ID	Description	Orig Dur
	Ground Level	
1050	M&E Underground Services	27
1060	Low Walls (Grade Beams)	55
1070	Subdrainage/Fill to Grade/Prep SOG	7
1080	Aspalt Paving	4
	Phase C, Grid A-H	
	Typical Levels	
	All Levels	
2090	CIP Windframe (Shear Walls)	13
2092	Erect Precast Structure	31
2095	M & E Rough-In	35
2100	Fire Protection	30
2920	Superstructure Complete	0
	Level Two	
2110	Place PT Slab	10
	Level Three	
2115	Place PT Slab	10
	Level Four	
2120	Place PT Slab	8
	Level Five	
2125	Place PT Slab	12
	Level Six	
2130	Place PT Slab	6
	Phase C, Grid J-S	
	Typical Levels	
	All Levels	
2135	CIP Windframe (Shear Walls)	30
2137	Erect Precast Structure	25
2140	M & E Rough-In	35
2930	Superstructure Complete	0
	Level Two	
2155	Place PT Slab	11
	Level Three	
2160	Place PT Slab	12
	Level Four	
2165	Place PT Slab	11
	Level Five	
2170	Place PT Slab	13
	Level Six	
2175	Place PT Slab	12
	Phase D	
	Ground Level	
	Ground Level	
1090	M&E Underground Services	46



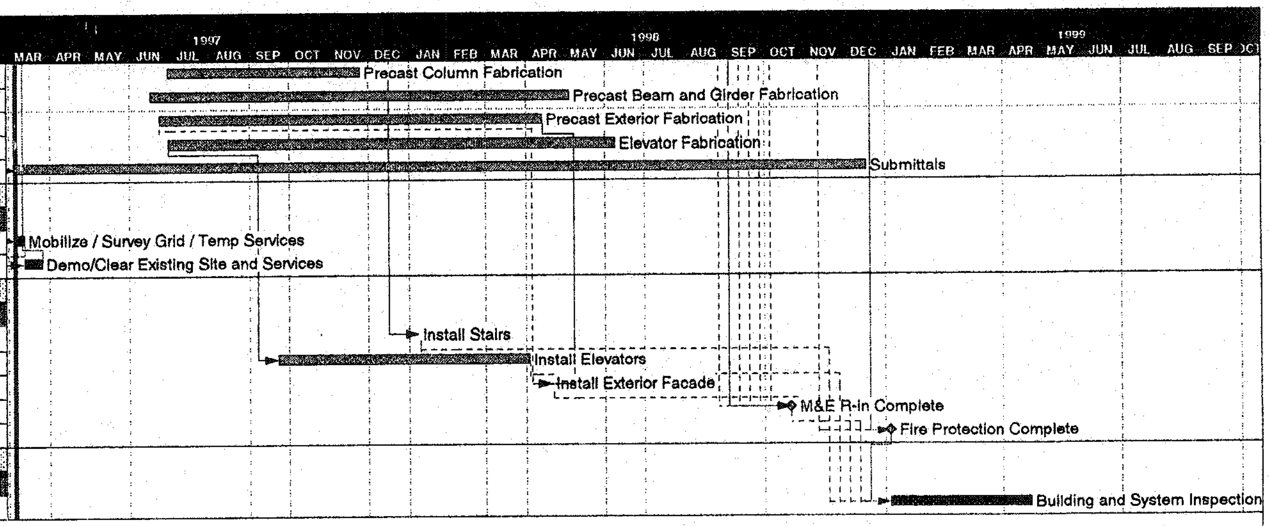
Precast/PT Slab - Project #4 As-Built

Act ID	Description	Orig Dur
1100	Low Walls (Grade Beams)	69
1110	Subdrainage/Fill to Grade/Prep SOG	42
1120	Asphalt Paving	54
Phase 0, Grid A-H		
Typical Levels		
All Levels		
2180	CIP Windframe (Shear Walls)	15
2182	Erect Precast Structure	21
2185	M & E Rough-In	35
2190	Fire Protection	56
2940	Superstructure Complete	0
Level Two		
2205	Place PT Slab	13
Level Three		
2210	Place PT Slab	12
Level Four		
2215	Place PT Slab	17
Level Five		
2220	Place PT Slab	9
Level Six		
2226	Place PT Slab	11
Phase D, Grid J-S		
Typical Levels		
All Levels		
2230	CIP Windframe	35
2232	Erect Precast Structure	34
2235	M & E Rough-In	35
2950	Superstructure Complete	0
Level Two		
2250	Place PT Slab	12
Level Three		
2255	Place PT Slab	7
Level Four		
2260	Place PT Slab	10
Level Five		
2265	Place PT Slab	12
Level Six		
2270	Place PT Slab	11
All Phases		
Preconstruction / Procurement / Fabrication		
All Levels		
0010	Contract Award	0
0020	Award Subcontracts	0
0030	Foundation and Building Permits	84



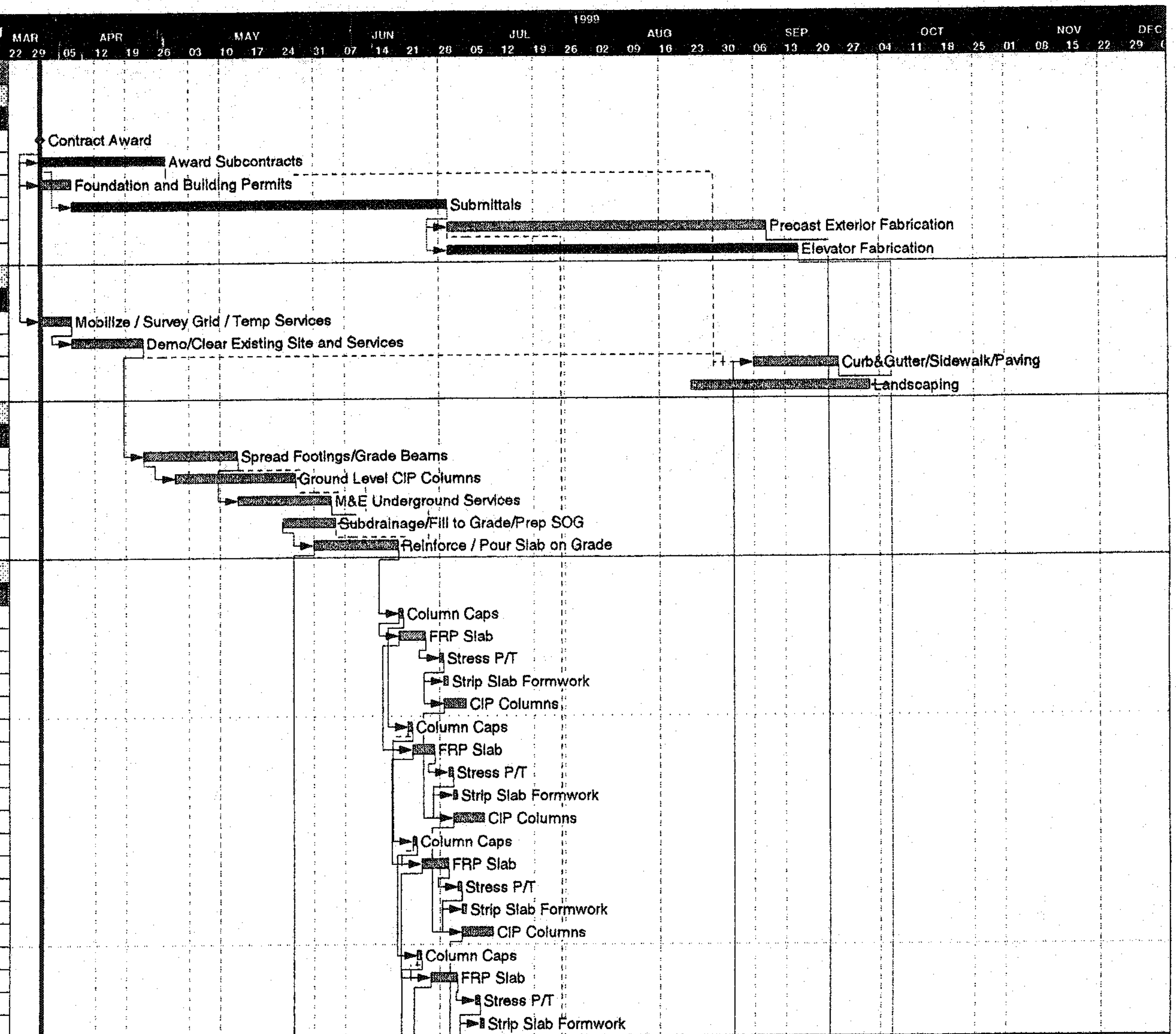
Precast/PT Slab - Project #4 As-Built

Act ID	Description	Orig Dur
0040	Precast Column Fabrication	106
0050	Precast Beam and Girder Fabrication	230
0060	Precast Exterior Fabrication	210
0070	Elevator Fabrication	245
0080	Submittals	466
Sitework		
All Levels		
0510	Mobilize / Survey Grid / Temp Services	5
0520	Demo/Clear Existing Site and Services	10
General Activities		
All Levels		
3020	Install Stairs	0
3030	Install Elevators	139
3040	Install Exterior Facade	0
3050	M&E R-in Complete	0
3060	Fire Protection Complete	0
Close Out		
All Levels		
4010	Building and System Inspections	78



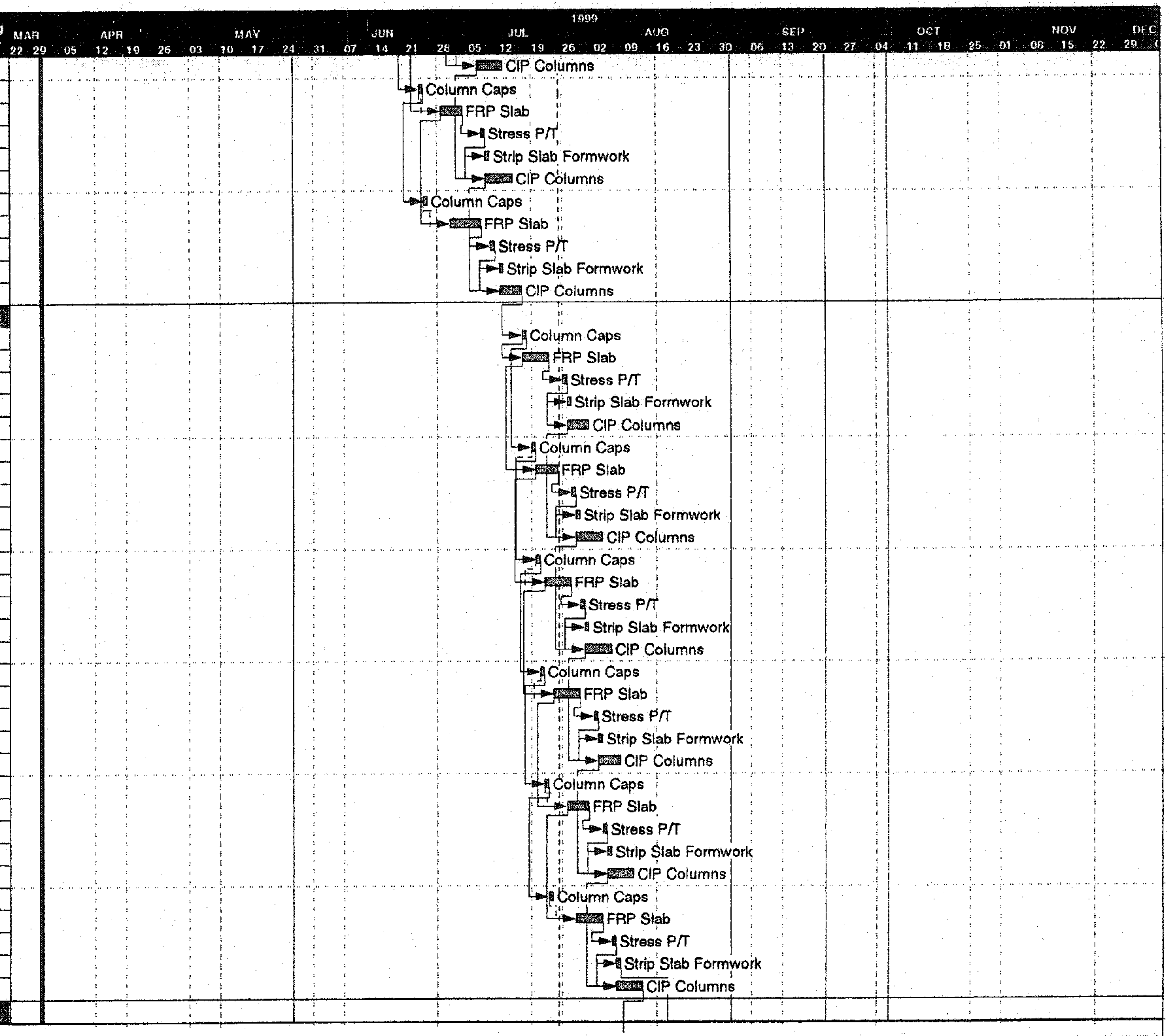
Precast/PT Slab - Project #4 As-Built

Act ID	Description	Orig Dur
All Phases		
Preconstruction / Procurement / Fabrication		
All Levels		
0010	Contract Award	0
0020	Award Subcontracts	20
0030	Foundation and Building Permits	5
0040	Submittals	60
0050	Precast Exterior Fabrication	50
0060	Elevator Fabrication	55
Sitework		
All Levels		
0510	Mobilize / Survey Grid / Temp Services	5
0520	Demo/Clear Existing Site and Services	12
0530	Curb&Gutter/Sidewalk/Paving	15
0540	Landscaping	30
Ground Level		
Ground Level		
1010	Spread Footings/Grade Beams	15
1020	Ground Level CIP Columns	19
1030	M&E Underground Services	15
1040	Subdrainage/Fill to Grade/Prep SOG	10
1050	Reinforce / Pour Slab on Grade	15
Typical Levels		
Level Two		
2005	Column Caps	1
2010	FRP Slab	5
2015	Stress P/T	1
2020	Strip Slab Formwork	1
2025	CIP Columns	5
2030	Column Caps	1
2035	FRP Slab	5
2040	Stress P/T	1
2045	Strip Slab Formwork	1
2050	CIP Columns	5
2055	Column Caps	1
2060	FRP Slab	5
2065	Stress P/T	1
2070	Strip Slab Formwork	1
2075	CIP Columns	5
2080	Column Caps	1
2085	FRP Slab	5
2090	Stress P/T	1
2095	Strip Slab Formwork	1



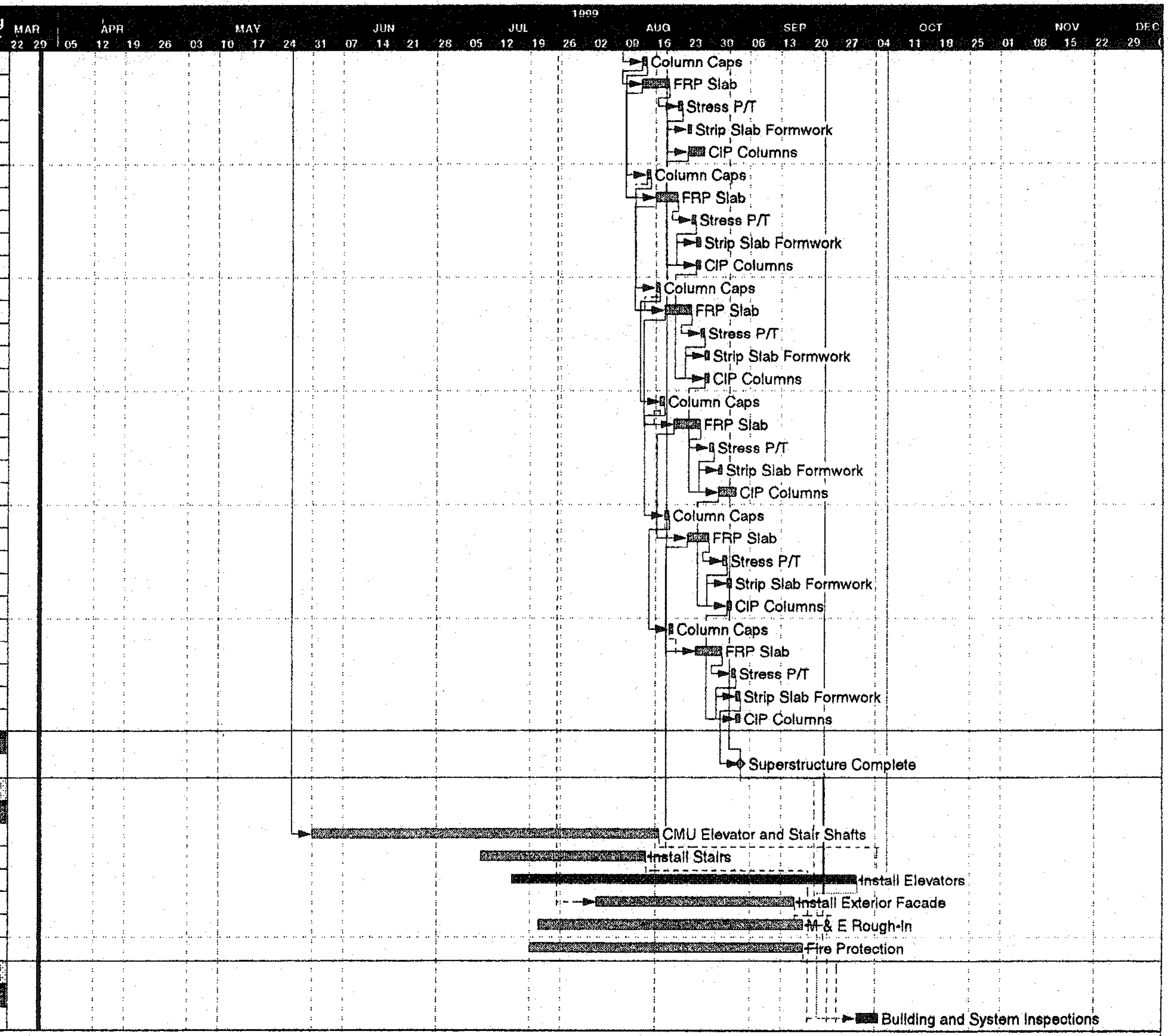
CIP System - Project #5 Plan

Act ID	Description	Orig Dur
2100	CIP Columns	5
2105	Column Caps	1
2110	FRP Slab	5
2115	Stress P/T	1
2120	Strip Slab Formwork	1
2125	CIP Columns	5
2130	Column Caps	1
2135	FRP Slab	5
2140	Stress P/T	1
2145	Strip Slab Formwork	1
2150	CIP Columns	5
Level Three		
2155	Column Caps	1
2160	FRP Slab	5
2165	Stress P/T	1
2170	Strip Slab Formwork	1
2175	CIP Columns	5
2180	Column Caps	1
2185	FRP Slab	5
2190	Stress P/T	1
2195	Strip Slab Formwork	1
2200	CIP Columns	5
2205	Column Caps	1
2210	FRP Slab	5
2215	Stress P/T	1
2220	Strip Slab Formwork	1
2225	CIP Columns	5
2230	Column Caps	1
2235	FRP Slab	5
2240	Stress P/T	1
2245	Strip Slab Formwork	1
2250	CIP Columns	5
2255	Column Caps	1
2260	FRP Slab	5
2265	Stress P/T	1
2270	Strip Slab Formwork	1
2275	CIP Columns	5
2280	Column Caps	1
2285	FRP Slab	5
2290	Stress P/T	1
2295	Strip Slab Formwork	1
2300	CIP Columns	5
Level Four		



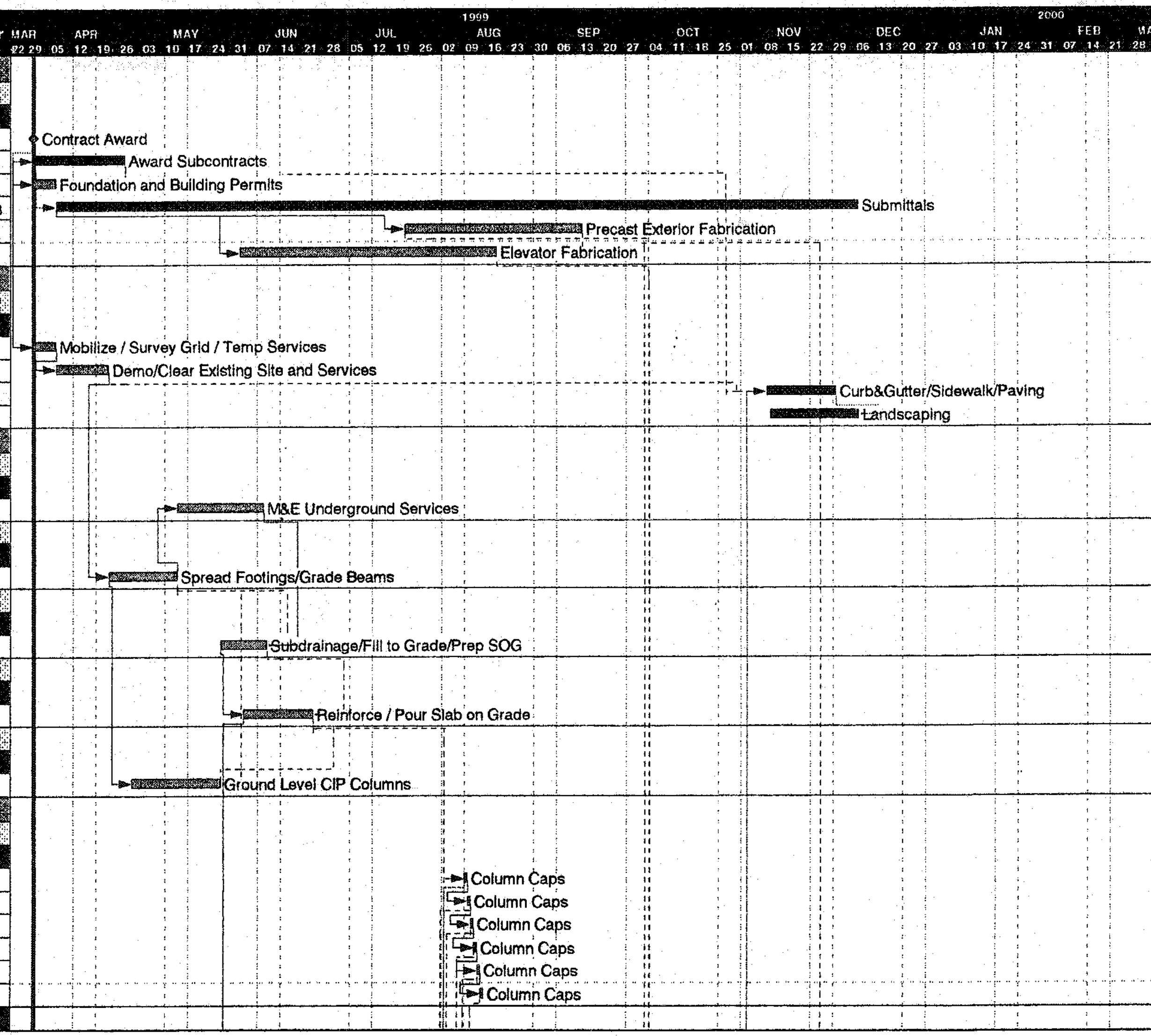
CIP System - Project #5 Plan

Act ID	Description	Orig Dur
2305	Column Caps	1
2310	FRP Slab	5
2315	Stress P/T	1
2320	Strip Slab Formwork	1
2325	CIP Columns	4
2330	Column Caps	1
2335	FRP Slab	5
2340	Stress P/T	1
2345	Strip Slab Formwork	1
2350	CIP Columns	1
2355	Column Caps	1
2360	FRP Slab	5
2365	Stress P/T	1
2370	Strip Slab Formwork	1
2375	CIP Columns	1
2380	Column Caps	1
2385	FRP Slab	5
2390	Stress P/T	1
2395	Strip Slab Formwork	1
2400	CIP Columns	4
2405	Column Caps	1
2410	FRP Slab	5
2415	Stress P/T	1
2420	Strip Slab Formwork	1
2425	CIP Columns	1
2430	Column Caps	1
2435	FRP Slab	5
2440	Stress P/T	1
2445	Strip Slab Formwork	1
2450	CIP Columns	1
All Levels		
2999	Superstructure Complete	0
General Activities		
All Levels		
3010	CMU Elevator and Stair Shafts	55
3020	Install Stairs	27
3030	Install Elevators	55
3040	Install Exterior Facade	32
3050	M & E Rough-In	43
3060	Fire Protection	45
Close Out		
All Levels		
4010	Building and System Inspections	3



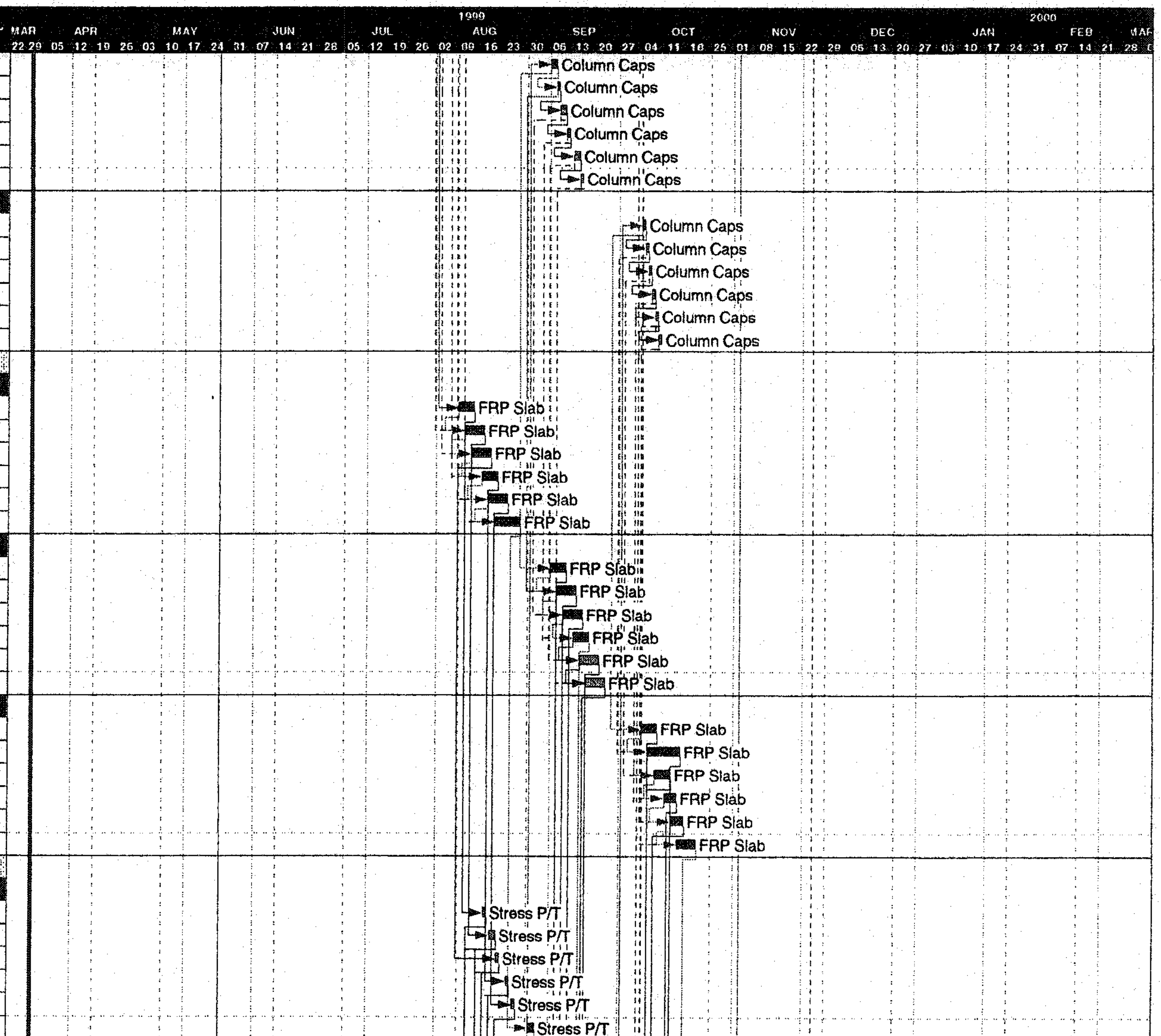
CIP System - Project #5 Plan

Act ID	Description	Dur
Preconstruction / Procurement / Fabrication		
General Activities		
All Levels		
0010	Contract Award	0
0020	Award Subcontracts	20
0030	Foundation and Building Permits	5
0040	Submittals	173
0050	Precast Exterior Fabrication	38
0060	Elevator Fabrication	55
Sitework		
General Activities		
All Levels		
0510	Mobilize / Survey Grid / Temp Services	5
0520	Demo/Clear Existing Site and Services	12
0530	Curb&Gutter/Sidewalk/Paving	15
0540	Landscaping	19
Ground Level		
M&E Underground Services		
Ground Level		
1030	M&E Underground Services	18
Grade Beams		
Ground Level		
1010	Spread Footings/Grade Beams	15
Subdrainage, Fill to Grade, Prepare SOG		
Ground Level		
1040	Subdrainage/Fill to Grade/Prep SOG	10
Reinforce/Pour Slab on Grade		
Ground Level		
1050	Reinforce / Pour Slab on Grade	15
Ground Level CIP Columns		
Ground Level		
1020	Ground Level CIP Columns	19
Typical Levels		
Column Caps		
Level Two		
2005	Column Caps	1
2030	Column Caps	1
2055	Column Caps	1
2080	Column Caps	1
2105	Column Caps	1
2130	Column Caps	1
Level Three		



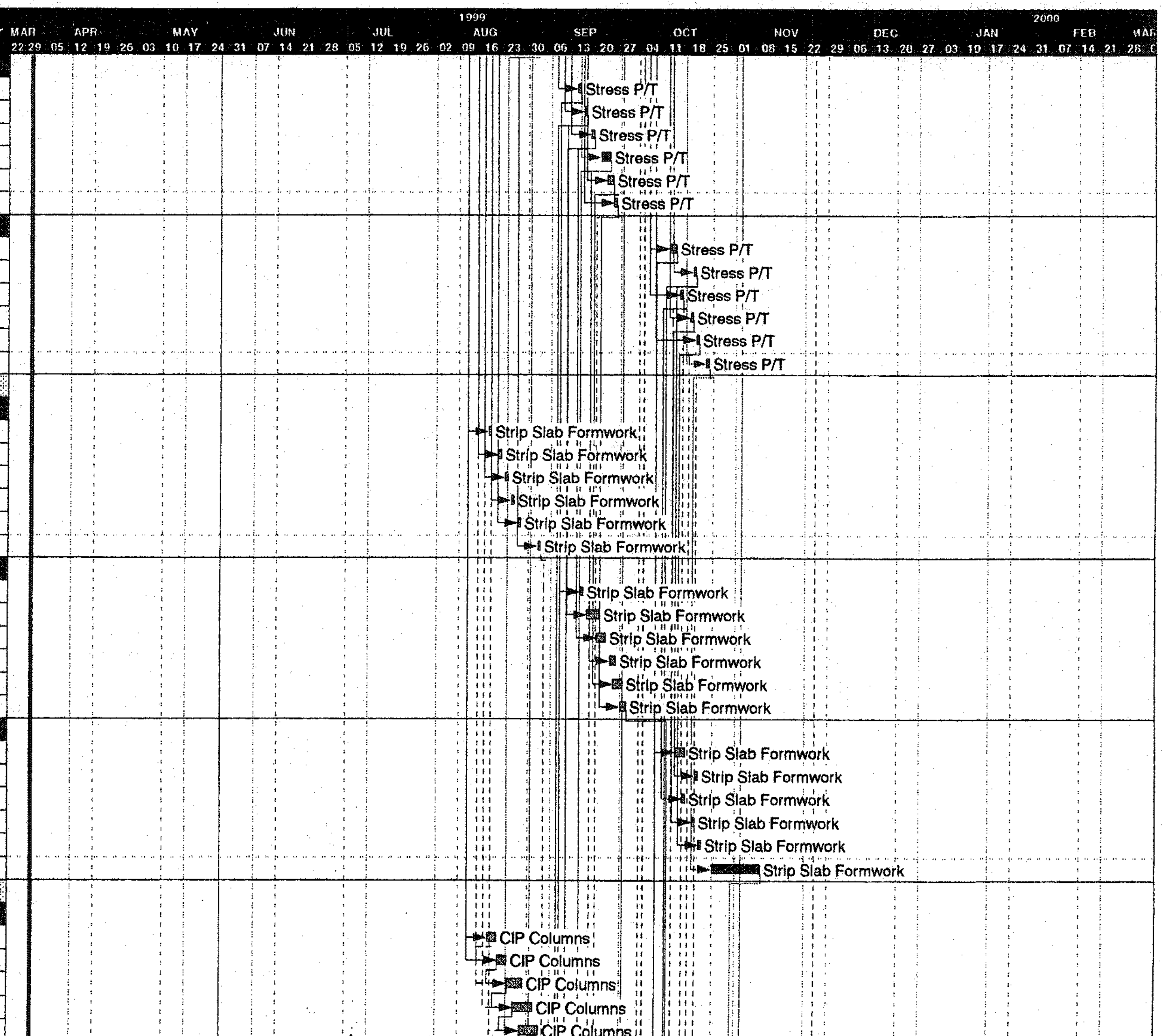
CIP System - Project #5 As-Built

Act ID	Description	Dur
2155	Column Caps	2
2180	Column Caps	1
2205	Column Caps	2
2230	Column Caps	1
2255	Column Caps	2
2280	Column Caps	1
Level Four		
2305	Column Caps	1
2330	Column Caps	1
2355	Column Caps	1
2380	Column Caps	1
2405	Column Caps	1
2430	Column Caps	1
FRP Slab		
Level Two		
2010	FRP Slab	5
2035	FRP Slab	5
2060	FRP Slab	5
2085	FRP Slab	5
2110	FRP Slab	5
2135	FRP Slab	7
Level Three		
2160	FRP Slab	5
2185	FRP Slab	5
2210	FRP Slab	5
2235	FRP Slab	5
2260	FRP Slab	5
2285	FRP Slab	5
Level Four		
2310	FRP Slab	5
2335	FRP Slab	9
2360	FRP Slab	4
2385	FRP Slab	4
2410	FRP Slab	4
2435	FRP Slab	5
Stress P/T		
Level Two		
2015	Stress P/T	1
2040	Stress P/T	2
2065	Stress P/T	1
2090	Stress P/T	1
2115	Stress P/T	1
2140	Stress P/T	2



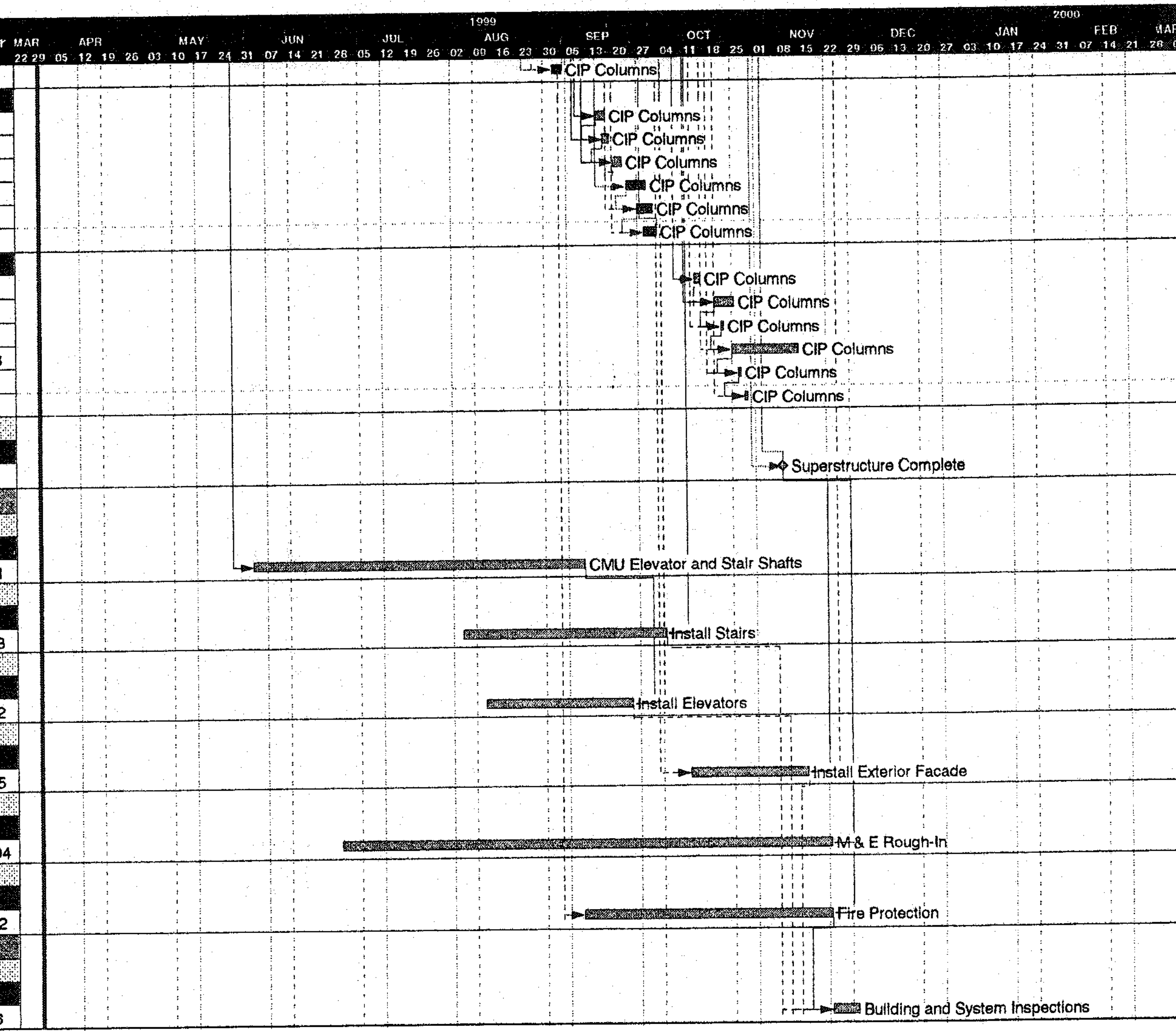
CIP System - Project #5 As-Built

Act ID	Description	Dur
Level Three		
2165	Stress P/T	1
2190	Stress P/T	1
2215	Stress P/T	1
2240	Stress P/T	3
2265	Stress P/T	2
2290	Stress P/T	1
Level Four		
2315	Stress P/T	2
2340	Stress P/T	1
2365	Stress P/T	1
2390	Stress P/T	1
2415	Stress P/T	1
2440	Stress P/T	1
Strip Slab Formwork		
Level Two		
2020	Strip Slab Formwork	1
2045	Strip Slab Formwork	1
2070	Strip Slab Formwork	1
2095	Strip Slab Formwork	1
2120	Strip Slab Formwork	1
2145	Strip Slab Formwork	1
Level Three		
2170	Strip Slab Formwork	1
2195	Strip Slab Formwork	3
2220	Strip Slab Formwork	3
2245	Strip Slab Formwork	2
2270	Strip Slab Formwork	2
2295	Strip Slab Formwork	2
Level Four		
2320	Strip Slab Formwork	3
2345	Strip Slab Formwork	1
2370	Strip Slab Formwork	1
2395	Strip Slab Formwork	1
2420	Strip Slab Formwork	1
2445	Strip Slab Formwork	13
Typical Level CIP Columns		
Level Two		
2025	CIP Columns	3
2050	CIP Columns	2
2075	CIP Columns	5
2100	CIP Columns	5
2125	CIP Columns	5



CIP System - Project #5 As-Built

Act ID	Description	Dur
2150	CIP Columns	3
Level Three		
2175	CIP Columns	3
2200	CIP Columns	2
2225	CIP Columns	3
2250	CIP Columns	5
2275	CIP Columns	5
2300	CIP Columns	4
Level Four		
2325	CIP Columns	2
2350	CIP Columns	5
2375	CIP Columns	1
2400	CIP Columns	18
2425	CIP Columns	1
2450	CIP Columns	1
General Activities		
All Levels		
2999	Superstructure Complete	0
General Activities		
Elevator Shafts/Shear Walls		
All Levels		
3010	CMU Elevator and Stair Shafts	71
Install Stairs		
All Levels		
3020	Install Stairs	43
Install Elevators		
All Levels		
3030	Install Elevators	32
Install Exterior Facade		
All Levels		
3040	Install Exterior Facade	25
M & E Rough-In		
All Levels		
3050	M & E Rough-In	104
Fire Protection		
All Levels		
3080	Fire Protection	52
Close Out		
General Activities		
All Levels		
4010	Building and System Inspections	6



CIP System - Project #5 As-Built

APPENDIX L – CONSTRUCTION TIPS FOR PARKING STRUCTURES

Tips From Project Managers for Constructing Parking Structures

Activity	Method Used	Effect
Contract		
Contract Type	Design/Build	Can cause gaps in design information. Construction on-site often drives design.
Planning		
Safety Program	Plan Intensively	Efficiency of labour is enhanced
Sequence Activities	Complete Difficult Activities First	Allows for maximum float in high finish areas
Ramps to Upper Levels	Complete First	Makes material handling more efficient for upper levels
Fire Protection	Design	Owner/architect may not understand city regulations and under-design system - Structure will not pass inspections.
Construction		
Foundation Walls	Gang Forms	Fast but more expensive system
Columns/Beams	Steel Forms	Fast cycle time (set up/pour/strip in 24 hrs)
Forming System	Steel Forms	Increased demand on crane hook time due to lower cycle times leaves reduced capacity for other activities
Forming System	Insulated Forms	Allows pouring of concrete to continue through inclement weather
Form Deck/Beams	Utilize Equipment	Enhanced productivity when manual labour is minimized
Form Deck/Beams	Patented Steel Beam Forming System	Steep learning curve for small structures
Double-Tees	Precast	Requires precise planning of production, storage and installation if design does not allow DTees to be interchanged when being installed
Traffic Coating	Concrete Topping	Susceptible to leaking to lower levels
Installation of Steel Stairs	Subcontract	Can become critical in schedule if subcontractor does not perform
Curtain Wall	Subcontract	Quality of subcontractors extremely variable - watch quality and timeliness of work

APPENDIX M – SAMPLE INTERVIEW WORKSHEETS

Standard Questions for Parking Structures

Project Name:	
District:	

Activities that had durations different from those planned

Activity Type	Estimate Duration	Actual Duration	Days Variance	% Variance
1)				
2)				
3)				
4)				
5)				
6)				
7)				
8)				
9)				
10)				
11)				
12)				
13)				
14)				
15)				
16)				
17)				
18)				
19)				
20)				
21)				
22)				
23)				
24)				
25)				
26)				
27)				
28)				
29)				
30)				
31)				
32)				
33)				
34)				
35)				
36)				
37)				
38)				
39)				
40)				

Standard Questions for Parking Structures

Project Name:	
District:	
What factors caused variances in the schedule?	
1)	
2)	
3)	
4)	
5)	
6)	
What numerical measure is usually used to assess each factor?	
1)	
2)	
3)	
4)	
5)	
6)	
What range of values for the variables match descriptors of each factor?	
1)	Unfavourable: Normal: Favourable:
2)	Unfavourable: Normal: Favourable:
3)	Unfavourable: Normal: Favourable:
4)	Unfavourable: Normal: Favourable:
5)	Unfavourable: Normal: Favourable:
6)	Unfavourable: Normal: Favourable:
What values did the variables assume for the project?	
1)	
2)	
3)	
4)	
5)	
6)	

Standard Questions for Parking Structures

Project Name:		
District:		
What portion of each schedule variance observed was due to each factor?		
Activity:	Factor:	% of Variance =
	Factor:	% of Variance =
	Factor:	% of Variance =
	Factor:	% of Variance =
	Factor:	% of Variance =
Activity:	Factor:	% of Variance =
	Factor:	% of Variance =
	Factor:	% of Variance =
	Factor:	% of Variance =
	Factor:	% of Variance =
Activity:	Factor:	% of Variance =
	Factor:	% of Variance =
	Factor:	% of Variance =
	Factor:	% of Variance =
	Factor:	% of Variance =
Activity:	Factor:	% of Variance =
	Factor:	% of Variance =
	Factor:	% of Variance =
	Factor:	% of Variance =
	Factor:	% of Variance =
Activity:	Factor:	% of Variance =
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Activity:	Factor:	% of Variance =
	Factor:	% of Variance =
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	Factor:	% of Variance =
	Factor:	% of Variance =
Activity:	Factor:	% of Variance =
	Factor:	% of Variance =
	Factor:	% of Variance =
	Factor:	% of Variance =
	Factor:	% of Variance =

Standard Questions for Parking Structures

Project Name:	
District:	

Are activities missing from the schedule that you feel should be included?

If a change in lead/lag relationships was observed between the planned and as-built schedules, is the planned schedule "normal" and does the as-built represent a "compressed" schedule? If not, what lead/lag relationships represent "normal" and "compressed" schedules?

Were any construction methods used that had an effect on schedule significant enough to flag for future reference?

Activity:	Method Used:
Effect:	
Activity:	Method Used:
Effect:	
Activity:	Method Used:
Effect:	
Activity:	Method Used:
Effect:	
Activity:	Method Used:
Effect:	

APPENDIX N – FREQUENCY DIAGRAMS FOR INPUT FACTORS

Design Errors/Completeness of Design

	Unfavourable			Normal			Favourable		
	Proj #2	Proj #4	Frequency	Proj #2	Proj #4	Frequency	Proj #2	Proj #4	Frequency
1	1	1	2			0			0
2	1		1		1	1			0
3			0	1		1		1	1
4			0	1		1		1	1
5			0	1		1		1	1
6			0	1		1		1	1
7			0			0	1	1	2
8			0			0	1	1	2
9			0			0	1	1	2
10			0			0	1	1	2

Fitted Membership Functions

	Unfavourable	Normal	Favourable
-5	1	0	0
-4	1	0	0
-3	0.5	0.33	0
-2	0	0.67	0
-1	0	1	0.25
0	0	0.67	0.5
1	0	0.33	0.75
2	0	0	1
3	0	0	1
4	0	0	1
5	0	0	1

Changes to Design (Change Orders)

	Unfavourable					Normal					Favourable				
	Proj #2	Proj #4	Proj #5	Proj #1	Frequency	Proj #2	Proj #4	Proj #5	Proj #1	Frequency	Proj #2	Proj #4	Proj #5	Proj #1	Frequency
1	1	1	1	1	4					0					0
2		1	1		2	1			1	2					0
3		1			1	1		1		2				1	1
4		1			1					0	1		1	1	3
5					0		1			1	1		1	1	3
6					0					0	1	1	1	1	4
7					0					0	1	1	1	1	4
8					0					0	1	1	1	1	4
9					0					0	1	1	1	1	4
10					0					0	1	1	1	1	4

Fitted Membership Functions

	Unfavourable	Normal	Favourable
-5	1	0	0
-4	0.75	0.5	0
-3	0.5	1	0
-2	0.25	1	0
-1	0	0.67	0
0	0	0.33	0.5
1	0	0	1
2	0	0	1
3	0	0	1
4	0	0	1
5	0	0	1

Disputes in Contract Interpretation

	Unfavourable		Normal		Favourable	
	Proj #5	Frequency	Proj #5	Frequency	Proj #5	Frequency
1	1	1		0		0
2	1	1		0		0
3	1	1		0		0
4	1	1		0		0
5		0	1	1		0
6		0		0	1	1
7		0		0	1	1
8		0		0	1	1
9		0		0	1	1
10		0		0	1	1

Fitted Membership Functions

	Unfavourable	Normal	Favourable
-5	1	0	0
-4	0.8	0.2	0
-3	0.6	0.4	0
-2	0.4	0.6	0
-1	0.2	0.8	0
0	0	1	0
1	0	0.8	0.2
2	0	0.6	0.4
3	0	0.4	0.6
4	0	0.2	0.8
5	0	0	1

Speed of Owner's Decisions

	Unfavourable		Normal		Favourable	
	Proj #1	Frequency	Proj #1	Frequency	Proj #1	Frequency
1	1	1		0		0
2	1	1		0		0
3	1	1		0		0
4		0	1	1		0
5		0		0	1	1
6		0		0	1	1
7		0		0	1	1
8		0		0	1	1
9		0		0	1	1
10		0		0	1	1

Fitted Membership Functions

	Unfavourable	Normal	Favourable
-5	1	0	0
-4	0.75	0.25	0
-3	0.5	0.5	0
-2	0.25	0.75	0
-1	0	1	0
0	0	0.85	0.17
1	0	0.68	0.34
2	0	0.51	0.51
3	0	0.34	0.68
4	0	0.17	0.85
5	0	0	1

Interference By Owner ***POOR DATA - NOT USED***

	Unfavourable		Normal		Favourable	
	Proj #4	Frequency	Proj #4	Frequency	Proj #4	Frequency
1	1	1		0		0
2	1	1		0		0
3	1	1		0		0
4	1	1		0		0
5	1	1		0	0	0
6	1	1		0	0	0
7	1	1		0	0	0
8	1	1		0	0	0
9	1	1		0	0	0
10		0	1	1	0	0

Fitted Membership Functions

	Unfavourable	Normal	Favourable
-5	1	0	0
-4	1	0	0
-3	1	0	0
-2	1	0	0
-1	1	0	0
0	1	0	0
1	1	0	0
2	1	0	0
3	1	0	0
4	1	0	0
5	0	1	0

Quality of Initial Schedule Plan

	Unfavourable			Normal			Favourable		
	Proj #3	Proj #5	Frequency	Proj #3	Proj #5	Frequency	Proj #3	Proj #5	Frequency
1	1	1	2			0			0
2	1	1	2			0			0
3	1		1		1	1			0
4	1		1		1	1			0
5	1		1			0		1	1
6	1		1			0		1	1
7	1		1			0		1	1
8			0	1		1		1	1
9			0			0	1	1	2
10			0			0	1	1	2

Fitted Membership Functions

	Unfavourable	Normal	Favourable
-5	1	0	0
-4	1	0	0
-3	1	0	0
-2	0.75	0.25	0
-1	0.5	0.5	0
0	0.25	0.75	0
1	0	1	0
2	0	0.67	0.33
3	0	0.33	0.67
4	0	0	1
5	0	0	1

Skill of Workforce (Quality of Subcontractors)

	Unfavourable					Normal					Favourable				
	Proj #3	Proj #4	Proj #5	Proj #1	Frequency	Proj #3	Proj #4	Proj #5	Proj #1	Frequency	Proj #3	Proj #4	Proj #5	Proj #1	Frequency
1	1	1	1	1	4					0					0
2	1	1	1	1	4					0					0
3		1	1	1	3	1				1					0
4		1		1	2			1		1	1				1
5					0		1		1	2	1		1		2
6					0					0	1	1	1	1	4
7					0					0	1	1	1	1	4
8					0					0	1	1	1	1	4
9					0					0	1	1	1	1	4
10					0					0	1	1	1	1	4

Fitted Membership Functions

	Unfavourable	Normal	Favourable
-5	1		
-4	1	0	0
-3	1	0	0
-2	0.5	0.33	0
-1	0	0.67	0
0	0	1	0.5
1	0	0	1
2	0	0	1
3	0	0	1
4	0	0	1
5	0	0	1

Quality of Workmanship

	Unfavourable			Normal			Favourable		
	Proj #3	Proj #2	Frequency	Proj #3	Proj #2	Frequency	Proj #3	Proj #2	Frequency
1	1	1	2			0			0
2	1	1	2			0			0
3	1	1	2			0			0
4	1		1		1	1			0
5			0	1	1	2			0
6			0		1	1	1		1
7			0			0	1	1	2
8			0			0	1	1	2
9			0			0	1	1	2
10			0			0	1	1	2

Fitted Membership Functions

	Unfavourable	Normal	Favourable
-5	1	0	0
-4	1	0	0
-3	1	0	0
-2	1	0	0
-1	0.5	0.5	0
0	0	1	0
1	0	0.5	0.5
2	0	0	1
3	0	0	1
4	0	0	1
5	0	0	1

APPENDIX O – OUTPUT MEMBERSHIP FUNCTIONS AND SENSITIVITY VALUES

Disputes in Contract Interpretation

Submittals

	Portion	Total Delay	Delay	Norm Rating	Unfav Rating	Scaled Output
Proj #5	1	1.88	1.88	0.25	0.75	2.51

Sensititvity: 1.00

	Calculated	Assigned
Favourable Output	**None**	**-0.10**
Unfavourable Output	**2.51**	**2.51**

Speed of Owner's Decisions

Demo Existing

	Portion	Total Delay	Delay	Norm Rating	Unfav Rating	Scaled Output
Proj #1	0.5	4.2	2.1	0	1	2.10

Sensititvity: 1.00

	Calculated	Assigned
Favourable Output	**None**	**-0.25**
Unfavourable Output	**2.10**	**2.10**

Interference By Owner

Building Inspections

	Portion	Total Delay	Delay	Norm Rating	Unfav Rating	Scaled Output
Proj #4	1	0.95	0.95	0	1	0.95

Sensititvity: 1.00

	Calculated	Assigned
Favourable Output	**None**	**-0.10**
Unfavourable Output	**0.95**	**0.95**

Design Errors / Completeness of Design

Fdn Walls

	Portion	Total Delay	Delay	Norm Rating	Unfav Rating	Scaled Output
Proj #2	0.8	0.6	0.48	0.33	0.5	0.80

Sensititvity: **1.00**

Expansion Joints

	Portion	Total Delay	Delay	Norm Rating	Unfav Rating	Scaled Output
Proj #2	0.2	0.9	0.18	0.33	0.5	0.30

Sensititvity: **0.38**

Exterior Façade

	Portion	Total Delay	Delay	Norm Rating	Unfav Rating	Scaled Output
Proj #2	1	0.32	0.32	0.33	0.5	0.53

Sensititvity: **0.67**

	Calculated	Assigned
Favourable Output	**None**	**-0.25**
Unfavourable Output	**0.80**	**0.80**

Changes in Design

Permits

	Portion	Total Delay	Delay	Norm Rating	Unfav Rating	Scaled Output
Proj #2	1	1	1	1	0.67	2.49
Proj #4	1	0.4	0.4	1	0.33	1.61
					Average:	2.05
					Sensititvity:	**1.00**

Fdn Walls

	Portion	Total Delay	Delay	Norm Rating	Unfav Rating	Scaled Output
Proj #2	0.2	0.6	0.12	1	0.67	0.30
					Sensititvity	**0.15**

Reinforce/Pour SOG

	Portion	Total Delay	Delay	Norm Rating	Unfav Rating	Scaled Output
Proj #2	0.8	0.32	0.256	1	0.67	0.64
					Sensititvity	**0.31**

CIP Columns

	Portion	Total Delay	Delay	Norm Rating	Unfav Rating	Scaled Output
Proj #2	1	0.13	0.13	1	0.67	0.32
					Sensititvity	**0.16**

Stair/Elevator Shafts

	Portion	Total Delay	Delay	Norm Rating	Unfav Rating	Scaled Output
Proj #2	0.5	1.06	0.53	1	0.67	1.32
					Sensititvity	**0.64**

Fire Protection

	Portion	Total Delay	Delay	Norm Rating	Unfav Rating	Scaled Output
Proj #1	1	0.5	0.5	0	1	0.50
					Sensititvity	**0.24**

	Calculated	**Assigned**
Favourable Output	**None**	**-0.20**
Unfavourable Output	**2.05**	**2.05**

Skill of Workforce (Quality of Subcontractors)

Demo Existing

	Portion	Total Delay	Delay	Norm Rating	Unfav Rating	Scaled Output
Proj #1	0.25	4.2	1.05	0.33	0.5	1.74

Sensititvity **1.00**

Fab Precast Exterior

	Portion	Total Delay	Delay	Norm Rating	Fav Rating	Scaled Output
Proj #5	1	-0.12	-0.12	0	1	-0.12

Sensititvity: **0.57**

Fdn Walls

	Portion	Total Delay	Delay	Norm Rating	Unfav Rating	Scaled Output
Proj #3	1	-0.06	-0.06	0	1	-0.06

Sensititvity **0.29**

Stress PT

	Portion	Total Delay	Delay	Norm Rating	Unfav Rating	Scaled Output
Proj #5	1	0.33	0.33	0	1	0.33

Sensititvity **0.19**

Install Elevators

	Portion	Total Delay	Delay	Norm Rating	Fav Rating	Scaled Output
Proj #5	0.5	-0.42	-0.21	0	1	-0.21

Sensititvity **1.00**

	Calculated	Assigned
Favourable Output	**-0.21**	**-0.21**
Unfavourable Output	**1.74**	**1.74**

Quality of Workmanship

Deep Fdns

	Portion	Total Delay	Delay	Norm Rating	Unfav Rating	Scaled Output
Proj #3	1	0.35	0.35	0	1	0.35
					Sensititvity:	**0.24**

Expansion Joints

	Portion	Total Delay	Delay	Norm Rating	Unfav Rating	Scaled Output
Proj #2	0.8	0.9	0.72	0.5	0.5	1.44
					Sensititvity	**1.00**

	Calculated	**Assigned**
Favourable Output	**None**	**-0.10**
Unfavourable Output	**1.44**	**1.44**

APPENDIX P – TESTING SCENARIOS

Instructions

Please adjust the activity durations for each scenario included in this package after taking into account the ratings of the risk factors given. The baseline durations assume all factors are rated "normal". All baseline activity durations represent working days and have been calculated using the productivities from previously completed PCL projects. The schedule accompanying each scenario is included to help you visualize the project.

The most effective method of completing each scenario is to go through the summary activities one-by-one. For each activity, weigh all the rated factors in your mind and assign a new duration for the activity after considering the significance of the values assigned to the risk factors.

Some scenarios may use linguistic descriptors such as "unfavourable" to rate the likely effect a risk factor will have on the overall project. Others will use crisp ratings on a scale such as "-3 on a scale from –5 to 5". This has been done to test the system's response when presented with general ratings in comparison to being given exact ratings. Please assess the effects of these ratings to the best of your ability. Don't worry about what a rating like "unfavourable" means exactly – I just want you to adjust the activities based on your own feeling of what the ratings mean.

Please fax me the filled out forms by [redacted]. The number is: [redacted].

Thank you very much for agreeing to help me test the system – I know your time is valuable so I have tried to streamline the process as much as possible.

Scenario 1 – Ratings as Crisp Numbers

Description:
714 spaces
AT Curd Structural System
250 000 GSF
50 000 sf footprint
5 parking levels
Above Grade
Shallow Foundations Only (no piles)
2 Elevator Banks
20 Pours for Elevated Slabs, each 10 000 sf

Ratings of Factors:

Factor	-5	-4	-3	-2	-1	0	1	2	3	4	5
Interference by Owner:		↓									
	-5	-4	-3	-2	-1	0	1	2	3	4	5
	Very Unfavourable								**Very Favourable**		
Quality of Initial Schedule Plan:										↓	
	-5	-4	-3	-2	-1	0	1	2	3	4	5
	Very **Unfavourable**								Very Favourable		
Quality of Field Management:									↓		
	-5	-4	-3	-2	-1	0	1	2	3	4	5
	Very Unfavourable								Very Favourable		

Scenario 1 – Ratings as Crisp Numbers

Activity Durations:

Activity	Baseline Duration (days)	Adjusted Duration (days)
Award Subcontracts	35	
Permits	20	
Submittals	60	
Precast Fab	20	
Elevator Fab	60	
Mobilize	10	
Demo	5	
Curb&Gutter/Sidewalk	15	
Landscaping	15	
Shallow Foundations	32	
M&E UG	25	
Prep SOG	7	
Pour SOG	15	
Erect Precast Columns	10	
Install Precast Beams	14	
*FRP Slab	100	
Stress P/T	20	
Strip Slab Formwork	20	
Elevator Shafts	40	
Install Stairs	25	
Install Elevators	40	
Install Exterior Façade	22	
M&E R-in	25	
Fire Protection	17	
Inspections	15	

* *This activity overlaps locations due to multiple tasks within the defined activity. The duration shown represents the sum of the total days working each location NOT the time from when the activity started at the first location to the time when it finished at the last location.*

Scenario 1 – Ratings as Linguistic Descriptors

Description:

714 spaces
AT Curd Structural System
250 000 GSF
50 000 sf footprint
5 parking levels
Above Grade
Shallow Foundations Only (no piles)
2 Elevator Banks
20 Pours for Elevated Slabs, each 10 000 sf

Ratings of Factors:

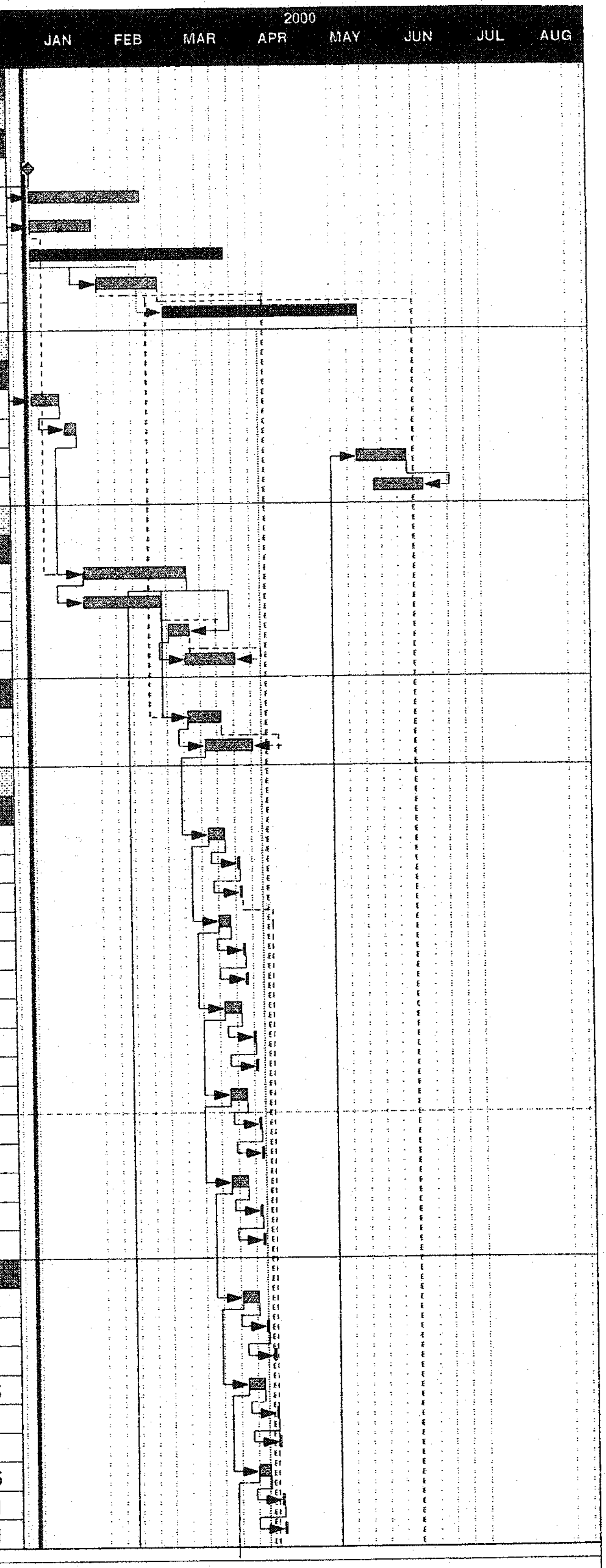
Ground Conditions: *Unfavourable*
Interference by Owner: *Unfavourable*
Quality of Field Management: *Favourable*

Activity Durations:

Activity	Baseline Duration (days)	Adjusted Duration (days)
Award Subcontracts	35	
Permits	20	
Submittals	60	
Precast Fab	20	
Elevator Fab	60	
Mobilize	10	
Demo	5	
Curb&Gutter/Sidewalk	15	
Landscaping	15	
Shallow Foundations	32	
M&E UG	25	
Prep SOG	7	
Pour SOG	15	
Erect Precast Columns	10	
Install Precast Beams	14	
*FRP Slab	100	
Stress P/T	20	
Strip Slab Formwork	20	
Elevator Shafts	40	
Install Stairs	25	
Install Elevators	40	
Install Exterior Façade	22	
M&E R-in	25	
Fire Protection	17	
Inspections	15	

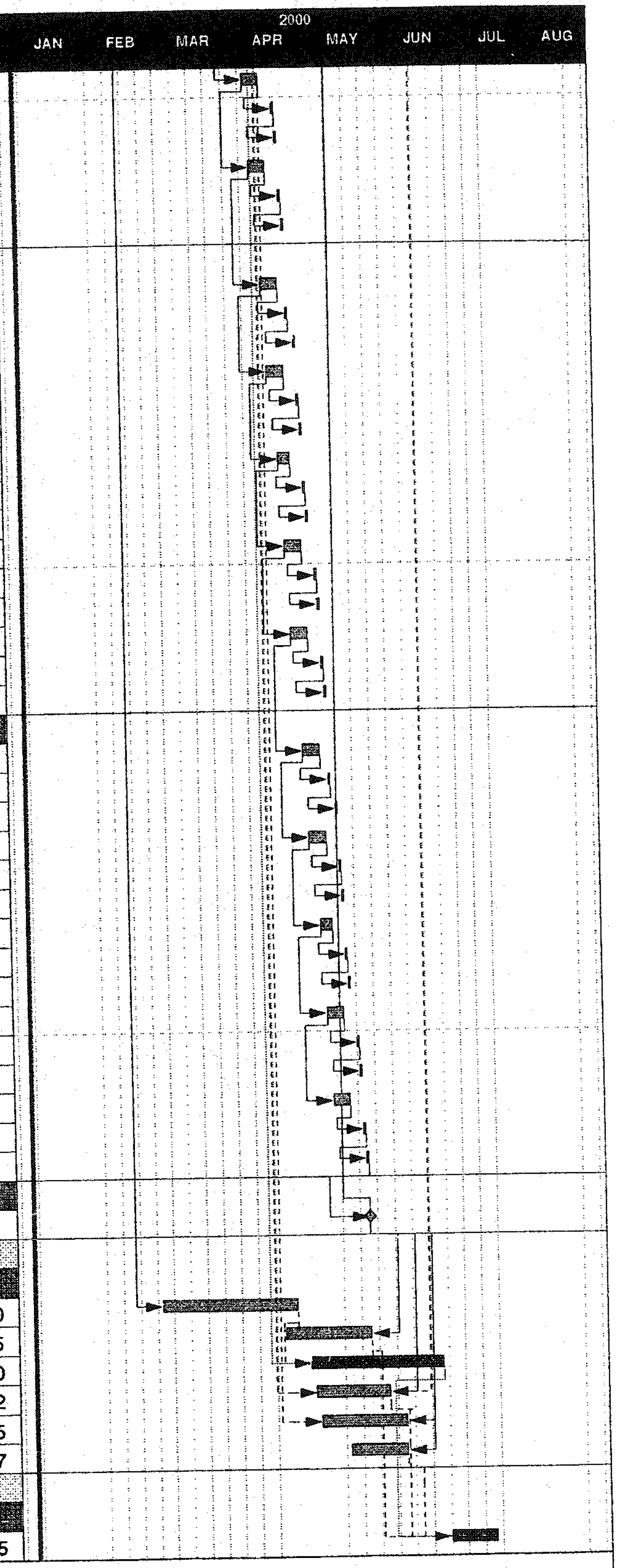
* *This activity overlaps locations due to multiple tasks within the defined activity. The duration shown represents the sum of the total days working each location NOT the time from when the activity started at the first location to the time when it finished at the last location.*

Act ID	Description	Orig Dur
	All Phases	
	Preconstruction / Procurement / Fabrication	
	All Levels	
0010	Contract Award	0
0020	Award Subcontracts	35
0030	Foundation and Building Permits	20
0040	Submittals	60
0050	Precast Fabrication	20
0060	Elevator Fabrication	60
	Sitework	
	All Levels	
0510	Mobilize/Survey Grid/Temp Services	10
0520	Demo/Clear Existing Site and Services	5
0530	Curb&Gutter/Sidewalk/Paving	15
0540	Landscaping	15
	Ground Level	
	Ground Level	
1030	Shallow Foundations	32
1050	M&E Underground Services	25
1060	Subdrainage/Fill to Grade/Prep SOG	7
1070	Reinforce/Pour Slab on Grade	15
	All Levels	
1100	Erect Precast Columns	10
1110	Install Precast Beams	14
	Typical Level	
	Level 2	
2020	FRP Slab - Pour #1	5
2030	Stress P/T - Pour #1	1
2040	Strip Slab Formwork - Pour #1	1
2050	FRP Slab - Pour #2	5
2060	Stress P/T - Pour #2	1
2070	Strip Slab Formwork - Pour #2	1
2080	FRP Slab - Pour #3	5
2090	Stress P/T - Pour #3	1
2100	Strip Slab Formwork - Pour #3	1
2110	FRP Slab - Pour #4	5
2120	Stress P/T - Pour #4	1
2130	Strip Slab Formwork - Pour #4	1
2140	FRP Slab - Pour #5	5
2150	Stress P/T - Pour #5	1
2160	Strip Slab Formwork - Pour #5	1
	Level 3	
2170	FRP Slab - Pour #6	5
2180	Stress P/T - Pour #6	1
2190	Strip Slab Formwork - Pour #6	1
2200	FRP Slab - Pour #7	5
2210	Stress P/T - Pour #7	1
2220	Strip Slab Formwork - Pour #7	1
2230	FRP Slab - Pour #8	5
2240	Stress P/T - Pour #8	1
2250	Strip Slab Formwork - Pour #8	1



Scenario 1 - Hybrid System, 5 Levels, 714 spaces

Act ID	Description	Orig Dur
2260	FRP Slab - Pour #9	5
2270	Stress P/T - Pour #9	1
2280	Strip Slab Formwork - Pour #9	1
2290	FRP Slab - Pour #10	5
2300	Stress P/T - Pour #10	1
2320	Strip Slab Formwork - Pour #10	1
Level 4		
2330	FRP Slab - Pour #11	5
2340	Stress P/T - Pour #11	1
2350	Strip Slab Formwork - Pour #11	1
2360	FRP Slab - Pour #12	5
2370	Stress P/T - Pour #12	1
2380	Strip Slab Formwork - Pour #12	1
2390	FRP Slab - Pour #13	5
2400	Stress P/T - Pour #13	1
2410	Strip Slab Formwork - Pour #13	1
2420	FRP Slab - Pour #14	5
2430	Stress P/T - Pour #14	1
2440	Strip Slab Formwork - Pour #14	1
2450	FRP Slab - Pour #15	5
2460	Stress P/T - Pour #15	1
2470	Strip Slab Formwork - Pour #15	1
Level 5		
2480	FRP Slab - Pour #16	5
2490	Stress P/T - Pour #16	1
2500	Strip Slab Formwork - Pour #16	1
2510	FRP Slab - Pour #17	5
2520	Stress P/T - Pour #17	1
2530	Strip Slab Formwork - Pour #17	1
2540	FRP Slab - Pour #18	5
2550	Stress P/T - Pour #18	1
2560	Strip Slab Formwork - Pour #18	1
2570	FRP Slab - Pour #19	5
2580	Stress P/T - Pour #19	1
2590	Strip Slab Formwork - Pour #19	1
2600	FRP Slab - Pour #20	5
2610	Stress P/T - Pour #20	1
2620	Strip Slab Formwork - Pour #20	1
All Levels		
2999	Superstructure Complete	0
General Activities		
All Levels		
3010	Elevator Shafts/Shear Walls	40
3020	Install Stairs	25
3030	Install Elevators	40
3040	Install Exterior Facade	22
3050	M & E Rough-In	25
3060	Fire Protection	17
Close Out		
All Levels		
4010	Building and System Inspections	15



Scenario 1 - Hybrid System, 5 Levels, 714 spaces

Scenario 2 – Ratings as Crisp Numbers

Description:
686 spaces
Cast in Place Structural System
240 000 GSF
80 000 sf footprint
3 parking levels
1 level below grade
Pile Foundation
1 Elevator Bank
16 Pours for Elevated Slabs, each 10 000 sf
32 600 cy bulk excavation

Ratings of Factors:

				↓							
Ground Conditions:	-5	-4	-3	-2	-1	0	1	2	3	4	5
	Very Unfavourable								**Very Favourable**		
				↓							
Speed of Owner's Decisions:	-5	-4	-3	-2	-1	0	1	2	3	4	5
	Very Unfavourable								**Very Favourable**		
			↓								
Changes to Design (COs):	-5	-4	-3	-2	-1	0	1	2	3	4	5
	Very Unfavourable								**Very Favourable**		
								↓			
Skill of Workforce (Subs):	-5	-4	-3	-2	-1	0	1	2	3	4	5
	Very Unfavourable								**Very Favourable**		

Scenario 2 – Ratings as Crisp Numbers

Activity Durations:

Activity	Baseline Duration (days)	Adjusted Duration (days)
Award Subcontracts	35	
Permits	20	
Submittals	60	
Precast Exterior Fab	40	
Elevator Fab	30	
Mobilize	10	
Demo	5	
Curb&Gutter/Sidewalk	15	
Landscaping	15	
Bulk Excavation	24	
Deep Foundations	22	
Shallow Foundations	17	
Foundation Walls	50	
M&E UG	25	
Prep SOG	12	
Pour SOG	23	
Ground Level Columns	19	
Column Caps	16	
*FRP Slab	80	
Stress P/T	16	
Strip Slab Formwork	16	
*CIP Columns	80	
Elevator Shafts	38	
Install Stairs	15	
Install Elevators	20	
Install Exterior Façade	7	
M&E R-in	20	
Fire Protection	16	
Inspections	15	

* *This activity overlaps locations due to multiple tasks within the defined activity. The duration shown represents the sum of the total days working each location NOT the time from when the activity started at the first location to the time when it finished at the last location.*

Scenario 2 – Ratings as Linguistic Descriptors

Description:
686 spaces
Cast in Place Structural System
240 000 GSF
80 000 sf footprint
3 parking levels
1 level below grade, 32 600 cy bulk excavation
Pile Foundation
1 Elevator Bank
16 Pours for Elevated Slabs, each 10 000 sf

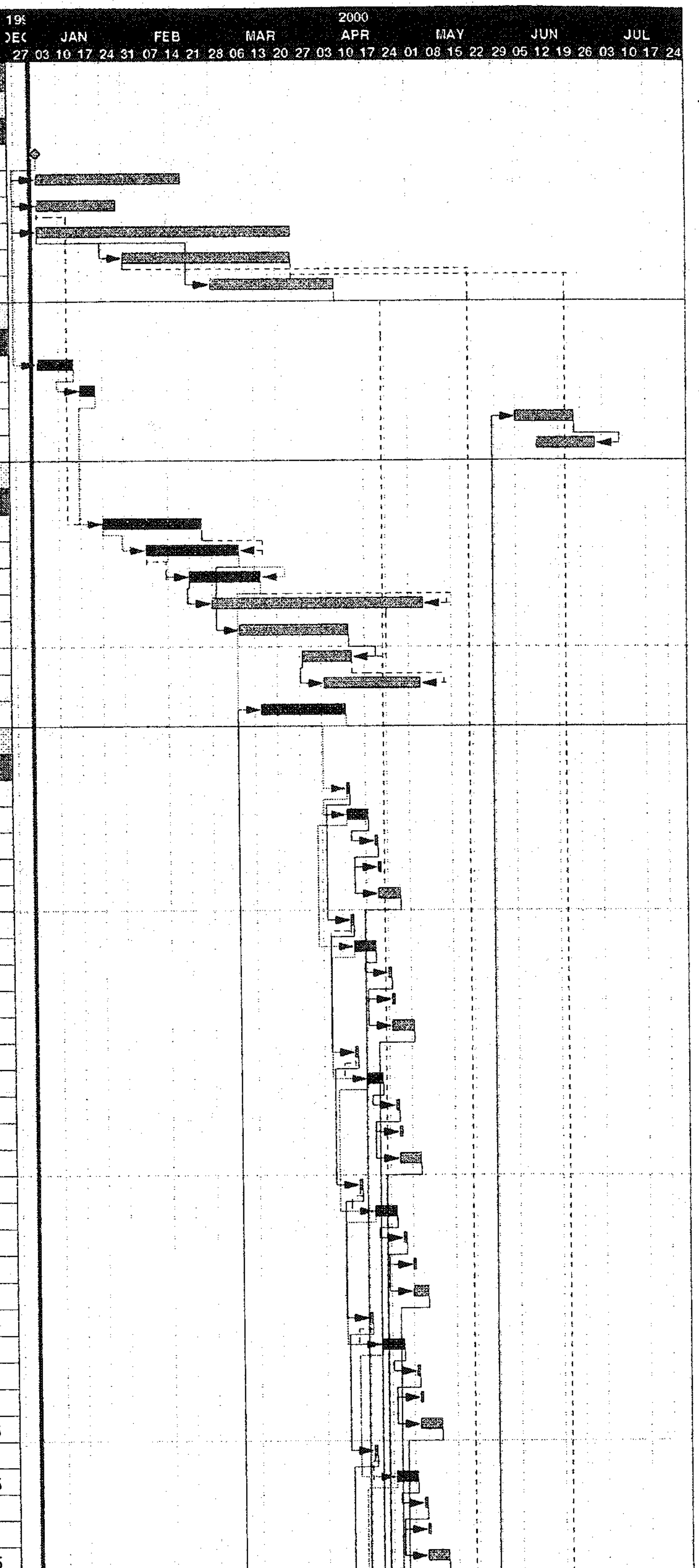
Ratings of Factors:
Ground Conditions: *Unfavourable*
Speed of Owner's Decisions: *Unfavourable*
Changes to Design (Change Orders): *Unfavourable*
Skill of Workforce (Quality of Subs): *Favourable*

Activity Durations:

Activity	Baseline Duration (days)	Adjusted Duration (days)
Award Subcontracts	35	
Permits	20	
Submittals	60	
Precast Exterior Fab	40	
Elevator Fab	30	
Mobilize	10	
Demo	5	
Curb&Gutter/Sidewalk	15	
Landscaping	15	
Bulk Excavation	24	
Deep Foundations	22	
Shallow Foundations	17	
Foundation Walls	50	
M&E UG	25	
Prep SOG	12	
Pour SOG	23	
Ground Level Columns	19	
Column Caps	16	
*FRP Slab	80	
Stress P/T	16	
Strip Slab Formwork	16	
*CIP Columns	80	
Elevator Shafts	38	
Install Stairs	15	
Install Elevators	20	
Install Exterior Façade	7	
M&E R-in	20	
Fire Protection	16	
Inspections	15	

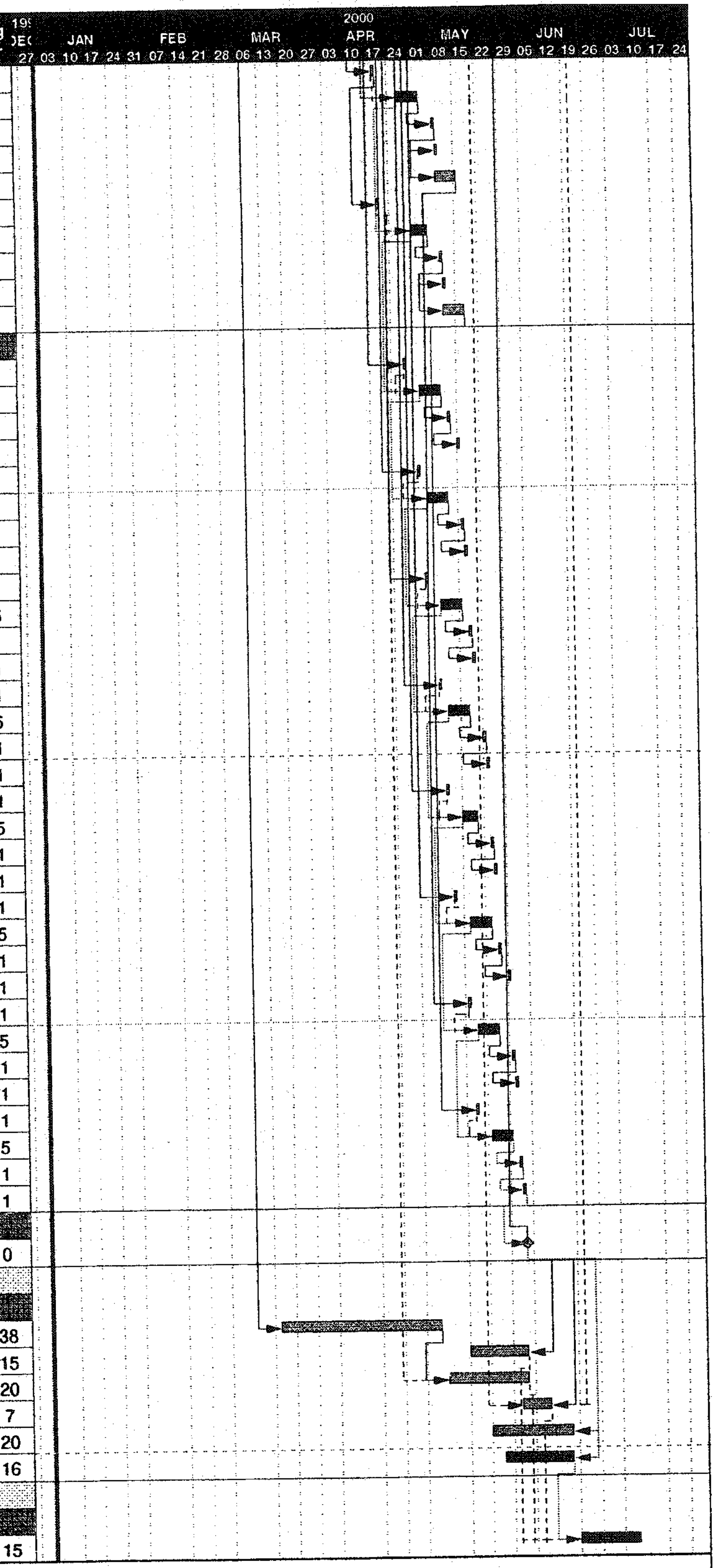
* *This activity overlaps locations due to multiple tasks within the defined activity. The duration shown represents the sum of the total days working each location NOT the time from when the activity started at the first location to the time when it finished at the last location.*

Act ID	Description	Orig Dur
All Phases		
Preconstruction / Procurement / Fabrication		
All Levels		
0010	Contract Award	0
0020	Award Subcontracts	35
0030	Foundation and Building Permits	20
0040	Submittals	60
0060	Precast Exterior Fabrication	40
0070	Elevator Fabrication	30
Sitework		
All Levels		
0510	Mobilize/Survey Grid/Temp	10
0520	Demo/Clear Existing Site and	5
0530	Curb&Gutter/Sidewalk/Paving	15
0540	Landscaping	15
Ground Level		
Ground Level		
1010	Bulk Excavation	24
1020	Deep Foundations	22
1030	Shallow Foundations	17
1040	Foundation Walls	50
1050	M&E Underground Services	25
1060	Subdrainage/Fill to Grade/Prep	12
1070	Reinforce/Pour Slab on Grade	23
1080	Ground Level CIP Columns	19
Typical Level		
Level 1		
2010	Column Caps - Pour #1	1
2020	FRP Slab - Pour #1	5
2030	Stress P/T - Pour #1	1
2040	Strip Slab Formwork - Pour #1	1
2050	CIP Columns - Pour #1	5
2060	Column Caps - Pour #2	1
2070	FRP Slab - Pour #2	5
2080	Stress P/T - Pour #2	1
2090	Strip Slab Formwork - Pour #2	1
2100	CIP Columns - Pour #2	5
2110	Column Caps - Pour #3	1
2120	FRP Slab - Pour #3	5
2130	Stress P/T - Pour #3	1
2140	Strip Slab Formwork - Pour #3	1
2150	CIP Columns - Pour #3	5
2160	Column Caps - Pour #4	1
2170	FRP Slab - Pour #4	5
2180	Stress P/T - Pour #4	1
2190	Strip Slab Formwork - Pour #4	1
2200	CIP Columns - Pour #4	5
2210	Column Caps - Pour #1	1
2220	FRP Slab - Pour #5	5
2230	Stress P/T - Pour #5	1
2240	Strip Slab Formwork - Pour #5	1
2250	CIP Columns - Pour #5	5
2260	Column Caps - Pour #6	1
2270	FRP Slab - Pour #6	5
2280	Stress P/T - Pour #6	1
2290	Strip Slab Formwork - Pour #6	1
2300	CIP Columns - Pour #6	5



Scenario 2 - CIP 3 Levels, 1 Below Gr., 686 Cars

Act ID	Description	Orig Dur
2310	Column Caps - Pour #7	1
2320	FRP Slab - Pour #7	5
2330	Stress P/T - Pour #7	1
2340	Strip Slab Formwork - Pour #7	1
2350	CIP Columns - Pour #7	5
2360	Column Caps - Pour #8	1
2370	FRP Slab - Pour #8	5
2380	Stress P/T - Pour #8	1
2390	Strip Slab Formwork - Pour #8	1
2400	CIP Columns - Pour #8	5
Level 2		
2410	Column Caps - Pour #9	1
2420	FRP Slab - Pour #9	5
2430	Stress P/T - Pour #9	1
2440	Strip Slab Formwork - Pour #9	1
2460	Column Caps - Pour #10	1
2470	FRP Slab - Pour #10	5
2480	Stress P/T - Pour #10	1
2490	Strip Slab Formwork - Pour #10	1
2510	Column Caps - Pour #11	1
2520	FRP Slab - Pour #11	5
2530	Stress P/T - Pour #11	1
2540	Strip Slab Formwork - Pour #11	1
2560	Column Caps - Pour #12	1
2570	FRP Slab - Pour #12	5
2580	Stress P/T - Pour #12	1
2590	Strip Slab Formwork - Pour #12	1
2610	Column Caps - Pour #13	1
2620	FRP Slab - Pour #13	5
2630	Stress P/T - Pour #13	1
2640	Strip Slab Formwork - Pour #13	1
2660	Column Caps - Pour #14	1
2670	FRP Slab - Pour #14	5
2680	Stress P/T - Pour #14	1
2690	Strip Slab Formwork - Pour #14	1
2710	Column Caps - Pour #15	1
2720	FRP Slab - Pour #15	5
2730	Stress P/T - Pour #15	1
2740	Strip Slab Formwork - Pour #15	1
2760	Column Caps - Pour #16	1
2770	FRP Slab - Pour #16	5
2780	Stress P/T - Pour #16	1
2790	Strip Slab Formwork - Pour #16	1
All Levels		
2999	Superstructure Complete	0
General Activities		
All Levels		
3010	Elevator Shafts, Shear Walls	38
3020	Install Stairs	15
3030	Install Elevators	20
3040	Install Exterior Facade	7
3050	M & E Rough-In	20
3060	Fire Protection	16
Close Out		
All Levels		
4010	Building and System Inspections	15



Scenario 2 - CIP 3 Levels, 1 Below Gr., 686 Cars

Scenario 3 – Ratings as Crisp Numbers

Description: 5143 spaces
Precast Structural System
225 000 sf Footprint
1 800 000 GSF
8 Parking Levels
2 Levels Below Grade, 91 667 cy Bulk Excavation
Pile Foundation
3 Elevator Banks
Field-topped Double-Tees

Ratings of Factors:

Regulatory Timeliness:

↓										
-5	-4	-3	-2	-1	0	1	2	3	4	5
Very Unfavourable								**Very Favourable**		

Interference by Owner:

									↓	
-5	-4	-3	-2	-1	0	1	2	3	4	5
Very Unfavourable								**Very Favourable**		

Changes to Design (COs):

		↓								
-5	-4	-3	-2	-1	0	1	2	3	4	5
Very Unfavourable								**Very Favourable**		

Quality of Workmanship:

		↓								
-5	-4	-3	-2	-1	0	1	2	3	4	5
Very Unfavourable								**Very Favourable**		

Scenario 3 – Ratings as Crisp Numbers

Activity Durations:

Activity	Baseline Duration (days)	Adjusted Duration (days)
Award Subcontracts	35	
Permits	20	
Submittals	60	
Precast Fab	237	
Elevator Fab	90	
Mobilize	10	
Demo	5	
Curb&Gutter/Sidewalk	15	
Landscaping	15	
Bulk Excavation	69	
Deep Foundations	62	
Shallow Foundations	47	
Foundation Walls	167	
M&E UG	25	
Prep SOG	32	
Pour SOG	65	
Erect Precast Structure	315	
Place Topping	141	
Elevator Shafts	286	
Install Stairs	40	
Install Elevators	60	
Install Exterior Façade	58	
M&E R-in	180	
Fire Protection	120	
Inspections	15	

Scenario 3 – Ratings as Linguistic Descriptors

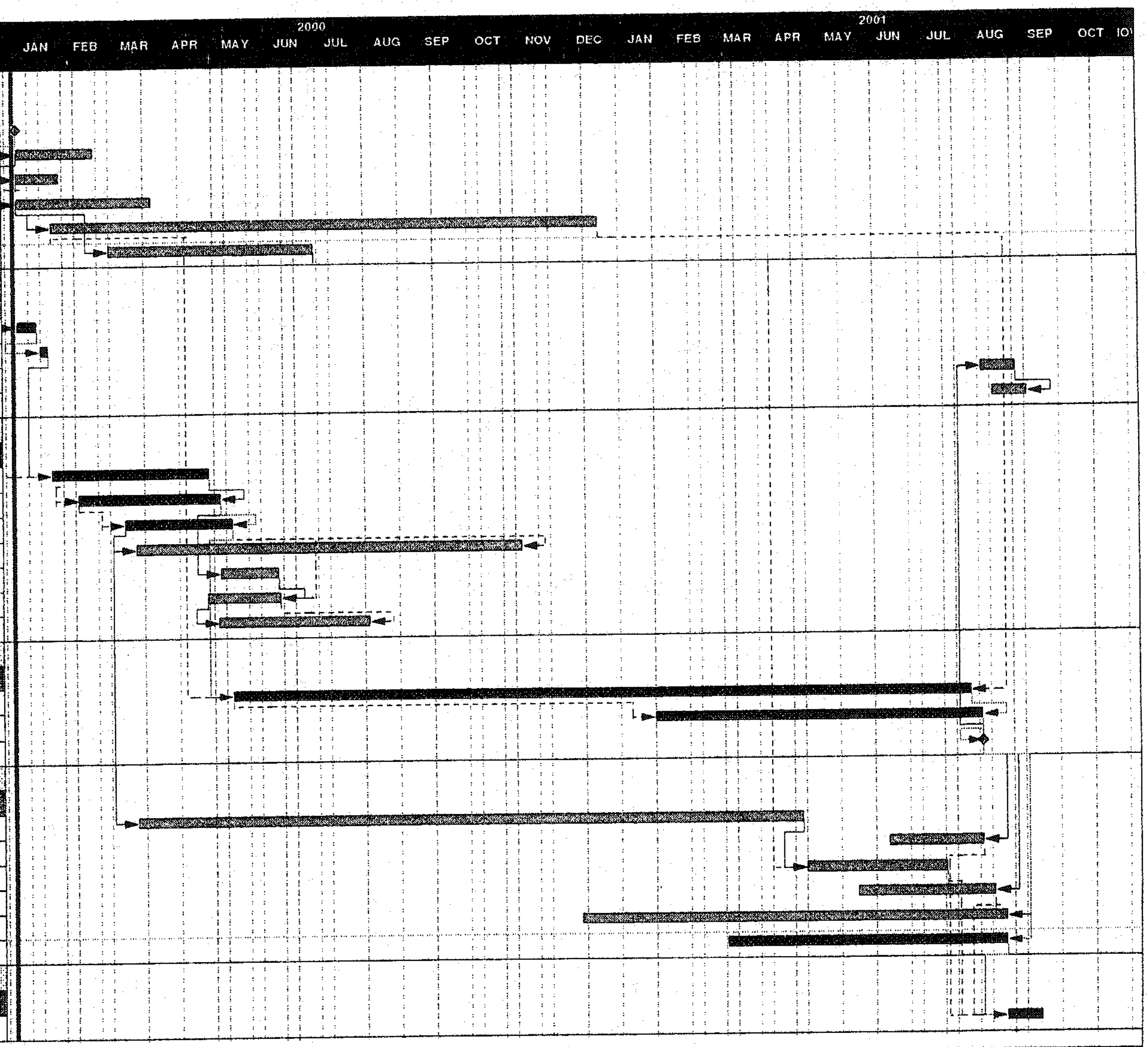
Description: 5143 spaces
Precast Structural System
225 000 sf Footprint
1 800 000 GSF
8 Parking Levels
2 Levels Below Grade, 91 667 cy Bulk Excavation
Pile Foundation
3 Elevator Banks
Field-topped Double Tees

Ratings of Factors: Timeliness of Permitting and Inspections: *Unfavourable*
Interference by Owner: *Favourable*
Changes to Design (Change Orders): *Unfavourable*
Quality of Workmanship: *Unfavourable*

Activity Durations:

Activity	Baseline Duration (days)	Adjusted Duration (days)
Award Subcontracts	35	
Permits	20	
Submittals	60	
Precast Fab	237	
Elevator Fab	90	
Mobilize	10	
Demo	5	
Curb&Gutter/Sidewalk	15	
Landscaping	15	
Bulk Excavation	69	
Deep Foundations	62	
Shallow Foundations	47	
Foundation Walls	167	
M&E UG	25	
Prep SOG	32	
Pour SOG	65	
Erect Precast Structure	315	
Place Topping	141	
Elevator Shafts	286	
Install Stairs	40	
Install Elevators	60	
Install Exterior Façade	58	
M&E R-in	180	
Fire Protection	120	
Inspections	15	

Act ID	Description	Orig Dur
Preconstruction / Procurement / Fabrication		
All Levels		
0010	Contract Award	0
0020	Award Subcontracts	35
0030	Foundation and Building Permits	20
0040	Submittals	60
0050	Precast Fabrication	237
0060	Elevator Fabrication	90
Sitework		
All Levels		
0510	Mobilize/Survey Grid/Temp Services	10
0520	Demo/Clear Existing Site and Services	5
0530	Curb&Gutter/Sidewalk/Paving	15
0540	Landscaping	15
Ground Level		
Ground Level		
1010	Bulk Excavation	69
1020	Deep Foundations	62
1030	Shallow Foundations	47
1040	Foundation Walls	167
1050	M&E Underground Services	25
1060	Subdrainage/Fill to Grade/Prep SOG	32
1070	Reinforce/Pour Slab on Grade	65
Elevated Levels		
All Levels		
2010	Erect Structure	315
2030	Place Topping	141
2999	Superstructure Complete	0
General Activities		
All Levels		
3010	Elevator Shafts/Shear Walls	286
3020	Install Stairs	40
3030	Install Elevators	60
3040	Install Exterior Facade	58
3050	M & E Rough-In	180
3060	Fire Protection	120
Close Out		
All Levels		
4010	Building and System Inspections	15



Scenario 3 - Precast, 5143 cars, 8 Levels-2 Below

Scenario 4 – Ratings as Crisp Numbers

Description:

10 000 spaces
AT Curd Structural System
3 500 000 GSF
500 000 sf Footprint
7 Parking Levels
Above Grade
Pile Foundation
3 Elevator Banks
120 Pours, each 25 000 sf

Ratings of Factors:

Speed of Owner's Decisions:

-5	-4	-3	**-2** ↓	-1	0	1	2	3	4	5
Very Unfavourable								**Very Favourable**		

Quality of Field Management:

-5	-4	**-3** ↓	-2	-1	0	1	2	3	4	5
Very Unfavourable								**Very Favourable**		

Skill of Workforce:

-5	-4	-3	**-2** ↓	-1	0	1	2	3	4	5
Very Unfavourable								**Very Favourable**		

Scenario 4 – Ratings as Crisp Numbers

Activity Durations:

Activity	Baseline Duration (days)	Adjusted Duration (days)
Award Subcontracts	35	
Permits	20	
Submittals	60	
Precast Fab	300	
Elevator Fab	90	
Mobilize	10	
Demo	5	
Curb&Gutter/Sidewalk	15	
Landscaping	15	
Deep Foundations	138	
Shallow Foundations	105	
M&E UG	25	
Prep SOG	70	
Pour SOG	143	
Erect Precast Columns	155	
Install Precast Beams	203	
*FRP Slab	600	
Stress P/T	120	
Strip Slab Formwork	120	
Elevator Shafts	200	
Install Stairs	35	
Install Elevators	60	
Install Exterior Façade	103	
M&E R-in	200	
Fire Protection	234	
Inspections	15	

* *This activity overlaps locations due to multiple tasks within the defined activity. The duration shown represents the sum of the total days working each location NOT the time from when the activity started at the first location to the time when it finished at the last location.*

Scenario 4 – Ratings as Linguistic Descriptors

Description: 10 000 spaces
AT Curd Structural System
3 500 000 GSF
500 000 sf Footprint
7 Parking Levels
Above Grade
Pile Foundation
3 Elevator Banks
120 Pours, each 25 000 sf

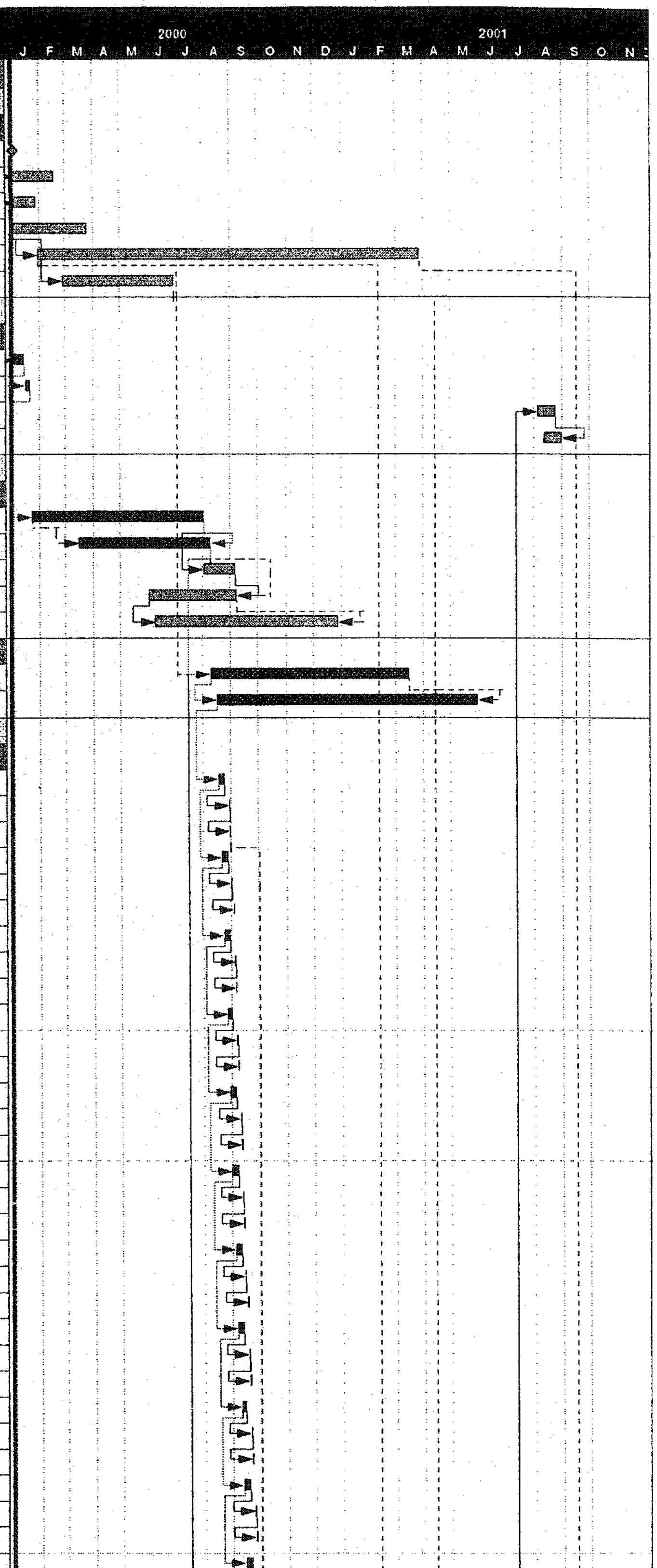
Ratings of Factors: Speed of Owner's Decisions: *Unfavourable*
Quality of Field Management: *Unfavourable*
Skill of Workforce: *Unfavourable*

Activity Durations:

Activity	Baseline Duration (days)	Adjusted Duration (days)
Award Subcontracts	35	
Permits	20	
Submittals	60	
Precast Fab	300	
Elevator Fab	90	
Mobilize	10	
Demo	5	
Curb&Gutter/Sidewalk	15	
Landscaping	15	
Deep Foundations	138	
Shallow Foundations	105	
M&E UG	25	
Prep SOG	70	
Pour SOG	143	
Erect Precast Columns	155	
Install Precast Beams	203	
*FRP Slab	600	
Stress P/T	120	
Strip Slab Formwork	120	
Elevator Shafts	200	
Install Stairs	35	
Install Elevators	60	
Install Exterior Façade	103	
M&E R-in	200	
Fire Protection	234	
Inspections	15	

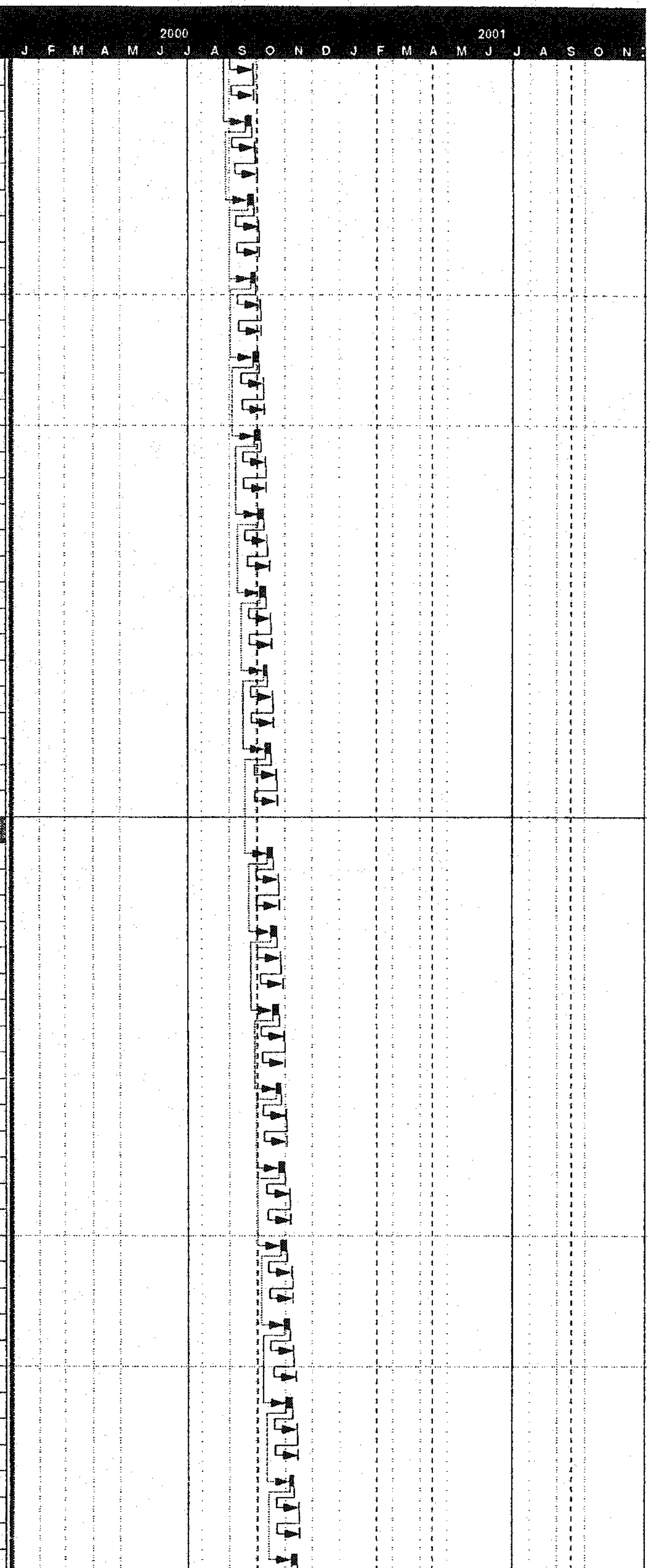
* *This activity overlaps locations due to multiple tasks within the defined activity. The duration shown represents the sum of the total days working each location NOT the time from when the activity started at the first location to the time when it finished at the last location.*

Act ID	Description	Orig Dur
All Phases		
Preconstruction / Procurement / Fabrication		
All Levels		
0010	Contract Award	0
0020	Award Subcontracts	35
0030	Foundation and Building Permits	20
0040	Submittals	60
0050	Precast Fabrication	300
0060	Elevator Fabrication	90
Sitework		
All Levels		
0510	Mobilize/Survey Grid/Temp Services	10
0520	Demo/Clear Existing Site and Services	5
0530	Curb&Gutter/Sidewalk/Paving	15
0540	Landscaping	15
Ground Level		
Ground Level		
1020	Deep Foundations	138
1030	Shallow Foundations	105
1050	M&E Underground Services	25
1060	Subdrainage/Fill to Grade/Prep SOG	70
1070	Reinforce/Pour Slab on Grade	143
All Levels		
1100	Erect Precast Columns	155
1110	Install Precast Beams	203
Typical Level		
Level 2		
2020	FRP Slab - Pour #1	5
2025	Stress P/T - Pour #1	1
2030	Strip Slab Formwork - Pour #1	1
2035	FRP Slab - Pour #2	5
2040	Stress P/T - Pour #2	1
2045	Strip Slab Formwork - Pour #2	1
2050	FRP Slab - Pour #3	5
2055	Stress P/T - Pour #3	1
2060	Strip Slab Formwork - Pour #3	1
2065	FRP Slab - Pour #4	5
2070	Stress P/T - Pour #4	1
2075	Strip Slab Formwork - Pour #4	1
2080	FRP Slab - Pour #5	5
2085	Stress P/T - Pour #5	1
2090	Strip Slab Formwork - Pour #5	1
2095	FRP Slab - Pour #6	5
2100	Stress P/T - Pour #6	1
2105	Strip Slab Formwork - Pour #6	1
2110	FRP Slab - Pour #7	5
2115	Stress P/T - Pour #7	1
2120	Strip Slab Formwork - Pour #7	1
2125	FRP Slab - Pour #8	5
2130	Stress P/T - Pour #8	1
2135	Strip Slab Formwork - Pour #8	1
2140	FRP Slab - Pour #9	5
2145	Stress P/T - Pour #9	1
2150	Strip Slab Formwork - Pour #9	1
2155	FRP Slab - Pour #10	5
2160	Stress P/T - Pour #10	1
2165	Strip Slab Formwork - Pour #10	1
2170	FRP Slab - Pour #11	5



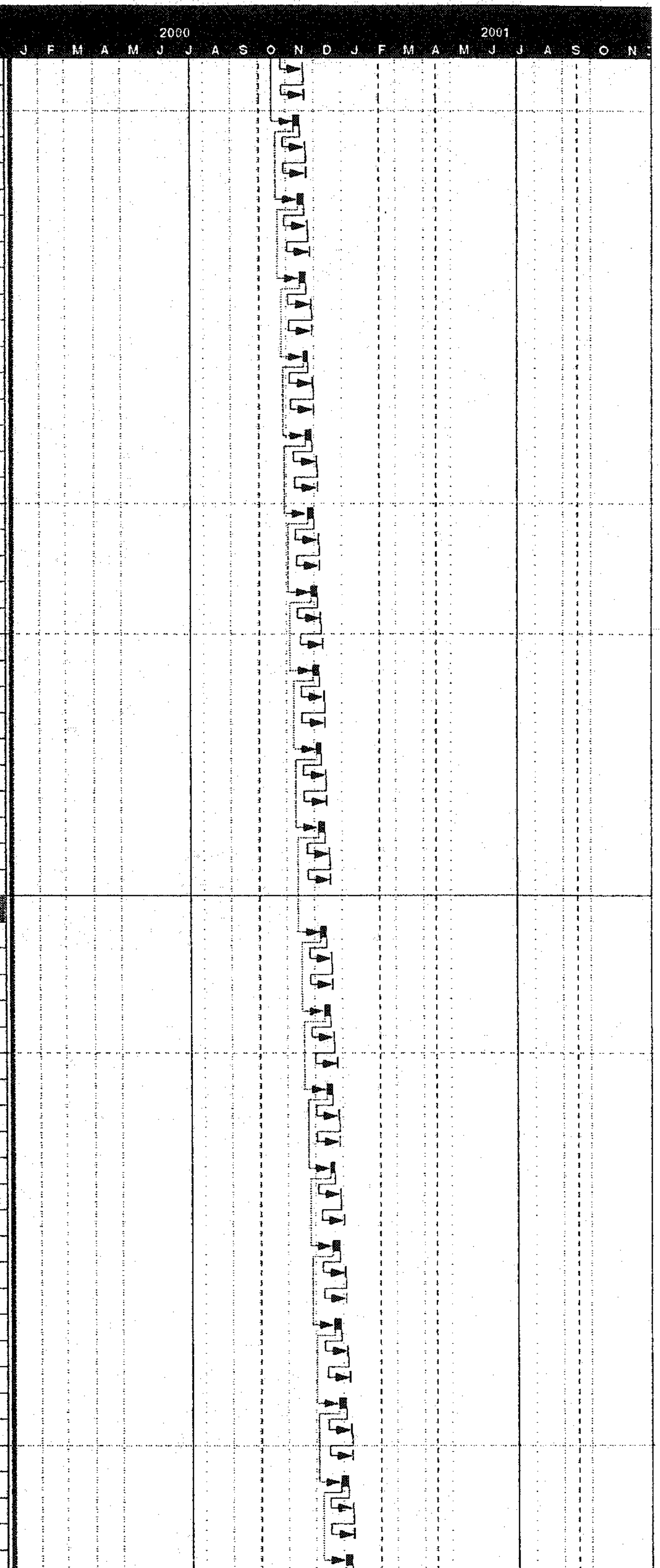
Scenario 4 - Hybrid System, 7 levels, 10 000 cars

Act ID	Description	Orig Dur
2175	Stress P/T - Pour #11	1
2180	Strip Slab Formwork - Pour #11	1
2185	FRP Slab - Pour #12	5
2190	Stress P/T - Pour #12	1
2195	Strip Slab Formwork - Pour #12	1
2200	FRP Slab - Pour #13	5
2205	Stress P/T - Pour #13	1
2210	Strip Slab Formwork - Pour #13	1
2215	FRP Slab - Pour #14	5
2220	Stress P/T - Pour #14	1
2225	Strip Slab Formwork - Pour #14	1
2230	FRP Slab - Pour #15	5
2235	Stress P/T - Pour #15	1
2240	Strip Slab Formwork - Pour #15	1
2245	FRP Slab - Pour #16	5
2250	Stress P/T - Pour #16	1
2255	Strip Slab Formwork - Pour #16	1
2260	FRP Slab - Pour #17	5
2265	Stress P/T - Pour #17	1
2270	Strip Slab Formwork - Pour #17	1
2275	FRP Slab - Pour #18	5
2280	Stress P/T - Pour #18	1
2285	Strip Slab Formwork - Pour #18	1
2290	FRP Slab - Pour #19	5
2295	Stress P/T - Pour #19	1
2300	Strip Slab Formwork - Pour #19	1
2305	FRP Slab - Pour #20	5
2310	Stress P/T - Pour #20	1
2315	Strip Slab Formwork - Pour #20	1
Level 3		
2320	FRP Slab - Pour #21	5
2325	Stress P/T - Pour #21	1
2330	Strip Slab Formwork - Pour #21	1
2335	FRP Slab - Pour #22	5
2340	Stress P/T - Pour #22	1
2345	Strip Slab Formwork - Pour #22	1
2350	FRP Slab - Pour #23	5
2355	Stress P/T - Pour #23	1
2360	Strip Slab Formwork - Pour #23	1
2365	FRP Slab - Pour #24	5
2370	Stress P/T - Pour #24	1
2375	Strip Slab Formwork - Pour #24	1
2380	FRP Slab - Pour #25	5
2385	Stress P/T - Pour #25	1
2390	Strip Slab Formwork - Pour #25	1
2395	FRP Slab - Pour #26	5
2400	Stress P/T - Pour #26	1
2405	Strip Slab Formwork - Pour #26	1
2410	FRP Slab - Pour #27	5
2415	Stress P/T - Pour #27	1
2420	Strip Slab Formwork - Pour #27	1
2425	FRP Slab - Pour #28	5
2430	Stress P/T - Pour #28	1
2435	Strip Slab Formwork - Pour #28	1
2440	FRP Slab - Pour #29	5
2445	Stress P/T - Pour #29	1
2450	Strip Slab Formwork - Pour #29	1
2455	FRP Slab - Pour #30	5



Scenario 4 - Hybrid System, 7 levels, 10 000 cars

Act ID	Description	Orig Dur
2460	Stress P/T - Pour #30	1
2465	Strip Slab Formwork - Pour #30	1
2470	FRP Slab - Pour #31	5
2475	Stress P/T - Pour #31	1
2480	Strip Slab Formwork - Pour #31	1
2485	FRP Slab - Pour #32	5
2490	Stress P/T - Pour #32	1
2495	Strip Slab Formwork - Pour #32	1
2500	FRP Slab - Pour #33	5
2505	Stress P/T - Pour #33	1
2510	Strip Slab Formwork - Pour #33	1
2515	FRP Slab - Pour #34	5
2520	Stress P/T - Pour #34	1
2525	Strip Slab Formwork - Pour #34	1
2530	FRP Slab - Pour #35	5
2535	Stress P/T - Pour #35	1
2540	Strip Slab Formwork - Pour #35	1
2545	FRP Slab - Pour #36	5
2550	Stress P/T - Pour #36	1
2555	Strip Slab Formwork - Pour #36	1
2560	FRP Slab - Pour #37	5
2565	Stress P/T - Pour #37	1
2570	Strip Slab Formwork - Pour #37	1
2575	FRP Slab - Pour #38	5
2580	Stress P/T - Pour #38	1
2585	Strip Slab Formwork - Pour #38	1
2590	FRP Slab - Pour #39	5
2595	Stress P/T - Pour #39	1
2600	Strip Slab Formwork - Pour #39	1
2605	FRP Slab - Pour #40	5
2610	Stress P/T - Pour #40	1
2615	Strip Slab Formwork - Pour #40	1
Level 4		
2620	FRP Slab - Pour #41	5
2625	Stress P/T - Pour #41	1
2630	Strip Slab Formwork - Pour #41	1
2635	FRP Slab - Pour #42	5
2640	Stress P/T - Pour #42	1
2645	Strip Slab Formwork - Pour #42	1
2650	FRP Slab - Pour #43	5
2655	Stress P/T - Pour #43	1
2660	Strip Slab Formwork - Pour #43	1
2665	FRP Slab - Pour #44	5
2670	Stress P/T - Pour #44	1
2675	Strip Slab Formwork - Pour #44	1
2680	FRP Slab - Pour #45	5
2685	Stress P/T - Pour #45	1
2690	Strip Slab Formwork - Pour #45	1
2695	FRP Slab - Pour #46	5
2700	Stress P/T - Pour #46	1
2705	Strip Slab Formwork - Pour #46	1
2710	FRP Slab - Pour #47	5
2715	Stress P/T - Pour #47	1
2720	Strip Slab Formwork - Pour #47	1
2725	FRP Slab - Pour #48	5
2730	Stress P/T - Pour #48	1
2735	Strip Slab Formwork - Pour #48	1
2740	FRP Slab - Pour #49	5



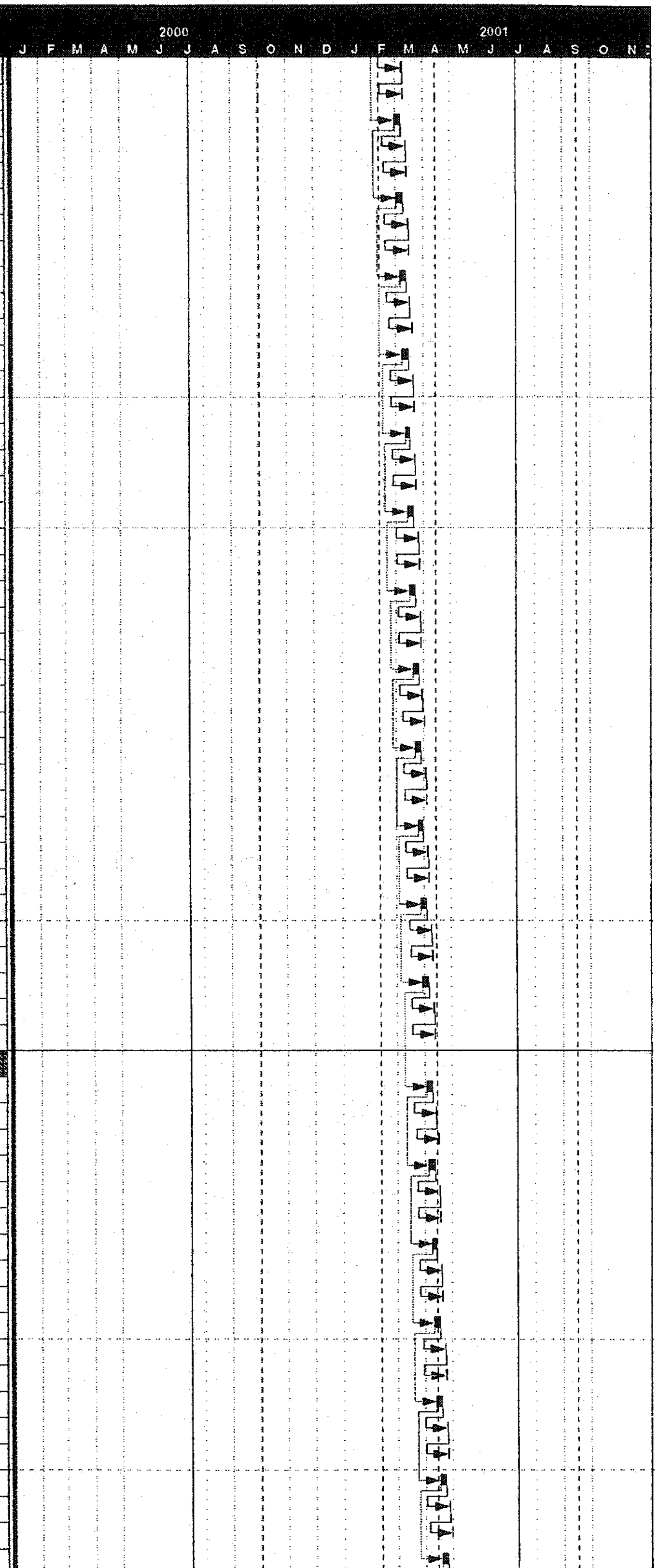
Scenario 4 - Hybrid System, 7 levels, 10 000 cars

Act ID	Description	Orig Dur
2745	Stress P/T - Pour #49	1
2750	Strip Slab Formwork - Pour #49	1
2755	FRP Slab - Pour #50	5
2760	Stress P/T - Pour #50	1
2765	Strip Slab Formwork - Pour #50	1
2770	FRP Slab - Pour #51	5
2775	Stress P/T - Pour #51	1
2780	Strip Slab Formwork - Pour #51	1
2785	FRP Slab - Pour #52	5
2790	Stress P/T - Pour #52	1
2795	Strip Slab Formwork - Pour #52	1
2800	FRP Slab - Pour #53	5
2805	Stress P/T - Pour #53	1
2810	Strip Slab Formwork - Pour #53	1
2815	FRP Slab - Pour #54	5
2820	Stress P/T - Pour #54	1
2825	Strip Slab Formwork - Pour #54	1
2830	FRP Slab - Pour #55	5
2835	Stress P/T - Pour #55	1
2840	Strip Slab Formwork - Pour #55	1
2845	FRP Slab - Pour #56	5
2850	Stress P/T - Pour #56	1
2855	Strip Slab Formwork - Pour #56	1
2860	FRP Slab - Pour #57	5
2865	Stress P/T - Pour #57	1
2870	Strip Slab Formwork - Pour #57	1
2875	FRP Slab - Pour #58	5
2880	Stress P/T - Pour #58	1
2885	Strip Slab Formwork - Pour #58	1
2890	FRP Slab - Pour #59	5
2895	Stress P/T - Pour #59	1
2900	Strip Slab Formwork - Pour #59	1
2905	FRP Slab - Pour #60	5
2910	Stress P/T - Pour #60	1
2915	Strip Slab Formwork - Pour #60	1
Level 5		
2920	FRP Slab - Pour #61	5
2925	Stress P/T - Pour #61	1
2930	Strip Slab Formwork - Pour #61	1
2935	FRP Slab - Pour #62	5
2940	Stress P/T - Pour #62	1
2945	Strip Slab Formwork - Pour #62	1
2950	FRP Slab - Pour #63	5
2955	Stress P/T - Pour #63	1
2960	Strip Slab Formwork - Pour #63	1
2965	FRP Slab - Pour #64	5
2970	Stress P/T - Pour #64	1
2980	Strip Slab Formwork - Pour #64	1
2985	FRP Slab - Pour #65	5
2990	Stress P/T - Pour #65	1
2995	Strip Slab Formwork - Pour #65	1
3000	FRP Slab - Pour #66	5
3005	Stress P/T - Pour #66	1
3010	Strip Slab Formwork - Pour #66	1
3015	FRP Slab - Pour #67	5
3020	Stress P/T - Pour #67	1
3025	Strip Slab Formwork - Pour #67	1
3030	FRP Slab - Pour #68	5

2000: J F M A M J J A S O N D — 2001: J F M A M J J A S O N

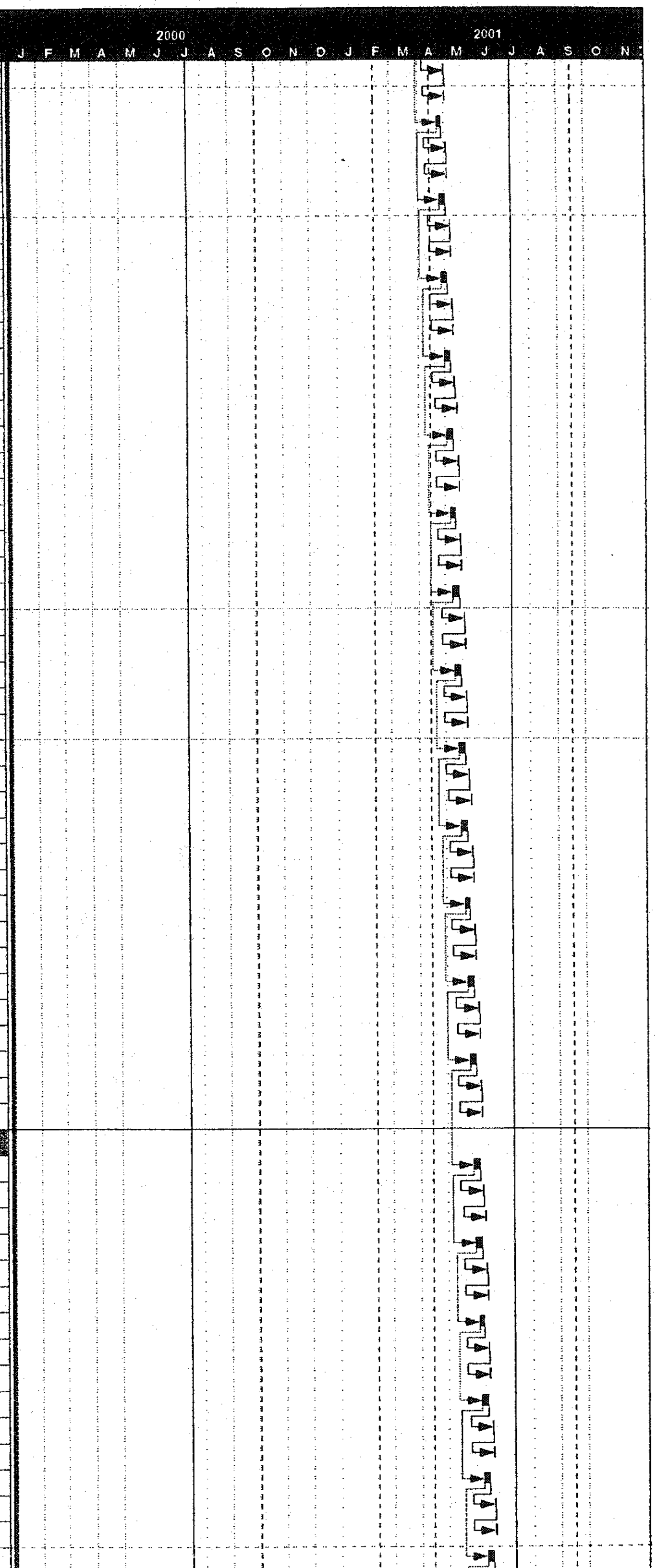
Scenario 4 - Hybrid System, 7 levels, 10 000 cars

Act ID	Description	Orig Dur
3035	Stress P/T - Pour #68	1
3040	Strip Slab Formwork - Pour #68	1
3045	FRP Slab - Pour #69	5
3050	Stress P/T - Pour #69	1
3055	Strip Slab Formwork - Pour #69	1
3060	FRP Slab - Pour #70	5
3065	Stress P/T - Pour #70	1
3070	Strip Slab Formwork - Pour #70	1
3075	FRP Slab - Pour #71	5
3080	Stress P/T - Pour #71	1
3085	Strip Slab Formwork - Pour #71	1
3090	FRP Slab - Pour #72	5
3095	Stress P/T - Pour #72	1
3100	Strip Slab Formwork - Pour #72	1
3105	FRP Slab - Pour #73	5
3110	Stress P/T - Pour #73	1
3115	Strip Slab Formwork - Pour #73	1
3120	FRP Slab - Pour #74	5
3125	Stress P/T - Pour #74	1
3130	Strip Slab Formwork - Pour #74	1
3135	FRP Slab - Pour #75	5
3140	Stress P/T - Pour #75	1
3145	Strip Slab Formwork - Pour #75	1
3150	FRP Slab - Pour #76	5
3155	Stress P/T - Pour #76	1
3160	Strip Slab Formwork - Pour #76	1
3165	FRP Slab - Pour #77	5
3170	Stress P/T - Pour #77	1
3175	Strip Slab Formwork - Pour #77	1
3180	FRP Slab - Pour #78	5
3185	Stress P/T - Pour #78	1
3190	Strip Slab Formwork - Pour #78	1
3195	FRP Slab - Pour #79	5
3200	Stress P/T - Pour #79	1
3205	Strip Slab Formwork - Pour #79	1
3210	FRP Slab - Pour #80	5
3215	Stress P/T - Pour #80	1
3220	Strip Slab Formwork - Pour #80	1
Level 6		
3225	FRP Slab - Pour #81	5
3230	Stress P/T - Pour #81	1
3235	Strip Slab Formwork - Pour #81	1
3240	FRP Slab - Pour #82	5
3245	Stress P/T - Pour #82	1
3250	Strip Slab Formwork - Pour #82	1
3255	FRP Slab - Pour #83	5
3260	Stress P/T - Pour #83	1
3265	Strip Slab Formwork - Pour #83	1
3270	FRP Slab - Pour #84	5
3275	Stress P/T - Pour #84	1
3280	Strip Slab Formwork - Pour #84	1
3285	FRP Slab - Pour #85	5
3290	Stress P/T - Pour #85	1
3295	Strip Slab Formwork - Pour #85	1
3300	FRP Slab - Pour #86	5
3305	Stress P/T - Pour #86	1
3310	Strip Slab Formwork - Pour #86	1
3315	FRP Slab - Pour #87	5



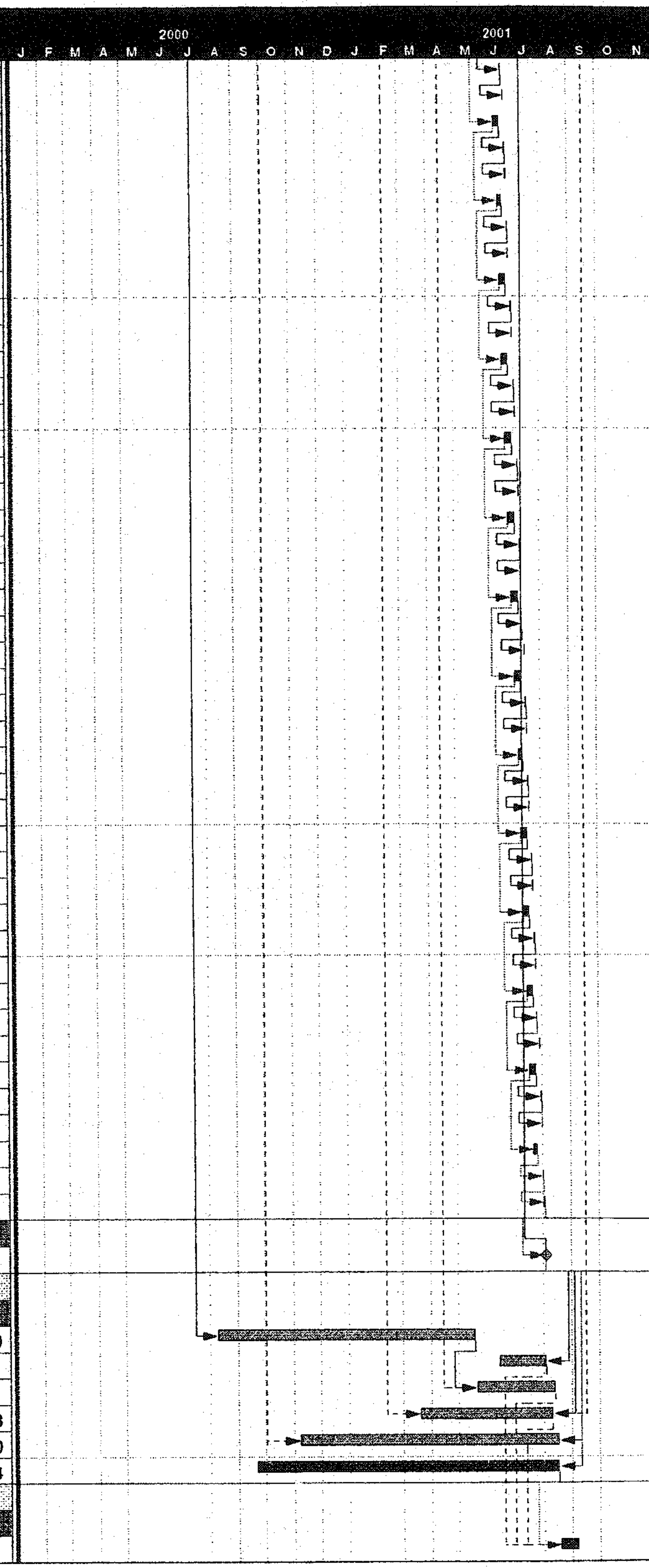
Scenario 4 - Hybrid System, 7 levels, 10 000 cars

Act ID	Description	Orig Dur
3320	Stress P/T - Pour #87	1
3325	Strip Slab Formwork - Pour #87	1
3330	FRP Slab - Pour #88	5
3335	Stress P/T - Pour #88	1
3340	Strip Slab Formwork - Pour #88	1
3345	FRP Slab - Pour #89	5
3350	Stress P/T - Pour #89	1
3355	Strip Slab Formwork - Pour #89	1
3360	FRP Slab - Pour #90	5
3365	Stress P/T - Pour #90	1
3370	Strip Slab Formwork - Pour #90	1
3375	FRP Slab - Pour #91	5
3380	Stress P/T - Pour #91	1
3385	Strip Slab Formwork - Pour #91	1
3390	FRP Slab - Pour #92	5
3395	Stress P/T - Pour #92	1
3400	Strip Slab Formwork - Pour #92	1
3405	FRP Slab - Pour #93	5
3410	Stress P/T - Pour #93	1
3415	Strip Slab Formwork - Pour #93	1
3420	FRP Slab - Pour #94	5
3425	Stress P/T - Pour #94	1
3430	Strip Slab Formwork - Pour #94	1
3435	FRP Slab - Pour #95	5
3440	Stress P/T - Pour #95	1
3445	Strip Slab Formwork - Pour #95	1
3450	FRP Slab - Pour #96	5
3455	Stress P/T - Pour #96	1
3460	Strip Slab Formwork - Pour #96	1
3465	FRP Slab - Pour #97	5
3470	Stress P/T - Pour #97	1
3475	Strip Slab Formwork - Pour #97	1
3480	FRP Slab - Pour #98	5
3485	Stress P/T - Pour #98	1
3490	Strip Slab Formwork - Pour #98	1
3495	FRP Slab - Pour #99	5
3500	Stress P/T - Pour #99	1
3505	Strip Slab Formwork - Pour #99	1
3510	FRP Slab - Pour #100	5
3515	Stress P/T - Pour #100	1
3520	Strip Slab Formwork - Pour #100	1
Level 7		
3525	FRP Slab - Pour #101	5
3530	Stress P/T - Pour #101	1
3535	Strip Slab Formwork - Pour #101	1
3540	FRP Slab - Pour #102	5
3545	Stress P/T - Pour #102	1
3550	Strip Slab Formwork - Pour #102	1
3555	FRP Slab - Pour #103	5
3560	Stress P/T - Pour #103	1
3565	Strip Slab Formwork - Pour #103	1
3570	FRP Slab - Pour #104	5
3575	Stress P/T - Pour #104	1
3580	Strip Slab Formwork - Pour #104	1
3585	FRP Slab - Pour #105	5
3590	Stress P/T - Pour #105	1
3595	Strip Slab Formwork - Pour #105	1
3600	FRP Slab - Pour #106	5



Scenario 4 - Hybrid System, 7 levels, 10 000 cars

Act ID	Description	Orig Dur
3605	Stress P/T - Pour #106	1
3610	Strip Slab Formwork - Pour #106	1
3615	FRP Slab - Pour #107	5
3620	Stress P/T - Pour #107	1
3625	Strip Slab Formwork - Pour #107	1
3630	FRP Slab - Pour #108	5
3635	Stress P/T - Pour #108	1
3640	Strip Slab Formwork - Pour #108	1
3645	FRP Slab - Pour #109	5
3650	Stress P/T - Pour #109	1
3655	Strip Slab Formwork - Pour #109	1
3660	FRP Slab - Pour #110	5
3665	Stress P/T - Pour #110	1
3670	Strip Slab Formwork - Pour #110	1
3675	FRP Slab - Pour #111	5
3680	Stress P/T - Pour #111	1
3685	Strip Slab Formwork - Pour #111	1
3690	FRP Slab - Pour #112	5
3695	Stress P/T - Pour #112	1
3700	Strip Slab Formwork - Pour #112	1
3705	FRP Slab - Pour #113	5
3710	Stress P/T - Pour #113	1
3715	Strip Slab Formwork - Pour #113	1
3720	FRP Slab - Pour #114	5
3725	Stress P/T - Pour #114	1
3730	Strip Slab Formwork - Pour #114	1
3735	FRP Slab - Pour #115	5
3740	Stress P/T - Pour #115	1
3745	Strip Slab Formwork - Pour #115	1
3750	FRP Slab - Pour #116	5
3755	Stress P/T - Pour #116	1
3760	Strip Slab Formwork - Pour #116	1
3765	FRP Slab - Pour #117	5
3770	Stress P/T - Pour #117	1
3775	Strip Slab Formwork - Pour #117	1
3780	FRP Slab - Pour #118	5
3785	Stress P/T - Pour #118	1
3790	Strip Slab Formwork - Pour #118	1
3795	FRP Slab - Pour #119	5
3800	Stress P/T - Pour #119	1
3805	Strip Slab Formwork - Pour #119	1
3810	FRP Slab - Pour #120	5
3815	Stress P/T - Pour #120	1
3820	Strip Slab Formwork - Pour #120	1
All Levels		
3999	Superstructure Complete	0
General Activities		
All Levels		
4010	Elevator Shafts/Shear Walls	200
4020	Install Stairs	35
4030	Install Elevators	60
4040	Install Exterior Facade	103
4050	M & E Rough-In	200
4060	Fire Protection	234
Close Out		
All Levels		
5010	Building and System Inspections	15



Scenario 4 - Hybrid System, 7 levels, 10 000 cars

Scenario 5 – Ratings as Crisp Numbers

Description: 1286 spaces
Cast in Place Structural System
450 000 GSF
90 000 sf Footprint
5 Parking Levels
Above Grade
Shallow Foundations (no piles)
1 Elevator Bank
36 Pours, each 10 000 sf

Ratings of Factors:

Factor	-5	-4	-3	-2	-1	0	1	2	3	4	5
Ground Conditions:									↓		
Contract Interpretation Disputes:		↓									
Design Errors/Completness:			↓								
Quality of Initial Schedule Plan:				↓							
Quality of Workmanship:								↓			
	Very Unfavourable								**Very Favourable**		

<u>Scenario 5 – Ratings as Crisp Numbers</u>

Activity Durations:

Activity	Baseline Duration (days)	Adjusted Duration (days)
Award Subcontracts	35	
Permits	20	
Submittals	60	
Precast Exterior Fab	40	
Elevator Fab	30	
Mobilize	10	
Demo	5	
Curb&Gutter/Sidewalk	15	
Landscaping	15	
Shallow Foundations	57	
M&E UG	25	
Prep SOG	13	
Pour SOG	26	
Ground Level Columns	21	
Column Caps	36	
*FRP Slab	180	
Stress P/T	36	
Strip Slab Formwork	36	
*CIP Columns	180	
Elevator Shafts	72	
Install Stairs	25	
Install Elevators	20	
Install Exterior Façade	29	
M&E R-in	45	
Fire Protection	30	
Inspections	15	

* *This activity overlaps locations due to multiple tasks within the defined activity. The duration shown represents the sum of the total days working each location NOT the time from when the activity started at the first location to the time when it finished at the last location.*

Scenario 5 – Ratings as Linguistic Descriptors

Description:
1286 spaces
Cast in Place Structural System
450 000 GSF
90 000 sf Footprint
5 Parking Levels
Above Grade
Shallow Foundations (no piles)
1 Elevator Bank
36 Pours, each 10 000 sf

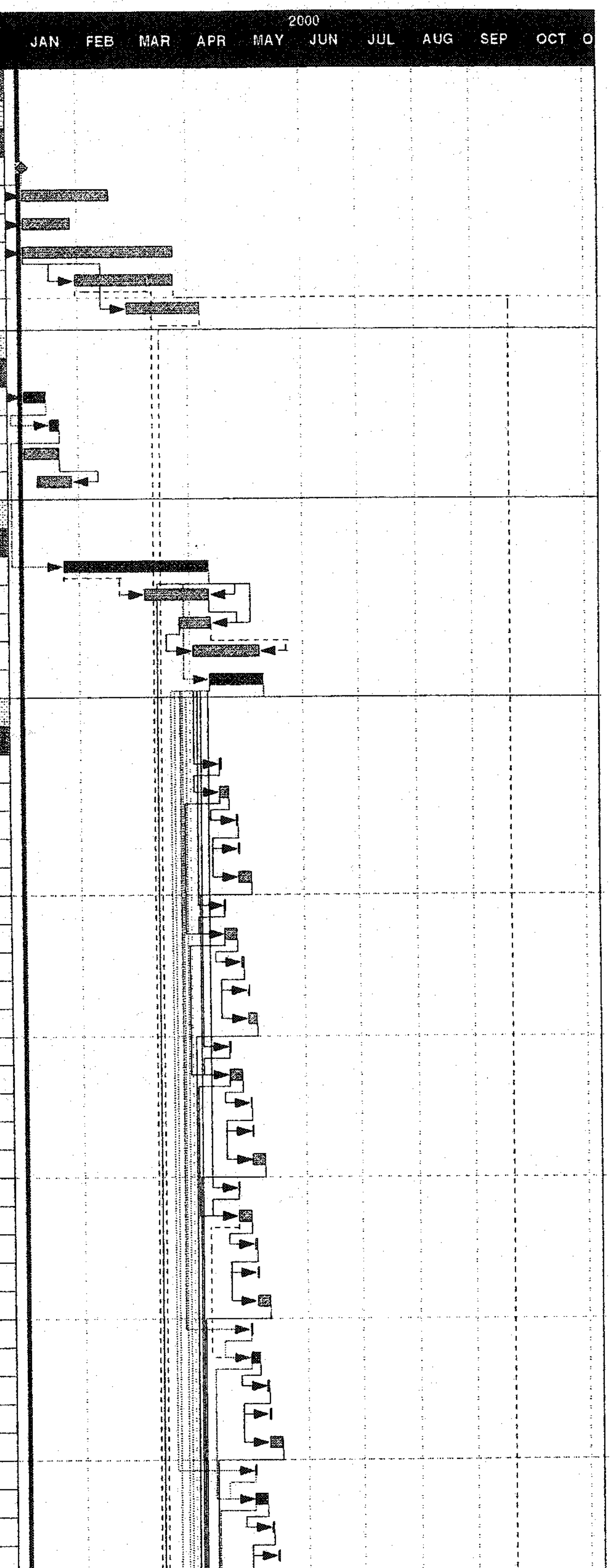
Ratings of Factors:
Ground Conditions: *Favourable*
Disputes in Contract Interpretation: *Unfavourable*
Design Errors/Completeness of Design: *Unfavourable*
Quality of Initial Schedule Plan: *Unfavourable*
Quality of Workmanship: *Favourable*

Activity Durations:

Activity	Baseline Duration (days)	Adjusted Duration (days)
Award Subcontracts	35	
Permits	20	
Submittals	60	
Precast Exterior Fab	40	
Elevator Fab	30	
Mobilize	10	
Demo	5	
Curb&Gutter/Sidewalk	15	
Landscaping	15	
Shallow Foundations	57	
M&E UG	25	
Prep SOG	13	
Pour SOG	26	
Ground Level Columns	21	
Column Caps	36	
*FRP Slab	180	
Stress P/T	36	
Strip Slab Formwork	36	
*CIP Columns	180	
Elevator Shafts	72	
Install Stairs	25	
Install Elevators	20	
Install Exterior Façade	29	
M&E R-in	45	
Fire Protection	30	
Inspections	15	

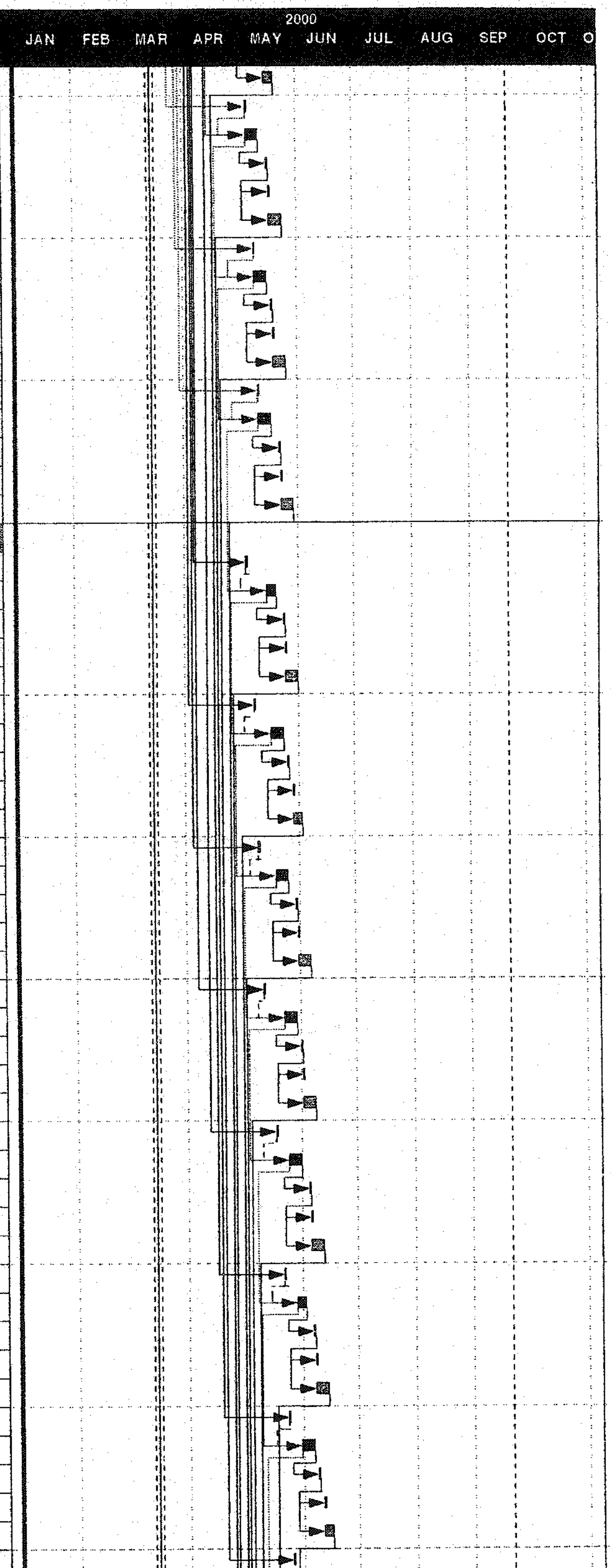
* *This activity overlaps locations due to multiple tasks within the defined activity. The duration shown represents the sum of the total days working each location NOT the time from when the activity started at the first location to the time when it finished at the last location*

Act ID	Description	Orig Dur
All Phases		
Preconstruction / Procurement / Fabrication		
All Levels		
0010	Contract Award	0
0020	Award Subcontracts	35
0030	Foundation and Building Permits	20
0040	Submittals	60
0060	Precast Exterior Fabrication	40
0070	Elevator Fabrication	30
Sitework		
All Levels		
0510	Mobilize/Survey Grid/Temp Services	10
0520	Demo/Clear Existing Site and Services	5
0530	Curb&Gutter/Sidewalk/Paving	15
0540	Landscaping	15
Ground Level		
Ground Level		
1030	Shallow Foundations	57
1050	M&E Underground Services	25
1060	Subdrainage/Fill to Grade/Prep SOG	13
1070	Reinforce/Pour Slab on Grade	26
1080	Ground Level CIP Columns	21
Typical Level		
Level 2		
2010	Column Caps - Pour #1	1
2015	FRP Slab - Pour #1	5
2020	Stress P/T - Pour #1	1
2025	Strip Slab Formwork - Pour #1	1
2030	CIP Columns - Pour #1	5
2035	Column Caps - Pour #2	1
2040	FRP Slab - Pour #2	5
2045	Stress P/T - Pour #2	1
2050	Strip Slab Formwork - Pour #2	1
2055	CIP Columns - Pour #2	5
2060	Column Caps - Pour #3	1
2065	FRP Slab - Pour #3	5
2070	Stress P/T - Pour #3	1
2075	Strip Slab Formwork - Pour #3	1
2080	CIP Columns - Pour #3	5
2085	Column Caps - Pour #4	1
2090	FRP Slab - Pour #4	5
2095	Stress P/T - Pour #4	1
2100	Strip Slab Formwork - Pour #4	1
2105	CIP Columns - Pour #4	5
2110	Column Caps - Pour #5	1
2115	FRP Slab - Pour #5	5
2120	Stress P/T - Pour #5	1
2125	Strip Slab Formwork - Pour #5	1
2130	CIP Columns - Pour #5	5
2135	Column Caps - Pour #6	1
2140	FRP Slab - Pour #6	5
2145	Stress P/T - Pour #6	1
2150	Strip Slab Formwork - Pour #6	1



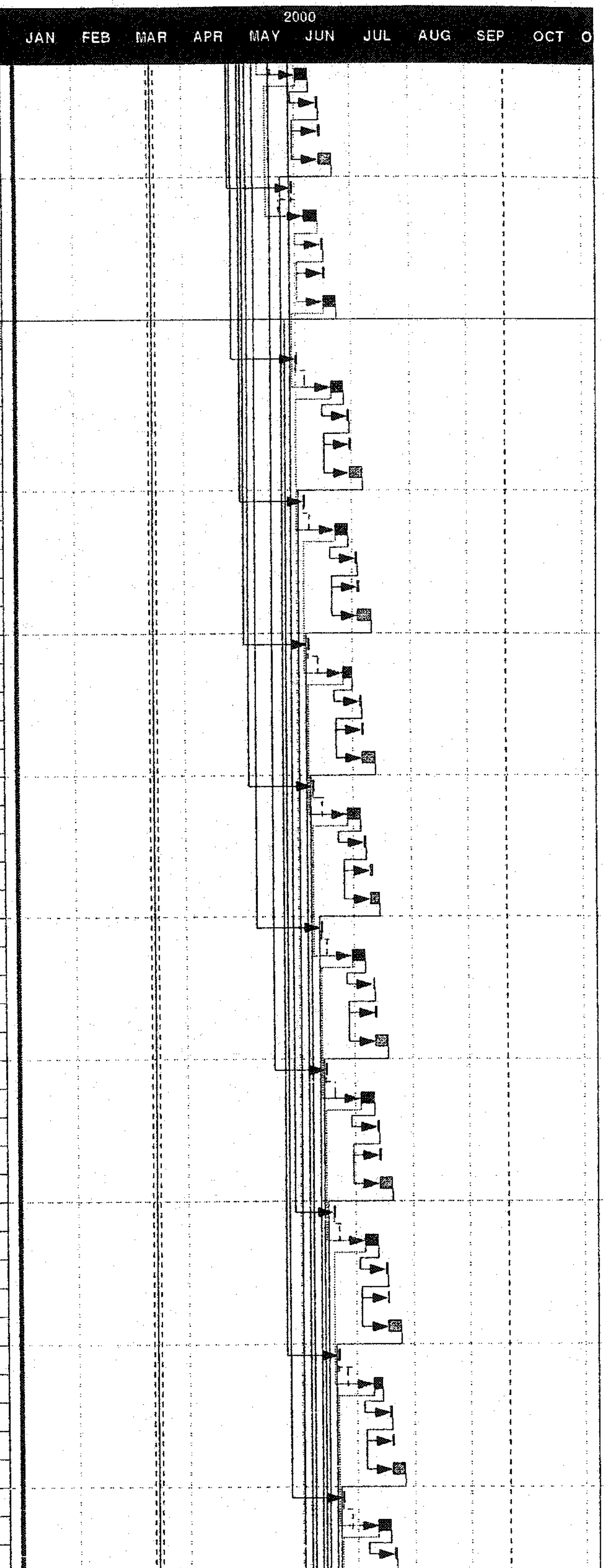
Scenario 5 - Cast in Place, 5 Levels, 1286 spaces

Act ID	Description	Orig Dur
2155	CIP Columns - Pour #6	5
2160	Column Caps - Pour #7	1
2165	FRP Slab - Pour #7	5
2170	Stress P/T - Pour #7	1
2175	Strip Slab Formwork - Pour #7	1
2180	CIP Columns - Pour #7	5
2185	Column Caps - Pour #8	1
2190	FRP Slab - Pour #8	5
2195	Stress P/T - Pour #8	1
2200	Strip Slab Formwork - Pour #8	1
2205	CIP Columns - Pour #8	5
2210	Column Caps - Pour #9	1
2215	FRP Slab - Pour #9	5
2220	Stress P/T - Pour #9	1
2225	Strip Slab Formwork - Pour #9	1
2230	CIP Columns - Pour #9	5
Level 3		
2235	Column Caps - Pour #10	1
2240	FRP Slab - Pour #10	5
2245	Stress P/T - Pour #10	1
2250	Strip Slab Formwork - Pour #10	1
2255	CIP Columns - Pour #10	5
2260	Column Caps - Pour #11	1
2265	FRP Slab - Pour #11	5
2270	Stress P/T - Pour #11	1
2275	Strip Slab Formwork - Pour #11	1
2280	CIP Columns - Pour #11	5
2285	Column Caps - Pour #12	1
2290	FRP Slab - Pour #12	5
2295	Stress P/T - Pour #12	1
2300	Strip Slab Formwork - Pour #12	1
2305	CIP Columns - Pour #12	5
2310	Column Caps - Pour #13	1
2315	FRP Slab - Pour #13	5
2320	Stress P/T - Pour #13	1
2325	Strip Slab Formwork - Pour #13	1
2330	CIP Columns - Pour #13	5
2335	Column Caps - Pour #14	1
2340	FRP Slab - Pour #14	5
2345	Stress P/T - Pour #14	1
2350	Strip Slab Formwork - Pour #14	1
2355	CIP Columns - Pour #14	5
2360	Column Caps - Pour #15	1
2365	FRP Slab - Pour #15	5
2370	Stress P/T - Pour #15	1
2375	Strip Slab Formwork - Pour #15	1
2380	CIP Columns - Pour #15	5
2385	Column Caps - Pour #16	1
2390	FRP Slab - Pour #16	5
2395	Stress P/T - Pour #16	1
2400	Strip Slab Formwork - Pour #16	1
2405	CIP Columns - Pour #16	5
2410	Column Caps - Pour #17	1



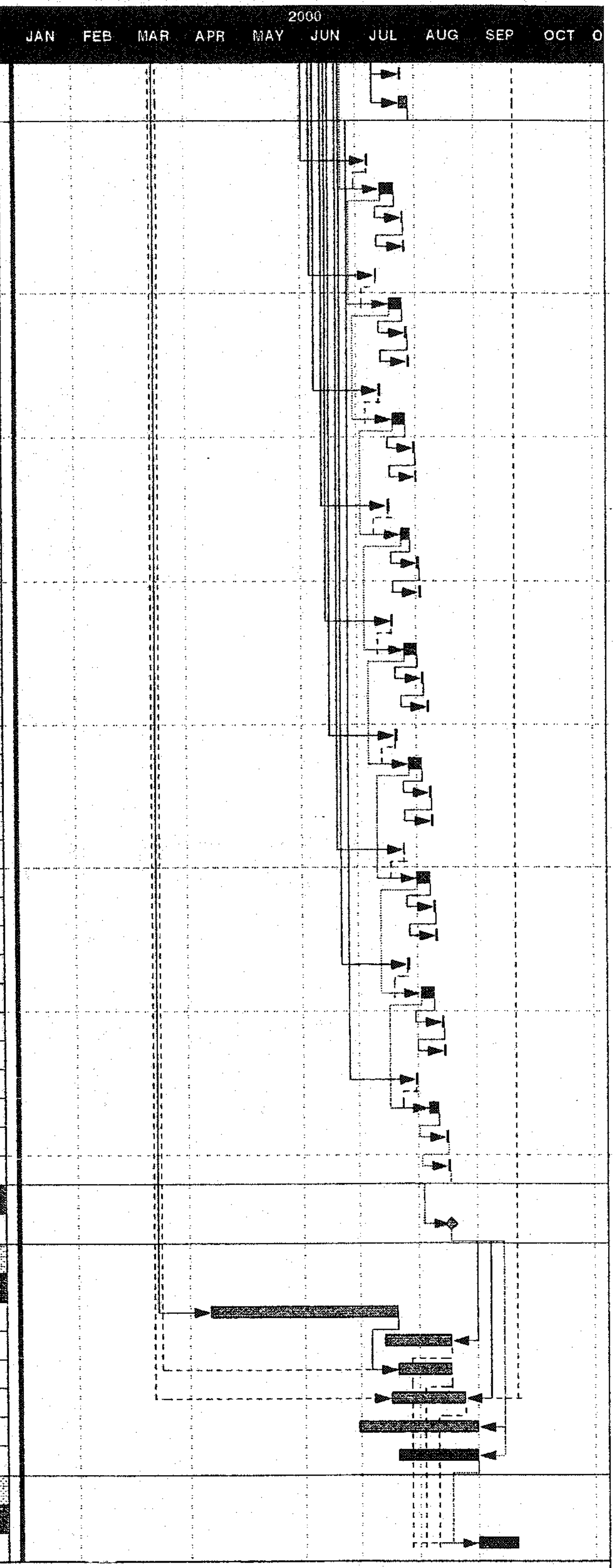
Scenario 5 - Cast in Place, 5 Levels, 1286 spaces

Act ID	Description	Orig Dur
2415	FRP Slab - Pour #17	5
2420	Stress P/T - Pour #17	1
2425	Strip Slab Formwork - Pour #17	1
2430	CIP Columns - Pour #18	5
2435	Column Caps - Pour #18	1
2440	FRP Slab - Pour #18	5
2445	Stress P/T - Pour #18	1
2450	Strip Slab Formwork - Pour #18	1
2455	CIP Columns - Pour #18	5
Level 4		
2460	Column Caps - Pour #19	1
2465	FRP Slab - Pour #19	5
2470	Stress P/T - Pour #19	1
2475	Strip Slab Formwork - Pour #19	1
2480	CIP Columns - Pour #19	5
2485	Column Caps - Pour #20	1
2490	FRP Slab - Pour #20	5
2495	Stress P/T - Pour #20	1
2500	Strip Slab Formwork - Pour #20	1
2505	CIP Columns - Pour #20	5
2510	Column Caps - Pour #21	1
2515	FRP Slab - Pour #21	5
2520	Stress P/T - Pour #21	1
2525	Strip Slab Formwork - Pour #21	1
2530	CIP Columns - Pour #21	5
2535	Column Caps - Pour #22	1
2540	FRP Slab - Pour #22	5
2545	Stress P/T - Pour #22	1
2550	Strip Slab Formwork - Pour #22	1
2555	CIP Columns - Pour #22	5
2560	Column Caps - Pour #23	1
2565	FRP Slab - Pour #23	5
2570	Stress P/T - Pour #23	1
2575	Strip Slab Formwork - Pour #23	1
2580	CIP Columns - Pour #23	5
2585	Column Caps - Pour #24	1
2590	FRP Slab - Pour #24	5
2595	Stress P/T - Pour #24	1
2600	Strip Slab Formwork - Pour #24	1
2605	CIP Columns - Pour #24	5
2610	Column Caps - Pour #25	1
2615	FRP Slab - Pour #25	5
2620	Stress P/T - Pour #25	1
2625	Strip Slab Formwork - Pour #25	1
2630	CIP Columns - Pour #25	5
2635	Column Caps - Pour #26	1
2640	FRP Slab - Pour #26	5
2645	Stress P/T - Pour #26	1
2650	Strip Slab Formwork - Pour #26	1
2655	CIP Columns - Pour #26	5
2660	Column Caps - Pour #27	1
2665	FRP Slab - Pour #27	5
2670	Stress P/T - Pour #27	1



Scenario 5 - Cast in Place, 5 Levels, 1286 spaces

Act ID	Description	Orig Dur
2675	Strip Slab Formwork - Pour #27	1
2680	CIP Columns - Pour #27	5
Level 5		
2685	Column Caps - Pour #28	1
2690	FRP Slab - Pour #28	5
2695	Stress P/T - Pour #28	1
2700	Strip Slab Formwork - Pour #28	1
2710	Column Caps - Pour #29	1
2715	FRP Slab - Pour #29	5
2720	Stress P/T - Pour #29	1
2725	Strip Slab Formwork - Pour #29	1
2735	Column Caps - Pour #30	1
2740	FRP Slab - Pour #30	5
2745	Stress P/T - Pour #30	1
2750	Strip Slab Formwork - Pour #30	1
2760	Column Caps - Pour #31	1
2765	FRP Slab - Pour #31	5
2770	Stress P/T - Pour #31	1
2775	Strip Slab Formwork - Pour #31	1
2785	Column Caps - Pour #32	1
2790	FRP Slab - Pour #32	5
2795	Stress P/T - Pour #32	1
2800	Strip Slab Formwork - Pour #32	1
2810	Column Caps - Pour #33	1
2815	FRP Slab - Pour #33	5
2820	Stress P/T - Pour #33	1
2825	Strip Slab Formwork - Pour #33	1
2835	Column Caps - Pour #34	1
2840	FRP Slab - Pour #34	5
2845	Stress P/T - Pour #34	1
2850	Strip Slab Formwork - Pour #34	1
2860	Column Caps - Pour #35	1
2865	FRP Slab - Pour #35	5
2870	Stress P/T - Pour #35	1
2875	Strip Slab Formwork - Pour #35	1
2885	Column Caps - Pour #36	1
2890	FRP Slab - Pour #36	5
2895	Stress P/T - Pour #36	1
2900	Strip Slab Formwork - Pour #36	1
All Levels		
2999	Superstructure Complete	0
General Activities		
All Levels		
3010	Elevator Shafts, Shear Walls	72
3020	Install Stairs	25
3030	Install Elevators	20
3040	Install Exterior Facade	29
3050	M & E Rough-In	45
3060	Fire Protection	30
Close Out		
All Levels		
4010	Building and System Inspections	15



Scenario 5 - Cast in Place, 5 Levels, 1286 spaces

APPENDIX Q – RESULTS OF TESTING SCENARIOS

Scenario 1 - Linguistic Descriptors

Ground Conditions: Unfavourable
Interference by Owner: Unfavourable
Quality of Field Management: Favourable

Ground Conditions

		Unfavourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	1.00	3.00	0.55	0.00	0.00	0.00
Permits	20	1.00	3.00	0.55	0.00	0.00	0.00
Submittals	60	1.00	3.00	0.55	0.00	0.00	0.00
Precast Fab	20	1.00	3.00	0.55	0.00	0.00	0.00
Elevator Fab	60	1.00	3.00	0.55	0.00	0.00	0.00
Mobilize	10	1.00	3.00	0.55	0.00	0.00	0.00
Demo	5	1.00	3.00	0.55	0.00	0.50	0.97
Curb&Gutter/Sidewalk	15	1.00	3.00	0.55	0.00	0.50	0.97
Landscaping	15	1.00	3.00	0.55	0.00	0.50	0.97
Shallow Foundations	32	1.00	3.00	0.55	0.00	0.75	1.45
M&E UG	25	1.00	3.00	0.55	0.00	1.00	1.94
Prep SOG	7	1.00	3.00	0.55	0.00	0.50	0.97
Pour SOG	15	1.00	3.00	0.55	0.00	0.00	0.00
Erect Precast Columns	10	1.00	3.00	0.55	0.00	0.00	0.00
Install Precast Beams	14	1.00	3.00	0.55	0.00	0.00	0.00
*FRP Slab	100	1.00	3.00	0.55	0.00	0.00	0.00
Stress P/T	20	1.00	3.00	0.55	0.00	0.00	0.00
Strip Slab Formwork	20	1.00	3.00	0.55	0.00	0.00	0.00
Elevator Shafts	40	1.00	3.00	0.55	0.00	0.00	0.00
Install Stairs	25	1.00	3.00	0.55	0.00	0.00	0.00
Install Elevators	40	1.00	3.00	0.55	0.00	0.00	0.00
Install Exterior Façade	22	1.00	3.00	0.55	0.00	0.00	0.00
M&E R-in	25	1.00	3.00	0.55	0.00	0.00	0.00
Fire Protection	17	1.00	3.00	0.55	0.00	0.00	0.00
Inspections	15	1.00	3.00	0.55	0.00	0.00	0.00

Interference by Owner

		Unfavourable		Normal			
Activity	Initial Duration	MF Value	Full Var.	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	1.00	0.95	0.40	0.00	1.00	0.68
Permits	20	1.00	0.95	0.40	0.00	0.00	0.00
Submittals	60	1.00	0.95	0.40	0.00	1.00	0.68
Precast Fab	20	1.00	0.95	0.40	0.00	1.00	0.68
Elevator Fab	60	1.00	0.95	0.40	0.00	1.00	0.68
Mobilize	10	1.00	0.95	0.40	0.00	1.00	0.68
Demo	5	1.00	0.95	0.40	0.00	1.00	0.68
Curb&Gutter/Sidewalk	15	1.00	0.95	0.40	0.00	1.00	0.68
Landscaping	15	1.00	0.95	0.40	0.00	1.00	0.68
Shallow Foundations	32	1.00	0.95	0.40	0.00	1.00	0.68
M&E UG	25	1.00	0.95	0.40	0.00	1.00	0.68
Prep SOG	7	1.00	0.95	0.40	0.00	1.00	0.68
Pour SOG	15	1.00	0.95	0.40	0.00	1.00	0.68
Erect Precast Columns	10	1.00	0.95	0.40	0.00	1.00	0.68
Install Precast Beams	14	1.00	0.95	0.40	0.00	1.00	0.68
*FRP Slab	100	1.00	0.95	0.40	0.00	1.00	0.68
Stress P/T	20	1.00	0.95	0.40	0.00	1.00	0.68
Strip Slab Formwork	20	1.00	0.95	0.40	0.00	1.00	0.68
Elevator Shafts	40	1.00	0.95	0.40	0.00	1.00	0.68
Install Stairs	25	1.00	0.95	0.40	0.00	1.00	0.68
Install Elevators	40	1.00	0.95	0.40	0.00	1.00	0.68
Install Exterior Façade	22	1.00	0.95	0.40	0.00	1.00	0.68
M&E R-in	25	1.00	0.95	0.40	0.00	1.00	0.68
Fire Protection	17	1.00	0.95	0.40	0.00	1.00	0.68
Inspections	15	1.00	0.95	0.40	0.00	1.00	0.68

Quality of Field Management

		Favourable		Normal			
Activity	Initial Duration	MF Value	Full Var.	MF Value	Output	Sensitivity	Scaled Var.

Award Subcontracts	35	1.00	-0.25	0.57	0.00	0.00	0.00
Permits	20	1.00	-0.25	0.57	0.00	0.00	0.00
Submittals	60	1.00	-0.25	0.57	0.00	0.00	0.00
Precast Fab	20	1.00	-0.25	0.57	0.00	0.00	0.00
Elevator Fab	60	1.00	-0.25	0.57	0.00	0.00	0.00
Mobilize	10	1.00	-0.25	0.57	0.00	1.00	-0.16
Demo	5	1.00	-0.25	0.57	0.00	1.00	-0.16
Curb&Gutter/Sidewalk	15	1.00	-0.25	0.57	0.00	1.00	-0.16
Landscaping	15	1.00	-0.25	0.57	0.00	1.00	-0.16
Shallow Foundations	32	1.00	-0.25	0.57	0.00	1.00	-0.16
M&E UG	25	1.00	-0.25	0.57	0.00	1.00	-0.16
Prep SOG	7	1.00	-0.25	0.57	0.00	1.00	-0.16
Pour SOG	15	1.00	-0.25	0.57	0.00	1.00	-0.16
Erect Precast Columns	10	1.00	-0.25	0.57	0.00	1.00	-0.16
Install Precast Beams	14	1.00	-0.25	0.57	0.00	1.00	-0.16
*FRP Slab	100	1.00	-0.25	0.57	0.00	1.00	-0.16
Stress P/T	20	1.00	-0.25	0.57	0.00	1.00	-0.16
Strip Slab Formwork	20	1.00	-0.25	0.57	0.00	1.00	-0.16
Elevator Shafts	40	1.00	-0.25	0.57	0.00	1.00	-0.16
Install Stairs	25	1.00	-0.25	0.57	0.00	1.00	-0.16
Install Elevators	40	1.00	-0.25	0.57	0.00	1.00	-0.16
Install Exterior Façade	22	1.00	-0.25	0.57	0.00	1.00	-0.16
M&E R-in	25	1.00	-0.25	0.57	0.00	1.00	-0.16
Fire Protection	17	1.00	-0.25	0.57	0.00	1.00	-0.16
Inspections	15	1.00	-0.25	0.57	0.00	0.00	0.00

Activity	Initial Duration	FES	Jim	Error Δ_J-Δ_{FES}/Δ_J
Award Subcontracts	35	59	30	5.7500
Permits	20	20	20	Infinity
Submittals	60	101	80	-1.0357
Precast Fab	20	34	20	Infinity
Elevator Fab	60	101	60	Infinity
Mobilize	10	15	10	Infinity
Demo	5	12	5	Infinity
Curb&Gutter/Sidewalk	15	37	25	-1.2306
Landscaping	15	37	15	Infinity
Shallow Foundations	32	95	42	-5.3070
M&E UG	25	86	25	Infinity
Prep SOG	7	17	5	6.2048
Pour SOG	15	23	13	4.8950
Erect Precast Columns	10	15	15	-0.0387
Install Precast Beams	14	21	21	-0.0387
*FRP Slab	100	152	93	8.4191
Stress P/T	20	30	20	Infinity
Strip Slab Formwork	20	30	20	Infinity
Elevator Shafts	40	61	40	Infinity
Install Stairs	25	38	30	-1.5967
Install Elevators	40	61	40	Infinity
Install Exterior Façade	22	33	30	-0.4282
M&E R-in	25	38	25	Infinity
Fire Protection	17	26	17	Infinity
Inspections	15	25	15	Infinity

Scenario 1 - Crisp Ratings
Interference by Owner: -4
Quality of Initial Schedule Plan: 4
Quality of Field Management: 3

Interference by Owner

Activity	Initial Duration	Unfavourable		Normal		Sensitivity	Scaled Var.
		MF Value	Output	MF Value	Output		
Award Subcontracts	35	1.00	0.95	0.00	0.00	1.00	0.95
Permits	20	1.00	0.95	0.00	0.00	0.00	0
Submittals	60	1.00	0.95	0.00	0.00	1.00	0.95
Precast Fab	20	1.00	0.95	0.00	0.00	1.00	0.95
Elevator Fab	60	1.00	0.95	0.00	0.00	1.00	0.95
Mobilize	10	1.00	0.95	0.00	0.00	1.00	0.95
Demo	5	1.00	0.95	0.00	0.00	1.00	0.95
Curb&Gutter/Sidewalk	15	1.00	0.95	0.00	0.00	1.00	0.95
Landscaping	15	1.00	0.95	0.00	0.00	1.00	0.95
Shallow Foundations	32	1.00	0.95	0.00	0.00	1.00	0.95
M&E UG	25	1.00	0.95	0.00	0.00	1.00	0.95
Prep SOG	7	1.00	0.95	0.00	0.00	1.00	0.95
Pour SOG	15	1.00	0.95	0.00	0.00	1.00	0.95
Erect Precast Columns	10	1.00	0.95	0.00	0.00	1.00	0.95
Install Precast Beams	14	1.00	0.95	0.00	0.00	1.00	0.95
*FRP Slab	100	1.00	0.95	0.00	0.00	1.00	0.95
Stress P/T	20	1.00	0.95	0.00	0.00	1.00	0.95
Strip Slab Formwork	20	1.00	0.95	0.00	0.00	1.00	0.95
Elevator Shafts	40	1.00	0.95	0.00	0.00	1.00	0.95
Install Stairs	25	1.00	0.95	0.00	0.00	1.00	0.95
Install Elevators	40	1.00	0.95	0.00	0.00	1.00	0.95
Install Exterior Façade	22	1.00	0.95	0.00	0.00	1.00	0.95
M&E R-in	25	1.00	0.95	0.00	0.00	1.00	0.95
Fire Protection	17	1.00	0.95	0.00	0.00	1.00	0.95
Inspections	15	1.00	0.95	0.00	0.00	1.00	0.95

Quality of Initial Schedule Plan

Activity	Initial Duration	Favourable		Normal		Random	Sensitivity	Scaled Var.
		MF Value	Full Var.	MF Value	Output			
Award Subcontracts	35	1.00	0.00	0.00	0.05	0.852854496	-1.00	0
Permits	20	1.00	0.00	0.00	0.05	0.095332985	1.00	0
Submittals	60	1.00	0.00	0.00	0.05	0.476571181	1.00	0
Precast Fab	20	1.00	0.00	0.00	0.05	0.616896408	-1.00	0
Elevator Fab	60	1.00	0.00	0.00	0.05	0.750952429	-1.00	0
Mobilize	10	1.00	0.00	0.00	0.05	0.315129893	1.00	0
Demo	5	1.00	0.00	0.00	0.05	0.102005669	1.00	0
Curb&Gutter/Sidewalk	15	1.00	0.00	0.00	0.05	0.009004579	1.00	0
Landscaping	15	1.00	0.00	0.00	0.05	0.6452984	-1.00	0
Shallow Foundations	32	1.00	0.00	0.00	0.05	0.686916525	-1.00	0
M&E UG	25	1.00	0.00	0.00	0.05	0.418519928	1.00	0
Prep SOG	7	1.00	0.00	0.00	0.05	0.495542132	1.00	0
Pour SOG	15	1.00	0.00	0.00	0.05	0.93060841	-1.00	0
Erect Precast Columns	10	1.00	0.00	0.00	0.05	0.716518788	-1.00	0
Install Precast Beams	14	1.00	0.00	0.00	0.05	0.14234819	1.00	0
*FRP Slab	100	1.00	0.00	0.00	0.05	0.212903168	1.00	0
Stress P/T	20	1.00	0.00	0.00	0.05	0.133340219	1.00	0
Strip Slab Formwork	20	1.00	0.00	0.00	0.05	0.745620273	-1.00	0
Elevator Shafts	40	1.00	0.00	0.00	0.05	0.948025726	-1.00	0
Install Stairs	25	1.00	0.00	0.00	0.05	0.77198105	-1.00	0
Install Elevators	40	1.00	0.00	0.00	0.05	0.837217125	-1.00	0
Install Exterior Façade	22	1.00	0.00	0.00	0.05	0.520712563	-1.00	0
M&E R-in	25	1.00	0.00	0.00	0.05	0.129409871	1.00	0
Fire Protection	17	1.00	0.00	0.00	0.05	0.145665967	1.00	0
Inspections	15	1.00	0.00	0.00	0.05	0.796793102	-1.00	0

Quality of Field Management

Activity	Initial Duration	Favourable		Normal		Sensitivity	Scaled Var.
		MF Value	Full Var.	MF Value	Output		
Award Subcontracts	35	0.50	-0.25	0.67	0.00	0.00	0.00
Permits	20	0.50	-0.25	0.67	0.00	0.00	0.00
Submittals	60	0.50	-0.25	0.67	0.00	0.00	0.00
Precast Fab	20	0.50	-0.25	0.67	0.00	0.00	0.00
Elevator Fab	60	0.50	-0.25	0.67	0.00	0.00	0.00
Mobilize	10	0.50	-0.25	0.67	0.00	1.00	-0.11
Demo	5	0.50	-0.25	0.67	0.00	1.00	-0.11
Curb&Gutter/Sidewalk	15	0.50	-0.25	0.67	0.00	1.00	-0.11

Landscaping	15	0.50	-0.25	0.67	0.00	1.00	-0.11
Shallow Foundations	32	0.50	-0.25	0.67	0.00	1.00	-0.11
M&E UG	25	0.50	-0.25	0.67	0.00	1.00	-0.11
Prep SOG	7	0.50	-0.25	0.67	0.00	1.00	-0.11
Pour SOG	15	0.50	-0.25	0.67	0.00	1.00	-0.11
Erect Precast Columns	10	0.50	-0.25	0.67	0.00	1.00	-0.11
Install Precast Beams	14	0.50	-0.25	0.67	0.00	1.00	-0.11
*FRP Slab	100	0.50	-0.25	0.67	0.00	1.00	-0.11
Stress P/T	20	0.50	-0.25	0.67	0.00	1.00	-0.11
Strip Slab Formwork	20	0.50	-0.25	0.67	0.00	1.00	-0.11
Elevator Shafts	40	0.50	-0.25	0.67	0.00	1.00	-0.11
Install Stairs	25	0.50	-0.25	0.67	0.00	1.00	-0.11
Install Elevators	40	0.50	-0.25	0.67	0.00	1.00	-0.11
Install Exterior Façade	22	0.50	-0.25	0.67	0.00	1.00	-0.11
M&E R-in	25	0.50	-0.25	0.67	0.00	1.00	-0.11
Fire Protection	17	0.50	-0.25	0.67	0.00	1.00	-0.11
Inspections	15	0.50	-0.25	0.67	0.00	0.00	0.00

Activity	Initial Duration	FES	Ron	Error Δ_R-Δ_{FES}/Δ_r
Award Subcontracts	35	68	35	Infinity
Permits	20	20	20	Infinity
Submittals	60	117	90	-0.9000
Precast Fab	20	39	40	0.0500
Elevator Fab	60	117	60	Infinity
Mobilize	10	18	10	Infinity
Demo	5	9	5	Infinity
Curb&Gutter/Sidewalk	15	28	15	Infinity
Landscaping	15	28	15	Infinity
Shallow Foundations	32	59	32	Infinity
M&E UG	25	46	25	Infinity
Prep SOG	7	13	7	Infinity
Pour SOG	15	28	15	Infinity
Erect Precast Columns	10	18	10	Infinity
Install Precast Beams	14	26	14	Infinity
*FRP Slab	100	184	100	Infinity
Stress P/T	20	37	20	Infinity
Strip Slab Formwork	20	37	20	Infinity
Elevator Shafts	40	74	40	Infinity
Install Stairs	25	46	25	Infinity
Install Elevators	40	74	40	Infinity
Install Exterior Façade	22	41	22	Infinity
M&E R-in	25	46	25	Infinity
Fire Protection	17	31	17	Infinity
Inspections	15	29	30	0.0500

Scenario 2 - Linguistic Descriptors

Ground Conditions: Unfavourable
Speed of Owner's Decisions: Unfavourable
Changes to Design (Change Orders): Unfavourable
Skill of Workforce (Quality of Subs): Favourable

Ground Conditions

		Unfavourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	1.00	3.00	0.55	0.00	0.00	0.00
Permits	20	1.00	3.00	0.55	0.00	0.00	0.00
Submittals	60	1.00	3.00	0.55	0.00	0.00	0.00
Precast Exterior Fab	40	1.00	3.00	0.55	0.00	0.00	0.00
Elevator Fab	30	1.00	3.00	0.55	0.00	0.00	0.00
Mobilize	10	1.00	3.00	0.55	0.00	0.00	0.00
Demo	5	1.00	3.00	0.55	0.00	0.50	0.97
Curb&Gutter/Sidewalk	15	1.00	3.00	0.55	0.00	0.50	0.97
Landscaping	15	1.00	3.00	0.55	0.00	0.50	0.97
Bulk Excavation	24	1.00	3.00	0.55	0.00	1.00	1.94
Deep Foundations	22	1.00	3.00	0.55	0.00	1.00	1.94
Shallow Foundations	17	1.00	3.00	0.55	0.00	0.75	1.45
Foundation Walls	50	1.00	3.00	0.55	0.00	0.50	0.97
M&E UG	25	1.00	3.00	0.55	0.00	1.00	1.94
Prep SOG	12	1.00	3.00	0.55	0.00	0.50	0.97
Pour SOG	23	1.00	3.00	0.55	0.00	0.00	0.00
Ground Level Columns	19	1.00	3.00	0.55	0.00	0.00	0.00
Column Caps	16	1.00	3.00	0.55	0.00	0.00	0.00
*FRP Slab	80	1.00	3.00	0.55	0.00	0.00	0.00
Stress P/T	16	1.00	3.00	0.55	0.00	0.00	0.00
Strip Slab Formwork	16	1.00	3.00	0.55	0.00	0.00	0.00
*CIP Columns	80	1.00	3.00	0.55	0.00	0.00	0.00
Elevator Shafts	38	1.00	3.00	0.55	0.00	0.00	0.00
Install Stairs	15	1.00	3.00	0.55	0.00	0.00	0.00
Install Elevators	20	1.00	3.00	0.55	0.00	0.00	0.00
Install Exterior Façade	7	1.00	3.00	0.55	0.00	0.00	0.00
M&E R-in	20	1.00	3.00	0.55	0.00	0.00	0.00
Fire Protection	16	1.00	3.00	0.55	0.00	0.00	0.00
Inspections	15	1.00	3.00	0.55	0.00	0.00	0.00

Speed of Owner's Decisions

		Unfavourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	1.00	2.10	0.50	0.00	0.00	0
Permits	20	1.00	2.10	0.50	0.00	0.00	0
Submittals	60	1.00	2.10	0.50	0.00	1.00	1.4
Precast Exterior Fab	40	1.00	2.10	0.50	0.00	1.00	1.4
Elevator Fab	30	1.00	2.10	0.50	0.00	1.00	1.4
Mobilize	10	1.00	2.10	0.50	0.00	1.00	1.4
Demo	5	1.00	2.10	0.50	0.00	1.00	1.4
Curb&Gutter/Sidewalk	15	1.00	2.10	0.50	0.00	1.00	1.4
Landscaping	15	1.00	2.10	0.50	0.00	1.00	1.4
Bulk Excavation	24	1.00	2.10	0.50	0.00	1.00	1.4
Deep Foundations	22	1.00	2.10	0.50	0.00	1.00	1.4
Shallow Foundations	17	1.00	2.10	0.50	0.00	1.00	1.4
Foundation Walls	50	1.00	2.10	0.50	0.00	1.00	1.4
M&E UG	25	1.00	2.10	0.50	0.00	1.00	1.4
Prep SOG	12	1.00	2.10	0.50	0.00	1.00	1.4
Pour SOG	23	1.00	2.10	0.50	0.00	1.00	1.4
Ground Level Columns	19	1.00	2.10	0.50	0.00	1.00	1.4
Column Caps	16	1.00	2.10	0.50	0.00	1.00	1.4
*FRP Slab	80	1.00	2.10	0.50	0.00	1.00	1.4
Stress P/T	16	1.00	2.10	0.50	0.00	1.00	1.4
Strip Slab Formwork	16	1.00	2.10	0.50	0.00	1.00	1.4
*CIP Columns	80	1.00	2.10	0.50	0.00	1.00	1.4
Elevator Shafts	38	1.00	2.10	0.50	0.00	1.00	1.4
Install Stairs	15	1.00	2.10	0.50	0.00	1.00	1.4

Install Elevators	20	1.00	2.10	0.50	0.00	1.00	1.4
Install Exterior Façade	7	1.00	2.10	0.50	0.00	1.00	1.4
M&E R-in	20	1.00	2.10	0.50	0.00	1.00	1.4
Fire Protection	16	1.00	2.10	0.50	0.00	1.00	1.4
Inspections	15	1.00	2.10	0.50	0.00	0.00	0

Changes to Design (Change Orders)

		Unfavourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	1.00	2.05	0.67	0.00	1.00	1.23
Permits	20	1.00	2.05	0.67	0.00	1.00	1.23
Submittals	60	1.00	2.05	0.67	0.00	1.00	1.23
Precast Exterior Fab	40	1.00	2.05	0.67	0.00	1.00	1.23
Elevator Fab	30	1.00	2.05	0.67	0.00	1.00	1.23
Mobilize	10	1.00	2.05	0.67	0.00	0.00	0.00
Demo	5	1.00	2.05	0.67	0.00	1.00	1.23
Curb&Gutter/Sidewalk	15	1.00	2.05	0.67	0.00	0.50	0.61
Landscaping	15	1.00	2.05	0.67	0.00	0.50	0.61
Bulk Excavation	24	1.00	2.05	0.67	0.00	1.00	1.23
Deep Foundations	22	1.00	2.05	0.67	0.00	0.50	0.61
Shallow Foundations	17	1.00	2.05	0.67	0.00	0.50	0.61
Foundation Walls	50	1.00	2.05	0.67	0.00	0.15	0.18
M&E UG	25	1.00	2.05	0.67	0.00	0.25	0.31
Prep SOG	12	1.00	2.05	0.67	0.00	0.25	0.31
Pour SOG	23	1.00	2.05	0.67	0.00	0.31	0.38
Ground Level Columns	19	1.00	2.05	0.67	0.00	0.25	0.31
Column Caps	16	1.00	2.05	0.67	0.00	0.25	0.31
*FRP Slab	80	1.00	2.05	0.67	0.00	0.25	0.31
Stress P/T	16	1.00	2.05	0.67	0.00	0.10	0.12
Strip Slab Formwork	16	1.00	2.05	0.67	0.00	0.25	0.31
*CIP Columns	80	1.00	2.05	0.67	0.00	0.16	0.20
Elevator Shafts	38	1.00	2.05	0.67	0.00	0.64	0.79
Install Stairs	15	1.00	2.05	0.67	0.00	0.50	0.61
Install Elevators	20	1.00	2.05	0.67	0.00	0.25	0.31
Install Exterior Façade	7	1.00	2.05	0.67	0.00	0.75	0.92
M&E R-in	20	1.00	2.05	0.67	0.00	0.25	0.31
Fire Protection	16	1.00	2.05	0.67	0.00	0.24	0.29
Inspections	15	1.00	2.05	0.67	0.00	0.00	0.00

Skill of Workforce (Quality of Subcontractors

		Favourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	1.00	-0.21	0.67	0.00	0.00	0.00
Permits	20	1.00	-0.21	0.67	0.00	0.00	0.00
Submittals	60	1.00	-0.21	0.67	0.00	1.00	-0.13
Precast Exterior Fab	40	1.00	-0.21	0.67	0.00	0.57	-0.07
Elevator Fab	30	1.00	-0.21	0.67	0.00	0.50	-0.06
Mobilize	10	1.00	-0.21	0.67	0.00	0.25	-0.03
Demo	5	1.00	-0.21	0.67	0.00	1.00	-0.13
Curb&Gutter/Sidewalk	15	1.00	-0.21	0.67	0.00	0.50	-0.06
Landscaping	15	1.00	-0.21	0.67	0.00	0.50	-0.06
Bulk Excavation	24	1.00	-0.21	0.67	0.00	0.50	-0.06
Deep Foundations	22	1.00	-0.21	0.67	0.00	1.00	-0.13
Shallow Foundations	17	1.00	-0.21	0.67	0.00	1.00	-0.13
Foundation Walls	50	1.00	-0.21	0.67	0.00	0.29	-0.04
M&E UG	25	1.00	-0.21	0.67	0.00	1.00	-0.13
Prep SOG	12	1.00	-0.21	0.67	0.00	0.75	-0.09
Pour SOG	23	1.00	-0.21	0.67	0.00	0.75	-0.09
Ground Level Columns	19	1.00	-0.21	0.67	0.00	0.75	-0.09
Column Caps	16	1.00	-0.21	0.67	0.00	0.75	-0.09
*FRP Slab	80	1.00	-0.21	0.67	0.00	1.00	-0.13
Stress P/T	16	1.00	-0.21	0.67	0.00	0.19	-0.02
Strip Slab Formwork	16	1.00	-0.21	0.67	0.00	0.25	-0.03
*CIP Columns	80	1.00	-0.21	0.67	0.00	0.75	-0.09
Elevator Shafts	38	1.00	-0.21	0.67	0.00	1.00	-0.13
Install Stairs	15	1.00	-0.21	0.67	0.00	1.00	-0.13

Install Elevators	20	1.00	-0.21	0.67	0.00	1.00	-0.13
Install Exterior Façade	7	1.00	-0.21	0.67	0.00	1.00	-0.13
M&E R-in	20	1.00	-0.21	0.67	0.00	1.00	-0.13
Fire Protection	16	1.00	-0.21	0.67	0.00	1.00	-0.13
Inspections	15	1.00	-0.21	0.67	0.00	0.00	0.00

Activity	Initial Duration	FES	Jim	Error Δ_J-Δ_{FES}/Δ_J	Ron	Error Δ_R-Δ_{FES}/Δ_R
Award Subcontracts	35	78	30	9.5928	35	Infinity
Permits	20	45	20	Infinity	20	Infinity
Submittals	60	210	80	-6.5054	90	-4.0036
Precast Exterior Fab	40	142	40	Infinity	40	Infinity
Elevator Fab	30	107	30	Infinity	30	Infinity
Mobilize	10	24	10	Infinity	10	Infinity
Demo	5	22	5	Infinity	5	Infinity
Curb&Gutter/Sidewalk	15	59	20	-7.7559	15	Infinity
Landscaping	15	59	20	-7.7559	15	Infinity
Bulk Excavation	24	132	35	-8.8185	44	-4.4002
Deep Foundations	22	106	32	-7.4117	67	-0.8693
Shallow Foundations	17	74	27	-4.6774	62	-0.2616
Foundation Walls	50	176	50	Infinity	50	Infinity
M&E UG	25	113	20	18.5831	25	Infinity
Prep SOG	12	43	10	16.4819	12	Infinity
Pour SOG	23	62	20	13.9277	23	Infinity
Ground Level Columns	19	50	25	-4.1065	19	Infinity
Column Caps	16	42	15	26.8012	16	Infinity
*FRP Slab	80	206	75	26.2982	80	Infinity
Stress P/T	16	40	16	Infinity	16	Infinity
Strip Slab Formwork	16	43	16	Infinity	16	Infinity
*CIP Columns	80	200	80	Infinity	80	Infinity
Elevator Shafts	38	116	38	Infinity	38	Infinity
Install Stairs	15	43	25	-1.8320	15	Infinity
Install Elevators	20	52	20	Infinity	20	Infinity
Install Exterior Façade	7	22	14	-1.1949	7	Infinity
M&E R-in	20	52	20	Infinity	20	Infinity
Fire Protection	16	41	15	26.1018	16	Infinity
Inspections	15	15	15	Infinity	30	1.0000

Scenario 2 - Crisp Ratings

Ground Conditions: -2
Speed of Owner's Decisions: -2
Changes to Design (Change Orders): -3
Skill of Workforce (Quality of Subs): 2

Ground Conditions

		Unfavourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	0.40	3.00	0.75	0.00	0.00	0.00
Permits	20	0.40	3.00	0.75	0.00	0.00	0.00
Submittals	60	0.40	3.00	0.75	0.00	0.00	0.00
Precast Exterior Fab	40	0.40	3.00	0.75	0.00	0.00	0.00
Elevator Fab	30	0.40	3.00	0.75	0.00	0.00	0.00
Mobilize	10	0.40	3.00	0.75	0.00	0.00	0.00
Demo	5	0.40	3.00	0.75	0.00	0.50	0.52
Curb&Gutter/Sidewalk	15	0.40	3.00	0.75	0.00	0.50	0.52
Landscaping	15	0.40	3.00	0.75	0.00	0.50	0.52
Bulk Excavation	24	0.40	3.00	0.75	0.00	1.00	1.04
Deep Foundations	22	0.40	3.00	0.75	0.00	1.00	1.04
Shallow Foundations	17	0.40	3.00	0.75	0.00	0.75	0.78
Foundation Walls	50	0.40	3.00	0.75	0.00	0.50	0.52
M&E UG	25	0.40	3.00	0.75	0.00	1.00	1.04
Prep SOG	12	0.40	3.00	0.75	0.00	0.50	0.52
Pour SOG	23	0.40	3.00	0.75	0.00	0.00	0.00
Ground Level Columns	19	0.40	3.00	0.75	0.00	0.00	0.00
Column Caps	16	0.40	3.00	0.75	0.00	0.00	0.00
*FRP Slab	80	0.40	3.00	0.75	0.00	0.00	0.00
Stress P/T	16	0.40	3.00	0.75	0.00	0.00	0.00
Strip Slab Formwork	16	0.40	3.00	0.75	0.00	0.00	0.00
*CIP Columns	80	0.40	3.00	0.75	0.00	0.00	0.00
Elevator Shafts	38	0.40	3.00	0.75	0.00	0.00	0.00
Install Stairs	15	0.40	3.00	0.75	0.00	0.00	0.00
Install Elevators	20	0.40	3.00	0.75	0.00	0.00	0.00
Install Exterior Façade	7	0.40	3.00	0.75	0.00	0.00	0.00
M&E R-in	20	0.40	3.00	0.75	0.00	0.00	0.00
Fire Protection	16	0.40	3.00	0.75	0.00	0.00	0.00
Inspections	15	0.40	3.00	0.75	0.00	0.00	0.00

Speed of Owner's Decisions

		Unfavourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	0.25	2.10	0.75	0.00	0.00	0.00
Permits	20	0.25	2.10	0.75	0.00	0.00	0.00
Submittals	60	0.25	2.10	0.75	0.00	1.00	0.53
Precast Exterior Fab	40	0.25	2.10	0.75	0.00	1.00	0.53
Elevator Fab	30	0.25	2.10	0.75	0.00	1.00	0.53
Mobilize	10	0.25	2.10	0.75	0.00	1.00	0.53
Demo	5	0.25	2.10	0.75	0.00	1.00	0.53
Curb&Gutter/Sidewalk	15	0.25	2.10	0.75	0.00	1.00	0.53
Landscaping	15	0.25	2.10	0.75	0.00	1.00	0.53
Bulk Excavation	24	0.25	2.10	0.75	0.00	1.00	0.53
Deep Foundations	22	0.25	2.10	0.75	0.00	1.00	0.53
Shallow Foundations	17	0.25	2.10	0.75	0.00	1.00	0.53
Foundation Walls	50	0.25	2.10	0.75	0.00	1.00	0.53
M&E UG	25	0.25	2.10	0.75	0.00	1.00	0.53
Prep SOG	12	0.25	2.10	0.75	0.00	1.00	0.53
Pour SOG	23	0.25	2.10	0.75	0.00	1.00	0.53
Ground Level Columns	19	0.25	2.10	0.75	0.00	1.00	0.53
Column Caps	16	0.25	2.10	0.75	0.00	1.00	0.53
*FRP Slab	80	0.25	2.10	0.75	0.00	1.00	0.53
Stress P/T	16	0.25	2.10	0.75	0.00	1.00	0.53
Strip Slab Formwork	16	0.25	2.10	0.75	0.00	1.00	0.53
*CIP Columns	80	0.25	2.10	0.75	0.00	1.00	0.53
Elevator Shafts	38	0.25	2.10	0.75	0.00	1.00	0.53

Install Stairs	15	0.25	2.10	0.75	0.00	1.00	0.53
Install Elevators	20	0.25	2.10	0.75	0.00	1.00	0.53
Install Exterior Façade	7	0.25	2.10	0.75	0.00	1.00	0.53
M&E R-in	20	0.25	2.10	0.75	0.00	1.00	0.53
Fire Protection	16	0.25	2.10	0.75	0.00	1.00	0.53
Inspections	15	0.25	2.10	0.75	0.00	0.00	0.00

Changes to Design (Change Orders)

		Unfavourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	0.50	2.05	1.00	0.00	1.00	0.68
Permits	20	0.50	2.05	1.00	0.00	1.00	0.68
Submittals	60	0.50	2.05	1.00	0.00	1.00	0.68
Precast Exterior Fab	40	0.50	2.05	1.00	0.00	1.00	0.68
Elevator Fab	30	0.50	2.05	1.00	0.00	1.00	0.68
Mobilize	10	0.50	2.05	1.00	0.00	0.00	0.00
Demo	5	0.50	2.05	1.00	0.00	1.00	0.68
Curb&Gutter/Sidewalk	15	0.50	2.05	1.00	0.00	0.50	0.34
Landscaping	15	0.50	2.05	1.00	0.00	0.50	0.34
Bulk Excavation	24	0.50	2.05	1.00	0.00	1.00	0.68
Deep Foundations	22	0.50	2.05	1.00	0.00	0.50	0.34
Shallow Foundations	17	0.50	2.05	1.00	0.00	0.50	0.34
Foundation Walls	50	0.50	2.05	1.00	0.00	0.15	0.10
M&E UG	25	0.50	2.05	1.00	0.00	0.25	0.17
Prep SOG	12	0.50	2.05	1.00	0.00	0.25	0.17
Pour SOG	23	0.50	2.05	1.00	0.00	0.31	0.21
Ground Level Columns	19	0.50	2.05	1.00	0.00	0.25	0.17
Column Caps	16	0.50	2.05	1.00	0.00	0.25	0.17
*FRP Slab	80	0.50	2.05	1.00	0.00	0.25	0.17
Stress P/T	16	0.50	2.05	1.00	0.00	0.10	0.07
Strip Slab Formwork	16	0.50	2.05	1.00	0.00	0.25	0.17
*CIP Columns	80	0.50	2.05	1.00	0.00	0.16	0.11
Elevator Shafts	38	0.50	2.05	1.00	0.00	0.64	0.44
Install Stairs	15	0.50	2.05	1.00	0.00	0.50	0.34
Install Elevators	20	0.50	2.05	1.00	0.00	0.25	0.17
Install Exterior Façade	7	0.50	2.05	1.00	0.00	0.75	0.51
M&E R-in	20	0.50	2.05	1.00	0.00	0.25	0.17
Fire Protection	16	0.50	2.05	1.00	0.00	0.24	0.16
Inspections	15	0.50	2.05	1.00	0.00	0.00	0.00

Skill of Workforce (Quality of Subcontractors

		Favourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	1.00	-0.21	0.00	0.00	0.00	0
Permits	20	1.00	-0.21	0.00	0.00	0.00	0
Submittals	60	1.00	-0.21	0.00	0.00	1.00	-0.21
Precast Exterior Fab	40	1.00	-0.21	0.00	0.00	0.57	-0.1197
Elevator Fab	30	1.00	-0.21	0.00	0.00	0.50	-0.105
Mobilize	10	1.00	-0.21	0.00	0.00	0.25	-0.0525
Demo	5	1.00	-0.21	0.00	0.00	1.00	-0.21
Curb&Gutter/Sidewalk	15	1.00	-0.21	0.00	0.00	0.50	-0.105
Landscaping	15	1.00	-0.21	0.00	0.00	0.50	-0.105
Bulk Excavation	24	1.00	-0.21	0.00	0.00	0.50	-0.105
Deep Foundations	22	1.00	-0.21	0.00	0.00	1.00	-0.21
Shallow Foundations	17	1.00	-0.21	0.00	0.00	1.00	-0.21
Foundation Walls	50	1.00	-0.21	0.00	0.00	0.29	-0.0609
M&E UG	25	1.00	-0.21	0.00	0.00	1.00	-0.21
Prep SOG	12	1.00	-0.21	0.00	0.00	0.75	-0.1575
Pour SOG	23	1.00	-0.21	0.00	0.00	0.75	-0.1575
Ground Level Columns	19	1.00	-0.21	0.00	0.00	0.75	-0.1575
Column Caps	16	1.00	-0.21	0.00	0.00	0.75	-0.1575
*FRP Slab	80	1.00	-0.21	0.00	0.00	1.00	-0.21
Stress P/T	16	1.00	-0.21	0.00	0.00	0.19	-0.0399
Strip Slab Formwork	16	1.00	-0.21	0.00	0.00	0.25	-0.0525
*CIP Columns	80	1.00	-0.21	0.00	0.00	0.75	-0.1575

Elevator Shafts	38	1.00	-0.21	0.00	0.00	1.00	-0.21
Install Stairs	15	1.00	-0.21	0.00	0.00	1.00	-0.21
Install Elevators	20	1.00	-0.21	0.00	0.00	1.00	-0.21
Install Exterior Façade	7	1.00	-0.21	0.00	0.00	1.00	-0.21
M&E R-in	20	1.00	-0.21	0.00	0.00	1.00	-0.21
Fire Protection	16	1.00	-0.21	0.00	0.00	1.00	-0.21
Inspections	15	1.00	-0.21	0.00	0.00	0.00	0

Activity	Initial Duration	FES	Scott	Error $(\Delta_S-\Delta_{FES})/\Delta_S$
Award Subcontracts	35	59	35	Infinity
Permits	20	34	20	Infinity
Submittals	60	120	80	-1.9950
Precast Exterior Fab	40	84	60	-1.1773
Elevator Fab	30	63	30	Infinity
Mobilize	10	15	10	Infinity
Demo	5	13	5	Infinity
Curb&Gutter/Sidewalk	15	34	15	Infinity
Landscaping	15	34	15	Infinity
Bulk Excavation	24	76	30	-7.5872
Deep Foundations	22	59	28	-5.2339
Shallow Foundations	17	41	17	Infinity
Foundation Walls	50	104	45	11.8834
M&E UG	25	63	25	Infinity
Prep SOG	12	25	15	-3.2403
Pour SOG	23	36	20	5.4416
Ground Level Columns	19	29	19	Infinity
Column Caps	16	25	16	Infinity
*FRP Slab	80	119	70	4.8867
Stress P/T	16	25	16	Infinity
Strip Slab Formwork	16	26	14	6.1467
*CIP Columns	80	118	70	4.8147
Elevator Shafts	38	67	38	Infinity
Install Stairs	15	25	15	Infinity
Install Elevators	20	30	20	Infinity
Install Exterior Façade	7	13	7	Infinity
M&E R-in	20	30	20	Infinity
Fire Protection	16	24	16	Infinity
Inspections	15	15	15	Infinity

Scenario 3 - Linguistic Descriptors

Timeliness of Permitting/Inspections: Unfavourable
Interference by Owner: Favourable
Changes to Design: Unfavourable
Quality of Workmanship: Unfavourable

Timeliness of Permitting/Inspections

		Unfavourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	1.00	2.00	0.43	0.00	0.00	0.00
Permits	20	1.00	2.00	0.43	0.00	1.00	1.40
Submittals	60	1.00	2.00	0.43	0.00	0.00	0.00
Precast Fab	237	1.00	2.00	0.43	0.00	0.00	0.00
Elevator Fab	90	1.00	2.00	0.43	0.00	0.00	0.00
Mobilize	10	1.00	2.00	0.43	0.00	0.00	0.00
Demo	5	1.00	2.00	0.43	0.00	0.00	0.00
Curb&Gutter/Sidewalk	15	1.00	2.00	0.43	0.00	0.00	0.00
Landscaping	15	1.00	2.00	0.43	0.00	0.00	0.00
Bulk Excavation	69	1.00	2.00	0.43	0.00	0.00	0.00
Deep Foundations	62	1.00	2.00	0.43	0.00	0.00	0.00
Shallow Foundations	47	1.00	2.00	0.43	0.00	0.00	0.00
Foundation Walls	167	1.00	2.00	0.43	0.00	0.00	0.00
M&E UG	25	1.00	2.00	0.43	0.00	0.00	0.00
Prep SOG	32	1.00	2.00	0.43	0.00	0.00	0.00
Pour SOG	65	1.00	2.00	0.43	0.00	0.00	0.00
Erect Precast Structure	315	1.00	2.00	0.43	0.00	0.00	0.00
Place Topping	141	1.00	2.00	0.43	0.00	0.00	0.00
Elevator Shafts	286	1.00	2.00	0.43	0.00	0.00	0.00
Install Stairs	40	1.00	2.00	0.43	0.00	0.00	0.00
Install Elevators	60	1.00	2.00	0.43	0.00	0.00	0.00
Install Exterior Façade	58	1.00	2.00	0.43	0.00	0.00	0.00
M&E R-in	180	1.00	2.00	0.43	0.00	0.00	0.00
Fire Protection	120	1.00	2.00	0.43	0.00	0.00	0.00
Inspections	15	1.00	2.00	0.43	0.00	1.00	1.40

Interference by Owner

		Favourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	1.00	-0.10	0.40	0.00	1.00	-0.07
Permits	20	1.00	-0.10	0.40	0.00	0.00	0.00
Submittals	60	1.00	-0.10	0.40	0.00	1.00	-0.07
Precast Fab	237	1.00	-0.10	0.40	0.00	1.00	-0.07
Elevator Fab	90	1.00	-0.10	0.40	0.00	1.00	-0.07
Mobilize	10	1.00	-0.10	0.40	0.00	1.00	-0.07
Demo	5	1.00	-0.10	0.40	0.00	1.00	-0.07
Curb&Gutter/Sidewalk	15	1.00	-0.10	0.40	0.00	1.00	-0.07
Landscaping	15	1.00	-0.10	0.40	0.00	1.00	-0.07
Bulk Excavation	69	1.00	-0.10	0.40	0.00	1.00	-0.07
Deep Foundations	62	1.00	-0.10	0.40	0.00	1.00	-0.07
Shallow Foundations	47	1.00	-0.10	0.40	0.00	1.00	-0.07
Foundation Walls	167	1.00	-0.10	0.40	0.00	1.00	-0.07
M&E UG	25	1.00	-0.10	0.40	0.00	1.00	-0.07
Prep SOG	32	1.00	-0.10	0.40	0.00	1.00	-0.07
Pour SOG	65	1.00	-0.10	0.40	0.00	1.00	-0.07
Erect Precast Structure	315	1.00	-0.10	0.40	0.00	1.00	-0.07
Place Topping	141	1.00	-0.10	0.40	0.00	1.00	-0.07
Elevator Shafts	286	1.00	-0.10	0.40	0.00	1.00	-0.07
Install Stairs	40	1.00	-0.10	0.40	0.00	1.00	-0.07
Install Elevators	60	1.00	-0.10	0.40	0.00	1.00	-0.07
Install Exterior Façade	58	1.00	-0.10	0.40	0.00	1.00	-0.07
M&E R-in	180	1.00	-0.10	0.40	0.00	1.00	-0.07
Fire Protection	120	1.00	-0.10	0.40	0.00	1.00	-0.07
Inspections	15	1.00	-0.10	0.40	0.00	1.00	-0.07

Changes to Design (Change Orders)

		Unfavourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	1.00	2.05	0.67	0.00	1.00	1.23
Permits	20	1.00	2.05	0.67	0.00	1.00	1.23
Submittals	60	1.00	2.05	0.67	0.00	1.00	1.23
Precast Fab	237	1.00	2.05	0.67	0.00	1.00	1.23
Elevator Fab	90	1.00	2.05	0.67	0.00	1.00	1.23
Mobilize	10	1.00	2.05	0.67	0.00	0.00	0.00
Demo	5	1.00	2.05	0.67	0.00	1.00	1.23
Curb&Gutter/Sidewalk	15	1.00	2.05	0.67	0.00	0.50	0.61
Landscaping	15	1.00	2.05	0.67	0.00	0.50	0.61

Bulk Excavation	69	1.00	2.05	0.67	0.00	1.00	1.23
Deep Foundations	62	1.00	2.05	0.67	0.00	0.50	0.61
Shallow Foundations	47	1.00	2.05	0.67	0.00	0.50	0.61
Foundation Walls	167	1.00	2.05	0.67	0.00	0.15	0.18
M&E UG	25	1.00	2.05	0.67	0.00	0.25	0.31
Prep SOG	32	1.00	2.05	0.67	0.00	0.25	0.31
Pour SOG	65	1.00	2.05	0.67	0.00	0.31	0.38
Erect Precast Structure	315	1.00	2.05	0.67	0.00	0.50	0.61
Place Topping	141	1.00	2.05	0.67	0.00	0.10	0.12
Elevator Shafts	286	1.00	2.05	0.67	0.00	0.64	0.79
Install Stairs	40	1.00	2.05	0.67	0.00	0.50	0.61
Install Elevators	60	1.00	2.05	0.67	0.00	0.25	0.31
Install Exterior Façade	58	1.00	2.05	0.67	0.00	0.75	0.92
M&E R-in	180	1.00	2.05	0.67	0.00	0.25	0.31
Fire Protection	120	1.00	2.05	0.67	0.00	0.24	0.29
Inspections	15	1.00	2.05	0.67	0.00	0.00	0.00

Quality of Workmanship

		Unfavourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	1.00	1.44	0.50	0.00	0.00	0.00
Permits	20	1.00	1.44	0.50	0.00	0.00	0.00
Submittals	60	1.00	1.44	0.50	0.00	0.00	0.00
Precast Fab	237	1.00	1.44	0.50	0.00	1.00	0.96
Elevator Fab	90	1.00	1.44	0.50	0.00	0.25	0.24
Mobilize	10	1.00	1.44	0.50	0.00	0.00	0.00
Demo	5	1.00	1.44	0.50	0.00	0.25	0.24
Curb&Gutter/Sidewalk	15	1.00	1.44	0.50	0.00	0.50	0.48
Landscaping	15	1.00	1.44	0.50	0.00	0.50	0.48
Bulk Excavation	69	1.00	1.44	0.50	0.00	0.25	0.24
Deep Foundations	62	1.00	1.44	0.50	0.00	0.24	0.23
Shallow Foundations	47	1.00	1.44	0.50	0.00	0.25	0.24
Foundation Walls	167	1.00	1.44	0.50	0.00	0.25	0.24
M&E UG	25	1.00	1.44	0.50	0.00	0.50	0.48
Prep SOG	32	1.00	1.44	0.50	0.00	0.25	0.24
Pour SOG	65	1.00	1.44	0.50	0.00	0.25	0.24
Erect Precast Structure	315	1.00	1.44	0.50	0.00	1.00	0.96
Place Topping	141	1.00	1.44	0.50	0.00	0.50	0.48
Elevator Shafts	286	1.00	1.44	0.50	0.00	0.25	0.24
Install Stairs	40	1.00	1.44	0.50	0.00	1.00	0.96
Install Elevators	60	1.00	1.44	0.50	0.00	1.00	0.96
Install Exterior Façade	58	1.00	1.44	0.50	0.00	1.00	0.96
M&E R-in	180	1.00	1.44	0.50	0.00	0.50	0.48
Fire Protection	120	1.00	1.44	0.50	0.00	0.50	0.48
Inspections	15	1.00	1.44	0.50	0.00	0.00	0.00

Activity	Initial Duration	FES	Ron	Error Δ_R-Δ_{FES}/Δ_R
Award Subcontracts	35	75	35	Infinity
Permits	20	73	40	-1.6261
Submittals	60	129	60	Infinity
Precast Fab	237	739	267	-15.7173
Elevator Fab	90	216	90	Infinity
Mobilize	10	9	10	Infinity
Demo	5	12	5	Infinity
Curb&Gutter/Sidewalk	15	30	15	Infinity
Landscaping	15	30	15	Infinity
Bulk Excavation	69	165	84	-5.4221
Deep Foundations	62	110	77	-2.1940
Shallow Foundations	47	84	47	Infinity
Foundation Walls	167	226	167	Infinity
M&E UG	25	43	30	-2.5773
Prep SOG	32	47	32	Infinity
Pour SOG	65	101	65	Infinity
Erect Precast Structure	315	788	315	Infinity
Place Topping	141	216	141	Infinity
Elevator Shafts	286	559	286	Infinity
Install Stairs	40	100	40	Infinity
Install Elevators	60	132	60	Infinity
Install Exterior Façade	58	163	58	Infinity
M&E R-in	180	309	180	Infinity
Fire Protection	120	204	120	Infinity
Inspections	15	35	30	-0.3272

Scenario 3 - Crisp Ratings

Timeliness of Permitting/Inspections: -5
Interference by Owner: 4
Changes to Design: -3
Quality of Workmanship: -3

Timeliness of Permitting/Inspections

		Unfavourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	1.00	2.00	0.00	0.00	0.00	0.00
Permits	20	1.00	2.00	0.00	0.00	1.00	2.00
Submittals	60	1.00	2.00	0.00	0.00	0.00	0.00
Precast Fab	237	1.00	2.00	0.00	0.00	0.00	0.00
Elevator Fab	90	1.00	2.00	0.00	0.00	0.00	0.00
Mobilize	10	1.00	2.00	0.00	0.00	0.00	0.00
Demo	5	1.00	2.00	0.00	0.00	0.00	0.00
Curb&Gutter/Sidewalk	15	1.00	2.00	0.00	0.00	0.00	0.00
Landscaping	15	1.00	2.00	0.00	0.00	0.00	0.00
Bulk Excavation	69	1.00	2.00	0.00	0.00	0.00	0.00
Deep Foundations	62	1.00	2.00	0.00	0.00	0.00	0.00
Shallow Foundations	47	1.00	2.00	0.00	0.00	0.00	0.00
Foundation Walls	167	1.00	2.00	0.00	0.00	0.00	0.00
M&E UG	25	1.00	2.00	0.00	0.00	0.00	0.00
Prep SOG	32	1.00	2.00	0.00	0.00	0.00	0.00
Pour SOG	65	1.00	2.00	0.00	0.00	0.00	0.00
Erect Precast Structure	315	1.00	2.00	0.00	0.00	0.00	0.00
Place Topping	141	1.00	2.00	0.00	0.00	0.00	0.00
Elevator Shafts	286	1.00	2.00	0.00	0.00	0.00	0.00
Install Stairs	40	1.00	2.00	0.00	0.00	0.00	0.00
Install Elevators	60	1.00	2.00	0.00	0.00	0.00	0.00
Install Exterior Façade	58	1.00	2.00	0.00	0.00	0.00	0.00
M&E R-in	180	1.00	2.00	0.00	0.00	0.00	0.00
Fire Protection	120	1.00	2.00	0.00	0.00	0.00	0.00
Inspections	15	1.00	2.00	0.00	0.00	1.00	2.00

Interference by Owner

		Favourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	1.00	-0.10	0.00	0.00	1.00	-0.10
Permits	20	1.00	-0.10	0.00	0.00	0.00	0.00
Submittals	60	1.00	-0.10	0.00	0.00	1.00	-0.10
Precast Fab	237	1.00	-0.10	0.00	0.00	1.00	-0.10
Elevator Fab	90	1.00	-0.10	0.00	0.00	1.00	-0.10
Mobilize	10	1.00	-0.10	0.00	0.00	1.00	-0.10
Demo	5	1.00	-0.10	0.00	0.00	1.00	-0.10
Curb&Gutter/Sidewalk	15	1.00	-0.10	0.00	0.00	1.00	-0.10
Landscaping	15	1.00	-0.10	0.00	0.00	1.00	-0.10
Bulk Excavation	69	1.00	-0.10	0.00	0.00	1.00	-0.10
Deep Foundations	62	1.00	-0.10	0.00	0.00	1.00	-0.10
Shallow Foundations	47	1.00	-0.10	0.00	0.00	1.00	-0.10
Foundation Walls	167	1.00	-0.10	0.00	0.00	1.00	-0.10
M&E UG	25	1.00	-0.10	0.00	0.00	1.00	-0.10
Prep SOG	32	1.00	-0.10	0.00	0.00	1.00	-0.10
Pour SOG	65	1.00	-0.10	0.00	0.00	1.00	-0.10
Erect Precast Structure	315	1.00	-0.10	0.00	0.00	1.00	-0.10
Place Topping	141	1.00	-0.10	0.00	0.00	1.00	-0.10
Elevator Shafts	286	1.00	-0.10	0.00	0.00	1.00	-0.10
Install Stairs	40	1.00	-0.10	0.00	0.00	1.00	-0.10
Install Elevators	60	1.00	-0.10	0.00	0.00	1.00	-0.10
Install Exterior Façade	58	1.00	-0.10	0.00	0.00	1.00	-0.10
M&E R-in	180	1.00	-0.10	0.00	0.00	1.00	-0.10
Fire Protection	120	1.00	-0.10	0.00	0.00	1.00	-0.10
Inspections	15	1.00	-0.10	0.00	0.00	1.00	-0.10

Changes to Design (Change Orders)

		Unfavourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	0.50	2.05	1.00	0.00	1.00	0.68
Permits	20	0.50	2.05	1.00	0.00	1.00	0.68
Submittals	60	0.50	2.05	1.00	0.00	1.00	0.68
Precast Fab	237	0.50	2.05	1.00	0.00	1.00	0.68
Elevator Fab	90	0.50	2.05	1.00	0.00	1.00	0.68
Mobilize	10	0.50	2.05	1.00	0.00	0.00	0.00
Demo	5	0.50	2.05	1.00	0.00	1.00	0.68
Curb&Gutter/Sidewalk	15	0.50	2.05	1.00	0.00	0.50	0.34
Landscaping	15	0.50	2.05	1.00	0.00	0.50	0.34

Bulk Excavation	69	0.50	2.05	1.00	0.00	1.00	0.68
Deep Foundations	62	0.50	2.05	1.00	0.00	0.50	0.34
Shallow Foundations	47	0.50	2.05	1.00	0.00	0.50	0.34
Foundation Walls	167	0.50	2.05	1.00	0.00	0.15	0.10
M&E UG	25	0.50	2.05	1.00	0.00	0.25	0.17
Prep SOG	32	0.50	2.05	1.00	0.00	0.25	0.17
Pour SOG	65	0.50	2.05	1.00	0.00	0.31	0.21
Erect Precast Structure	315	0.50	2.05	1.00	0.00	0.50	0.34
Place Topping	141	0.50	2.05	1.00	0.00	0.10	0.07
Elevator Shafts	286	0.50	2.05	1.00	0.00	0.64	0.44
Install Stairs	40	0.50	2.05	1.00	0.00	0.50	0.34
Install Elevators	60	0.50	2.05	1.00	0.00	0.25	0.17
Install Exterior Façade	58	0.50	2.05	1.00	0.00	0.75	0.51
M&E R-in	180	0.50	2.05	1.00	0.00	0.25	0.17
Fire Protection	120	0.50	2.05	1.00	0.00	0.24	0.16
Inspections	15	0.50	2.05	1.00	0.00	0.00	0.00

Quality of Workmanship

		Unfavourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	1.00	1.44	0.00	0.00	0.00	0.00
Permits	20	1.00	1.44	0.00	0.00	0.00	0.00
Submittals	60	1.00	1.44	0.00	0.00	0.00	0.00
Precast Fab	237	1.00	1.44	0.00	0.00	1.00	1.44
Elevator Fab	90	1.00	1.44	0.00	0.00	0.25	0.36
Mobilize	10	1.00	1.44	0.00	0.00	0.00	0.00
Demo	5	1.00	1.44	0.00	0.00	0.25	0.36
Curb&Gutter/Sidewalk	15	1.00	1.44	0.00	0.00	0.50	0.72
Landscaping	15	1.00	1.44	0.00	0.00	0.50	0.72
Bulk Excavation	69	1.00	1.44	0.00	0.00	0.25	0.36
Deep Foundations	62	1.00	1.44	0.00	0.00	0.24	0.35
Shallow Foundations	47	1.00	1.44	0.00	0.00	0.25	0.36
Foundation Walls	167	1.00	1.44	0.00	0.00	0.25	0.36
M&E UG	25	1.00	1.44	0.00	0.00	0.50	0.72
Prep SOG	32	1.00	1.44	0.00	0.00	0.25	0.36
Pour SOG	65	1.00	1.44	0.00	0.00	0.25	0.36
Erect Precast Structure	315	1.00	1.44	0.00	0.00	1.00	1.44
Place Topping	141	1.00	1.44	0.00	0.00	0.50	0.72
Elevator Shafts	286	1.00	1.44	0.00	0.00	0.25	0.36
Install Stairs	40	1.00	1.44	0.00	0.00	1.00	1.44
Install Elevators	60	1.00	1.44	0.00	0.00	1.00	1.44
Install Exterior Façade	58	1.00	1.44	0.00	0.00	1.00	1.44
M&E R-in	180	1.00	1.44	0.00	0.00	0.50	0.72
Fire Protection	120	1.00	1.44	0.00	0.00	0.50	0.72
Inspections	15	1.00	1.44	0.00	0.00	0.00	0.00

Activity	Initial Duration	FES	Jim	Error Δ_J-Δ_{FES}/Δ_J	AI	Error Δ_A-Δ_{FES}/Δ_A
Award Subcontracts	35	55	35	Infinity	35	Infinity
Permits	20	74	40	-1.6833	40	-1.6833
Submittals	60	95	60	Infinity	60	Infinity
Precast Fab	237	717	237	Infinity	237	Infinity
Elevator Fab	90	175	90	Infinity	90	Infinity
Mobilize	10	9	10	Infinity	10	Infinity
Demo	5	10	5	Infinity	5	Infinity
Curb&Gutter/Sidewalk	15	29	20	-1.8850	18	-3.8083
Landscaping	15	29	20	-1.8850	16	-13.4250
Bulk Excavation	69	134	90	-2.0995	69	Infinity
Deep Foundations	62	98	90	-0.3004	62	Infinity
Shallow Foundations	47	75	60	-1.1753	57	-1.8278
Foundation Walls	167	228	180	-3.6567	187	-2.0269
M&E UG	25	45	30	-2.9542	30	-2.9542
Prep SOG	32	46	35	-3.5956	35	-3.5956
Pour SOG	65	96	70	-5.1338	75	-2.0669
Erect Precast Structure	315	845	330	-34.3150	340	-20.1890
Place Topping	141	238	155	-5.9325	150	-9.7839
Elevator Shafts	286	485	300	-13.2455	300	-13.2455
Install Stairs	40	107	60	-2.3633	42	-32.6333
Install Elevators	60	151	60	Infinity	80	-3.5325
Install Exterior Façade	58	165	80	-3.8839	65	-14.3493
M&E R-in	180	322	200	-6.1175	200	-6.1175
Fire Protection	120	214	130	-8.4080	130	-8.4080
Inspections	15	44	30	-0.9000	30	-0.9000

Scenario 4 - Linguistic Descriptors

Speed of Owner's Decisions: Unfavourable
Quality of Field Management: Unfavourable
Skill of Workforce: Unfavourable

Speed of Owner's Decisions

		Unfavourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	1.00	2.10	0.50	0.00	0.00	0.00
Permits	20	1.00	2.10	0.50	0.00	0.00	0.00
Submittals	60	1.00	2.10	0.50	0.00	1.00	1.40
Precast Fab	300	1.00	2.10	0.50	0.00	1.00	1.40
Elevator Fab	90	1.00	2.10	0.50	0.00	1.00	1.40
Mobilize	10	1.00	2.10	0.50	0.00	1.00	1.40
Demo	5	1.00	2.10	0.50	0.00	1.00	1.40
Curb&Gutter/Sidewalk	15	1.00	2.10	0.50	0.00	1.00	1.40
Landscaping	15	1.00	2.10	0.50	0.00	1.00	1.40
Deep Foundations	138	1.00	2.10	0.50	0.00	1.00	1.40
Shallow Foundations	105	1.00	2.10	0.50	0.00	1.00	1.40
M&E UG	25	1.00	2.10	0.50	0.00	1.00	1.40
Prep SOG	70	1.00	2.10	0.50	0.00	1.00	1.40
Pour SOG	143	1.00	2.10	0.50	0.00	1.00	1.40
Erect Precast Columns	155	1.00	2.10	0.50	0.00	1.00	1.40
Install Precast Beams	203	1.00	2.10	0.50	0.00	1.00	1.40
*FRP Slab	600	1.00	2.10	0.50	0.00	1.00	1.40
Stress P/T	120	1.00	2.10	0.50	0.00	1.00	1.40
Strip Slab Formwork	120	1.00	2.10	0.50	0.00	1.00	1.40
Elevator Shafts	200	1.00	2.10	0.50	0.00	1.00	1.40
Install Stairs	35	1.00	2.10	0.50	0.00	1.00	1.40
Install Elevators	60	1.00	2.10	0.50	0.00	1.00	1.40
Install Exterior Façade	103	1.00	2.10	0.50	0.00	1.00	1.40
M&E R-in	200	1.00	2.10	0.50	0.00	1.00	1.40
Fire Protection	234	1.00	2.10	0.50	0.00	1.00	1.40
Inspections	15	1.00	2.10	0.50	0.00	0.00	0.00

Quality of Field Management

		Unfavourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	1.00	2.00	0.43	0.00	0.00	0.00
Permits	20	1.00	2.00	0.43	0.00	0.00	0.00
Submittals	60	1.00	2.00	0.43	0.00	0.00	0.00
Precast Fab	300	1.00	2.00	0.43	0.00	0.00	0.00
Elevator Fab	90	1.00	2.00	0.43	0.00	0.00	0.00
Mobilize	10	1.00	2.00	0.43	0.00	1.00	1.40
Demo	5	1.00	2.00	0.43	0.00	1.00	1.40
Curb&Gutter/Sidewalk	15	1.00	2.00	0.43	0.00	1.00	1.40
Landscaping	15	1.00	2.00	0.43	0.00	1.00	1.40
Deep Foundations	138	1.00	2.00	0.43	0.00	1.00	1.40
Shallow Foundations	105	1.00	2.00	0.43	0.00	1.00	1.40
M&E UG	25	1.00	2.00	0.43	0.00	1.00	1.40
Prep SOG	70	1.00	2.00	0.43	0.00	1.00	1.40
Pour SOG	143	1.00	2.00	0.43	0.00	1.00	1.40
Erect Precast Columns	155	1.00	2.00	0.43	0.00	1.00	1.40
Install Precast Beams	203	1.00	2.00	0.43	0.00	1.00	1.40
*FRP Slab	600	1.00	2.00	0.43	0.00	1.00	1.40
Stress P/T	120	1.00	2.00	0.43	0.00	1.00	1.40
Strip Slab Formwork	120	1.00	2.00	0.43	0.00	1.00	1.40
Elevator Shafts	200	1.00	2.00	0.43	0.00	1.00	1.40
Install Stairs	35	1.00	2.00	0.43	0.00	1.00	1.40
Install Elevators	60	1.00	2.00	0.43	0.00	1.00	1.40
Install Exterior Façade	103	1.00	2.00	0.43	0.00	1.00	1.40
M&E R-in	200	1.00	2.00	0.43	0.00	1.00	1.40
Fire Protection	234	1.00	2.00	0.43	0.00	1.00	1.40
Inspections	15	1.00	2.00	0.43	0.00	0.00	0.00

Skill of Workforce (Quality of Subs)

Activity	Initial Duration	Unfavourable		Normal		Sensitivity	Scaled Var.
		MF Value	Output	MF Value	Output		
Award Subcontracts	35	1.00	1.74	0.40	0.00	0.00	0.00
Permits	20	1.00	1.74	0.40	0.00	0.00	0.00
Submittals	60	1.00	1.74	0.40	0.00	1.00	1.24
Precast Fab	300	1.00	1.74	0.40	0.00	0.50	0.62
Elevator Fab	90	1.00	1.74	0.40	0.00	0.50	0.62
Mobilize	10	1.00	1.74	0.40	0.00	0.25	0.31
Demo	5	1.00	1.74	0.40	0.00	1.00	1.24
Curb&Gutter/Sidewalk	15	1.00	1.74	0.40	0.00	0.50	0.62
Landscaping	15	1.00	1.74	0.40	0.00	0.50	0.62
Deep Foundations	138	1.00	1.74	0.40	0.00	1.00	1.24
Shallow Foundations	105	1.00	1.74	0.40	0.00	1.00	1.24
M&E UG	25	1.00	1.74	0.40	0.00	1.00	1.24
Prep SOG	70	1.00	1.74	0.40	0.00	0.75	0.93
Pour SOG	143	1.00	1.74	0.40	0.00	0.75	0.93
Erect Precast Columns	155	1.00	1.74	0.40	0.00	1.00	1.24
Install Precast Beams	203	1.00	1.74	0.40	0.00	1.00	1.24
*FRP Slab	600	1.00	1.74	0.40	0.00	1.00	1.24
Stress P/T	120	1.00	1.74	0.40	0.00	0.19	0.24
Strip Slab Formwork	120	1.00	1.74	0.40	0.00	0.25	0.31
Elevator Shafts	200	1.00	1.74	0.40	0.00	1.00	1.24
Install Stairs	35	1.00	1.74	0.40	0.00	1.00	1.24
Install Elevators	60	1.00	1.74	0.40	0.00	1.00	1.24
Install Exterior Façade	103	1.00	1.74	0.40	0.00	1.00	1.24
M&E R-in	200	1.00	1.74	0.40	0.00	1.00	1.24
Fire Protection	234	1.00	1.74	0.40	0.00	1.00	1.24
Inspections	15	1.00	1.74	0.40	0.00	0.00	0.00

Activity	Initial Duration	FES	AI	Error $\Delta_A-\Delta_{FES}/\Delta_A$
Award Subcontracts	35	35	35	Infinity
Permits	20	20	25	1.0000
Submittals	60	219	60	Infinity
Precast Fab	300	906	300	Infinity
Elevator Fab	90	272	90	Infinity
Mobilize	10	41	12	-14.5466
Demo	5	25	7	-9.1036
Curb&Gutter/Sidewalk	15	66	20	-9.2601
Landscaping	15	66	20	-9.2601
Deep Foundations	138	696	150	-45.4768
Shallow Foundations	105	529	120	-27.2902
M&E UG	25	126	30	-19.2073
Prep SOG	70	331	80	-25.1152
Pour SOG	143	676	160	-30.3821
Erect Precast Columns	155	781	165	-61.6426
Install Precast Beams	203	1023	215	-67.3680
*FRP Slab	600	3025	700	-23.2488
Stress P/T	120	484	140	-17.2085
Strip Slab Formwork	120	493	140	-17.6559
Elevator Shafts	200	1008	240	-19.2073
Install Stairs	35	176	42	-19.2073
Install Elevators	60	302	85	-8.6995
Install Exterior Façade	103	519	115	-33.6892
M&E R-in	200	1008	230	-25.9431
Fire Protection	234	1180	250	-58.1063
Inspections	15	15	17	1.0000

Scenario 4 - Crisp Ratings

Speed of Owner's Decisions: -2
Quality of Field Management: -3
Skill of Workforce: -2

Speed of Owner's Decisions

		Unfavourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	0.25	2.10	0.75	0.00	0.00	0.00
Permits	20	0.25	2.10	0.75	0.00	0.00	0.00
Submittals	60	0.25	2.10	0.75	0.00	1.00	0.53
Precast Fab	300	0.25	2.10	0.75	0.00	1.00	0.53
Elevator Fab	90	0.25	2.10	0.75	0.00	1.00	0.53
Mobilize	10	0.25	2.10	0.75	0.00	1.00	0.53
Demo	5	0.25	2.10	0.75	0.00	1.00	0.53
Curb&Gutter/Sidewalk	15	0.25	2.10	0.75	0.00	1.00	0.53
Landscaping	15	0.25	2.10	0.75	0.00	1.00	0.53
Deep Foundations	138	0.25	2.10	0.75	0.00	1.00	0.53
Shallow Foundations	105	0.25	2.10	0.75	0.00	1.00	0.53
M&E UG	25	0.25	2.10	0.75	0.00	1.00	0.53
Prep SOG	70	0.25	2.10	0.75	0.00	1.00	0.53
Pour SOG	143	0.25	2.10	0.75	0.00	1.00	0.53
Erect Precast Columns	155	0.25	2.10	0.75	0.00	1.00	0.53
Install Precast Beams	203	0.25	2.10	0.75	0.00	1.00	0.53
*FRP Slab	600	0.25	2.10	0.75	0.00	1.00	0.53
Stress P/T	120	0.25	2.10	0.75	0.00	1.00	0.53
Strip Slab Formwork	120	0.25	2.10	0.75	0.00	1.00	0.53
Elevator Shafts	200	0.25	2.10	0.75	0.00	1.00	0.53
Install Stairs	35	0.25	2.10	0.75	0.00	1.00	0.53
Install Elevators	60	0.25	2.10	0.75	0.00	1.00	0.53
Install Exterior Façade	103	0.25	2.10	0.75	0.00	1.00	0.53
M&E R-in	200	0.25	2.10	0.75	0.00	1.00	0.53
Fire Protection	234	0.25	2.10	0.75	0.00	1.00	0.53
Inspections	15	0.25	2.10	0.75	0.00	0.00	0.00

Quality of Field Management

		Unfavourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	0.75	2.00	0.00	0.00	0.00	0.00
Permits	20	0.75	2.00	0.00	0.00	0.00	0.00
Submittals	60	0.75	2.00	0.00	0.00	0.00	0.00
Precast Fab	300	0.75	2.00	0.00	0.00	0.00	0.00
Elevator Fab	90	0.75	2.00	0.00	0.00	0.00	0.00
Mobilize	10	0.75	2.00	0.00	0.00	1.00	2.00
Demo	5	0.75	2.00	0.00	0.00	1.00	2.00
Curb&Gutter/Sidewalk	15	0.75	2.00	0.00	0.00	1.00	2.00
Landscaping	15	0.75	2.00	0.00	0.00	1.00	2.00
Deep Foundations	138	0.75	2.00	0.00	0.00	1.00	2.00
Shallow Foundations	105	0.75	2.00	0.00	0.00	1.00	2.00
M&E UG	25	0.75	2.00	0.00	0.00	1.00	2.00
Prep SOG	70	0.75	2.00	0.00	0.00	1.00	2.00
Pour SOG	143	0.75	2.00	0.00	0.00	1.00	2.00
Erect Precast Columns	155	0.75	2.00	0.00	0.00	1.00	2.00
Install Precast Beams	203	0.75	2.00	0.00	0.00	1.00	2.00
*FRP Slab	600	0.75	2.00	0.00	0.00	1.00	2.00
Stress P/T	120	0.75	2.00	0.00	0.00	1.00	2.00
Strip Slab Formwork	120	0.75	2.00	0.00	0.00	1.00	2.00
Elevator Shafts	200	0.75	2.00	0.00	0.00	1.00	2.00
Install Stairs	35	0.75	2.00	0.00	0.00	1.00	2.00
Install Elevators	60	0.75	2.00	0.00	0.00	1.00	2.00
Install Exterior Façade	103	0.75	2.00	0.00	0.00	1.00	2.00
M&E R-in	200	0.75	2.00	0.00	0.00	1.00	2.00
Fire Protection	234	0.75	2.00	0.00	0.00	1.00	2.00
Inspections	15	0.75	2.00	0.00	0.00	0.00	0.00

Skill of Workforce (Quality of Subs)

		Unfavourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	0.50	1.74	0.33	0.00	0.00	0
Permits	20	0.50	1.74	0.33	0.00	0.00	0.00
Submittals	60	0.50	1.74	0.33	0.00	1.00	1.05
Precast Fab	300	0.50	1.74	0.33	0.00	0.50	0.52
Elevator Fab	90	0.50	1.74	0.33	0.00	0.50	0.52
Mobilize	10	0.50	1.74	0.33	0.00	0.25	0.26
Demo	5	0.50	1.74	0.33	0.00	1.00	1.05
Curb&Gutter/Sidewalk	15	0.50	1.74	0.33	0.00	0.50	0.52
Landscaping	15	0.50	1.74	0.33	0.00	0.50	0.52
Deep Foundations	138	0.50	1.74	0.33	0.00	1.00	1.05
Shallow Foundations	105	0.50	1.74	0.33	0.00	1.00	1.05
M&E UG	25	0.50	1.74	0.33	0.00	1.00	1.05
Prep SOG	70	0.50	1.74	0.33	0.00	0.75	0.79
Pour SOG	143	0.50	1.74	0.33	0.00	0.75	0.79
Erect Precast Columns	155	0.50	1.74	0.33	0.00	1.00	1.05
Install Precast Beams	203	0.50	1.74	0.33	0.00	1.00	1.05
*FRP Slab	600	0.50	1.74	0.33	0.00	1.00	1.05
Stress P/T	120	0.50	1.74	0.33	0.00	0.19	0.20
Strip Slab Formwork	120	0.50	1.74	0.33	0.00	0.25	0.26
Elevator Shafts	200	0.50	1.74	0.33	0.00	1.00	1.05
Install Stairs	35	0.50	1.74	0.33	0.00	1.00	1.05
Install Elevators	60	0.50	1.74	0.33	0.00	1.00	1.05
Install Exterior Façade	103	0.50	1.74	0.33	0.00	1.00	1.05
M&E R-in	200	0.50	1.74	0.33	0.00	1.00	1.05
Fire Protection	234	0.50	1.74	0.33	0.00	1.00	1.05
Inspections	15	0.50	1.74	0.33	0.00	0.00	0.00

Activity	Initial Duration	FES	Scott	Error $(\Delta_S-\Delta_{FES})/\Delta_S$
Award Subcontracts	35	35	35	Infinity
Permits	20	20	20	Infinity
Submittals	60	154	80	-3.7196
Precast Fab	300	615	330	-9.4910
Elevator Fab	90	184	90	Infinity
Mobilize	10	38	10	Infinity
Demo	5	23	5	Infinity
Curb&Gutter/Sidewalk	15	61	15	Infinity
Landscaping	15	61	15	Infinity
Deep Foundations	138	631	150	-40.0917
Shallow Foundations	105	480	105	Infinity
M&E UG	25	114	30	-16.8660
Prep SOG	70	302	70	Infinity
Pour SOG	143	616	143	Infinity
Erect Precast Columns	155	709	175	-26.6922
Install Precast Beams	203	928	220	-41.6681
*FRP Slab	600	2744	620	-106.1958
Stress P/T	120	447	120	Infinity
Strip Slab Formwork	120	454	120	Infinity
Elevator Shafts	200	915	200	Infinity
Install Stairs	35	160	45	-11.5062
Install Elevators	60	274	60	Infinity
Install Exterior Façade	103	471	120	-20.6493
M&E R-in	200	915	215	-46.6426
Fire Protection	234	1070	245	-75.0116
Inspections	15	15	15	Infinity

Scenario 5 - Linguistic Descriptors

Ground Conditions: Favourable
Disputes in Contract Interpretation: Unfavourable
Design Errors/Completeness of Design: Unfavourable
Quality of Initial Schedule Plan: Unfavourable
Quality of Workmanship: Favourable

Ground Conditions

		Favourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	1.00	-0.20	0.45	0.00	0.00	0.00
Permits	20	1.00	-0.20	0.45	0.00	0.00	0.00
Submittals	60	1.00	-0.20	0.45	0.00	0.00	0.00
Precast Exterior Fab	40	1.00	-0.20	0.45	0.00	0.00	0.00
Elevator Fab	30	1.00	-0.20	0.45	0.00	0.00	0.00
Mobilize	10	1.00	-0.20	0.45	0.00	0.00	0.00
Demo	5	1.00	-0.20	0.45	0.00	0.50	-0.07
Curb&Gutter/Sidewalk	15	1.00	-0.20	0.45	0.00	0.50	-0.07
Landscaping	15	1.00	-0.20	0.45	0.00	0.50	-0.07
Shallow Foundations	57	1.00	-0.20	0.45	0.00	0.75	-0.10
M&E UG	25	1.00	-0.20	0.45	0.00	1.00	-0.14
Prep SOG	13	1.00	-0.20	0.45	0.00	0.50	-0.07
Pour SOG	26	1.00	-0.20	0.45	0.00	0.00	0.00
Ground Level Columns	21	1.00	-0.20	0.45	0.00	0.00	0.00
Column Caps	36	1.00	-0.20	0.45	0.00	0.00	0.00
*FRP Slab	180	1.00	-0.20	0.45	0.00	0.00	0.00
Stress P/T	36	1.00	-0.20	0.45	0.00	0.00	0.00
Strip Slab Formwork	36	1.00	-0.20	0.45	0.00	0.00	0.00
*CIP Columns	180	1.00	-0.20	0.45	0.00	0.00	0.00
Elevator Shafts	72	1.00	-0.20	0.45	0.00	0.00	0.00
Install Stairs	25	1.00	-0.20	0.45	0.00	0.00	0.00
Install Elevators	20	1.00	-0.20	0.45	0.00	0.00	0.00
Install Exterior Façade	29	1.00	-0.20	0.45	0.00	0.00	0.00
M&E R-in	45	1.00	-0.20	0.45	0.00	0.00	0.00
Fire Protection	30	1.00	-0.20	0.45	0.00	0.00	0.00
Inspections	15	1.00	-0.20	0.45	0.00	0.00	0.00

Disputes in Contract Interpretation

		Unfavourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	1.00	2.51	0.50	0.00	1.00	1.67
Permits	20	1.00	2.51	0.50	0.00	0.00	0.00
Submittals	60	1.00	2.51	0.50	0.00	1.00	1.67
Precast Exterior Fab	40	1.00	2.51	0.50	0.00	1.00	1.67
Elevator Fab	30	1.00	2.51	0.50	0.00	1.00	1.67
Mobilize	10	1.00	2.51	0.50	0.00	1.00	1.67
Demo	5	1.00	2.51	0.50	0.00	1.00	1.67
Curb&Gutter/Sidewalk	15	1.00	2.51	0.50	0.00	1.00	1.67
Landscaping	15	1.00	2.51	0.50	0.00	1.00	1.67
Shallow Foundations	57	1.00	2.51	0.50	0.00	1.00	1.67
M&E UG	25	1.00	2.51	0.50	0.00	1.00	1.67
Prep SOG	13	1.00	2.51	0.50	0.00	1.00	1.67
Pour SOG	26	1.00	2.51	0.50	0.00	1.00	1.67
Ground Level Columns	21	1.00	2.51	0.50	0.00	1.00	1.67
Column Caps	36	1.00	2.51	0.50	0.00	1.00	1.67
*FRP Slab	180	1.00	2.51	0.50	0.00	1.00	1.67
Stress P/T	36	1.00	2.51	0.50	0.00	1.00	1.67
Strip Slab Formwork	36	1.00	2.51	0.50	0.00	1.00	1.67
*CIP Columns	180	1.00	2.51	0.50	0.00	1.00	1.67
Elevator Shafts	72	1.00	2.51	0.50	0.00	1.00	1.67
Install Stairs	25	1.00	2.51	0.50	0.00	1.00	1.67
Install Elevators	20	1.00	2.51	0.50	0.00	1.00	1.67
Install Exterior Façade	29	1.00	2.51	0.50	0.00	1.00	1.67
M&E R-in	45	1.00	2.51	0.50	0.00	1.00	1.67
Fire Protection	30	1.00	2.51	0.50	0.00	1.00	1.67
Inspections	15	1.00	2.51	0.50	0.00	0.00	0.00

Design Errors/Completeness of Design

		Unfavourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	1.00	0.80	0.40	0.00	1.00	0.57
Permits	20	1.00	0.80	0.40	0.00	1.00	0.57
Submittals	60	1.00	0.80	0.40	0.00	1.00	0.57
Precast Exterior Fab	40	1.00	0.80	0.40	0.00	0.25	0.14

Elevator Fab	30	1.00	0.80	0.40	0.00	0.25	0.14
Mobilize	10	1.00	0.80	0.40	0.00	0.00	0.00
Demo	5	1.00	0.80	0.40	0.00	0.50	0.29
Curb&Gutter/Sidewalk	15	1.00	0.80	0.40	0.00	0.25	0.14
Landscaping	15	1.00	0.80	0.40	0.00	0.25	0.14
Shallow Foundations	57	1.00	0.80	0.40	0.00	0.50	0.29
M&E UG	25	1.00	0.80	0.40	0.00	1.00	0.57
Prep SOG	13	1.00	0.80	0.40	0.00	0.50	0.29
Pour SOG	26	1.00	0.80	0.40	0.00	0.50	0.29
Ground Level Columns	21	1.00	0.80	0.40	0.00	0.50	0.29
Column Caps	36	1.00	0.80	0.40	0.00	0.50	0.29
*FRP Slab	180	1.00	0.80	0.40	0.00	0.50	0.29
Stress P/T	36	1.00	0.80	0.40	0.00	0.25	0.14
Strip Slab Formwork	36	1.00	0.80	0.40	0.00	0.25	0.14
*CIP Columns	180	1.00	0.80	0.40	0.00	0.50	0.29
Elevator Shafts	72	1.00	0.80	0.40	0.00	0.75	0.43
Install Stairs	25	1.00	0.80	0.40	0.00	0.50	0.29
Install Elevators	20	1.00	0.80	0.40	0.00	0.50	0.29
Install Exterior Façade	29	1.00	0.80	0.40	0.00	0.67	0.38
M&E R-in	45	1.00	0.80	0.40	0.00	1.00	0.57
Fire Protection	30	1.00	0.80	0.40	0.00	1.00	0.57
Inspections	15	1.00	0.80	0.40	0.00	0.00	0.00

Quality of Initial Schedule Plan

		Unfavourable			Normal			
Activity	Initial Duration	MF Value	Rand	Output	MF Value	Rand	Output	Scaled Var.
Award Subcontracts	35	1.00	0.48	-0.25	0.50	0.14	-0.05	-0.18
Permits	20	1.00	0.05	-0.25	0.50	1.00	0.05	-0.15
Submittals	60	1.00	0.75	0.25	0.50	0.07	-0.05	0.15
Precast Exterior Fab	40	1.00	0.54	0.25	0.50	0.46	-0.05	0.15
Elevator Fab	30	1.00	0.96	0.25	0.50	0.24	-0.05	0.15
Mobilize	10	1.00	0.09	-0.25	0.50	0.74	0.05	-0.15
Demo	5	1.00	0.07	-0.25	0.50	0.19	-0.05	-0.18
Curb&Gutter/Sidewalk	15	1.00	0.62	0.25	0.50	0.20	-0.05	0.15
Landscaping	15	1.00	0.63	0.25	0.50	0.45	-0.05	0.15
Shallow Foundations	57	1.00	0.91	0.25	0.50	0.12	-0.05	0.15
M&E UG	25	1.00	0.39	-0.25	0.50	0.62	0.05	-0.15
Prep SOG	13	1.00	0.42	-0.25	0.50	0.83	0.05	-0.15
Pour SOG	26	1.00	0.12	-0.25	0.50	0.68	0.05	-0.15
Ground Level Columns	21	1.00	0.68	0.25	0.50	0.19	-0.05	0.15
Column Caps	36	1.00	0.52	0.25	0.50	0.23	-0.05	0.15
*FRP Slab	180	1.00	0.77	0.25	0.50	0.69	0.05	0.18
Stress P/T	36	1.00	0.22	-0.25	0.50	0.17	-0.05	-0.18
Strip Slab Formwork	36	1.00	0.29	-0.25	0.50	0.85	0.05	-0.15
*CIP Columns	180	1.00	0.39	-0.25	0.50	0.28	-0.05	-0.18
Elevator Shafts	72	1.00	0.79	0.25	0.50	0.86	0.05	0.18
Install Stairs	25	1.00	0.63	0.25	0.50	0.06	-0.05	0.15
Install Elevators	20	1.00	0.98	0.25	0.50	0.89	0.05	0.18
Install Exterior Façade	29	1.00	0.36	-0.25	0.50	0.99	0.05	-0.15
M&E R-in	45	1.00	0.98	0.25	0.50	0.96	0.05	0.18
Fire Protection	30	1.00	0.59	0.25	0.50	0.01	-0.05	0.15
Inspections	15	1.00	0.61	0.25	0.50	0.57	0.05	0.18

Quality of Workmanship

		Favourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	1.00	-0.10	0.50	0.00	0.00	0.00
Permits	20	1.00	-0.10	0.50	0.00	0.00	0.00
Submittals	60	1.00	-0.10	0.50	0.00	0.00	0.00
Precast Exterior Fab	40	1.00	-0.10	0.50	0.00	1.00	-0.07
Elevator Fab	30	1.00	-0.10	0.50	0.00	0.25	-0.02
Mobilize	10	1.00	-0.10	0.50	0.00	0.00	0.00
Demo	5	1.00	-0.10	0.50	0.00	0.25	-0.02
Curb&Gutter/Sidewalk	15	1.00	-0.10	0.50	0.00	0.50	-0.03
Landscaping	15	1.00	-0.10	0.50	0.00	0.50	-0.03
Shallow Foundations	57	1.00	-0.10	0.50	0.00	0.25	-0.02
M&E UG	25	1.00	-0.10	0.50	0.00	0.50	-0.03
Prep SOG	13	1.00	-0.10	0.50	0.00	0.25	-0.02
Pour SOG	26	1.00	-0.10	0.50	0.00	0.25	-0.02
Ground Level Columns	21	1.00	-0.10	0.50	0.00	0.25	-0.02
Column Caps	36	1.00	-0.10	0.50	0.00	0.25	-0.02
*FRP Slab	180	1.00	-0.10	0.50	0.00	0.25	-0.02
Stress P/T	36	1.00	-0.10	0.50	0.00	1.00	-0.07
Strip Slab Formwork	36	1.00	-0.10	0.50	0.00	0.10	-0.01

*CIP Columns	180	1.00	-0.10	0.50	0.00	0.25	-0.02
Elevator Shafts	72	1.00	-0.10	0.50	0.00	0.25	-0.02
Install Stairs	25	1.00	-0.10	0.50	0.00	1.00	-0.07
Install Elevators	20	1.00	-0.10	0.50	0.00	1.00	-0.07
Install Exterior Façade	29	1.00	-0.10	0.50	0.00	1.00	-0.07
M&E R-in	45	1.00	-0.10	0.50	0.00	0.50	-0.03
Fire Protection	30	1.00	-0.10	0.50	0.00	0.50	-0.03
Inspections	15	1.00	-0.10	0.50	0.00	0.00	0.00

Activity	Initial Duration	FES	Scott	Error Δ_S-Δ_{FES}/Δ_S
Award Subcontracts	35	107	35	Infinity
Permits	20	28	20	Infinity
Submittals	60	204	80	-6.1843
Precast Exterior Fab	40	116	45	-14.1962
Elevator Fab	30	88	60	-0.9495
Mobilize	10	25	10	Infinity
Demo	5	13	5	Infinity
Curb&Gutter/Sidewalk	15	43	15	Infinity
Landscaping	15	43	15	Infinity
Shallow Foundations	57	170	40	7.6688
M&E UG	25	73	25	Infinity
Prep SOG	13	35	13	Infinity
Pour SOG	26	73	26	Infinity
Ground Level Columns	21	65	21	Infinity
Column Caps	36	111	36	Infinity
*FRP Slab	180	563	180	Infinity
Stress P/T	36	92	36	Infinity
Strip Slab Formwork	36	96	36	Infinity
*CIP Columns	180	497	180	Infinity
Elevator Shafts	72	235	72	Infinity
Install Stairs	25	76	25	Infinity
Install Elevators	20	62	20	Infinity
Install Exterior Façade	29	82	30	-52.3462
M&E R-in	45	153	45	Infinity
Fire Protection	30	101	45	-3.7229
Inspections	15	18	15	Infinity

Scenario 5 - Crisp Ratings

Ground Conditions: 3
Disputes in Contract Interpretation: -4
Design Errors/Completeness of Design: -3
Quality of Initial Schedule Plan: -2
Quality of Workmanship: 2

Ground Conditions

		Favourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	0.60	-0.20	0.25	0.00	0.00	0.00
Permits	20	0.60	-0.20	0.25	0.00	0.00	0.00
Submittals	60	0.60	-0.20	0.25	0.00	0.00	0.00
Precast Exterior Fab	40	0.60	-0.20	0.25	0.00	0.00	0.00
Elevator Fab	30	0.60	-0.20	0.25	0.00	0.00	0.00
Mobilize	10	0.60	-0.20	0.25	0.00	0.00	0.00
Demo	5	0.60	-0.20	0.25	0.00	0.50	-0.07
Curb&Gutter/Sidewalk	15	0.60	-0.20	0.25	0.00	0.50	-0.07
Landscaping	15	0.60	-0.20	0.25	0.00	0.50	-0.07
Shallow Foundations	57	0.60	-0.20	0.25	0.00	0.75	-0.11
M&E UG	25	0.60	-0.20	0.25	0.00	1.00	-0.14
Prep SOG	13	0.60	-0.20	0.25	0.00	0.50	-0.07
Pour SOG	26	0.60	-0.20	0.25	0.00	0.00	0.00
Ground Level Columns	21	0.60	-0.20	0.25	0.00	0.00	0.00
Column Caps	36	0.60	-0.20	0.25	0.00	0.00	0.00
*FRP Slab	180	0.60	-0.20	0.25	0.00	0.00	0.00
Stress P/T	36	0.60	-0.20	0.25	0.00	0.00	0.00
Strip Slab Formwork	36	0.60	-0.20	0.25	0.00	0.00	0.00
*CIP Columns	180	0.60	-0.20	0.25	0.00	0.00	0.00
Elevator Shafts	72	0.60	-0.20	0.25	0.00	0.00	0.00
Install Stairs	25	0.60	-0.20	0.25	0.00	0.00	0.00
Install Elevators	20	0.60	-0.20	0.25	0.00	0.00	0.00
Install Exterior Façade	29	0.60	-0.20	0.25	0.00	0.00	0.00
M&E R-in	45	0.60	-0.20	0.25	0.00	0.00	0.00
Fire Protection	30	0.60	-0.20	0.25	0.00	0.00	0.00
Inspections	15	0.60	-0.20	0.25	0.00	0.00	0.00

Disputes in Contract Interpretation

		Unfavourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	0.80	2.51	0.20	0.00	1.00	2.01
Permits	20	0.80	2.51	0.20	0.00	0.00	0.00
Submittals	60	0.80	2.51	0.20	0.00	1.00	2.01
Precast Exterior Fab	40	0.80	2.51	0.20	0.00	1.00	2.01
Elevator Fab	30	0.80	2.51	0.20	0.00	1.00	2.01
Mobilize	10	0.80	2.51	0.20	0.00	1.00	2.01
Demo	5	0.80	2.51	0.20	0.00	1.00	2.01
Curb&Gutter/Sidewalk	15	0.80	2.51	0.20	0.00	1.00	2.01
Landscaping	15	0.80	2.51	0.20	0.00	1.00	2.01
Shallow Foundations	57	0.80	2.51	0.20	0.00	1.00	2.01
M&E UG	25	0.80	2.51	0.20	0.00	1.00	2.01
Prep SOG	13	0.80	2.51	0.20	0.00	1.00	2.01
Pour SOG	26	0.80	2.51	0.20	0.00	1.00	2.01
Ground Level Columns	21	0.80	2.51	0.20	0.00	1.00	2.01
Column Caps	36	0.80	2.51	0.20	0.00	1.00	2.01
*FRP Slab	180	0.80	2.51	0.20	0.00	1.00	2.01
Stress P/T	36	0.80	2.51	0.20	0.00	1.00	2.01
Strip Slab Formwork	36	0.80	2.51	0.20	0.00	1.00	2.01
*CIP Columns	180	0.80	2.51	0.20	0.00	1.00	2.01
Elevator Shafts	72	0.80	2.51	0.20	0.00	1.00	2.01
Install Stairs	25	0.80	2.51	0.20	0.00	1.00	2.01
Install Elevators	20	0.80	2.51	0.20	0.00	1.00	2.01
Install Exterior Façade	29	0.80	2.51	0.20	0.00	1.00	2.01
M&E R-in	45	0.80	2.51	0.20	0.00	1.00	2.01
Fire Protection	30	0.80	2.51	0.20	0.00	1.00	2.01
Inspections	15	0.80	2.51	0.20	0.00	0.00	0.00

Design Errors/Completeness of Design

		Unfavourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	0.50	0.80	0.33	0.00	1.00	0.48
Permits	20	0.50	0.80	0.33	0.00	1.00	0.48

Submittals	60	0.50	0.80	0.33	0.00	1.00	0.48
Precast Exterior Fab	40	0.50	0.80	0.33	0.00	0.25	0.12
Elevator Fab	30	0.50	0.80	0.33	0.00	0.25	0.12
Mobilize	10	0.50	0.80	0.33	0.00	0.00	0.00
Demo	5	0.50	0.80	0.33	0.00	0.50	0.24
Curb&Gutter/Sidewalk	15	0.50	0.80	0.33	0.00	0.25	0.12
Landscaping	15	0.50	0.80	0.33	0.00	0.25	0.12
Shallow Foundations	57	0.50	0.80	0.33	0.00	0.50	0.24
M&E UG	25	0.50	0.80	0.33	0.00	1.00	0.48
Prep SOG	13	0.50	0.80	0.33	0.00	0.50	0.24
Pour SOG	26	0.50	0.80	0.33	0.00	0.50	0.24
Ground Level Columns	21	0.50	0.80	0.33	0.00	0.50	0.24
Column Caps	36	0.50	0.80	0.33	0.00	0.50	0.24
*FRP Slab	180	0.50	0.80	0.33	0.00	0.50	0.24
Stress P/T	36	0.50	0.80	0.33	0.00	0.25	0.12
Strip Slab Formwork	36	0.50	0.80	0.33	0.00	0.25	0.12
*CIP Columns	180	0.50	0.80	0.33	0.00	0.50	0.24
Elevator Shafts	72	0.50	0.80	0.33	0.00	0.75	0.36
Install Stairs	25	0.50	0.80	0.33	0.00	0.50	0.24
Install Elevators	20	0.50	0.80	0.33	0.00	0.50	0.24
Install Exterior Façade	29	0.50	0.80	0.33	0.00	0.67	0.32
M&E R-in	45	0.50	0.80	0.33	0.00	1.00	0.48
Fire Protection	30	0.50	0.80	0.33	0.00	1.00	0.48
Inspections	15	0.50	0.80	0.33	0.00	0.00	0.00

Quality of Initial Schedule Plan

		Unfavourable			Normal			
Activity	Initial Duration	MF Value	Rand	Output	MF Value	Rand	Output	Scaled Var.
Award Subcontracts	35	0.75	0.48	-0.25	0.25	0.14	-0.05	-0.20
Permits	20	0.75	0.05	-0.25	0.25	1.00	0.05	-0.18
Submittals	60	0.75	0.75	0.25	0.25	0.07	-0.05	0.18
Precast Exterior Fab	40	0.75	0.54	0.25	0.25	0.46	-0.05	0.18
Elevator Fab	30	0.75	0.96	0.25	0.25	0.24	-0.05	0.18
Mobilize	10	0.75	0.09	-0.25	0.25	0.74	0.05	-0.18
Demo	5	0.75	0.07	-0.25	0.25	0.19	-0.05	-0.20
Curb&Gutter/Sidewalk	15	0.75	0.62	0.25	0.25	0.20	-0.05	0.18
Landscaping	15	0.75	0.63	0.25	0.25	0.45	-0.05	0.18
Shallow Foundations	57	0.75	0.91	0.25	0.25	0.12	-0.05	0.18
M&E UG	25	0.75	0.39	-0.25	0.25	0.62	0.05	-0.18
Prep SOG	13	0.75	0.42	-0.25	0.25	0.83	0.05	-0.18
Pour SOG	26	0.75	0.12	-0.25	0.25	0.68	0.05	-0.18
Ground Level Columns	21	0.75	0.68	0.25	0.25	0.19	-0.05	0.18
Column Caps	36	0.75	0.52	0.25	0.25	0.23	-0.05	0.18
*FRP Slab	180	0.75	0.77	0.25	0.25	0.69	0.05	0.20
Stress P/T	36	0.75	0.22	-0.25	0.25	0.17	-0.05	-0.20
Strip Slab Formwork	36	0.75	0.29	-0.25	0.25	0.85	0.05	-0.18
*CIP Columns	180	0.75	0.39	-0.25	0.25	0.28	-0.05	-0.20
Elevator Shafts	72	0.75	0.79	0.25	0.25	0.86	0.05	0.20
Install Stairs	25	0.75	0.63	0.25	0.25	0.06	-0.05	0.18
Install Elevators	20	0.75	0.98	0.25	0.25	0.89	0.05	0.20
Install Exterior Façade	29	0.75	0.36	-0.25	0.25	0.99	0.05	-0.18
M&E R-in	45	0.75	0.98	0.25	0.25	0.96	0.05	0.20
Fire Protection	30	0.75	0.59	0.25	0.25	0.01	-0.05	0.18
Inspections	15	0.75	0.61	0.25	0.25	0.57	0.05	0.20

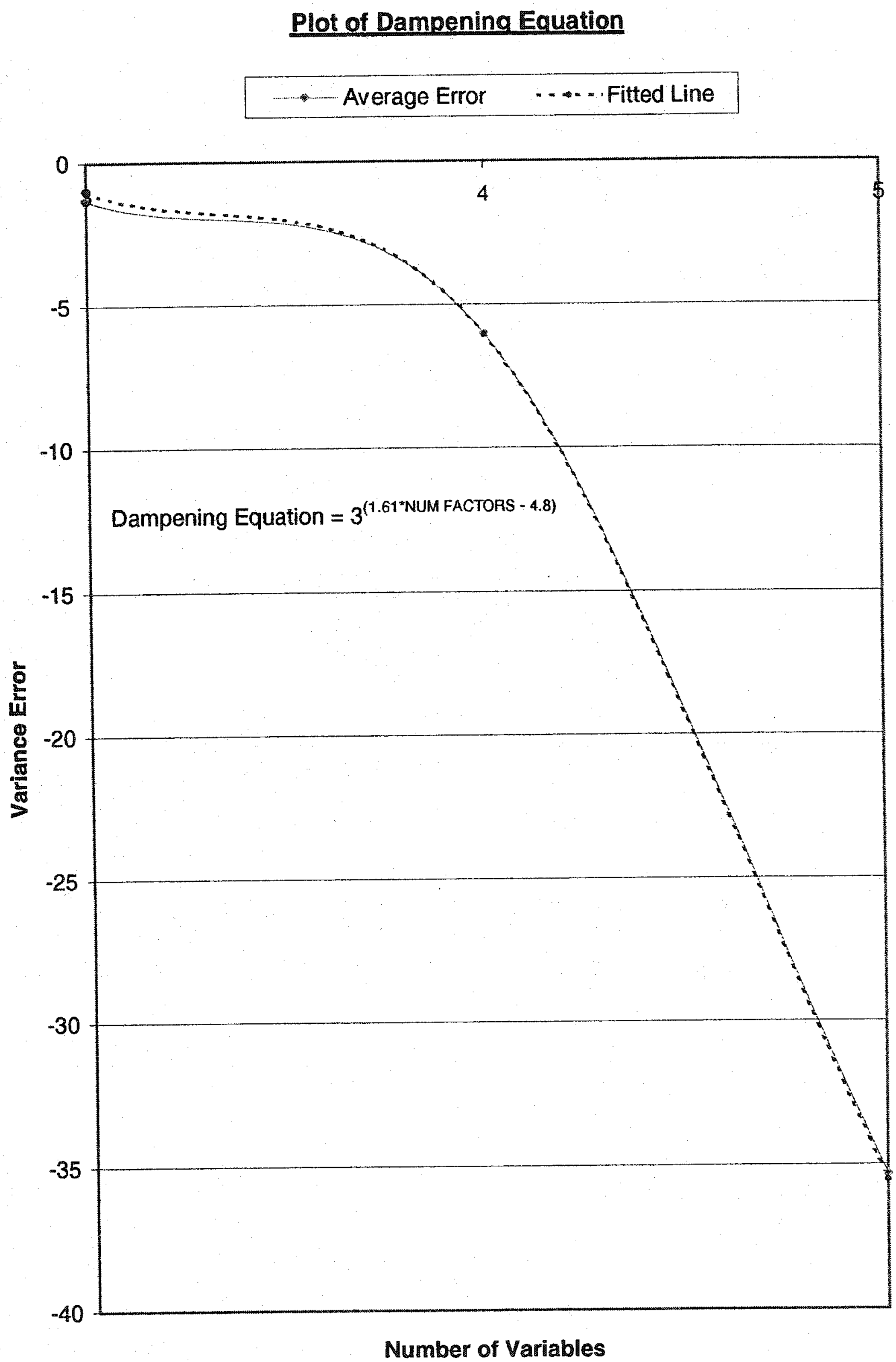
Quality of Workmanship

		Favourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	1.00	-0.10	0.00	0.00	0.00	0.00
Permits	20	1.00	-0.10	0.00	0.00	0.00	0.00
Submittals	60	1.00	-0.10	0.00	0.00	0.00	0.00
Precast Exterior Fab	40	1.00	-0.10	0.00	0.00	1.00	-0.10
Elevator Fab	30	1.00	-0.10	0.00	0.00	0.25	-0.03
Mobilize	10	1.00	-0.10	0.00	0.00	0.00	0.00
Demo	5	1.00	-0.10	0.00	0.00	0.25	-0.03
Curb&Gutter/Sidewalk	15	1.00	-0.10	0.00	0.00	0.50	-0.05
Landscaping	15	1.00	-0.10	0.00	0.00	0.50	-0.05
Shallow Foundations	57	1.00	-0.10	0.00	0.00	0.25	-0.03
M&E UG	25	1.00	-0.10	0.00	0.00	0.50	-0.05
Prep SOG	13	1.00	-0.10	0.00	0.00	0.25	-0.03
Pour SOG	26	1.00	-0.10	0.00	0.00	0.25	-0.03
Ground Level Columns	21	1.00	-0.10	0.00	0.00	0.25	-0.03

Column Caps	36	1.00	-0.10	0.00	0.00	0.25	-0.03
*FRP Slab	180	1.00	-0.10	0.00	0.00	0.25	-0.03
Stress P/T	36	1.00	-0.10	0.00	0.00	1.00	-0.10
Strip Slab Formwork	36	1.00	-0.10	0.00	0.00	0.10	-0.01
*CIP Columns	180	1.00	-0.10	0.00	0.00	0.25	-0.03
Elevator Shafts	72	1.00	-0.10	0.00	0.00	0.25	-0.03
Install Stairs	25	1.00	-0.10	0.00	0.00	1.00	-0.10
Install Elevators	20	1.00	-0.10	0.00	0.00	1.00	-0.10
Install Exterior Façade	29	1.00	-0.10	0.00	0.00	1.00	-0.10
M&E R-in	45	1.00	-0.10	0.00	0.00	0.50	-0.05
Fire Protection	30	1.00	-0.10	0.00	0.00	0.50	-0.05
Inspections	15	1.00	-0.10	0.00	0.00	0.00	0.00

Activity	Initial Duration	FES	AI	Error Δ_A-Δ_{FES}/Δ_A
Award Subcontracts	35	120	35	Infinity
Permits	20	31	20	Infinity
Submittals	60	206	63	-47.7986
Precast Exterior Fab	40	119	40	Infinity
Elevator Fab	30	92	30	Infinity
Mobilize	10	31	10	Infinity
Demo	5	16	4	11.5169
Curb&Gutter/Sidewalk	15	44	14	30.3684
Landscaping	15	44	13	15.6842
Shallow Foundations	57	175	57	Infinity
M&E UG	25	84	25	Infinity
Prep SOG	13	42	11	15.3219
Pour SOG	26	85	26	Infinity
Ground Level Columns	21	67	21	Infinity
Column Caps	36	114	36	Infinity
*FRP Slab	180	589	175	82.8627
Stress P/T	36	107	37	-70.2253
Strip Slab Formwork	36	114	36	Infinity
*CIP Columns	180	571	180	Infinity
Elevator Shafts	72	244	75	-56.4667
Install Stairs	25	77	25	Infinity
Install Elevators	20	64	20	Infinity
Install Exterior Façade	29	95	30	-65.1459
M&E R-in	45	157	48	-36.3489
Fire Protection	30	102	30	Infinity
Inspections	15	16	15	Infinity

APPENDIX R – GRAPH REPRESENTING DAMPENING EQUATION


Plot of Dampening Equation
Average Error
Fitted Line
0
-5
-10
-15
-20
-25
-30
-35
-40
3
4
5
Dampening Equation = 3(1.61*NUM FACTORS - 4.8)
Variance Error
Number of Variables

APPENDIX S – RESULTS OF CALIBRATION

Scenario 3 - Crisp Ratings

Timeliness of Permitting/Inspections: -5
Interference by Owner: 4
Changes to Design: -3
Quality of Workmanship: -3

Timeliness of Permitting/Inspections

		Unfavourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	1.00	2.00	0.00	0.00	0.00	0.00
Permits	20	1.00	2.00	0.00	0.00	1.00	2.00
Submittals	60	1.00	2.00	0.00	0.00	0.00	0.00
Precast Fab	237	1.00	2.00	0.00	0.00	0.00	0.00
Elevator Fab	90	1.00	2.00	0.00	0.00	0.00	0.00
Mobilize	10	1.00	2.00	0.00	0.00	0.00	0.00
Demo	5	1.00	2.00	0.00	0.00	0.00	0.00
Curb&Gutter/Sidewalk	15	1.00	2.00	0.00	0.00	0.00	0.00
Landscaping	15	1.00	2.00	0.00	0.00	0.00	0.00
Bulk Excavation	69	1.00	2.00	0.00	0.00	0.00	0.00
Deep Foundations	62	1.00	2.00	0.00	0.00	0.00	0.00
Shallow Foundations	47	1.00	2.00	0.00	0.00	0.00	0.00
Foundation Walls	167	1.00	2.00	0.00	0.00	0.00	0.00
M&E UG	25	1.00	2.00	0.00	0.00	0.00	0.00
Prep SOG	32	1.00	2.00	0.00	0.00	0.00	0.00
Pour SOG	65	1.00	2.00	0.00	0.00	0.00	0.00
Erect Precast Structure	315	1.00	2.00	0.00	0.00	0.00	0.00
Place Topping	141	1.00	2.00	0.00	0.00	0.00	0.00
Elevator Shafts	286	1.00	2.00	0.00	0.00	0.00	0.00
Install Stairs	40	1.00	2.00	0.00	0.00	0.00	0.00
Install Elevators	60	1.00	2.00	0.00	0.00	0.00	0.00
Install Exterior Façade	58	1.00	2.00	0.00	0.00	0.00	0.00
M&E R-in	180	1.00	2.00	0.00	0.00	0.00	0.00
Fire Protection	120	1.00	2.00	0.00	0.00	0.00	0.00
Inspections	15	1.00	2.00	0.00	0.00	1.00	2.00

Interference by Owner

Activity	Initial Duration	Favourable		Normal		Sensitivity	Scaled Var.
		MF Value	Output	MF Value	Output		
Award Subcontracts	35	1.00	-0.10	0.00	0.00	1.00	-0.10
Permits	20	1.00	-0.10	0.00	0.00	0.00	0.00
Submittals	60	1.00	-0.10	0.00	0.00	1.00	-0.10
Precast Fab	237	1.00	-0.10	0.00	0.00	1.00	-0.10
Elevator Fab	90	1.00	-0.10	0.00	0.00	1.00	-0.10
Mobilize	10	1.00	-0.10	0.00	0.00	1.00	-0.10
Demo	5	1.00	-0.10	0.00	0.00	1.00	-0.10
Curb&Gutter/Sidewalk	15	1.00	-0.10	0.00	0.00	1.00	-0.10
Landscaping	15	1.00	-0.10	0.00	0.00	1.00	-0.10
Bulk Excavation	69	1.00	-0.10	0.00	0.00	1.00	-0.10
Deep Foundations	62	1.00	-0.10	0.00	0.00	1.00	-0.10
Shallow Foundations	47	1.00	-0.10	0.00	0.00	1.00	-0.10
Foundation Walls	167	1.00	-0.10	0.00	0.00	1.00	-0.10
M&E UG	25	1.00	-0.10	0.00	0.00	1.00	-0.10
Prep SOG	32	1.00	-0.10	0.00	0.00	1.00	-0.10
Pour SOG	65	1.00	-0.10	0.00	0.00	1.00	-0.10
Erect Precast Structure	315	1.00	-0.10	0.00	0.00	1.00	-0.10
Place Topping	141	1.00	-0.10	0.00	0.00	1.00	-0.10
Elevator Shafts	286	1.00	-0.10	0.00	0.00	1.00	-0.10
Install Stairs	40	1.00	-0.10	0.00	0.00	1.00	-0.10
Install Elevators	60	1.00	-0.10	0.00	0.00	1.00	-0.10
Install Exterior Façade	58	1.00	-0.10	0.00	0.00	1.00	-0.10
M&E R-in	180	1.00	-0.10	0.00	0.00	1.00	-0.10
Fire Protection	120	1.00	-0.10	0.00	0.00	1.00	-0.10
Inspections	15	1.00	-0.10	0.00	0.00	1.00	-0.10

Changes to Design (Change Orders)

Activity	Initial Duration	Unfavourable		Normal		Sensitivity	Scaled Var.
		MF Value	Output	MF Value	Output		
Award Subcontracts	35	0.50	2.05	1.00	0.00	1.00	0.68

Permits	20	0.50	2.05	1.00	0.00	1.00	0.68
Submittals	60	0.50	2.05	1.00	0.00	1.00	0.68
Precast Fab	237	0.50	2.05	1.00	0.00	1.00	0.68
Elevator Fab	90	0.50	2.05	1.00	0.00	1.00	0.68
Mobilize	10	0.50	2.05	1.00	0.00	0.00	0.00
Demo	5	0.50	2.05	1.00	0.00	1.00	0.68
Curb&Gutter/Sidewalk	15	0.50	2.05	1.00	0.00	0.50	0.34
Landscaping	15	0.50	2.05	1.00	0.00	0.50	0.34
Bulk Excavation	69	0.50	2.05	1.00	0.00	1.00	0.68
Deep Foundations	62	0.50	2.05	1.00	0.00	0.50	0.34
Shallow Foundations	47	0.50	2.05	1.00	0.00	0.50	0.34
Foundation Walls	167	0.50	2.05	1.00	0.00	0.15	0.10
M&E UG	25	0.50	2.05	1.00	0.00	0.25	0.17
Prep SOG	32	0.50	2.05	1.00	0.00	0.25	0.17
Pour SOG	65	0.50	2.05	1.00	0.00	0.31	0.21
Erect Precast Structure	315	0.50	2.05	1.00	0.00	0.50	0.34
Place Topping	141	0.50	2.05	1.00	0.00	0.10	0.07
Elevator Shafts	286	0.50	2.05	1.00	0.00	0.64	0.44
Install Stairs	40	0.50	2.05	1.00	0.00	0.50	0.34
Install Elevators	60	0.50	2.05	1.00	0.00	0.25	0.17
Install Exterior Façade	58	0.50	2.05	1.00	0.00	0.75	0.51
M&E R-in	180	0.50	2.05	1.00	0.00	0.25	0.17
Fire Protection	120	0.50	2.05	1.00	0.00	0.24	0.16
Inspections	15	0.50	2.05	1.00	0.00	0.00	0.00

Quality of Workmanship

		Unfavourable		Normal			
Activity	Initial Duration	MF Value	Output	MF Value	Output	Sensitivity	Scaled Var.
Award Subcontracts	35	1.00	1.44	0.00	0.00	0.00	0.00
Permits	20	1.00	1.44	0.00	0.00	0.00	0.00
Submittals	60	1.00	1.44	0.00	0.00	0.00	0.00
Precast Fab	237	1.00	1.44	0.00	0.00	1.00	1.44
Elevator Fab	90	1.00	1.44	0.00	0.00	0.25	0.36
Mobilize	10	1.00	1.44	0.00	0.00	0.00	0.00

Demo	5	1.00	1.44	0.00	0.00	0.25	0.36
Curb&Gutter/Sidewalk	15	1.00	1.44	0.00	0.00	0.50	0.72
Landscaping	15	1.00	1.44	0.00	0.00	0.50	0.72
Bulk Excavation	69	1.00	1.44	0.00	0.00	0.25	0.36
Deep Foundations	62	1.00	1.44	0.00	0.00	0.24	0.35
Shallow Foundations	47	1.00	1.44	0.00	0.00	0.25	0.36
Foundation Walls	167	1.00	1.44	0.00	0.00	0.25	0.36
M&E UG	25	1.00	1.44	0.00	0.00	0.50	0.72
Prep SOG	32	1.00	1.44	0.00	0.00	0.25	0.36
Pour SOG	65	1.00	1.44	0.00	0.00	0.25	0.36
Erect Precast Structure	315	1.00	1.44	0.00	0.00	1.00	1.44
Place Topping	141	1.00	1.44	0.00	0.00	0.50	0.72
Elevator Shafts	286	1.00	1.44	0.00	0.00	0.25	0.36
Install Stairs	40	1.00	1.44	0.00	0.00	1.00	1.44
Install Elevators	60	1.00	1.44	0.00	0.00	1.00	1.44
Install Exterior Façade	58	1.00	1.44	0.00	0.00	1.00	1.44
M&E R-in	180	1.00	1.44	0.00	0.00	0.50	0.72
Fire Protection	120	1.00	1.44	0.00	0.00	0.50	0.72
Inspections	15	1.00	1.44	0.00	0.00	0.00	0.00

Number of Variables = 4
Scaling Factor = 6.0601

Activity	Initial Duration	FES	Jim	Scaled FES	Scaled Err Δ_J-Δ_{SFES}/Δ_J	Abs Err	Overpred. Only
Award Subcontracts	35	55	35	38	Infinity	N/A	N/A
Permits	20	74	40	29	0.5572	0.5572	N/A
Submittals	60	95	60	66	Infinity	N/A	N/A
Precast Fab	237	717	237	316	Infinity	N/A	N/A
Elevator Fab	90	175	90	104	Infinity	N/A	N/A
Mobilize	10	9	10	10	Infinity	N/A	N/A
Demo	5	10	5	6	Infinity	N/A	N/A
Curb&Gutter/Sidewalk	15	29	20	17	0.5239	0.5239	N/A
Landscaping	15	29	20	17	0.5239	0.5239	N/A
Bulk Excavation	69	134	90	80	0.4885	0.4885	N/A

Deep Foundations	62	98	90	68	0.7854	0.7854	N/A
Shallow Foundations	47	75	60	52	0.6411	0.6411	N/A
Foundation Walls	167	228	180	177	0.2316	0.2316	N/A
M&E UG	25	45	30	28	0.3475	0.3475	N/A
Prep SOG	32	46	35	34	0.2417	0.2417	N/A
Pour SOG	65	96	70	70	-0.0122	0.0122	0.0122
Erect Precast Structure	315	845	330	402	-4.8275	4.8275	4.8275
Place Topping	141	238	155	157	-0.1440	0.1440	0.1440
Elevator Shafts	286	485	300	319	-1.3507	1.3507	1.3507
Install Stairs	40	107	60	51	0.4450	0.4450	N/A
Install Elevators	60	151	60	75	Infinity	N/A	N/A
Install Exterior Façade	58	165	80	76	0.1941	0.1941	N/A
M&E R-in	180	322	200	203	-0.1745	0.1745	0.1745
Fire Protection	120	214	130	136	-0.5525	0.5525	0.5525
Inspections	15	44	30	20	0.6865	0.6865	N/A
Average						**0.7071**	**1.1769**