Development of Delays Claims Assessment Model

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Abstract

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Disputes in the construction industry originate primarily from the occurrence of delays, which are the major causes of time and cost overruns in construction projects. Delays affect project parties, the owner and the contractor. Loss of either anticipated revenue or opportunity cost, on the owner's side, and increased overhead, cost escalation and liquidated damages, on the contractor's side, are considered as the main impacts of delays on key project stakeholders. Meanwhile, preparing delay claims is a time consuming process that requires extensive resources. Facilitating this process will benefit both project parties. In this regard, this research presents a new systematic delay analysis technique that is capable of evaluating concurrent delays, while considering the critical path of the project. The developed technique precisely allocates delays among the different project parties. The technique is tested against a hypothetical case to highlight its advantages and limitations, in comparison to existing delay analysis methods. In support of the proposed technique, a robust expert system is designed to classify the different types of delays, as well as to offer recommendations on delays or delaying events. The expert system and the proposed delay analysis technique are integrated with a scheduling software which accesses to a project database. Likewise, an embedded feature of computing associated costs enhances the capability of the system. The developed system assist the analyst to reduce the time and cost associated with delay claim preparation in a systematic approach. Finally, the reliability of the integrated system is validated through a real case.

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GDP	: Gross Domestic Expenditure
CPM	: Critical Path Method
KBES	: Knowledge-Based expert Systems
EC	: Excusable Compensable
EN	: Excusable Non-Compensable
NE	: Non-Excusable Delay
EOT	: Extension of Time
TF	: Total Float
LFC	: Late Finish Cost
EFC	: Early Finish Cost
TFV	: Daily trade in value of total float
AACE	: The Association for the Advance of Cost Engineering
PERT	: The Project Evaluation and Review Technique
GIT	: Global Impact Technique
APT	: As-Planned Technique
ABT	: As-Built Technique
AABT	: Adjusted As-Built Technique
TIAT	: Time Impact Analysis Technique
BFT	: But-For Technique
MBFT	: Modified But-For Technique
IDT	: Isolated Delay Type
ICBF	: Isolated Collapsed But-For Technique
WST	: Windows Snapshot Technique
MWT	: Modified Windows Technique

DAMUDS	: Delay Analysis Method Using Delay Section
DWDA	: Daily Windows Delay Analysis
DD	:Direct Damages
CD	:Consequential Damages
BP	: Bid Price
TDW	: Time Depended Work
SOHP	:Site Overhead Percentage
PD	:Project Duration
HOOH	: Head Office Overhead
MIDT	: Modified Isolated Delay Type
FIDIC	: Fédération Internationale Des Ingénieurs Conseils
AD_{i-1}	: Actual Project Duration Before Starting Analysis Period i;
BD_i	: Baseline Schedule Duration for Analysis Period i;
ID_i^{NE}	: Impacted Schedule Duration for Analysis Period i due to NE Delays;
ID_i^{EC}	: Impacted Schedule Duration for Analysis Period i due to EC Delays;
ID_i^{EN}	: Impacted Schedule Duration for Analysis Period i due to EN Delays;
D_i^{NE}	: Difference Between $\mathrm{ID}_\mathrm{i}^\mathrm{NE}$ and Its Baseline Schedule due to NE Delays;
D_i^{EC}	: Difference Between $\mathrm{ID}_\mathrm{i}^\mathrm{EC}$ and Its Baseline Schedule due to EC Delays;
D_i^{EN}	: Difference Between $\mathrm{ID}_\mathrm{i}^\mathrm{EN}$ and Its Baseline Schedule due to EN Delays;
$R^{contractor}$	: Responsibility of Contracotr due to NE Delays
R^{Owner}	: Responsibility of Owner due to EC and EN Delays
C#	: C Sharp

Chapter 1

Introduction

1.1 Background

The construction industry is one of the largest sectors of the Canadian economy, valued at approximately $70 billion dollars in October 2009. According to Statistics Canada, the construction industry had a share of approximately 5.6% of the Gross Domestic Expenditure (GDE) in that year. From 1993 to 2009, there was a significant decrease of about 7% in the share of the Canadian construction industry. In 1993, the monetary value of construction projects was $94 billion dollars, which was 13.5% of GDE (Statistics Canada, 2009).

The construction industry has been described as a risky, complex, and multi-stakeholder business and a large number of disputes arise (Semple et al. 1994). In the domain of construction, on time and within budget completion of projects is an imperative, but delays remain an ongoing problem. As construction projects encounter costly delays, construction delay analysis has become an essential component of any large construction project (Alkass et al. 1995).

In construction, all extensions to the original time schedule are considered delays (Semple et al. 1994). In other words, delays are interpreted as the time beyond the contract completion date or past the date agreed upon between the contractor and the owner for delivering a specified project (O'Brein and Plotnick 1999).

Delays have an impact on both contract parties. The owner will be affected by the loss of anticipated revenue, by the loss of opportunity cost, and by the cost increase due to delays. The contractor will be affected by the increased overhead, by the likelihood of a cost escalation penalty or by liquidated damages (Marzouk et al. 2008). Delays may occur for one or several reasons, and Yang and Ou (2008) have classified them into six categories, as shown in Table 1.1.

Table 1.1: Causes of Construction Delay (Adopted from Yang et al., 2008)

Causes	Delay source
Contract Related:	• Change orders • Quantity change • Incorrect data provided by client • etc.
Management Related:	• Delays in material deliveries • Lack of resources • Inadequate contractor skill • etc.
Human Related:	• Labour strike • Infectious disease • War, rebellion or insurrection • etc.
Non-human Related:	• Weather • Inflation • Code or regulation change • etc.
Design Related:	• Inconsistency between site conditions and design outcomes • Complicated design • Inadequate design
Finance Related:	• Budget deficit • Contractor's financial difficulties • etc.

Too often, it is an onerous task for owners and contractors to come to an agreement on the cause(s) of a delay. Contractors try to show that the owners are responsible for any delays, while owners are prone to the view that delays are the fault of the contractor or of third parties (Zack 2001). In other words, owners and contractors have a consistently contradictory, even adversarial, perspective and motivation for deciding who (or what circumstance) is responsible for a delay (Kao *and Yang,* 2009). Delays are costly for all project parties and usually result in claims by one party to the contract on the other party.

A legal claim is described as occurring "If the Contractor considers him/herself to be entitled to any extension of the Time for Completion and or any additional payment, under any Clause of these conditions or otherwise in connection with the Contract" (FIDIC, 2006). In other words, a claim is a demand for contract modification by one of the contract parties, with the objective of allowing for a time extension, extra money or both, under contract clauses.

A sound claim is one that can address causation, liability, and damages (Keane and Caletka, 2008). Adrian (1993) defined "construction claim" as a request by a contractor for compensation, in addition to the agreed-upon contract amount, for additional work or damages supposedly resulting from events that were not included in the initial contract.

Claims may be issued for time lost, loss of productivity, price increases, interest on any remaining money, additional costs due to change orders, and others. The most common reason for construction claims are delays, which is in itself a complex concept requiring analysis. There are many methods for construction claim settlement. The common methods are negotiation, mediation, conciliation, arbitration, and litigation (Levin, 1998).

A recent study carried out in India shows that the average time taken for litigation is between 5 to 15 years after the arbitration stage (Iyer *et al.,* 2008). Claims are costly for clients and contractors, both from a monetary stance and from the point of view of relationships. Hohns (1979) states that the cost of litigation is usually 15% of the amount of money that transfers from one party to another.

Preparing delay claims demands substantial effort, as it requires the detailed review of large stacks of project documentation to classify and establish the causes of delays. This process is tedious, complicated, and costly, partly due to insufficient documentation in construction projects (Alkass et al. 1995). An effective presentation of a complicated delay claim requires both high quality and detailed information. Visual supplements such as 3D and 4D modeling in the presentation of a delay claim helps to make complex technical issues understandable. Therefore, visual aids have played a significant role in the analysis of complicated cases (Keane and Caletka, 2008).

The extraordinary increase in the power of microcomputers and their affordability has made it possible for the construction industry to use computers in its daily operations. They help construction managers evaluate the enormous amount of data required for controlling and monitoring a major project effectively and efficiently (Conlin and Retik, 1997). This research focuses on establishing a helpful and reliable computerized delay claims analysis procedure to ease the evaluation and allocation of liability for schedule delays, as well as to quantify the damages caused by delays, itself a complex procedure.

1.2 Delay Claims

The critical path method (CPM) has become the primary planning and scheduling technique in the construction industry, and most project planning software packages have adopted and built upon CPM techniques. A sound CPM schedule is a dynamic, forward looking, and transparent tool that can predict the impact of changes in a structured, logical, and systematic manner (Keane and Caletka, 2008). In large private and public construction projects, a contractor should submit a CPM schedule to the owners (client) and architect (agent), showing the critical and non-critical activities, and should update that schedule regularly (de la Garza *et al.,* 2007).

The CPM scheduling technique is an effective tool to evaluate the impact of delays on projects and to present those details in court (Levin, 1998). As the application of critical path method analysis has become a standard practice, the delay analysis assessment is much easier than before. Furthermore, by using CPM scheduling techniques, not only can delays be addressed, but also their impacts on other activities (Abdul-Malak et al., 2002). Finally, CPM scheduling provides more features for schedule analysis, such as float consumption and critical paths, and enables users to analyse what-if scenarios (Arditi and Pattanakitchamroon, 2006).

Delay analysis refers to a process of investigating events that caused the delay of a project by using either CPM or another type of scheduling technique to identify, quantify and explain the cause and effect relationship. The aim of delay analysis is to allocate the responsibility for delay(s) or delaying event(s) between the project parties and to quantify the financial consequences for the party responsible (Braimah and Ndekugri, 2009). Many researchers have invested enormous efforts to develop delay analysis techniques or to improve existing delay analysis techniques.

Various schedule-related issues have been raised regarding delay analysis procedures, such as float ownership, real time analysis, pacing delay, concurrent delay and resource allocation. Some studies have been conducted to overcome one or more of these issues (Alkass, 1996; Yang and Yin, 2009; Hegazy *et al.,* 2005; Schumacher, 1995; Ardeti and Pattanakitcharmroon, 2006). For instance, some studies have focused on scheduling analyses along with allocating total float ownership (Al-Ghatani and Mohan 2007). Other researchers considered the effects of resource allocation in delay analysis techniques (Ibbs and Nguyen 2007).

Yang and Yin (2009) have proposed a new technique combining the “Isolated delay technique” and the “But-For technique” to overcome the drawbacks of the individual technique. It should be noted that different results for the same situation can be obtained by using different techniques (Alkass *et al.,* 1996). Moreover, the same method can yield diverse outcomes for a single situation by considering different perspectives (Hegazy and Zhang, 2005).

Over the past decades, significant developments in computer technology, in conjunction with comprehensive project planning software, have improved the capabilities of delay analysis techniques (Pickavance, 2005). Computers have also been used to help with complex issues in the construction industry, such as decision-making in multi-attribute problems.

The construction industry, at both the company and project levels, is highly dependent on using subjective and judgmental expertise. An expert system in the field of construction delay claims brings together the knowledge and experience learned from previous construction disputes in the form of a computer program and helps to assess the legitimacy of construction claims (Minkarah and Ahmad 1989). An expert system can be described as an interactive computer program used to cope with real-world complicated dilemmas that require expert analysis. A computer modeling of experts' human logic can thereby solve ill-structured construction problems. Under similar circumstances, expert systems should generate the same outcome, as would an expert person (Cobb and Diekmann 1986).

Iyer et al. (2008) defined expert systems as acting like a storehouse of expert knowledge, primed to offer a solution with a particular approach based on a user's requirements and circumstances. Claim resolution is a field in which all the practitioners need legal advice. However, due to inaccessibility or expensive charges, practitioners persistently neglect to make use of legal advice. Several researchers have attempted to develop expert systems related to problems and delays in construction management. Diekmann and Al-Tabtabai (1992) developed an expert system for project control that used Artificial Intelligence Techniques, which is essentially a knowledge-based expert system.

McGartland and Hendrickson (1985) explained the application of knowledge-based expert systems (KBES) in the project monitoring field. KBES were developed based on “If-Then” rules. They state that KBES is desirable for construction project monitoring because it can deal with ill-structured problems and because the expert system can be updated over time.

Hendrickson et al. (1987) designed a knowledge-intensive expert system for construction planning. They claim that the system is able to generate project activity networks, cost estimates, and schedules. Their system was limited to high-rise buildings, including excavation, foundation and structural construction.

Moselhi et al. (1990) presented an integrated hybrid expert system for construction planning and scheduling that determines the logic among activities, and modifies the duration of these activities accordingly. The authors state that the implementation of the system in domains other than construction management could also be valid. Other domains could include teaching and training in construction management, analysis and preparation of construction claims and management of contract changes.

To instruct and train inexperienced engineers about the legal consequences of construction disputes, Diekmann and Kim (1992) designed a knowledge-based expert system intended to analyze claims changes. Bubbers et al. (1992) depicted a computerized assistance approach for claims resolution using a “Hypertext Information System”. The system provides relevant information for validating claims, although it has one major drawback compared to other expert systems: it has no decision-making capability.

Alkass et al. (1995) developed a computer system model for delay claims analysis and preparation, called Computerized Delay Claims Analysis (CDCA). They described how a customized expert system for a particular type of construction expertise claims was used to ease the progress of delay analysis and how it can reduce the cost and time of claims preparation. The need and objectives for a computer system to analyze delay claims will be discussed in more detail in the following chapters.

According to Ren et al. (2001), inadequate information and poor documentation are the two major problems in claim management. Project documentation plays a crucial role in claim analysis. In other words, project documents such as contract documents, letters, meeting minutes, and notes are the main sources of information for executing a sound claim. One important part of claim preparation is to provide documentation that is sound and solid enough to be presented in court and that clearly illustrates the delays caused by other parties.

Moreover, claim preparation requires a meticulous review of a tremendous amount of project documents to both organize them chronologically and to generate the information relevant to the delay(s) or delaying event(s). Therefore, it is highly desirable and would be cost effective for practitioners to have an automated method to carry out this process (Alkass *et al.,* 1995).

Hammed (2001) developed a framework to overcome the difficulties related to record keeping and retrieval procedures, called the Construction Project Document Information Centre (CPDICenter). In another study, Baram (1994) described an integrated system to support construction claims and litigation by supplying particular technical support for document control, productivity, schedule analysis, delay, and impact cost calculations.

More recently, Palaneeswaran and Kumaraswamy (2008) depicted an integrated web-based decision support framework, which was enhanced for a Pocket PC along with a portable database integration device to deal with time extension entitlement.

Ren *et al.* (2001) proposed an approach using intelligent agent technology, mainly a Multi-Agent System (MAS), to efficiently perform claim negotiation. Their approach helps the parties reach an agreement quickly, thereby mitigating the drawbacks of human mediator decisions in negotiations.

AbouRizk *et al.* (1993) used a computer simulation model to help resolve construction disputes arising from the inevitable changes in technical specifications. This model was developed to estimate the direct cost of operations before and after the modifications.

The delay responsibility, as well as the cost of damages, must be ascertained accurately and to the satisfaction of each party. One of the problematic aspects for researchers and project participants is quantifying the impact costs related to productivity losses caused by delays. Analysis of the loss of productivity has been the subject of considerable research in recent years. Researchers have demonstrated a relationship between change orders and loss of productivity (Leonard, 1988; Moselhi *et al.,* 1991; Moselhi *et al.,* 2005, Hanna *et al.,* 1999).

Even though substantial research has been conducted in this area, delay claim processes still need further improvement in time and cost quantification, as well as in claims procedures management.

1.3 Research Motivation and Problem Statement

Three criteria are critical for all construction projects: a project should be completed on time, within the assigned budget, and by involving a minimum of quality requirements to meet the desired specifications (Lester, 2007). Being on schedule is an indicator of project efficiency in the construction industry, but construction projects are sensitive to many variables, including unpredictable factors such as contractual relations, environmental conditions and resource availability (Assaf and Al-Hejji, 2005). Therefore, completing a project on time is a big challenge for all project participants.

Previously, essential construction project staff committed most of their time to project planning, monitoring, controlling, and managing. This earlier trend contrasts greatly with the current situation. Now, project staff spend a significant amount of time driving delay claims towards a meaningful resolution. Resolving delay claims is not only time consuming, often taking several years, but also is a very expensive process.

Moreover, this situation forces project personnel to make a huge effort in order to understand legal terms and issues. Clearly, analyzing delays to assess responsibility is a difficult task, using a tremendous amount of human resources, energy and time due to concurrent or multiple causes (Yates and Epstein, 2006). Calculating the direct costs of delays is a straightforward procedure compared to delay analysis and loss of productivity estimations. Determining and evaluating the indirect costs (overhead costs) related to delays is not as easily quantifiable as the project's direct costs (Abdul-Malak et al., 2002). Moreover, there is not yet a widely accepted method to calculate head office overhead (HOOH) caused by delay. In addition, the quantification of the cost of delays should be performed in a credible and acceptable manner, and should demonstrate compensable damages, which are the objectives of an improved delay analysis process. The cost and inefficiencies of the current procedures to analyze delays and quantify damages demonstrate the need for new developments in this area. Consequently, having a computerized tool to facilitate the procedures of delay claims analysis has been a subject of interest for many scholars (Ren et al., 2001; Alkass et al., 1995).

Assessing a claim involves engineering and legal knowledge. Thus, a well-defined system that can connect legal and engineering knowledge to mitigate analysis errors and minimize time and cost, regardless of the methods used for a claim resolution, is much needed. This system must reliably arrive at construction dispute settlements. In addition, it should be able to work as a forecasting tool to mitigate claims by providing expert advice for particular circumstances.

1.4 Scope and Objectives of the Research

The main objective of this research is to develop an integrated computer-based system for analyzing schedule delays to determine delay liability and the associated costs. To achieve this objective, several sub-objectives were considered, and are listed here:

1. Develop a careful understanding of the current situation in delay analysis;
2. Propose a reliable delay analysis technique to apportion delay between a project's parties using procedures reasonable to both parties, and that is also capable of evaluating concurrent delays and considering the true critical path of a project;

3. Design an expert system to determine the type of delays and to provide recommendations on delays or delaying events; and
4. Design a computerized platform linking various software packages for use in delay analysis and claim preparation.

1.5 Methodology

To achieve the above-mentioned objectives, the following methodology was followed:

- Perform a broad literature review to evaluate the current practice in analyzing delays;
- Study delay analysis techniques and adopt one;
- Identify the limitations of selected methods and propose improvements;
- Adopt and enhance an effective and logical method-based selection method for assessing construction delays considering concurrent situations and changes in the critical path;
- Design and implement a computer integrated system that classifies delays, provides guidelines, performs delay analysis, and calculates direct and indirect costs for the user; and
- Test and validate the system using case studies.

1.6 Thesis Organization

This thesis is comprised of six chapters. Chapter 1 is the introduction and presents the background, research motivation, problems, objectives, scope of this research and research methodology. Chapter 2 reviews the literature related to this research, including the subjects of schedule delay, delay analysis, float distribution, recoverable damages, and others. Chapter 3 presents a new delay analysis technique and compares the proposed technique with several existing analysis techniques by using a common test case. The advantages and limitations of each delay analysis technique are highlighted. Chapter 4 formulates the methodology behind the proposed integrated computer-based technique, along with describing the system's components. In Chapter 5, the proposed system and its capabilities are presented and tested against a real case study, which has already had a claim analysis conducted for it. Finally, Chapter 6 discusses the conclusions and recommendations for further research.

Chapter 2

Literature Review

2.1 Introduction

In the construction industry, complying with the agreed upon time for delivering a project is very important for project participants. Even though a project may be faced with various delays, project participants are aware that construction delay claims negatively affect most aspects of a project. Regardless of their size, projects frequently suffer from delays and delay claims.

A delay may be caused by the action or inaction of the owner, the contractor, a third party, or a combination of all the parties involved “directly or indirectly” in the project, in addition to other causes beyond human control. In achieving delay claim resolution, certain components must be considered, such as causation, entitlement, consequences of delays, and most importantly, a reliable delay analysis technique to monitor and regulate how these components interact with each other.

Moreover, Keane and Caletka (2008) state that each delay claim has a unique life cycle. The authors summarize the various stages as follows:

a) Baseline schedule is established

b) Project commences

c) Deviation from baseline schedule is identified (or projected)

d) Delay occurrence/discovery

e) Delay analysis

f) Delay claim submission and presentation

g) Delay claim response

h) Negotiations (and award of appropriate extension of time)

i) Revised baseline schedule is established

j) Dispute resolution procedures (if award is not mutually agreed)

k) Delay claim resolution

This chapter reviews the current conditions of delay claims and the related outstanding issues by reviewing pertinent publications. The major topics include:

a) Delays in Construction
b) Types of Construction Delays
c) Concurrency of Delays
d) Pacing Delays
e) Causes of Delay
f) Float and Ownership of Float
g) Types of Schedules
h) Delay Analysis Techniques
i) Delay Damages

2.2 Delays in Construction

Construction projects have a high potential risk due to two factors: schedule delays and delay claims. These two factors become more acute as the nature of the project itself becomes larger and more complex (Arditi et al., 2008).

According to Stumpf (2000), delay is defined as an action or event that makes the total duration of a project longer than the time agreed upon in a contract. Delay could occur because there is a need for extra working days before the start of an activity, previously determined in the "As-planned" schedule. A delay may also have an impact on the total scope of the project.

Delays can have a severe impact on the cost and time of a project. Therefore, contracting parties find themselves in a situation where it is necessary to make claims for delay damages caused by other parties. In such scenarios, the claimant should be able to ascertain the cause of the delay and its impact on both the overall project performance and on individual activities (Clough, 1994). Moreover, it is very important for project stakeholders to find out who is responsible for delays, based on the following (Stumpf 2000):

- An owner's concern is to determine who is legally responsible for delays in a project because a delay may lead to the evaluation of liquidated damages and supplementary reimbursement to the contractor. The American Association of Cost Engineering (AACE) defines the owner as the public or private entity that is in charge of the proper implementation of the project (AACEI[b], 2009).

- A contractor has the same motivations as an owner; however, in opposition to those of the owner's. Claims for the contractor would be for additional compensation and payment for liquidated damages. The contractor is the organization or individual in charge of implementing the work in accordance with the plans and specifications and the agreed-upon contract (AACEI[b], 2009).

- Taxpayers are concerned because delays can substantially magnify the total cost of public projects.
- Insurance companies are very interested because they are ultimately responsible for the contractor's performance.

Delays involve serious measurement problems; therefore, claimants should have a good understanding of the types of construction delays, causes, and categories for the recovery of damages. Kartam (1999) states that schedule delays can be classified in several ways, based on compensability, timing, and their origin.

Generally, construction delays are classified into two major categorises: excusable and inexcusable delays. An excusable delay, in itself, is categorized into either compensable or non-compensable delays (Rubin et al., 1983; Bramble et al., 1987; Schumacher, 1995; Finke, 1997; Alkass et al., 1996; Bramble and Callahan, 1999; Al-Gahtani et al., 2007; and Kao et al., 2009).

Fig. 2.1 illustrates a delay classification procedure and each party's accountability for a delay occurrence. Notably, based on the contract language, the entity of delay classification results is subject to change, as shown by the dotted arrows.

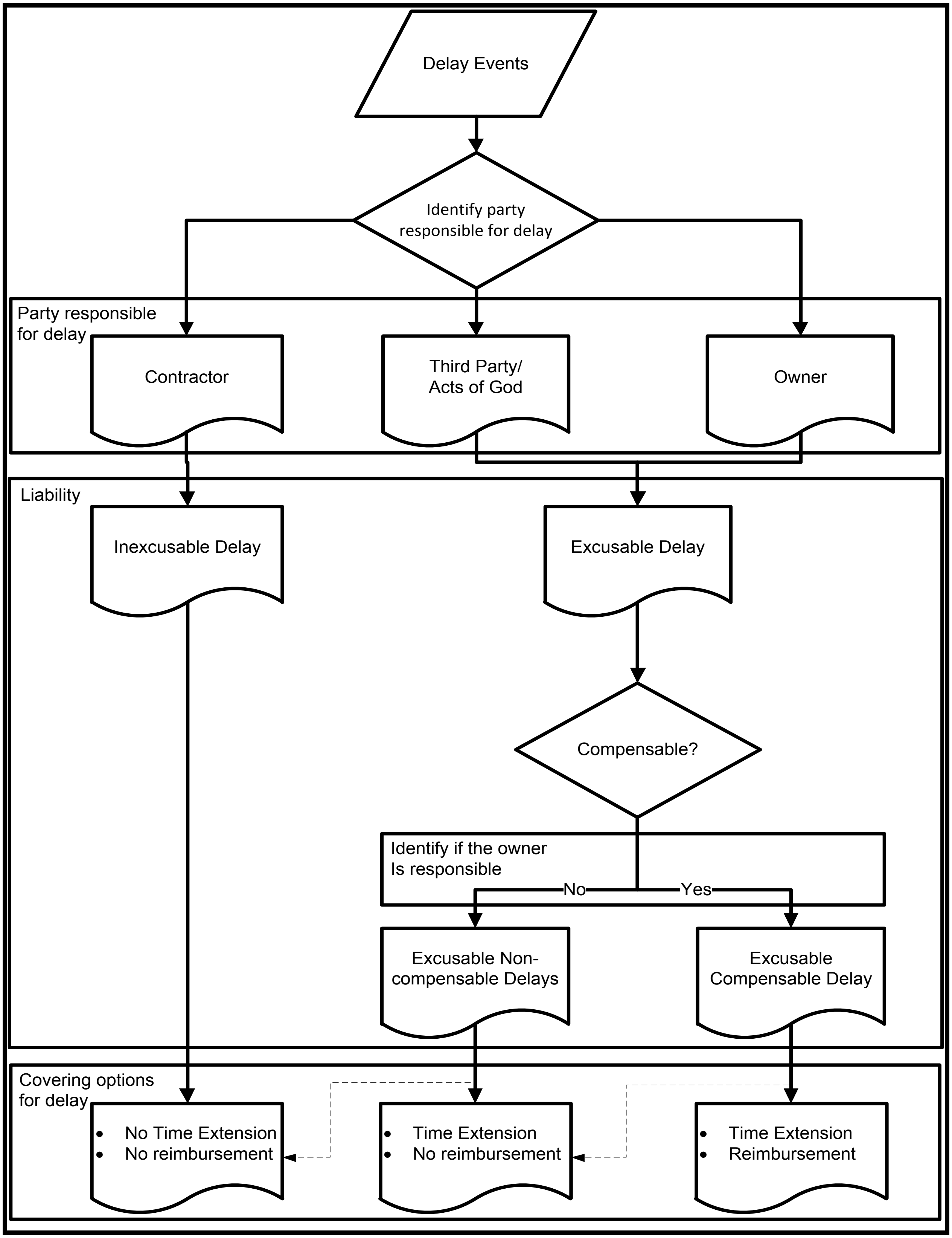


Figure 2.1: Process of Delay Classification and Response (Adopted from Kao and Yang, 2009)

2.2.1 Excusable delays

Stumpf (2000) describes excusable delays as delays in which the contractor has no control over the delay-causing elements; these typically include unforeseen events, which usually result in a time extension given to the contractor if the project's completion date is affected. Alkass *et al.* (1995) suggest that excusable delays may occur on the noncritical path(s) of a project, a circumstance that would require meticulous investigation to evaluate the possibility of covering that delay by either float consumption or by awarding a time extension. Furthermore, excusable delays warrant further investigation to determine whether they are compensable or non-compensable, as described in the following sections (Stumpf, 2000).

2.2.1.1 Excusable compensable delays

Excusable compensable delays may entitle the contractor for an extension of time and compensation for delay damages. These delays are within the control of the owner or a third party, where the owner is contractually accountable for the third party's actions (Arditi and Robinson, 1995). A third party could be an architect, engineer, construction manager, or another primary contractor (Stumpf, 2000). According to Yates and Epstein (2006), excusable compensable (EC) delays result from the following:

1. The owner could not make the project site accessible to the contractor in a timely manner;
2. The owner made changes in the work expected after a contract was agreed upon;
3. The owner delayed giving the notice to proceed with the work to the contractor;
4. The architect/engineer provided designs that included errors;

5. The owner could not harmonize the work with other contractors;
6. The owner could not supply the required equipment in the desired chronological manner;
7. The owner provided the contractor with ambiguous information;
8. The owner interrupted the work performance of the contractor;
9. The owner or the architect/engineer could not approve the contractor's shop drawing within an appropriate time frame; and
10. The site conditions mentioned in the contract were in contradiction with the field conditions faced by the contractor.

In situations that fall within the above list (which is not exhaustive), the contractor is usually entitled to an extension of time and to reimbursement for damages. According to Bramble and Callahan (1999), it is probable that a delay can be classified as an excusable compensable delay, but this does not automatically entitle the claimant to an extension of time, specifically if the delay occurred on non-critical path(s).

The evaluation of compensable delays is a very onerous assignment if a delay disclaimer clause was in the contract. Thomas et al. (2003) describe how the contractor can be affected by delay disclaimer clauses. The language of the contract plays a major role in determining the compensability of delays and a contractor should give full attention to the wording used in a contract. A typical delay disclaimer clause reads as follows:

"The contractor agrees to make no claim for damages for delay in the performance of the contract occasioned by any act or omission to act of the City or any of its representatives, and agree that any such claim shall be fully compensated for by an extension of time...,[Kalisch-Jarcho, Inc. V. City of New York, 448 N.E.2d 414(1983)]"

Ashley et al. (1989) found that a delay disclaimer clause adversely affects project performance and blurs the relationships between a project's participants. A delay disclaimer clause increases the likelihood of disputes and litigation over the course of a project. These authors state that reducing the overall project costs and controlling the amount of responsibility is not possible with a harsh or unjust contract. Delay disclaimer clauses are not cost effective to owners because of the increased number of disputes, usually followed by litigations. They recommend that delay disclaimer clauses are not suitable for projects with a high potential risk of delay.

2.2.1.2 Excusable non-compensable delays

Excusable non-compensable (EN) delays are delays that arise from neither the contractor's nor the owner's error or negligence. These delays are caused by "Acts of God" or unanticipated events which neither party has any power over. Usually, contracts include a clause for these delays under the name of "Force majeure" (Yates and Epstein, 2006).

According to Morgan (2005), force majeure is defined as "an unavoidable, overwhelming, difficult to foresee act of nature, not related to a deed of man." As stated by the "Federation Internationale Des Ingenieurs-Conseils", an event can be classified under the force majeure clause if it is (FIDIC General condition, 2006):

a) beyond the Party's control;

b) such that the Party could not reasonably have provided against it before entering into the contract;

c) has arisen such that the Party could not reasonably have avoided or overcome it; and

d) not substantially attributable to the other party.

The list of the causes of force majeure events includes, but is not limited to (FIDIC General Conditions, 2006):

1. War, hostilities (whether war be declared or not), invasion, act of foreign enemies;
2. Rebellion, terrorism, sabotage by persons other than the contractor's personnel, revolution, insurrection, military coup or usurped power, or civil war;
3. Riot, commotion, disorder, strike or lockout by persons other than the contractor's personnel;
4. Munitions of war, explosive materials, ionizing radiation or contamination by radioactivity, except as may be attributable to the contractor's use of such munitions, explosives, radiation or radioactivity; and
5. Natural catastrophes such as earthquake, hurricane, typhoon, or volcanic activity (Acts of God).

In the case of excusable non-compensable delays, the contractor is entitled to an extension of time (EOT), but no additional costs. However, the detailed definition of such a delay is based on the agreement made between the parties (Yates and Epstein, 2006).

2.2.2 Non-excusable Delay

If the contractor's or one of its subcontractor's actions or inactions give rise to Non-excusable (NE) delays, then the contractor is held accountable. In this situation, the contractor is not entitled to an extension of time or reimbursement, also could be exposed to liquidated or actual damages by the owner (Kraiem et al., 1987; Arditi and Robinson, 1995; Stumpf, 2000). The most common reasons for contractor-caused delays include, but are not limited to (Yates and Epstein., 2006):

1. Failing to organize the workforce and start the work at an appropriate time;
2. Failing to submit, in a timely manner, the shop drawings and related materials for the owner's acceptance;
3. Failing to provide adequate and sufficient construction equipment;
4. Inadequate workforce;
5. Failing to perform the work according to the specifications and plans;
6. Poor project management, such as improperly allocating resources;
7. Lack of coordination between subcontractors and tradesmen; and
8. Failure to complete different parts of the work in an appropriate timeframe.

It should be noted that the terms excusable, compensable, and inexcusable delays vary from the owner's and the contractor's perspective. For instance, a delay may seem excusable and compensable to the contractor, but inexcusable to the owner. In an attempt to classify the above delays, based on the time of their occurrence, they can fall into one of the following three categories (Arditi and Robinson, 1995; Stumpf, 2000):

- Independent Delays

- Serial Delays
- Concurrent Delays

2.3 Independent Delays

Arditi and Robinson (1995) define an independent delay as a particular delay occurring solely and without concurrency with other delays. Identifying this type of delay is straightforward and the consequences of such delays can be processed simply by assessing their effect on the project schedule. A serial delay may be caused by an independent delay (Stumpf, 2000).

2.4 Serial Delays

The action or inaction of one of the parties can give rise to a series of delays in a number of successor activities (Raid et al., 1991). The most important issue in the case of a serial delay is the timing of that delay in relation to other delays. As the name implies, a serial delay is a series of sequential, non-overlapping delays that are linked together (Arditi and Robinson, 1995; Stumpf, 2000). Measuring the impact of serial delays is comparatively simple as none of the individual delays interferes with one another (Arditi and Robinson, 1995).

2.5 Concurrent Delays

According to Bubshait and Cunningham (2004) and Stumpf (2000), concurrent delays are defined as two or more independent delays taking place at the same time or overlapping to some extent, causing a significant delay in the project duration. Such delays share the feature of having a similar impact on the project duration. Concurrent delays take place frequently, particularly when multiple-responsibility tasks are progressing simultaneously. Rubin et al. (1983) defines concurrent delay as two or more individual delays that take place at the same time or within a specific time period, each of which, had it occurred alone, would have delayed the project.

Furthermore, owners and contractors are motivated to use concurrent delays as protective measures against each other. An owner can bring concurrent delays into play to protect his/her interest in collecting liquidated damages, while a contractor can take advantage of concurrent delays to cover up delays that are his/her responsibility and thus avoid paying damages (Baram, 2000).

Concurrent delays may involve several delays related to a single activity or to different activities. The clarification of concurrent delays has been a controversial subject for both the industry and case law critics. This controversy is the result of identifying whether the events leading to delays must be concurrent or, as some authors imply, merely offsetting in effect (Bramble and Callahan, 1999). Consequently, two approaches exist:

- The timing of the delay events' occurrence : "Simultaneous"
- The long-term impact on project completion: "Offsetting"

Bramble and Callahan (1999) describe how the definition of concurrent delay is affected by these two approaches. In the simultaneous approach, delays are considered concurrent if the events occurred at the same time and had a similar impact on the project completion date. The main difference between this approach and the offsetting approach, extracted from case law, is the timing of the delays, which do not necessarily have to occur at the same time to be considered “concurrent delays”. In fact, the acceptable timeframe may vary from a few days to several months. It should be noted that the timeframe of a concurrent event must not exceed one-quarter of the total project duration. Stumpf (2000) states some of the properties of concurrent delays in the offsetting approach:

- Two independent delays happening in overlapping timeframes are concurrent if the delays exist on parallel critical paths;
- Two independent delays occurring in overlapping timeframes should not be considered concurrent delays if one of the delays is off the critical path; and
- Delays on the non-critical path become concurrent delays once they consume the total float remaining in those paths.

Concurrent delays can be caused by a combination of delays, as follows (Kraiem et al., 1987):

- Excusable compensable delays and Non-excusable delays;
- Excusable compensable delays and Excusable non-compensable delays;
- Excusable non-compensable delays and Non-excusable delays; and
- Excusable compensable, Excusable non-compensable and Non-excusable delays.

When reviewing the doctrines of concurrent delays, there is a variety of opinions on the assessment of concurrent delays. Table 2.1 reviews the different perspectives on concurrent delay evaluation from fourteen previous studies.

Moreover, it is possible for similar types of delay to take place simultaneously; this condition does not lead to any difficulty in apportioning liability for the overall project delay. For example, if two excusable compensable delays occur in two parallel critical paths, they would both be evaluated as excusable compensable delays. In such a scenario, the contractor should be awarded with a time extension for the combined effect of the two excusable compensable delays (Arditi and Robinson, 1995; Rubin, 1983).

Table 2.1: Different Evolutions of Concurrent Delays (Adopted from Peters, 2003)

Researchers	Excusable and Inexcusable	Excusable and Compensable	Compensable and Inexcusable
Rubin et al. (1983)	Excusable	Excusable	N/A
Ponce de Leon (1987)	Excusable	Compensable	Excusable
Kraiem et al. (1987)	Excusable	Excusable	Excusable or Apportioning
Reams (1989)	Excusable	Excusable	N/A
Construction claims monthly (1993)	Inexcusable	Excusable	Inexcusable
Alkass et al. (1995)	Excusable	Excusable	Excusable
Arditi and Robinson (1995)	Inexcusable	Excusable	N/A
Finke (1999)	Excusable	Excusable	Excusable or Apportioning
Baram (2000)	Inexcusable	Excusable	Excusable or Apportioning
Stumpf (2000)	Excusable	Excusable	Excusable
Reynolds and Revay (2001)	Excusable	Excusable	Excusable
Construction claims monthly (2002)	Inexcusable	Excusable	Inexcusable
Bubshait et al. (2004)	Excusable	Excusable	Excusable or Apportioning
Arditi and Pattankitchamroon (2006)	Excusable	Excusable	Excusable or Apportioning

It is possible that three different types of delays occur concurrently: excusable non-compensable, excusable compensable and Inexcusable delays. In this case, either the contractor may be awarded a time extension and reimbursement or the owner may assess liquidated damages, or neither the contractor nor the owner recovers damages (Arditi and Pattankitchamroon, 2006).

Concurrent delays are the most challenging type of delay due to their complicated nature. The processes of identifying, quantifying, and apportioning responsibility for each delay are not straightforward (Baram, 2000). Apportioning or “fair rules” is defined as the process of reasonably allocating liquidated damages between the owner and the contractor (Kraiem et al., 1987). The apportioning of concurrent delays and their compensability depends on the accepted practices and legitimate preferences (Arditi and Robinson, 1995).

Calculating the impact of the concurrent delays is difficult and requires a significant investment of time and valuable human resources. According to Mohan and Al-Gahtani (2006), three major issues amplify the difficulty of calculating concurrent delays:

- Firstly,an agreement on the concurrency period of two or more delays is difficult. Concurrent delays may occur in two or more parallel activities having different start and finish dates; thus, only segments of these activities may be concurrent;
- The occurrence of new critical path is second issue. Non-critical paths may become critical by consuming the total float of noncritical activities; and
- The issue of pacing delay complicates concurrent delay situations. If an owner causes a delay on a parallel critical path, a contractor may slow down his/her

performance on the parallel critical paths in an attempt to maintain pace with the owner's delay.

To avoid disputes and to facilitate the procedure of delay analysis, the project parties should adopt a reasonable and systematic approach for proactively apportioning concurrent delay damages.

2.6 Pacing Delays

A pacing delay is defined as the "Deceleration of the project work by one party to the contract, because of a delay to the end date of the project caused by the other party, so as to maintain steady progress with the revised overall project schedule" (Zack, 2000). Generally, various types of construction contracts permit contractors to perform the project with the least cost, in order to achieve maximum profits. However, Mohan and Al-Gahtani (2006) state that the right to decelerate the progress of work is not always applicable, because some of the problems in delay analysis have not been resolved to the satisfaction of all parties, such as:

- Who owns the total float in the as-planned schedule?
- Who has the right to take advantage or bear the burden of disadvantage for changing the total float?

To have a clear understanding of the abovementioned complications, Al-Ghahtani and Mohan (2007) present an example in which the owner causes a delay on the critical path that prolongs the overall project duration and increases the total float of the non-critical activities. In such a scenario, the contractor may decelerate the progress of work to consume the total float of the non-critical activities. The contractor would save on cost in two ways:

- The contractor could claim reimbursement for delay damages;
- The contractor would save money by naturalizing the progress of non-critical activities.

The authors explains that a pacing delay by the contractor could mislead the owner to judge such phenomena as a concurrent delay, and so they raise the question of how one should solve the issue of a pacing delay that falls within a concurrent delay. Rider and Finnegan (2005) gave some guidelines to solve this problem, as given below. However, they mention that these guidelines are not substitutes for professional representation of the problem.

- Know your contract
- Seek clarification
- Open dialogue
- Notify the owner
- Provide the supporting information for pacing delay
- Keep your team informed
- Record all actions contemporaneously
- Nobody is perfect/ take responsibility
- Make all agreements formal

Pacing delays are licit management decisions where a contractor has a legal right to decelerate the progress of project (Zack, 2000). By considering the above-mentioned steps, a contractor can increase the probability of proving a pacing delay and avoid misinterpretation and disagreement (Ronald and Finnegan, 2005).

2.7 Causes of Delays

Lo et al. (2006) conducted a broad literature review to identify the causes of delay as postulated in previous researches (Tables 2.2-2.4). According to Lovejoy (2004), either a specific party or a combination of parties can cause delays, or unexpected situations that are not attributable to any parties involved in the project.

Table 2.2: Causes of Delays for Construction Projects in different Countries (adopted from Lo et al., 2006)

Researchers	Year	Country	Major Causes of delay
Baldwin et al.	1971	U.S.	1. Inclement weather 2. Shortages of labour supply 3. Subcontracting system
Arditi et al.	1985	Turkey	1. Shortages of resources 2. Financial difficulties faced by public agencies and contractors 3. Organizational deficiencies 4. Delays in design work 5. Frequent changes in orders/ design
Sullivan and Harris	1986	UK	1. Waiting for information 2. Variation orders 3. Ground problems 4. Bad weather conditions 5. Design complexity
Okpala and Aniekwu	1988	Nigeria	1. Shortage of materials 2. Failure to pay for completed works 3. Poor contract management
Dlakwa and Culpin	1990	Nigeria	1. Delays in payment by agencies to contractors 2. Fluctuation in material, labour and plant costs
Mansfield et al.	1994	Nigeria	1. Improper financial payment to contractors 2. Poor contract management 3. Shortage of materials 4. Shortage of labour supply 5. Poor workmanship
Semple et al.	1994	Canada	1. Increase in the scope of works 2. Inclement weather 3. Restricted access

Table 2.3(Cont.): Causes of Delays in Construction Projects (Adopted from Lo et al., 2006)

Researchers	Year	Country	Major Causes of delay
Assaf et al.	1995	Saudi Arabia	1. Slow preparation and approval of shop drawing 2. Delays in payment to contractor 3. Changes of design /design error 4. Shortage of labour supply 5. Poor workmanship
Ogunlana et al.	1996	Thailand	1. Shortage of materials 2. Changes of design 3. Liaison problems among the contracting parties
Chan and Kumaraswamy	1996	Hong Kong	1. Unforeseen ground conditions 2. Poor site management and supervision 3. Slow decision making by project teams 4. Owner-initiated variations
Al-khall and Al-Ghafly	1999	Saudi Arabia	1. Cash flow problems/financial difficulties 2. Difficulties in obtaining permits 3. Lowest bid wins system
Al-Momani	2000	Jordan	1. Poor design 2. Change orders / design 3. Inclement weather 4. Unforeseen site conditions 5. Late delivery
Aibinu and Odeyinka	2006	Nigeria	1. Contractors' financial difficulties 2. Owners' financial difficulties 3. Architect's incomplete drawings 4. Slow mobilization of subcontractor(s) 5. Equipment breakdown and maintenance problems
Faridi and El-Sayegh	2006	UAE	1. Slow preparation and approval of drawings 2. Inadequate early planning of the project 3. Delayof the owner's decision-making process 4. Lack of manpower 5. Poor supervision/site management
Lo et al.	2006	Hong Kong	1. Inadequate resources due to contractor 2. Unforeseen ground conditions 3. Exceptionally low bids 4. Inexperienced contractor 5. Work in conflict with existing utilities 6. Poor site management /supervision

Table 2.4(Cont.): Causes of Delays in Construction Projects (Adopted from Lo et al., 2006)

Researchers	Year	Country	Major Causes of delay
Sambasivan and Soon	2007	Malaysia	1. Contractor's improper planning 2. Contractor's poor site management 3. Inadequate contractor experience 4. Inadequate owner finance and payments 5. Problems with subcontractors 6. Shortage of material
El-Razek et al.	2008	Egypt	1. Inadequate financing by contractor during construction 2. Delays in contractor's payment 3. Design changes by owner or his agent during construction 4. Partial payments during construction 5. No utilization of professional construction/contractual management 6. Slow delivery of materials
Yang and Wei	2010	Taiwan	1. Change in owner's requirements 2. Client's financial problems 3. Inadequate integration of project interfaces 4. Complicated administration process of client 5. Change order by code change 6. Poor scope definition

2.8 Float and Criticality

Float, also referred to as slack, is a crucial asset in the critical path method (CPM) of scheduling. Float is the amount of time that an activity can be delayed without affecting the completion date of the project, and it is calculated based on the difference between either the early start and late start or early finish and late finish of an activity (Nguyen and Ibbs, 2008). Total float (TF) is another term for float that is frequently used in CPM scheduling. When noncritical activities have been impacted by delays, they consume their own float time and can then become critical (Trauner, 2009).

In a construction project, float time is one of the essential elements, the ownership of which the parties negotiate for in the contract. Contractors use float time to provide flexibility for their timing and financial planning. Owners benefit by utilizing float time to neutralize the impact of change orders on a project (Arditi and Pattankitchamroon, 2006). Float time is an expiring time asset; if it is not used by any of the contracting parties, it progressively vanishes (de la Garza et al., 2007). However, project stakeholders should always be aware of float consumption, as it can lead to cost and/or time overruns (Sakka and El-Sayegh, 2007). Gong (1997) states that float consumption in noncritical activities with a high risk of time uncertainty may amplify the risk of cost and/or time overruns. Furthermore, over the past three decades, the construction industry has witnessed a multitude of arguments regarding who specifically should own a schedule's float. The question of "who owns the float" comes to the fore when there are claims for time extensions or the owner issues delay-causing change orders.

2.8.1 Float Consumption Management

Appropriate float allocation ensures an accurate and reasonable distribution of delay between parties. To better manage the float ownership issue, practitioners and researchers have developed several techniques over the past decades. A list of brief explanations of the different float distribution techniques follows (Al-Gahtani, 2009):

1. Owner has possession of the float. This doctrine implies that a project's float belongs to the owner by the reasoning that, since the owner provides the financial resources and owns the project, he/she has the right to own the

project float (Pasiphol and Popescu 1995). Such an assumption is not rational, simply because there are other factors inherent in a project that increase the overall project risk. A more rational argument is that, as the owner accepts the responsibility of the project's risks, he/she should also be entitled to manage the float times to reduce their project-associated risk (Al-Gahtani, 2009).

2. Contractor has possession of the float. According to Al-Gahtani (2009), many practitioners and researchers support the concept of contactor as float-owner of the project. This concept appears as one of the contractor's contractual rights that provides the contractor with the appropriate tools and methods to control the project schedule and sequencing between the activities. In addition, float ownership enables the contractor to reserve some of the float to control risk with no need of manipulating the project schedule.
3. Project has possession of the float. This is the most accepted method in allocating float in legal cases and it is the most straightforward method for resolving complicated float ownership circumstances (Al-Gahtani, 2009). Project possession of float is also referred to as the "first-come, first-serve" approach. This method considers the float time as available to all project parties, providing flexibility for both the owner and the contractor to manage change orders and resources (Al-Gahtani, 2009). However, Arditi and Pattanakitchamroon (2006) clarify how this method can influence the outcomes of delay analysis. To illustrate, they use a scenario in which an owner-caused delay on an activity takes place and consumes the project float time. If a contractor then causes a delay for this activity, he/she is held responsible, but if

the owner had not already caused the delay, then the float time of that activity would have been available for the contractor to cover his/her delays.

4. Fifty-fifty float allocation approach. Introduced by Prateapusanond (2003), the fifty-fifty approach is a combination of the three preceding methods; the owner, contractor, and project own the float approaches. The aim of this method is to overcome the drawbacks of the previous methods that is acceptable to both project parties. The float is distributed equally between the owner and the contractor, and the float consumption of each party should be recorded accurately. This method attempts to formulate the float consumption as it affects the critical path.
5. Float is traded as a commodity approach. de la Garza et al. (1991) introduced this approach, which considers float to be a tradable commodity between the owner and contractor. This approach gives the contractor full authority to manage float and allows the owner to consume the float if needed by purchasing it from the contractor, based on the following equation(Eq.2.1):

$$TFV = \frac{LFC - EFC}{TF} \quad (2.1)$$

TFV: Daily trade-in value of total float

LFC: The cost required to complete the project at late finish date (actual situation) due to the loss of flexibility afforded by early schedule to accommodate unexpected events

EFC: The cost required to complete the project at early finish date (perfect situation)

TF: Total float

6. Bar approach. Developed by de Leon (1986), this approach attempts to resolve the issue that, when performing delay analysis, it is not reasonable to evaluate the impact of delays solely on the critical path and neglect the effect of delays on non-critical paths. This approach not only considers the effect of delays on the critical path, but also that every consumption of float can be a potential critical delay. In this approach, a bar in a bar chart schedule represents the float time of each activity. Therefore, any delay would be considered a critical delay. This approach avoids disentitled float consumption by any party.
7. Contract risk approach. Householder and Rutland (1990) put forward this approach to establish a relationship between contract risks and float consumption. For instance, in a lump-sum contract, the project risk is shifted to the contractor. Accordingly, the contractor owns the float time. Conversely, if the owner agrees to take full responsibility of the project risk, the owner completely owns the project float time, such as in a cost-plus-fixed-fee contract, where the project risk is shifted to the owner. The authors state that in contracts that contain a maximum price guarantee and where the owner and the contractor share the project risk, the project parties should agree on the ratio of float ownership sharing. By modifying some of a contract's clauses, it could be possible to shift the project risk from one party to another (Al-Gahtani, 2009).

To sum up, float time indicates if an activity is critical or not and the extent to which a project schedule is flexible. In other words, it is the number of days that remain until an activity becomes critical (Al-Gahtani and Mohan 2007). It should be noted that float consumption might have a significant impact on the result of delay analysis.

2.9 Using the Critical Path Method (CPM)

The following technique is widely accepted within the community of construction management practitioners. James E Kelly, Jr., and Morgan Walker introduced the foundations of the CPM in 1956 when they developed a scheduling technique known as "Activity-on-Arrow." At the same time, the US Navy and the Lockheed Company were developing a new method called the Project Evaluation and Review Technique (PERT). Both techniques led to the emergence of the principles of the CPM scheduling technique. The CPM is a valuable tool for project teams to schedule and control a project. By employing the CPM scheduling technique, valuable data such as the shortest duration of a project, the critical path(s), and the float become clear to project teams (Kim and de la Garza, 2003).

CPM scheduling facilitates the assessment of delay claims. In most claim scenarios, the CPM is the best available option for schedule delay analysis. It is noteworthy that all of the CPM delay analysis methodologies in use today originated from the principles of CPM (Ottesen and Martin, 2010).

According to Kelleher (2004), the number of companies that practice CPM scheduling has significantly increased over time. Moreover, the percentage of claims applying the CPM in their analysis increased, between 1990 and 2003, from 71% to 86%. Furthermore, the number of publications pertaining to the application of CPM in delay analysis has continued to increase from the early 80's. Figure 2.3 illustrates the estimated number of AACE International papers on CPM delay analysis for the past decades (Ottesen and Martin, 2010).

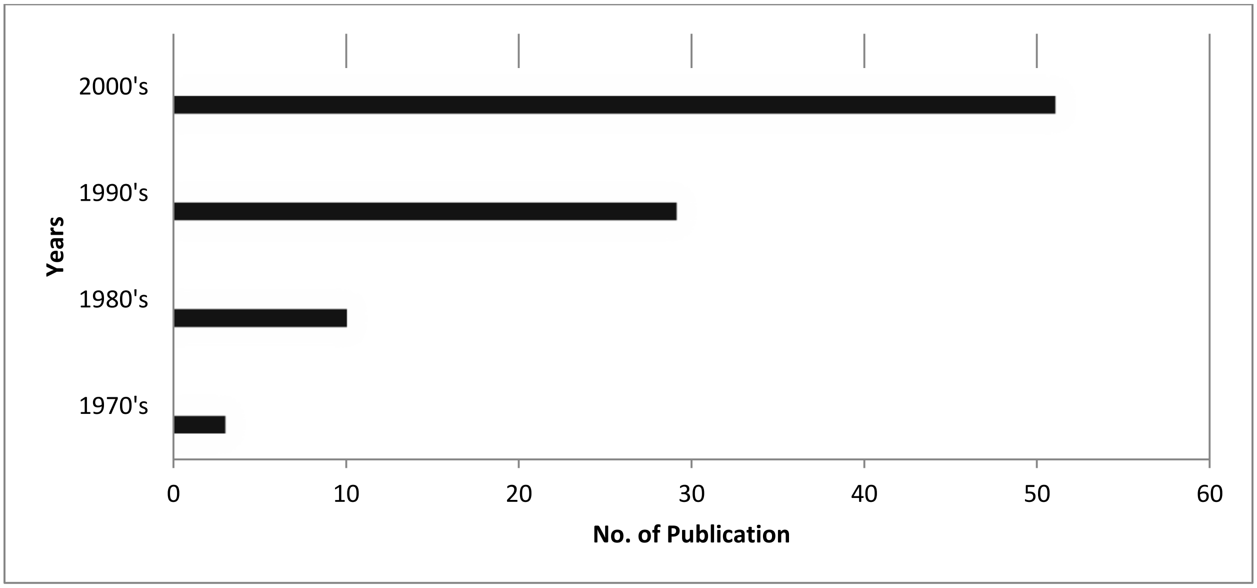


Figure 2.2: Number of AACE published papers on CPM Delay Analysis (Ottesen and Martin, 2010)

CPM Delay analysis techniques are commonly used by:

1. Owners, since they provide proof of whether the contractor qualifies for an extension of time and costs incurred resulting from change orders (McCullough, 1999);
2. Contractor, to evaluate the impact of delays considering the relationship between the activities and associated cost components in CPM schedules (Overcash and Harris, 2005); and
3. Boards of contract appeals and courts, in the proof and defense of delay claims (Wickwire and Ockman, 1999).

Consequently, CPM scheduling analysis techniques are essential for the success or failure of delay claims. According Braimah (2008), the CPM is known to be an effective means of delay analysis because it can assure both claimant and defendant of whether delays or delaying events had an impact on a project's completion date. At the same time, some practitioners argue that a CPM schedule could easily be manipulated for claim falsification (Galloway, 2006).

2.10 Scheduling Practices in Delay Claims

In project management, a schedule is an effective means to map out a project in a sequential order. The main functions of a construction schedule are that it (Keane and Caletka, 2008):

a) Identifies every activity;
b) Allocates resources and costs to each activity;
c) Establishes acceptable early and late start and finish dates for each activity (baselines);
d) Determines the total float for each activity; and
e) Determines the critical activities.

Consequently, project schedules are a powerful tool for monitoring and controlling project performance. Project scheduling is a very broad topic that consists of various methods; presenting a separate investigation focused on scheduling is beyond the scope of this research. This section reviews the literature to gather scheduling issues pertinent to those used in delay claim procedures.

From a delay claim perspective, any schedule variation should be evaluated based on three criteria: causation, liability, and damages (Battikha, 1994). The main purpose of delay analysis is to assess the relative damages and to quantify the scale of delay impact that is the responsibility of each project party.

Several types of CPM schedules are employed in analyzing the impact of the project completion date. Project schedules can be classified into five major types (Arditi and Robinson 1995; Alkass et al., 1996; Finke, 1999):

a) As-Planned Schedule
b) As-Built Schedule
c) Projected Schedule
d) Adjusted Schedule
e) Entitlement Schedule

2.10.1 As-Planned Schedule

The As-Planned schedule corresponds to the contractor's master schedule for delivering the project within the timeline agreed upon in the contract. The As-Planned schedule shows how and when the contractor should perform the project under normal circumstances in a situation-specific context. However, this schedule does not demonstrate the project's progress; it only illustrates the planned activities and one or more critical paths. The schedule must be well defined, and since there are no changes or delays, it could be used to develop an Entitlement schedule, which will be described later (Finke, 1997).

2.10.2 Adjusted Schedule

An adjusted schedule is one that is prepared to illustrate the effects of major events on the As-planned schedule in a sequential order. In other words, an Adjusted schedule shows the impacts of delays, accelerations, and change orders when they occur during the course of the project. The transformation of an As-planned to an As-Built schedule is represented by Adjusted-schedules (Fig. 2.2). Consequently, an Adjusted schedule is the starting point for the development of an Entitlement schedule (Arditi and Robinson 1995).

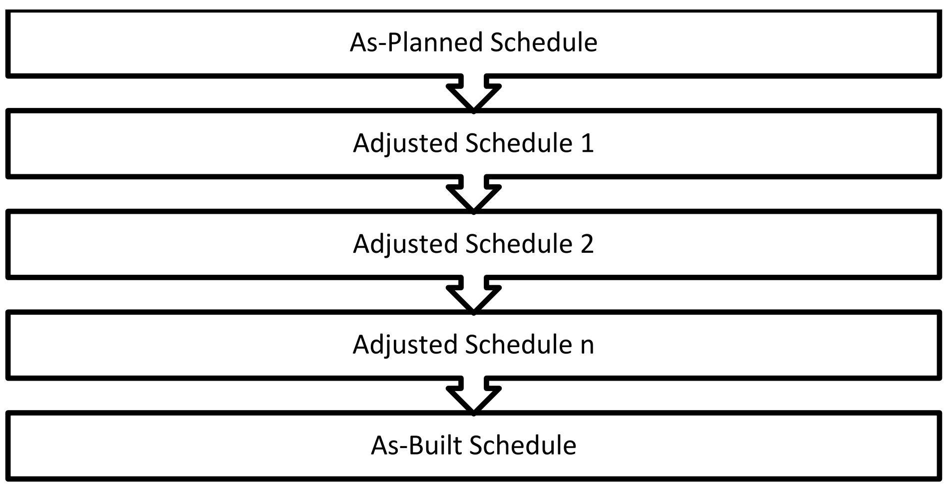


Figure 2.3: As-Planned transformation to an As-Built schedule

2.10.3 As-Built Schedule

The As-Built schedule is characterized by how and when the contractor actually performs a project. As the name implies, this schedule includes the actual activities' dates and the actual sequence of events. In other words, during the execution phase, the schedule is updated on a regular basis (e.g., monthly) and/or based on major events to determine the new project duration. At the end of the execution phase, the final updated schedule represents the As-Built schedule. This type of schedule reflects the effects of delays and changes on a project's progress over the course of the entire project. Furthermore, it should be observed that critical activities and paths that differ from those in an As-Planned schedule are possible (Finke, 1999; Alkass et al., 1996; Arditi and Robinson; 1995).

2.10.4 The Projected Schedule

When updating the schedule, if the project is still in the execution phase, the expected completion date should be recalculated, using the actual dates for the completed activities and incorporating modifications for the remaining activities (Arditi and Robinson, 1995).

2.10.5 Entitlement Schedule

An Entitlement schedule shows the initial contractual completion date and how this date has been effected by excusable delays (Alkass et al., 1996). The entitlement schedule is also referred to as an Accountable schedule, and is classified into two categories:

a) Owner-accountable schedule
b) Contractor-accountable schedule

These two schedules were developed to demonstrate the impact of owner-caused or contractor-caused events on the project completion date (Arditi and Robinson, 1995). It should be taken into consideration that the theoretical critical path may vary from the actual path, as only the effects of the particular party's events are imposed on the As-Planned schedule and due to dynamic nature of the critical path (Battikha,1994).

2.11 Process of Delay Analysis

Schedule delays take place frequently in construction projects. In the past two decades, various techniques have been proposed to quantify delay liability (Alkass *et al.*, 1995; Gothand, 2003; Hegazy and Zhang, 2005). More than thirty techniques are available to measure and quantify the impacts of delay on a project's completion date; such techniques are referred to as delay analysis methodologies. The American Association of Civil Engineering defines delay analysis as a study and detailed investigation of project files, CPM schedules, and their revised data, which is usually performed on an after-the-fact basis (AACEI[a], 2009).

Braimah and Ndekugri (2009) define delay analysis as the procedure of investigating the events that resulted in a project delay. They further state that delay analysis has the intention of determining the financial accountabilities of the contracting parties in relation to the delay. Moreover, delay analysis is a means of providing the validation and quantification of the time and/or cost consequences that are required to achieve resolution in the different scenarios of a delay claim.

Delay analysis is a combination of art and science, sensitive to expert judgment and opinion, and many subjective decisions must be made during the delay analysis procedure (AACEI[a], 2009). To help delay analysts deal with different items of contention or scopes of delay claims, several researchers have proposed various guidelines and processes. The following guidelines were suggested by Al-Saggaf (1998) for implementing construction delay analysis:

- Data gathering: Collecting all information related to the delay;
- Data analysis: Investigating the location and timing of the delay;
- Indemnification of the root causes: Clarifying the cause(s) of the delay and its impact on the project completion date;
- Taxonomy of the type of delay: Classifying delay based on its compensability; and
- Assigning accountability: Identifying the party responsible for the delay.

The procedures to follow to assess delay claims can be divided into the following phases, as shown in Fig. 2.4 (Yang and Kao, 2009):

- Preparation phase: All the necessary data, such as bid documents, daily construction reports, As-Planned and As-Built schedules are gathered.
- Diagnosis phase: The delaying events are identified and classified based on their liability.
- Analysis phase: Appropriate delay analysis methodology is employed to calculate the impact of the identified delaying events on the project date.
- Interpretation phase: The impact of delaying events on the critical path or on total project duration is determined. Meanwhile, for liability purposes, concurrent delays should also be taken into account for the contract parties.
- Summation phase: the analysis results are presented in an inclusive report.

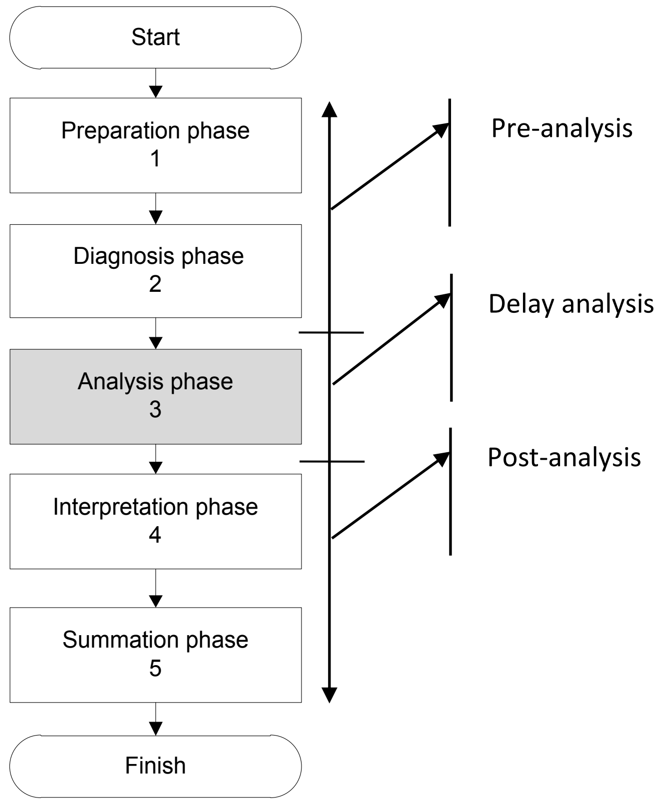


Figure 2.4: General Delay Analysis Processes (Yang and Kao, 2009)

It should be noted that the process of resolving a delay claims varies from one project to another due to the uniqueness of construction projects. However, whichever processes are employed, a practitioner must be able to answer the following four questions (Schumacher, 1995):

- What was supposed to happen?
- What did happen?
- What is the difference?
- How did this difference affect the project schedule?

This section focuses on the third question, which should be answered by implementing a delay analysis technique. Selecting the appropriate delay analysis technique for computing the effects of delay on a project is a critical decision, one that has to be made by an analyst (AACEI[a], 2009). Proper validation and precise results in analyzing a delay claim are linked to the analysis methodology used, and faulty techniques must be avoided (Al-Saggaf, 1998). The Society of Construction Law (SCL) has identified a number of factors that should be taken into account when selecting a delay analysis technique (SCL, 2002):

- The relevant conditions of the contract;
- The nature of the causative events;
- The value of the claims;
- The time available ;
- The recorded information;
- The schedule's accessible information; and
- The scheduler's experience with the project.

Arditi and Pattankitchamroon (2006) have discussed similar factors for method selection. They draw attention to four criteria:

- Data requirements
    - Availability of information
    - Type of Information
- Time of analysis
- Capability of the methodology

- Time and cost effort involved

Delay analysis techniques should include a means to scrutinize three types of activities: delayed, un-impacted, and time-shortened activities (Kim et al., 2005). An ideal delay technique should take into account all types of delays, accelerations, pacing delays and concurrent delays with respect to the resource allocation profile (Mohan and Al-Gahtani, 2006). Alkass et al. (1995) addresses three criteria to ensure the accuracy of delay analysis:

1. Delay type classification: to avoid an incorrect entitlement;
2. Concurrent delays: to avoid overstating the compensation; and
3. Real time analysis: employing the impacted CPM at the time of delay.

Researchers have classified delay analysis methods into different categories. Bordoli and Baldwin (1998) classify delay analysis techniques into two groups: “Basic Methods” and “Critical Path Analysis Methods”. The basic methods are uncomplicated in how they assign responsibility to a project’s parties, such as the “As-Planned Vs. As-Built” technique, which provides a simple visual statement of the difference between what was supposed to be performed and what was actually performed. Although this technique is simple to apply and clearly shows which activities deviated from the planned schedule, it has some major weaknesses that will be explained in the following sections.

Critical path analysis methods employ the CPM scheduling technique, introduced in the late 1950’s and now utilized by 88% of the contractors in the UK and in the USA (Aouad and Price, 1994). Furthermore, Ndekugri et al. (2008) has classified delay analysis techniques into two groups:

- Non-CPM based techniques such as S-curve, Net impact, and Global impact; and
- CPM-based techniques such as Windows analysis, Time-impacted analysis, and the Collapsed As-Built technique.

The AACE classifies delay analysis techniques into two divisions based on the timing of analysis:

1. Prospective analyses: these techniques are performed simultaneously with the delay event. They are employed as the project is in progress.
2. Retrospective analyses: these techniques are applied as the delay events occur and the impact(s) of delays are identified to the project parties.

Furthermore, retrospective techniques are classified into two subcategories: Observational and Modeled techniques. Observational methods review the project schedule by itself or with another schedule. By employing these types of techniques, the analyst does not make any changes to the schedule to develop any specific situation. In Modeled techniques, the analyst adds or subtracts delays to the corresponding activities and compares the generated results. AACE classification attempts to present a unified technological reference for the forensic application of the critical path method. All of these methods quantify the impact delay event on the project schedule by utilizing CPM schedules; however, not all methods are applicable to or acceptable in every case

(Ottesen and Martin, 2010). The following is a list of the delay analysis techniques that are currently used in the industry and by researchers:

1. Global impact technique (Alkass et al. 1996);
2. As-Planned technique (Bramble and Callahan, 2000);
3. As-Built technique (Bubshait and Cunningham, 1998);
4. Adjusted As-Built technique (Kumaraswamy and Yogeswaran, 2003);
5. Time impact analysis technique (Arditi and Pattanakitchamroon, 2006);
6. But-for technique (Schumacher, 1995);
7. Modified but-for technique (Mbabazi et al., 2005);
8. Isolated delay type (Alkass et al., 1995);
9. Isolated collapsed but-for technique (Yang and Yin, 2009); and
10. Windows snapshot technique (Alkass et al., 1996):
    - Modified windows technique (Gothand, 2003);
    - Delay selection technique (Kim et al., 2005); and
    - Daily windows technique (Hegazy and Zhang, 2005).

2.11.1 Global Impact Technique

The global impact technique (GIT) is easy to understand and implement. This method is not a CPM-based technique and delays and disruptions are plotted on a summary bar chart. For each delay, start and finish dates are calculated and the total delay to the project is the summation of the durations of delay events. Many researchers criticize this method. Major shortcomings of the global impact technique can be classified as follows (Alkass et al., 1996):

- Overlooks concurrent delays;
- Ignores different types of delays; and
- Considers every delay as if it has a similar impact on the project duration.

Accordingly, the generated result from this method is not solid, since the sum of the total delays is much greater than the project's actual delay, showing that the entitlement of delay is overestimated by this technique. The implementation of this technique includes the following steps (Mohan and Al-Ghahtani, 2006):

- Determine the start and finish dates of each delay event;
- Plot delays and distributions on a bar chart summary; and
- Determine the total project delay, equal to the sum of all of the delayed events' durations.

2.11.2 As-Planned Technique

As the name implies, the as-planned technique (APT) employs an As-planned schedule. The technique relies solely on the As-planned schedule to determine the impact of delays, and it does not apply the As-built schedule information to analyze the impact of delay. Contractor and owner-caused delays are added to the As-planned schedule, in order to measure and quantify the impact of these delays by comparing the schedules with and without them. Subsequently, the two schedules are compared to determine the total delay to the project (Bramble and Callahan, 1999). In this approach, delay events can be inserted into the baseline schedule in two ways. All the delays can be added into the schedule in one shot, or each delay can be inserted separately into the baseline schedule, to quantify their impacts on the As-Planned schedule (Bubshait and Cunningham, 1998). This approach is also known as "the impacted As-planned technique" (Trauner, 1990). When employing this approach, the following steps should be taken (Stumpf, 2000):

- Prepare the As-Planned schedule;
- Insert each owner-caused or contractor-caused delay into the As-Planned schedule; and
- Quantify the owner-caused delays and contractor-caused delays after each insertion.

Although the APT is a straightforward and simple technique, it does have major drawbacks. Firstly, it neglects the dynamic nature of the critical path. In other words, it assumes that the critical path is constant throughout the course of the project. Furthermore, it assumes that all of the activities' sequences and relationships would remain unchanged and valid (Braimah and Ndekugri, 2009). As a result, this technique does not accurately deal with concurrent delays and can thus generate flawed outcomes.

2.11.3 As-Built Technique

The as-built technique (ABT) is also known as the net impact technique. Palaneeswaran and Kumaraswamy (2008) consider the ABT to be a non-CPM technique, and one that is very similar to the global technique. The ABT illustrates the net effect of all delays, disruptions, change orders, suspensions, and concurrent delays on an As-built schedule. Furthermore, the difference between the As-built and the As-planned schedule is the requested time extension (Alkass et al., 1996). The As-planned and As-built schedules are plotted as two summary bar charts where only the net effect of the delays is presented. The amount of claimed time is the difference between these two bar charts.

The major drawbacks of this technique are that this method does not study the impact of the different types of delay. Thus, this technique might overestimate the number of influencing delays. Moreover, the AT does not employ CPM network schedules and, therefore, the actual effect of a delay on the project completion date may be misinterpreted (Alkass et al., 1996). Mohan and Al-Gahtani (2006) state that the real time delay over the progress of the project is neglected by this method, and it cannot address effects of concurrent delay on the project. Thus, this technique is not preferred one.

2.11.4 Adjusted As-Built Technique

As the name implies, the adjusted as-built technique (AABT) utilizes an As-Built schedule. The AABT is considered a CPM based technique and is utilized when the As-Built schedule is not accessible to the analyst (Mohan and Al-Gahtani, 2006).

Delay events are represented as activities, which are linked to particular task(s). The critical path is determined twice, first for the As-Planned schedule and second by the end of the project. The difference between the As-Planned and Adjusted As-Built completion dates is the amount of time for which a claimant would be asked for a time extension and/or reimbursement (Kumaraswamy and Yogeswaran, 2003).

Although this method uses the CPM schedule to evaluate the impact of delays, which gives the analyst insight to the inter-relationships between activities, this method does not scrutinize the different types of delay. In addition, the AABT only considers those delays that have had an effect on the critical path. As a result, it may fail to notice delays that are not so clearly visible in the schedule (Alkass et al., 1996).

2.11.5 Time Impact Analysis Technique

The time impact analysis technique (TIAT) is classified as a CPM-based technique, and it is a derivation of windows analysis. Different terms are used by researchers for this method, such as “End of every delay analysis” and the “Chronological and cumulative approach” (Chehayeb et al., 1995). The TIAT is a systematic approach to quantify the effect of delays by utilizing a CPM schedule. This technique is credited as one of the most reliable techniques (Arditi and Pattanakitchamroon, 2006). The TIAT scrutinizes the effects of delays or delay events on the project at different times during the duration of the project.

The TIAT focuses on a particular delay or delay event, not on a period that includes delays or delay events. The aim is to obtain a clear picture of the impact of a major delaying event before and after its occurrence. This technique evaluates the delaying events in a timely manner. It starts with the first delay event, inserting it into an updated CPM baseline schedule that reflects the actual progress of the contractor before the occurrence of delay. The discrepancy between two completion dates from two schedules is the amount of project delay for this particular delay event. This process is then repeated for all major delays (Alkass et al., 1996).

The TIAT is the preferred approach to quantify intricate disputes caused by delay and delay-related reimbursement. This technique overcomes the major drawbacks of the prior methods and can accurately trace the consumption of float, acceleration, and re-sequencing (Arditi and Pattanakitchamroon, 2006).

Although the TIAT is a desirable technique to evaluate delay claims, it does have some disadvantages. First, it requires a large amount of information to implement the analysis, which is a very time consuming approach. Second, this technique may not be appropriate in some cases where the time or budget is limited. Finally, the method fails to assess the issue of concurrent delay due to a lack of adequate precision (Alkass et al., 1996).

2.11.6 But-For Technique

According to Zack (2001), the but-for technique (BFT) is the most acceptable technique by US courts. Another common term for this approach is the collapsed as-built technique (Ndekugri et al., 2008). The BFT is based on “What-If” methodology and requires an accurate As-Built schedule, as well as containing all delays caused by the project parties. There is an alternative version of this method, which utilizes the As-Planned instead of the As-Built schedule (Alkass et al., 1995).

This technique is applied twice, once from the owner’s perspective and once from the contractor’s. The BFT technique from the owner’s perspective starts by deleting all contractor-caused delays from the As-Built schedule. In the absence of, or a deficiency in, an updated As-Built schedule, the first step that should be taken for evaluating delay claims is to develop an As-Built CPM schedule that includes all of the delays that occurred over the course of the project.

By comparing the As-Built schedule with the collapsed schedule, the contractor's delays for liquidated damages will be determined. The contractor's perspective follows the same procedures, except that all the owner-caused delays would first be removed from the As-Built schedule. The difference between the As-Built and the collapsed schedules represents the amount of delays that are attributable to the owner, for which the owner is responsible to provide extra time and/or money to the contractor (Mohan and Al-Gahtani, 2006).

According to Arditi and Pattanakitchamroon (2006), the but-for technique is employed when reliable schedules cannot be created from the project records or there is not sufficient information. Moreover, this method can be implemented in less time and at lower cost than time impact analysis. The BFT is an appropriate approach when the time and budget are limited.

Even though the BFT is widely accepted, it has several negative aspects (Arditi and Pattanakitchamroon, 2006). First, it is not capable of accurately addressing concurrent delay because contractor-caused and owner-caused delays are analysed individually. Second, this technique does not address any changes in the critical path during the course of the project. As a result, it is not easy to isolate each party's critical delays from non-critical ones. Third, this technique is very subjective and therefore can be manipulated. Arditi and Pattanakitchamroon (2006) state that the BFT is practical when sufficient information related to the As-Built schedule is available to the contract parties and they have a common interpretation of the information used to create the As-Built schedule.

2.11.7 Modified But-for Technique

The modified but-for technique (MBFT) was proposed to overcome the major drawbacks of the but-for technique. The MBFT was developed by Mbabzi et al. (2005) and has been enhanced to generate replicable results and to account for concurrent delay. The MBFT is an improvement on the BFT in three aspects, as follows:

1. A new illustration of activity interruption;
2. A new demonstration of the relations between the concurrent critical delays of various parties; and
3. A new approach, which includes the different project participant's perspectives.

The MBFT method employs a Venn diagram to evaluate concurrent critical delays, and a mathematical basis is proposed for integrating the various results related to each party's perspective (Mbabzi *et al.*, 2005). Since this technique applies a mathematical approach in its process, MBFT is more complicated and includes more steps compared to BFT that follows the "What-If" methodology. In addition, MBFT has not been comprehensively applied in the industry and academic areas, even though it eliminates the drawbacks of BFT.

2.11.8 Isolated Delay Type Technique

The isolated delay type technique (IDT) employs the systematic approach of Snapshot and Time impact analysis, while using the scrutinizing approach of the 'But-for' technique to overcome the deficiencies of previous delay analyses by proper delay classification, addressing concurrent delay, and using real time analysis (Alkass *et al.*, 1996). For delay analysis, project duration is divided into several windows. The length of each window is determined based on either key delaying events or after a series of delays have occurred.

The IDT identifies different types of delay and incorporates the relevant portion of delays in the related window, according to the contractor or owner's point of view. The deviation from the as-planned completion date can be determined by comparing the project's completion date before and after adding delays into the schedule. This deviation is credited to those delays that were inserted into the schedule (Alkass *et al.*, 1996). By accumulating delay values at each analysis window, the IDT can assign liability to each party. The authors explain the advantages of the IDT as follows:

- The method is a systematic and dynamic analysis that employs the Snapshot concept;
- Concurrent delays are evaluated and quantified carefully to resolve the issue of overstatement of the time extension;
- Delays are studied and classified according to their type, such as excusable non-compensable, excusable compensable and non-excusable delays, throughout the analysis. As a result, time is saved, future mistakes mitigated, and repetition of the analysis made more efficient;
- The method can be implemented at any phase of a project, making the IDT a valuable tool to employ during the execution phase of a project;
- Float is utilized by all parties of a project; and

- The method can be used for all project parties simultaneously, due to its objective analysis.

Although the IDT technique employs the positive features of other methods, such as the Snapshot and but-for techniques, there are some negative aspects to this technique as well. Firstly, the delays are added in one shot in each window, which is unrealistic. Secondly, it does not capture the fluctuations of critical path(s). Finally, the issue of concurrent delay is not assessed precisely enough (Mohan and Al-Gahtani, 2006).

2.11.9 Isolated Collapsed But-For Technique

The Isolated Collapsed But-For (ICBF) method is a new technique that uses the concept of IDT. This technique requires the As-Built schedule to start (Yang and Ying, 2009). The ICBF technique employs the positive features of the BFT and the IDT and overcomes their limitations.

The project duration is divided into several windows, similarly to the IDT, and the size of each window is determined based on major delay events. For each window, the project completion date is adjusted based on the delaying events. The adjusted schedule is a new baseline for quantifying the impact of a delay, and for assigning liability to each party.

The delay responsibility of each party is calculated by comparing the new baseline schedule and the affected schedule. The ICBF method is not only a systematic and dynamic analysis; it is also a comprehensible descriptive analysis process with an explicit approach to develop baseline schedule algorithms. The ICBF method is suitable for automation and repeatable calculation (Yang and Ying, 2009).

Although the ICBF technique is a new systematic and dynamic analysis, it still has some drawbacks: first, the ICBF requires a tremendous amount of information, such as the As-Planned and As-Built schedules, and information related to the delays (with proof). Second, the ICBF method cannot handle complex delay issues such as acceleration pacing delay, or delays due to a third party. Third, the ICBF method does not follow consistent rules for determining the analysis periods. Finally, the ICBF technique does not include an algorithm to allocate delay responsibility for the concurrent delays encountered (Yang and Ying, 2009).

2.11.10 Window Snapshot Technique

The window snapshot technique (WST) is one of the most accredited techniques and is also known as the contemporaneous analysis method. The window snapshot technique is a systematic and dynamic analysis, employed to determine the amount of delay, time of occurrence of the delay, and the related cause(s) of a delay (Mohan and Al-Gahtani, 2006).

In this CPM-based method, the total project duration is divided into several time frames or windows. The periods of these windows is usually determined based on major project milestones, key delaying events, and considerable changes in planning or times. In each window, the relationships and durations of the As-Planned schedule are adjusted to those of the As-Built schedule, and any activity not present in a currently-formed window would maintain its As-Planned schedule relations and durations.

The pre-established As-Planned completion date is compared to the altered project completion date after the adjustments to the As-Planned schedule. The comparison of completion dates is repeated after the formation of each window. The difference between completion dates is considered to be the magnitude of delay (caused by delaying events) in a given window; once the amount of the delay is calculated, the cause(s) of delay can be assessed.

The result accuracy depends on the number of windows chosen by the analyst (Kumaraswamy and Yogeswarm, 2003). In WST, both concurrent delays and the effects of delays are considered in time and CPM schedule implication (Alkass et al., 1996). The main advantage of this technique is its capability to consider the fluctuation of the critical path.

However, this technique is comparatively expensive to implement due to the extensive amount of time, effort, and project documentation required (Lovejoy, 2004). Although this technique offers a systematic and objective method of assessing the magnitude of delay in a project on a progressive basis, it has one major drawback: it does not analyse delay types prior to analyzing the impacts of delays on schedules. As a result, more analysis is required to assign delay entitlement to the project's parties (Alkass et al., 1996). Several researchers have attempted to overcome the limitations of the Window Snapshot technique (Gothand, 2003; Kim et al., 2005; Hegazy and Zhang, 2005). The following subsections discuss the different versions of the windows analysis method.

2.11.10.1 Modified Windows Technique

Gothand (2003) proposes a modified windows technique (MWT) which processes delay calculations similar to those in the WST, except that MWT unambiguously assigns delay responsibility to the contract parties. In other words, the MWT attempts to achieve a comprehensible delay liability prior to calculating the impact of delaying events by formulating an acceptable resolution for the project's parties.

This method can illustrate the consumption of float, day-to-day extension of time, issues of concurrent delays, acceleration, re-sequencing, and simulates the project's history. The logic behind this method is the same as with windows analysis, except for identifying delay responsibility.

Moreover, the MWT is mostly recognized as a retrospective analysis method, while the traditional windows technique is considered a real-time analysis method (Gothand, 2003). According to Kao and Yang (2009), the MWT offers improved analytical procedures, and has algorithms for calculating delay liability. The MWT describes three essential dates, as follows (Gothand, 2003):

- Baseline Impact Schedule Completion Date (BSCD): "it represents scheduled completion date for prior period without delaying events included from the analyzed period."
- Claimant Impact Schedule Completion Date (CSCD): "it represents claimant delaying events and the resultant completion date."
- Defendant Impact Schedule Completion Date (DSCD): "it represents defendant delaying events and the resultant completion date."

As a result, the amount of concurrent delay is equal to CSCD - BSCD and the amount of project delay is DSCD - BSCD. The MWT produces reliable outcomes by providing for earlier, meaningful negotiations of delay accountability.

2.11.10.2 Delay Analysis Method Using Delay Section

Kim et al. (2005) have proposed another variation of the windows analysis technique. The new method is called the delay analysis method using delay section (DAMUDS). The purpose of this technique is to overcome two major limitations of the existing methods: a) indistinctness in tracking concurrent delays, and b) insufficient consideration of accelerated activities. This technique includes two new concepts as follows:

1. Delay section (DS):

   In DS methodology, delayed activities fall into two different categories: a) Non-overlapped and b) Overlapped delays. In the first category, the single delay is considered as one "timeframe", whereas in the second category, the overlapped section of two or more delays is considered as a "timeframe". Notably, the remaining non-overlapped section(s) will be treated similarly to the first category.
2. Contractor's float (CF):

   In order to overcome the problem of handling time-shortened activities, the CF demonstrates the effort of a contractor to reduce the duration of activities, accordingly shortening the total project duration.

The DAMUDS procedures are based on these two new concepts and on a systematic approach of traditional windows analysis. Three discrete sections are used to calculate the delay impact on a project, namely as no delay, single delay, and two or more delays. DAMUDS provides comprehensible delay responsibilities for the owner and contractor by identifying and calculating the effect of delay (Kim et al., 2005).

2.11.10.3 Daily Windows Delay Analysis

The outcomes of windows-based analysis techniques are dependent upon the size of the windows. To resolve this limitation, Hegazy and Zhang (2005) have introduced a new modified windows technique, the daily windows delay analysis (DWDA).

This new technique is precise and produces replicable outcomes for assigning delay responsibility among a project's parties by analyzing the delay impact, based on day-by-day delay analysis throughout the project. In other words, the size of the windows in the DWDA is equal to one day for evaluating the effects of a delay(s) or delaying event(s) on the project completion date.

As a result, the technique overcomes the shortcomings inherent to the traditional windows technique. DWDA is not sensitive to the events of acceleration or deceleration within the analysis period, and critical path(s) fluctuation during the course of the project is tracked on a daily basis.

Furthermore, the technique is enhanced with a new representation of progress information (an intelligent bar chart, or IBC), which is a practical tool for site-data recoding on a regular basis and for delay analysis. DWDA is suitable for small and medium-size projects (Hegazy and Zhang, 2005).

2.11.10.4 Window-based Techniques Performance Comparison

According to Kao and Yang (2009), the most credible and accurate delay analysis methods are those based on the traditional windows method concept and which follow similar analytical procedural structures. The similarities and differences of the four windows-based methods are shown in Table 2.5.

Table 2.5: Similarities and differences among windows-based methods (Kao and Yang, 2009)

Category	Issued	WSA	MWA	DAMUDS	DWDA
Required schedule	As-Planned	Yes	Yes	Yes	Yes
	As-Built	Yes	Yes	Yes	Yes
	Update	Yes	No	Yes	Yes
	Fragnets	No	Yes	No	No
Application Timing	Forecasting	No	No	No	No
	Real time	No	No	No	Yes
	After delay occurred	No	No	Yes	Yes
	Project completion	Yes	Yes	Yes	Yes
Analysis procedure	Start timing	First delay	First delay	First delay	First delay
	Updating period	Arbitrary	Arbitrary	Delay section	Daily
Float consumption	TF on CP	No	No	Yes	Yes
	TF not on CP	No	No	No	Yes
Calculates impacts of NE,EN, and EC		No	No	Yes	Yes
Detects critical path change		No	No	Yes	Yes
Detecting delay or acceleration	Concurrent delay	No	No	Yes	Yes
	Pacing delay	No	No	Yes	Yes
	Project delay	Yes	Yes	Yes	Yes
	Project acceleration	No	No	No	Yes
Level of effort		Depends on the windows size	Depends on the windows size	Efficient	Huge
Result accuracy		**Good**	**Very good**	**Excellent**	**Excellent**

To sum up, all four windows-based techniques require As-Planned and As-Built schedule information. All four techniques are dynamic and can perform real-time delay analysis. However, WSA and MWA are less accurate and thus less reliable than the other two techniques. Furthermore, WSA and MWA require less effort than other techniques due to the arbitrary window size. On the other hand, DWDA evaluates the delay impact on the project based on day-by-day information in accordance with the actual progress, but it takes enormous effort to employ this technique. As a result, DAMUDS is more efficient than DWDA (Kao and Yang, 2009).

2.12 Delay Analysis, an Ongoing Debate

The level of accuracy of any delay analysis technique is directly related to the analyst's level of effort. Although various delay analysis techniques are available to evaluate construction schedule delays, no single technique is 100% acceptable to all project participants or is perfect for all delay circumstances. In the past few years, practitioners have attempted to resolve schedule-related issues such as float, float ownership, change in logic, and resource allocation; however, none of them have been able to tackle the related problems.

A survey illustrates that the as-planned versus as-built, collapsed as-built, and impacted as-planned techniques are amongst the simplest and the most widely applied methods for evaluating delays, even though their limitations are well known to practitioners. On the other hand, more accurate techniques such as, window-based techniques and time impact analysis, are less popular due to their convoluted nature. Table 2.6 summarizes the obstacles in the industry's use of delay analysis techniques (Bramimah and Ndekugri, 2009).

Table 2.6: Difficulties to employ delay analysis techniques (Bramimah and Ndekugri. 2009)

Rank	Obstacles
1	Lack of adequate project information
2	Poorly updated schedule
3	Baseline schedule without CPM network
4	High Cost involved in their use
5	High time consumption in using them
6	Difficulty in the use of the techniques
7	Unrealistic baseline schedule
8	Lack of familiarity with the techniques
9	Lack of suitable scheduling software
10	Lack of skill in using the techniques

The importance of applying more reliable and precise techniques by parties involved in the project is to mitigate the possibility of disputes on delay claims. The reasoning behind this assertion is that the accurate the delay analysis methodologies, the more precise the results, which in turn eases the process of settling delay claims.

2.13 Delay Damages and Applied Techniques

In all construction claim scenarios, two major steps should be taken to reach a resolution: delay entitlement and cost quantification. In other words, whenever there is an entitlement, there must be a reimbursement. In such a scenario, both the owner and the contractor are involved; as a result, two contradictory perspectives are applied to quantify the delay damages.

First, the owner is given the right to recover damages subject to a liquidated damages clause, if the contractor was deemed liable for the delay. Furthermore, if the contract lacks the liquidated damages clause, the owner can still recover the damages by quantifying the actual cost of an inexcusable delay.

Second, when the owner is liable for a delay, the contractor is entitled to an extension of time and cost reimbursement because of excusable compensable delays. This compensation includes direct, indirect, overhead, and impact costs. It should be noted that no-damages-for-delay clauses in a contract could place a contractor in an unfortunate position in regards to delay claims. This section covers some of the possible damages experienced by contractors and owners.

2.13.1 Owner's Damages for Delay

When a project is delayed, the owner may find him/herself in unfortunate financial circumstances, such as a loss of revenue and/or cost escalation. Therefore, owners seek reimbursement for contractor-caused delays. Due to the inherent complexity and uncertainty of calculating the actual cost of delay, some contracts include a clause for liquidated damages , provided that a contractor is responsible for delaying a project.

Heckman and Edwards (2004) define liquidated damages as "a sum contractually predetermined per day as a reasonable evaluation of genuine damages to be recovered by one party if the other party breaches." According to Cushman and Carter (2000), whenever a liquidated damages clause exists in a contract, recovery is restricted to those pre-determined values without considering the actual cost of delays, which may fluctuate around the liquidated damages value. The benefits of having liquidated damages provisions can be described as follows (Heckman and Edwards, 2004):

- Simplicity in the distribution of damages related to construction disputes;

- Creation of firm expectations for all project participants regarding what the damages for delay will be;
- Avoidance of significant proof issues associated with establishing and quantifying a delay claim; and
- The potential saving of attorney and expert fees, and other costs associated with proving an owner's delay damages.

Despite the benefits listed above, some owners are opposed to the idea of being restrained by a liquidated damages clause. Their reasons are: i) they prefer to calculate actual damages once the delay occurs, leading to a more desirable value, which coincides with the actual damages incurred; and ii) the lack of sufficient experience in calculating liquidated damages that forces them to rely on actual delay costs (McCormick, 2003). The owner's damages fall into the following two categories (Ibbs and Nguyen, 2007):

- Direct Damages (DD); and
- Consequential Damages (CD).

Direct damages are defined as damages that are the direct consequences of delay in a project. DD are one of the chief components of construction claims, and their quantification is a straightforward procedure. Direct damages may contain, but are not limited to (Cushman and Carter, 2000):

- Lost rental value of the property;
- Increase in material costs;
- Interest on construction loan(s);

- Additional engineering services;
- Extended construction supervision; and
- Overhead.

According to Dannecker et al. (2010), consequential damages are defined as those damages that are not incurred as an immediate consequence of the delay. In addition, consequential damages should be predictable and directly noticeable to be resulting from the delayed event. The amount of proof necessary to prove consequential damages is higher than for direct damages, and they must be claimed with greater specificity (Dannecker et al., 2010). Typical consequential damages may include, but are not limited to:

- Diminution of business prospects;
- Loss of credibility; and
- Loss of opportunity.

The distinction between direct and consequential damages is essential for evaluating delay claims. However, there is no general rule for separating consequential damages from direct damages (Dannecker et al., 2010). If damages fall into the direct damages category, they are considered compensable without presenting any supporting documents. Contrarily, if damages are classified as consequential damages, they are considered compensable provided that The claimant demonstrates the damages that were immediate consequences of delaying event(s) and reasonably predictable or not beyond the observation of involved parties while starting the project through the contract (Heckman and Edwards, 2004).

2.13.2 Contractor’s Damages for Delay

The construction industry is suffering the consequences of having no standard method to calculate delay costs. In certain situations, the problems associated with calculating damages may arise and act as hurdles in claim resolution. These problems include miscalculation of claim amounts, inadequate supportive documents related to claims for damages, and claims that contradict the terms of the contract (Trauner et al., 2009).

Even though many different methods exist for calculating related delay damages costs, the procedures for quantifying the contractor’s damages are convoluted and can be frustrating. Overcash and Harris (2005) state that the main reason for the frustration over verifying delay damages is related to misinterpretation and/or misunderstanding of the cost accounting systems used by the contractor. The following sections will attempt to explore the different types of allowable costs, calculating formulas, and conditions of damages recovery. Meanwhile, field and head office overheads are two controversial topics, which will be precisely explained.

2.13.2.1 Recoverable Costs of Damages

Depending on the project-specific circumstances, a contractor’s delay claim can contain many different cost elements. Some of the typical cost elements include extended and increased field costs, loss of productivity costs, insurance costs, site overhead costs, home office overhead costs, and other categories of delay damages (Trauner et al., 2009). These cost elements are usually recoverable; however, there are some costs that are not typically reimbursed, such as attorney fees and the cost of claim preparation. The aforementioned cost elements are briefly described below:

a) **Extended and Increased Field Costs**

Extended and increased field costs address additional labour, material, and equipment costs ensuing from project delays (Trauner et al., 2009):

- Labour costs: During the course of the project, in the occurrence of a delay, increasing the number of working hours of labourers, hiring more supervisory staff, and increasing labour wages are necessary.
- Material costs: The price of materials in the market always increases due to inflation or other economic factors known as “price escalation”. The contractor is forced to pay for additional materials in the new market with higher prices due to the occurrence of delay in the course of the project. The calculation method of this cost is similar to that of labour costs.
- Equipment costs: These costs are also known as “idle equipment cost”. Idle time means the period in which specific equipment does not work. The contractors are allowed to partially claim for these costs based on the provisions within the contract. In the absence of provisions, the contractor is able to claim the full actual cost of the equipment. It should be noted that in the case of renting equipment, this cost might be subjected to price escalation. The typical recoverable costs may include maintenance and repair costs, operating hours, initial cost, and depreciation.

b) Loss of Productivity

Loss of productivity or efficiency applies to situations where the implementation of an activity is prolonged or a different method of execution is applied. Typical causes of loss of productivity include work shifted due to unfavourable weather, changes in the sequence of work, frequent disruption in execution, and others. Loss of productivity damage is recoverable in the case of owner-caused delays, interference by other parties, and acceleration to meet an agreed upon completion date or a milestone. However, to precisely measure the loss of productivity is a complicated task (Rubin et al., 1999).

c) Insurance Costs

All projects must be fully insured prior to their start, so if the project completion date is delayed due to a compensable delay, the owner is urged to pay the contractor the premium as long as the claim is approved.

d) Site Overhead

Site or jobsite overhead costs are defined as those costs incurred at the jobsite relevant to the supervision and administration of the overall project. This cost cannot be assigned to an individual activity and so it is usually treated as an indirect cost. Typical jobsite overhead may include (Smith and Gray, 2001; Jentzen et al., 1996):

- Project manager, engineering, safety, quality assurance /quality control, clerical salaries;

- Jobsite trailer or office rent;
- Jobsite equipment, furniture, office supplies, telephone, etc.;
- Support craft labour, e.g., warehouse personnel, janitorial;
- Jobsite security service;
- Small tools and consumables; and
- Support equipment, e.g. forklifts and service cranes.

Jobsite overhead costs usually fluctuate as a function of changes in the magnitude of work executed and/or the duration of the project. For instance, as the duration of a project is prolonged, the contractor usually experiences additional costs for the stretched timeframe (Smith and Gray, 2001).

The contractor's cost can be divided into time-related and activity related costs. Only time-related costs should be considered when quantifying the jobsite overhead cost (Nguyen, 2007). To calculate site overhead, the following two methods are employed. The industry is not limited to these two methods, and other methods can be utilized for this computation (Lankenau, 2003; Jentzen et al., 1996):

- Percentage method
- Daily rate method

The percentage method depends on historical data or industry standards. The percentage of jobsite overhead charges varies from project to project. For example, R.S. Means designates 5 to 12% for site overhead and the preferred percentage within this range should be multiplied by the time-dependent factors. It is recommended that a range of 70 to 80 % of the overall project cost be used for the time dependent factor. The site overhead will be calculated by using the percentage method as shown in Eq. 2.2 (Jentzen et al., 1996):

$$Site\ Overhead = [BP * TDW * SOHP]/PD \qquad (2.2)$$

BP= Bid Price ($)

TDW= Time Depended Work (%)

SOHP= Site Overhead Percentage (%)

PD=Project Duration (d)

In the daily rate method, the contractor calculates the time-related costs and divides them by the planned project duration to determine an average daily rate. Finally, for computing the site overhead within the delay period, the number of compensable delays should be multiplied by the daily rate as shown in Eqs. 2.3-2.4 (Lankenau, 2003):

$$Daily\ Rate = (Total\ Time\ Dependet\ Costs)/(Project\ durtion) \qquad (2.3)$$

$$Site\ Overhead = (Amount\ of\ Compensable\ Delays) * (Daily\ Rate) \qquad (2.4)$$

The daily rate method is potentially unfair to the owner due to considering the owner's sole responsibility for all uprising project costs. Thus, four arising requirements must be met for US courts to approve the current method (Lankenau, 2003):

- It is not possible to quantify damages with reasonable accuracy;
- The bid price was realistic;
- The costs are reasonable; and

- The contractor was not held accountable for the costs.

The aforementioned methods have serious limitations in their capacity to assess jobsite overhead due to delays. The need for an accurate methodology is obvious. Detailed discussions on estimating jobsite overhead damages can be found in Lankenau (2003), Smith and Gray (2001), and Jentzen et al. (1996).

e) Head Office Overhead

Head office overhead is those indirect costs that are not directly allocated to an individual project, but must be collected during an individual project's billing so that the contractor can continue to operate in the market (Taam and Singh, 2003). In other words, HOOH is normally defined as the costs incurred by the contractor in supporting all of concurrent projects (Zack, 2001). The amount of HOOH, that is a percentage of direct costs, will usually be added to a contract price. The amount of head office overhead (HOOH) may increase due to compensable delays. Typical examples of the components of HOOH in the industry include, but are not limited to (Taam and Singh, 2003):

- Rent;
- Utilities;
- Executive staff salaries;
- Support and clerical staff salaries;
- Cost of preparing bids;
- Taxes; and

- Insurance premiums.

Head office overhead damages should be divided into two different types, namely extended HOOH and unabsorbed HOOH. Although these terms are two distinct concepts, they are often used interchangeably by courts, boards, and practitioners (Kauffman and Holman, 1994)

Unabsorbed overhead is a term which is commonly used in the manufacturing industry. However, construction contractors usually bear the unabsorbed overhead costs when a project is delayed. Unabsorbed or under-absorbed HOOH occurs as the contractor tolerates disproportionate home office overhead costs; so, the company experiences a rise in its overhead rate. This rise happens directly due to decreasing cash flow caused by compensable delays. In such scenarios, the contractor should provide supplementary income and lower contract billings to cover diminishing revenue caused by the delay (Cushman and Carter, 2000). Zack (2001) concluded from case law and court decisions that the following three prerequisites should be met to recover unabsorbed HOOH damages:

- Delays should be caused by the owner and be compensable;
- The excusable compensable delays must cause a considerable decrease in project cash flow;
- As a result of owner-caused delays, the contractor was unable to enrol in a new project due to the unclear duration of the delayed project, as well as his/her inability to perform other work in this particular project to cover HOOH costs;

- The owner must ask the contractor to remain idle to resume work once the problem is resolved;
- The project delay must not have been caused by direct changes or modifications; and
- For calculating unabsorbed HOOH, the contractor is only allowed to apply the original Eichleay Formula.

According to Schwartzkopf and McNamara (2001), the extended HOOH is a unique concept to the construction industry. Extended or overextended HOOH refers to the escalation of overhead cost due to the prolonged performance of a project. Furthermore, the HOOH cost for the period of compensable delays remains as a debt of the owner to the contractor (Zack, 2001). In such cases, a contractor allocates more overhead to the delayed project than was the assigned overhead when bidding on the project (Cushman and Carter, 2000).

f) Other Categories of Delay Damages

Trauner et al. (2009) state that a delay claim may contain other cost elements such as loss of opportunity costs, constrictive acceleration costs, interest on construction loan, and delay on noncritical path(s).

2.13.2.2 Calculating Head Office Overhead

Several methods are available for calculating the HOOH damages imposed on a project by compensable delays. However, the outcomes of these methods can be different even when applied to the same case. Taam and Singh (2003) applied various methods and formulas to the same case study. They concluded that the results of various methods will vary based on the particular situations, conditions, and assumptions utilized in each method. The following are the most frequently employed methods to calculate HOOH damages (Zack,2001):

1. Eichleay,
2. Modified Eichleay- Var.1,
3. Modified Eichleay- Var. 2,
4. Canadian (Hudson Method),
5. Ernstrom Formula,
6. Manshul Formula (Direct Cost Allocation Method),
7. Carteret Formula,
8. Allegheny Formula, and
9. Emden Formula.
10. Calculation based on actual records,

From the list above, two methods were selected for further discussion, the Eichleay and the Canadian. The reasons for choosing these two methods are that courts, boards, and practitioners commonly use the Eichleay method, and the Canadian method is used extensively in Canada. The explanations and examples for the rest of the above-mentioned methods can be found elsewhere (Taam and Singh, 2003; Zack, 2001).

The Eichleay method is the most commonly used method for calculating HOOH delay claims. The Armed Services Board of Contract Appeals accepted a formula proposed by the Eichleay Corporation for calculating HOOH damages; this method has been known as the Eichleay method since 1960. The formula is simple and straightforward, as shown in Eq. 2.5-2.7 (Zack, 2001):

$$\boldsymbol{Overhead\ Allocable\ to\ Contract} = \frac{\boldsymbol{Contrac\ Billings * Total\ HOOH(for\ all\ in\ progress\ project)}}{\boldsymbol{Total\ Billing\ for\ Contract\ period}} \qquad (\mathbf{2.5})$$

$$\boldsymbol{Daily\ Contarct\ Overhead} = \frac{\boldsymbol{Contrac\ Billings * Total\ HOOH(for\ all\ in\ progress\ project)}}{\boldsymbol{Total\ Days\ of\ Performance\ (including\ delay)}} \qquad (\mathbf{2.6})$$

$$\boldsymbol{Overhead\ Claim\ Amount\ = Daily\ contract\ Overhead * Number\ of\ Days\ Delay} \qquad (\mathbf{2.7})$$

According to Taam and Singh (2003), courts, attorneys, judges, and scholars usually criticize the Eichleay method in the following two areas:

1. Its overall concept of unabsorbed overhead; and
2. The accuracy of the formula.

Although the Eichleay formula is criticized on these issues, the technique remains one of the most appropriate formulas to calculate HOOH damages because of the certainty and ease of its application (Kauffman and Holman, 1994).

The Canadian method is widely utilized in Canada. The Canadian formula is also straightforward and logical for the calculation of HOOH delay-related damages. The Canadian formula considers the contractor’s actual mark-up in calculating HOOH damages. The actual mark-up can be calculated from bid documents or from historical data. Eqs. 2.8-2.9 represents the Canadian method:

$$\boldsymbol{Daily\ Overhead\ Rate} = \frac{\boldsymbol{Precntage\ Mark-up * Original\ Contract\ Sum}}{\boldsymbol{Original\ Number\ of\ days\ in\ the\ contract}} \qquad (\mathbf{2.8})$$

$$\boldsymbol{Overhead\ Claim\ Amount\ = Numbers\ of\ Compensable\ Delay * Daily\ Overhead\ \ rate} \qquad (\mathbf{2.9})$$

Although the Canadian formula is a simple and direct method for calculating HOOH cost, it has a major drawback in considering unallowable indirect costs in its calculation (Taam and Singh, 2003).

2.14 Summary of the Literature Review

This chapter has reviewed and discussed the most important subjects related to delay claims in the construction industry. The various techniques, methodologies, and theories utilized in delay claims were summarized, and their logic, advantages, and disadvantages were highlighted. Reviewing current delay analysis techniques proves that further refinements in the following areas are required: concurrent delay, pacing delay, and the effects of float consumption and resource allocation on the outcome of delay analysis. Although some new techniques have attempted to overcome these problems to some extent, applying a holistic approach for different scenarios can appropriately resolve the aforementioned shortcomings. The quantification of recoverable damages not only needs improvement in some aspects, but also the unclear concepts associated with the quantification of recoverable damages make the computing procedures convoluted. Therefore, using a standard dictionary in the construction industry, by all project stakeholders (owners, contractors, subcontractors, courts, and so on), is strongly recommended.

Chapter 3

The Modified Isolated Delay Type Technique

3.1 Introduction

Preparing construction delay claims is a complicated task, as are the proceedings for achieving claim resolution. These are costly and time-consuming tasks for all parties involved. It is quite normal for engineers and experts to be asked by the parties involved in claims assessment to aid in analyzing the causes and effects of delays. Numerous delay analysis techniques are employed by practitioners to evaluate construction-related (the impacts of delay on the project completion date) delays.

The levels of effort for implementing these techniques vary from virtually effortless, such as a simple duration comparison, to complex and overwhelming detailed analyses, such as windows-based methods. As mentioned in the previous chapter, these methods can provide a wide range of results for the same scenario. In order to calculate delay costs caused by the project parties, it is necessary to utilize delay analysis to demonstrate the effects of those delays on the project schedule.

.A sound delay claim must be supported by an accurate and reliable delay analysis technique. The objective of this chapter is to propose a new technique to overcome any limitations in dealing with different types of concurrent delays. To validate the proposed method, and to compare it to the techniques introduced in previous chapter, all techniques are applied to a common hypothetical case study. Then, the results are analyzed and the shortcomings and advantages of the current method are highlighted.

3.2 Modified Isolated Delay Type

Different delay analysis techniques are available for evaluating delay-related claims. Selecting a proper delay analysis technique depends on various factors such as the availability of information, time and cost. Furthermore, any selected delay analysis technique should have the following characteristics:

- be a CPM schedule;
- have a systematic approach;
- scrutinize different types of delays before analyzing the schedule;
- consider all different concurrent delay scenarios;
- has a reasonable total float distribuation between project parties
- consider real critical path(s) of the project; and
- be implementable with hindsight and foresight.

The isolated delay type analysis technique (IDT) is the approach that has been adopted and modified for this research, as it meets most of the above characteristics. Hereafter, this proposed technique is called Modified Isolated Delay Type (MIDT), using the contract's language as a main criteria for its calculation. Alkass et al. (1996) highlighted the advantages of the IDT technique. However, the IDT is unable to cover some issues related to concurrent delays (Mohan and Al-Gahtani, 2006). For example, a scenario where a concurrent delay has occurred on two parallel critical paths, one caused by the owner and other by the contractor. These delays are classified as excusable compensable and non-excusable delays, which are the owner's and contractor's failures, respectively. The IDT is unable to consider this kind of concurrent delays due to its limited analytical procedures.

The IDT does not consider the combined result of the overlapping classified individual delays caused by different parties on any concurrent delay. However, the MIDT has been enhanced to incorporate the synthesis (combination result) of concurrent delays into the analysis of the impacted schedule for the parties involved. This synthesis of concurrent delays employed in MIDT is simply based on the definitions stated in the concurrent delay clauses of a contract or agreement reached between the parties.

Another drawback of the IDT is imposing all types of excusable delays (EC and EN) at once to the related windows. Therefore, the outcome includes the effect of both EN and EC delays, which cumulatively appears at the end of the project. Thus, the IDT does not reflect any distinction between the EC and the EN influences on the generated result, and the analyst cannot provide a breakdown of the excusable delays. The MIDT attempts to overcome this shortcoming by imposing the EC and EN delays separately into related windows.

Furthermore, the IDT analysis does not consider the project's real critical path because the baseline schedules, except for the first analysis period, do not reflect the actual events that occurred during the course of the project for calculation purposes. In contrast, the baseline schedules are utilized for calculation by the MIDT, reflecting all delays or delaying events to ensure that the critical path(s) of the project coincides with the actual critical path(s). In the following sections, the procedures of applying MIDT will be demonstrated through a case study.

3.3 Analytical Process of the MIDT

The MIDT method uses the same concept as the IDT method does and maintains the advantages associated with the IDT technique. Both methods use similar documents in their analytical processes such as the as-planned schedule, as-built schedule, revised schedules and project documents. It should be noted that the project documents have an important impact on the MIDT's outcome. Therefore, they should contain relevant information about delay(s) or delaying event(s) that occurred during the course of the project.

Figure 3.1 illustrates the analytical processes used in the MIDT technique. The MIDT uses an as-planned schedule as a starting point, and performs delay analysis to clearly interpret the liabilities of the project parties; namely, the claimant and the defendant. Similar to the IDT technique, the MIDT technique must be executed from two different perspectives: the owner's and the contractor's.

In achieving accurate results, the as-planned schedule is divided into a number of analysis periods. The criteria used in MIDT to establish the size of each analysis period are the same as for the IDT method. These criteria originate from either major delay events, or changes in critical path(s), or periodic times. Considerable attention should be given to determining the size of each analysis period, since larger analysis periods increase the probability of losing critical path(s) tracking.

In the MIDT technique, the delays caused by the counter party are inserted into the baseline schedule, now known as "Impacted schedule". Meanwhile, inserting the combined result of concurrent delays into the schedule should be performed simultaneously with the independent delays.

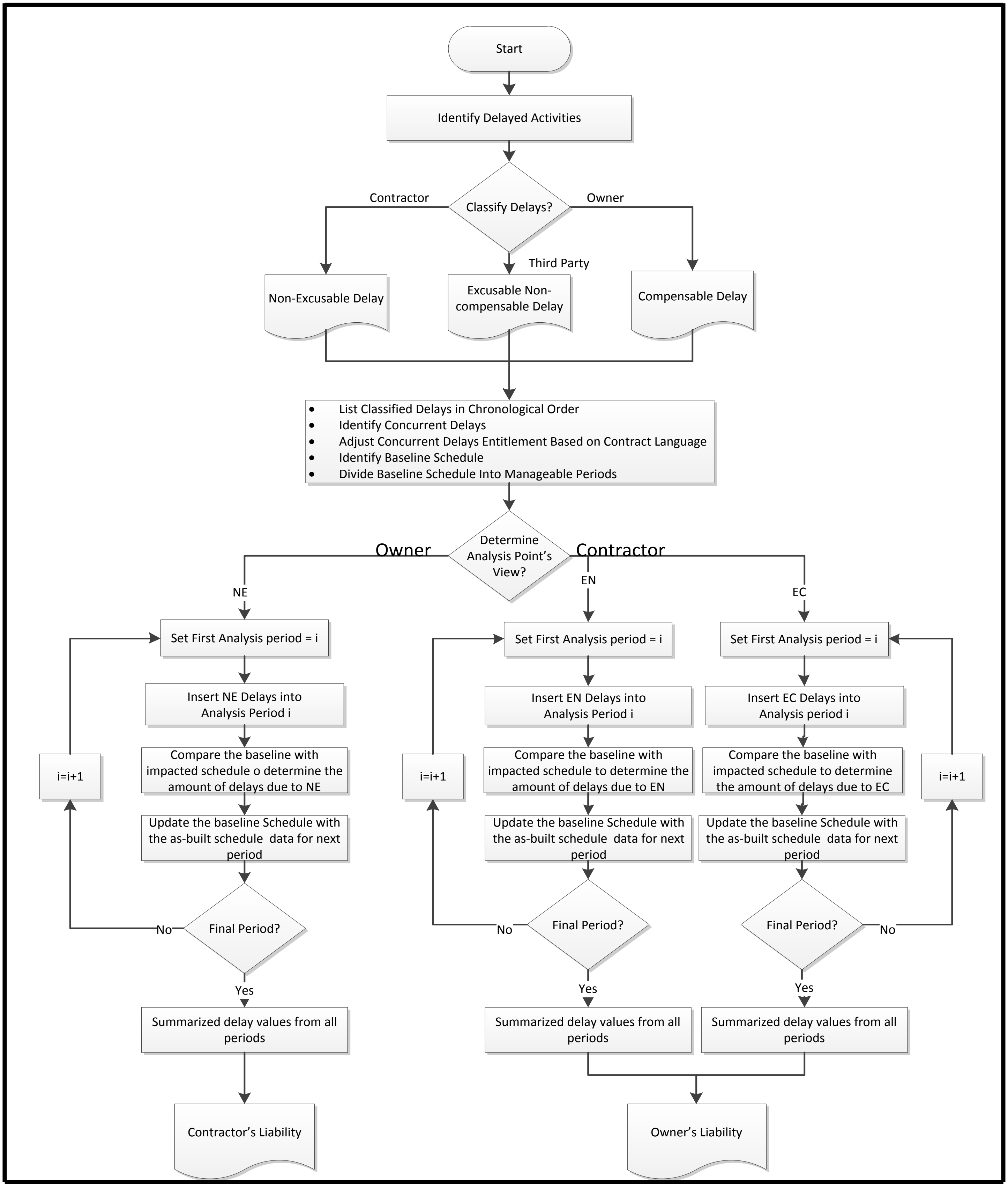


Figure 3.1: Analytical Processes of the MIDT Method

The impacted schedule must be compared to its correspondent baseline schedule to measure the impact of delay on the project. Before moving to the successor analysis period, its predecessor period must be modified to coincide with the durations and meet the logical relationship according to the timely actual progress. This is known as a new baseline schedule for the next analysis period. The activities, in MIDT, are classified into four types:

Type A: these are the activities which start and finish within the current analysis period. For the analysis of type A activities their durations have to be converted with As-built schedule. Type B: the activities of which neither their start and nor their finish dates are within the current analysis period. For these types of activities their durations must be the same as the as-planned schedule. Type C: These are activities starting in the current analysis period but are continued into the next analysis period(s). The analyst must adjust the start date of type C activities with their As-built (actual) start date with the actual start date. For the remaining duration of a type C activity its As-planned duration must be subtracted from its working days prior to the current analysis period. Type D: These are activities starting in an earlier analysis period but completed in the current analysis period. The analyst must only adjust the duration of the portion of activity falling within the current analysis period.

As stated earlier (in section 3.2), the contractor must apply the MIDT technique twice: once for excusable compensable delays and again for excusable non-compensable delays in either order. Thus, this approach facilitates achieving a well-structured excusable delays breakdown of both types. These procedures must be continued until all analysis periods' assessments are covered.

3.4 Calculation Procedures

For each analysis period, the baseline duration (BD_i) is calculated by adding the as-planned duration to the actual project duration (AD_{i-1}) before the analysis period starting date, as in Eq. 3.1. From the owner's perspective, the duration of the impacted schedule (ID_i^{NE}) is calculated from Eq. 3.2, which illustrates the effect of NE delays for each analysis period. Therefore, to measure the effects of delay on the baseline schedule, its duration should be subtracted from the impacted schedule duration (Eq. 3.3). The same procedures must be repeated for each analysis period. Finally, the amount of project delay due to owner-caused delays (EC and EN) is calculated using Eqs. 3.4 to 3.7.

The total project delay liability for the contractor is calculated by summing up all non-excusable durations that fall in each analysis period (Eq.3.8). For the owner, this value is obtained by adding the summation of total excusable delays to the summation of total excusable non-compensable delays that occurred within all analysis periods. This equation is simply shown in Eq. 3.9. It should be noted that, for cost liability, only the first summation is considered ($\sum_{i=1}^{n} D_i^{EC}$).

$$BD_i = PD + AD_{i-1} \quad \text{(Eq. 3.1)}$$

$$ID_i^{NE} = BD_i + NE \quad \text{(Eq. 3.2)}$$

$$D_i^{NE} = ID_i^{NE} - BD_i \quad \text{(Eq. 3.3)}$$

$$ID_i^{EC} = BD_i + EC \quad \text{(Eq. 3.4)}$$

$$D_i^{EC} = ID_i^{EC} - BD_i \quad \text{(Eq. 3.5)}$$

$$ID_i^{EN} = BD_i + EN \quad \text{(Eq. 3.6)}$$

$$R^{Contractor} = \sum_{i=1}^{n} D_i^{NE} \quad \text{(Eq. 3.8)}$$

$$R^{Owner} = \sum_{i=1}^{n} D_i^{EC} + \sum_{i=1}^{n} D_i^{EN} \quad \text{(Eq. 3.9)}$$

i: $0< i \leq$ number of analysis periods;

AD_{i-1}: actual project duration before starting analysis period i;

BD_i: baseline schedule duration for analysis period i;

ID_i^{NE}: impacted schedule duration for analysis period i due to NE delays;

ID_i^{EC}: impacted schedule duration for analysis period i due to EC delays;

ID_i^{EN}: impacted schedule duration for analysis period i due to EN delays;

D_i^{NE}: difference between impacted schedule and its baseline schedule due to NE delays;

D_i^{EC}: difference between impacted schedule and its baseline schedule due to EC delays;

D_i^{EN}: difference between impacted schedule and its baseline schedule due to EN delays;

$R^{Contractor}$: responsibility of contractor due to NE delays

R^{Owner}: responsibility of owner due to EC and EN delays

3.5 A hypothetical case study

To evaluate the delay analysis techniques mentioned above, a hypothetical case was adopted from the literature (Kraiem and Diekmanm, 1987). This case study was adopted because it was previously used to evaluate IDT (Alkass et al. 1996). Furthermore, this case study is straightforward and includes all the various delay types regarding compensability and concurrency.

The scheduling software used to test this method is MS Project 2007, a very common scheduling software. MS Project supports the precedence diagram method (PDM) that is utilized to assess delay analysis techniques. The PDM schedule is classified as a critical path method (CPM) scheduling technique. The case study consists of ten activities with two critical paths. The critical paths in the as-planned schedule of this hypothetical case study are as follows:

- First critical path:Activities 1, 3, 6 and 9
- Second critical path:Activities 2, 5, 8 and 10
- Non-critical path: Activities 4 and 7

The as-planned schedule illustrates that the project was planned to be delivered in 23 days (Fig 3.1). However, it was delayed by 18 days, so the total project duration was extended to 41 days. The changes are shown in the as-built schedule in Fig. 3.2. Furthermore, throughout the course of the project, the numbers of activities and their relationships did not change. Figure 3.3 illustrates the as-planned versus as-built schedule for comparison purposes.

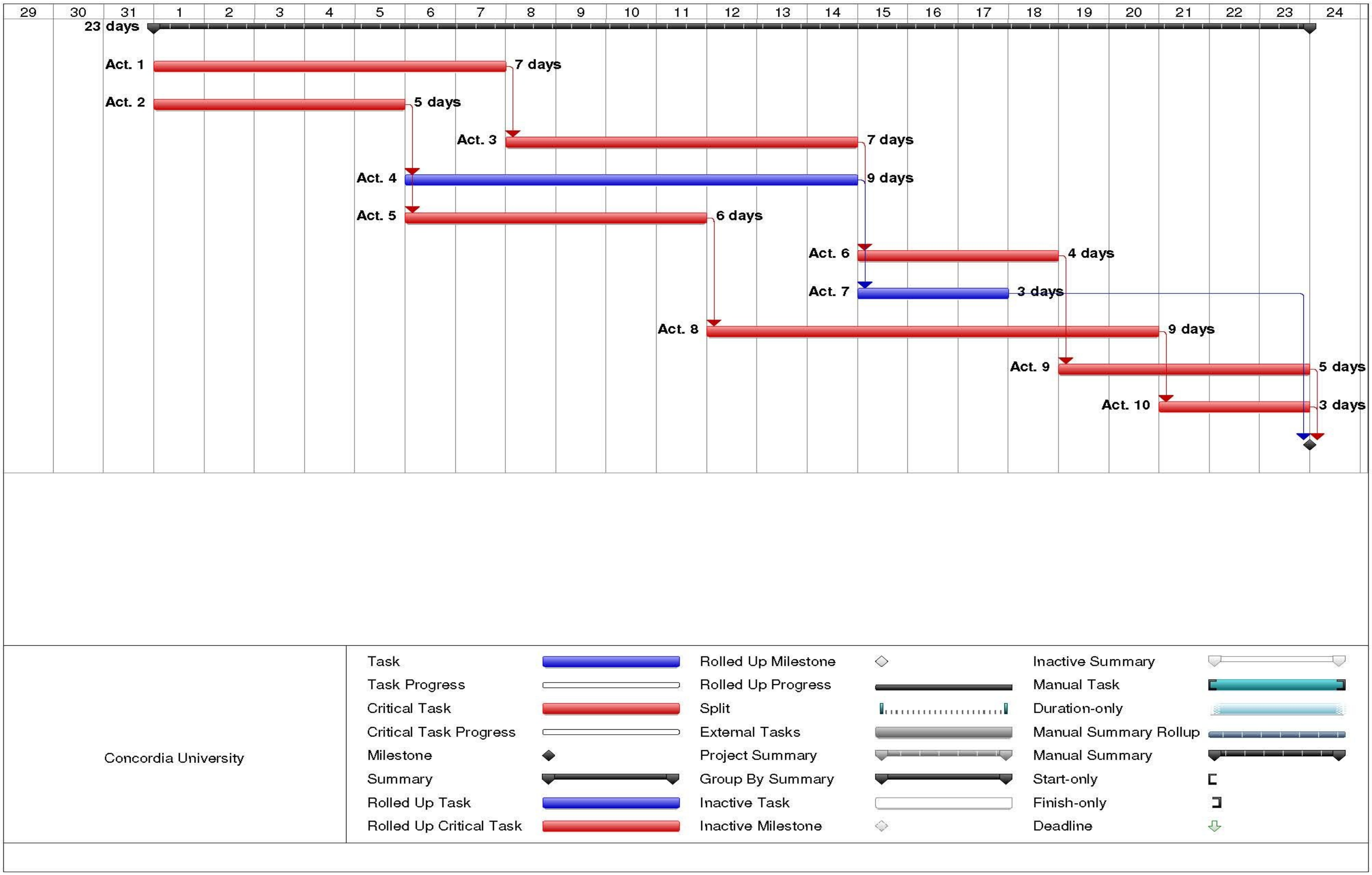


Figure 3.2: As-Planned Schedule

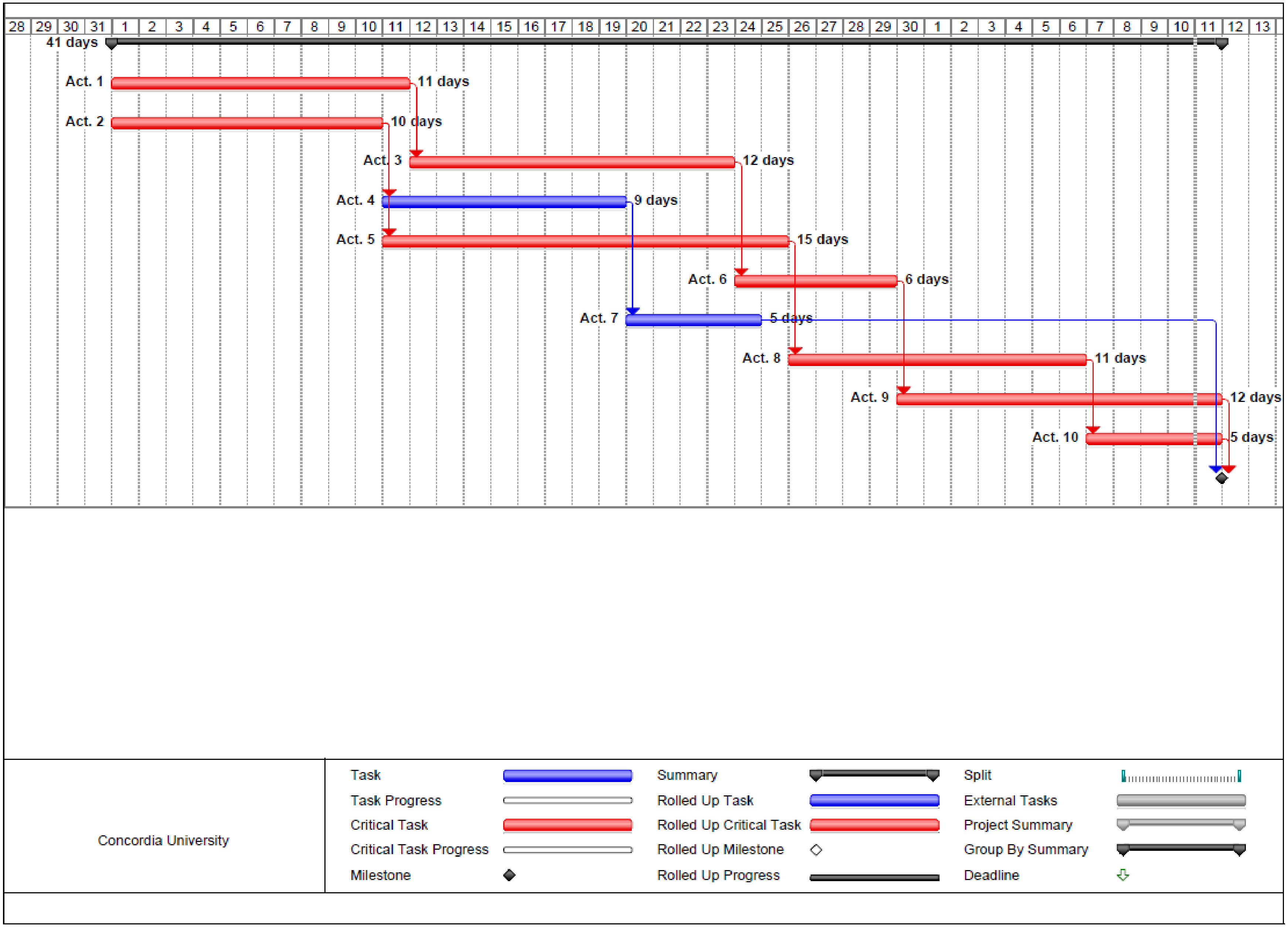


Figure 3.3: As-Built Schedule

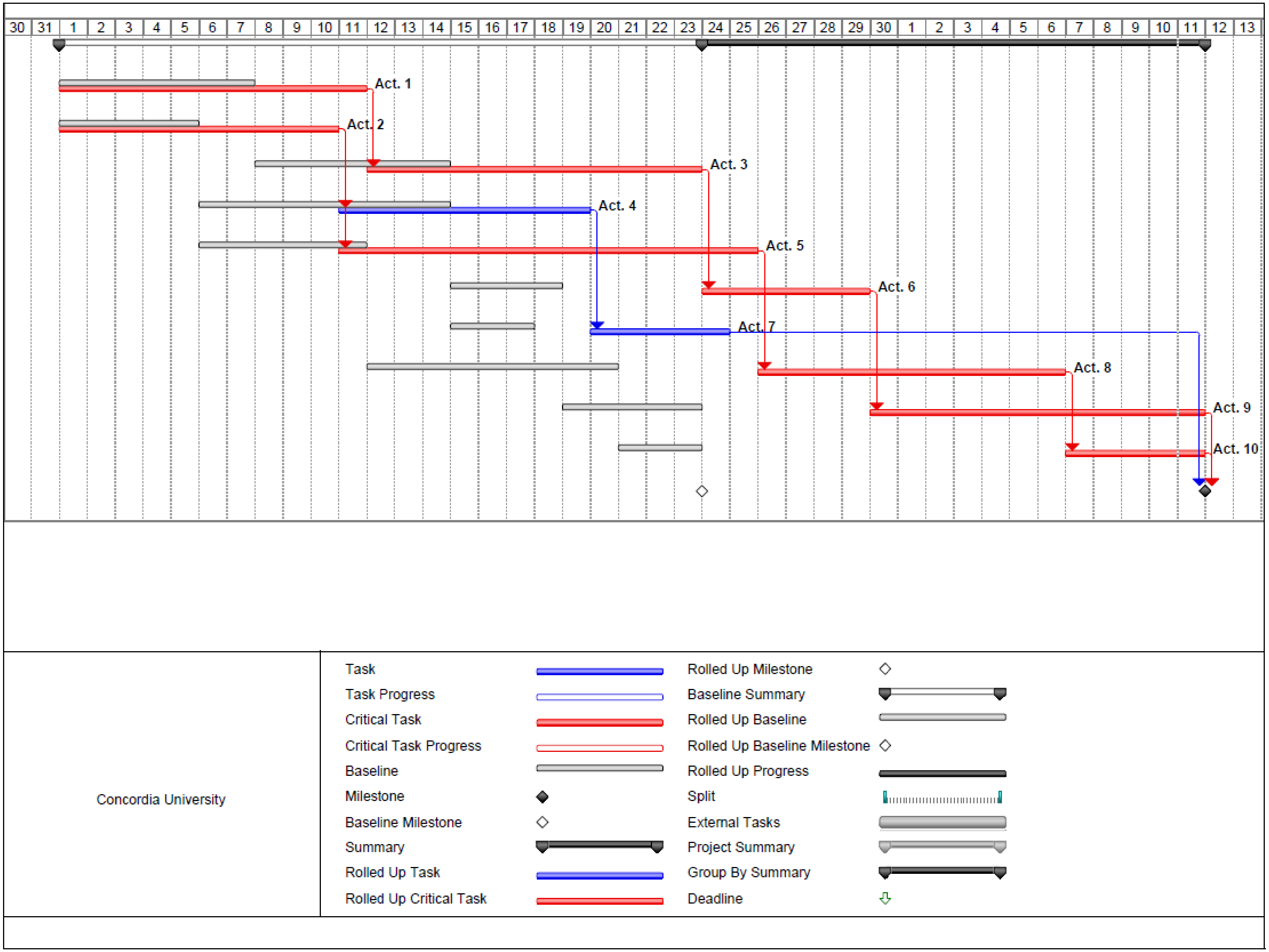


Figure 3.4: As-planned Vs. As-built Schedule

3.5.1 Delay Classification

In this case study, the delays are classified into three categories based on their compensability: excusable compensable (EC), excusable non-compensable (EN), and non-excusable delays (NE). Table 3.1 represents the summary of the corresponding delays and their duration.

Table 3.1: Summary of Delay Classification and Related Duration

Task ID	Types of Delay			Total
	EC	EN	NE	
Act. 1	Nil	1	3	**4**
Act. 2	1	3	1	**5**
Act. 3	2	Nil	3	**5**
Act. 4	Nil	Nil	Nil	**Nil**
Act. 5	3	5	1	**9**
Act. 6	2	Nil	Nil	**2**
Act. 7	1	Nil	1	**2**
Act. 8	1	1	Nil	**2**
Act. 9	2	2	3	**7**
Act. 10	Nil	2	Nil	**2**
Total	**12**	**14**	**12**	**38**

In addition, delays can be categorized based on their time of occurrence as either independent or concurrent delays. Table 3.2 represents the matrix-based breakdown of categorized delays:

Table 3.2: Categorizing matrix based on time of occurrence

Act #	Act. 1	Act. 2	Act. 3	Act. 4	Act. 5	Act. 6	Act. 7	Act. 8	Act. 9	Act. 10
Act. 1	**2**	2	-	-	-	-	-	-	-	-
Act. 2	2	**3**	-	-	-	-	-	-	-	-
Act. 3	-	-	**1**	-	4	-	-	-	-	-
Act. 4	-	-	-	-	-	-	-	-	-	-
Act. 5	-	-	4	-	**3**	-	2	-	-	-
Act. 6	-	-	-	-	-	**2**	-	-	-	-
Act. 7	-	-	-	-	2	-	-	-	-	-
Act. 8	-	-	-	-	-	-	-	**1**	1	-
Act. 9	-	-	-	-	-	-	-	1	**6**	-
Act. 10	-	-	-	-	-	-	-	-	-	**2**

In the above table, the numbers represent the amount of delays in days. Connecting the rows and columns of the activities determines the category of a delay. Since the rows and columns of this matrix are displayed in ascending order, independent delays can be found on the diagonal. Other cells of this matrix with delays are assigned to concurrent delays. In addition, concurrent delays are symmetric around the independent delays sited on the diagonal of this matrix.

3.6 Analysis Procedure

In this case study, four analysis periods are defined, where the last three have identical time intervals. The first interval starts on the first day and ends on the eleventh day. The remaining intervals end on the 21st, 31st, and 41st days, consecutively.

3.6.1 The MIDT for the Owner's Viewpoint

To utilize the MIDT, the delays or delaying events that fall within the first analysis period must be identified. After classifying the delays into types and identifying concurrent delays within this analysis period, it is time to incorporate contractor-caused delays into the first baseline schedule. In this case study, the concurrent delays are evaluated based on the following laws:

- Scenario 1: Excusable delay concurrent with Non-excusable delay, considered as a net Non-Excusable delay (Construction Claims Monthly, 2002; Arditi and Robinson, 1995; Baram, 2000);
- Scenario 2: Excusable delay concurrent with Compensable delay, considered as a net Excusable delay (Construction Claims Monthly, 2002; Reynolds and Revy, 2001; Baram,2000; Arditi and Robinson, 1995; Reams,1989);
- Scenario 3: Compensable delay concurrent with Non-excusable delay, considered as a net Non-Excusable delay (Construction Claims Monthly, 2002; Baram, 2000).

In this study, from the owner's point of view, only non-excusable delays and the combined result of concurrent delays are added to the first baseline schedule (impacted schedule). The project duration was re-calculated and compared to the baseline duration. The variation between the first baseline and the first MIDT is the amount of delay to the project caused by NE delays within the first analysis period (Fig. 3.5 and Fig. 3.6).

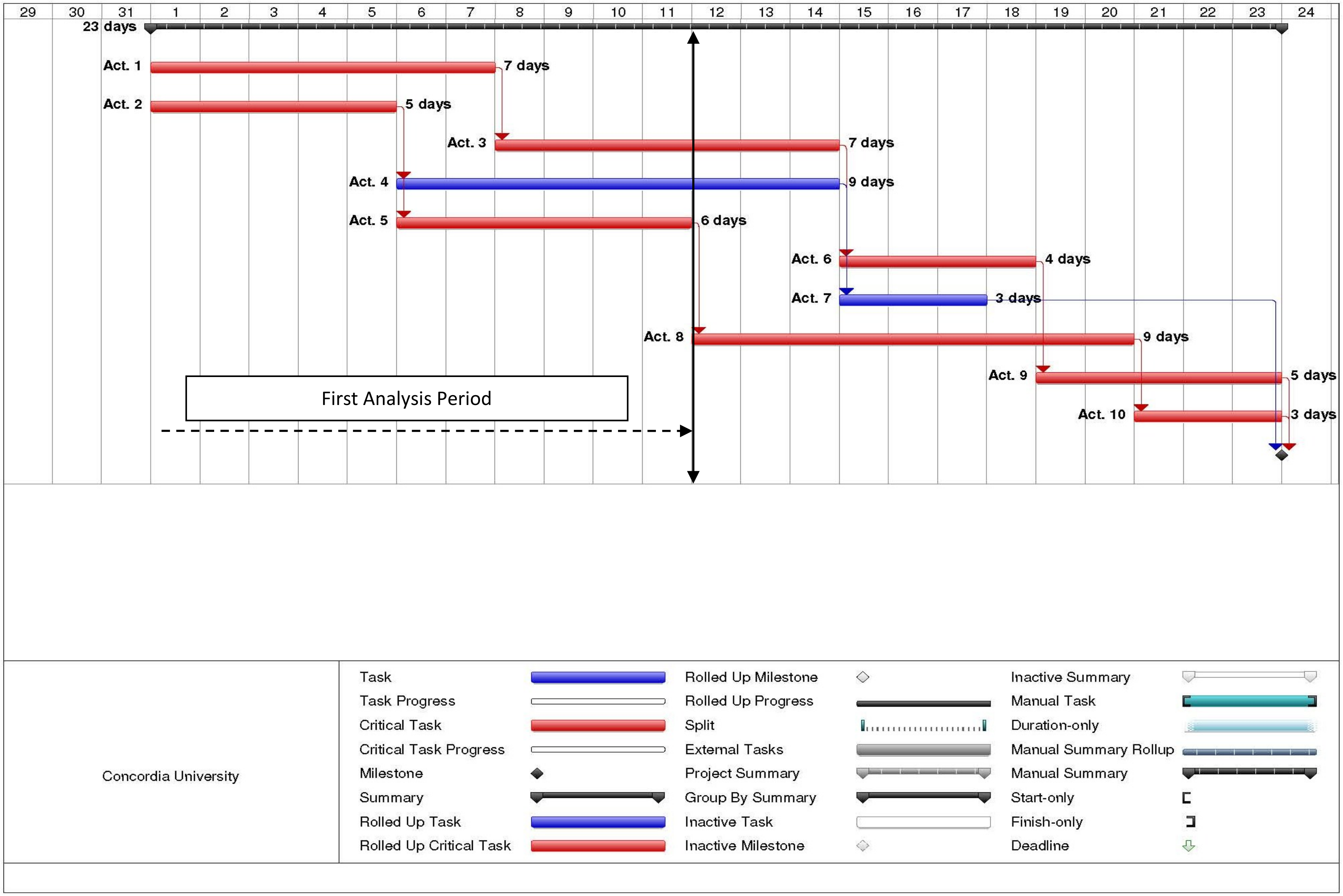
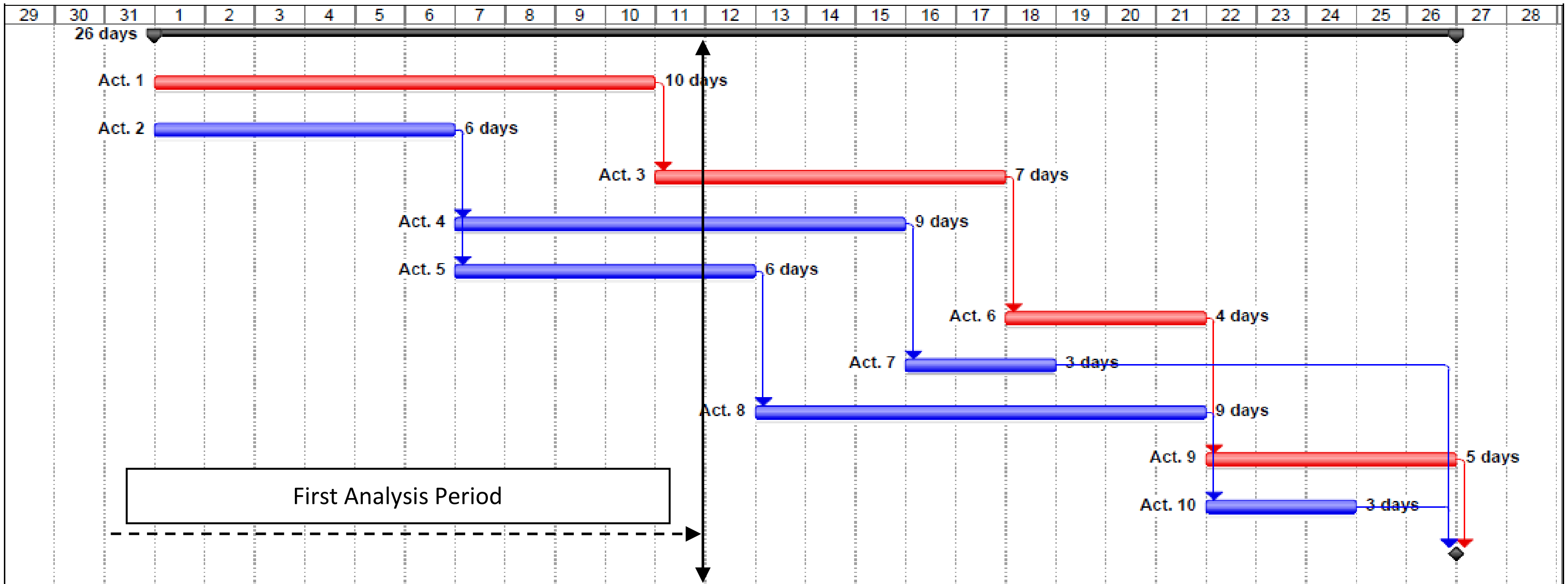


Figure 3.5: Baseline Schedule for First Analysis Period (Owner's Point of View)



Baseline Duration (in days):	After incorporating NE and NE Concurrent delays (in days):	Contractor liability for the first analysis period (in days):
$BD_1 = PD + AD_{1-1}$	$ID_1^{NE} = D_i^b + NE$	$R_1^{Contractor} = ID_1^{NE} - BD_1$
$BD_i = 23$	$ID_1^{NE} = 26$	$R_1^{Contractor} = 26 - 23 =$
		$R_1^{Contractor} = 3$

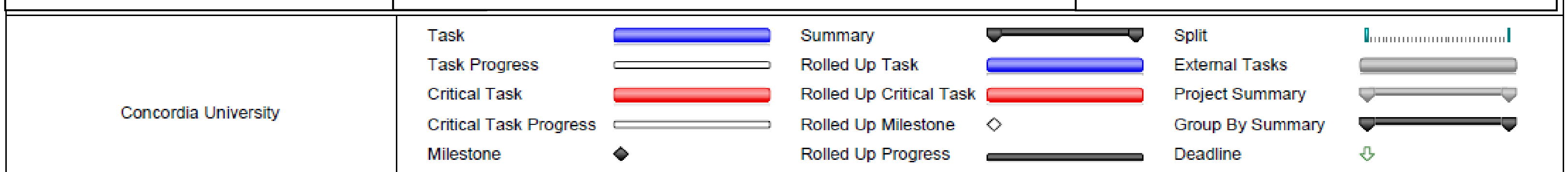


Figure 3.6: Impacted Schedule for First Analysis Period (Owner's Point of View, NE Delays)

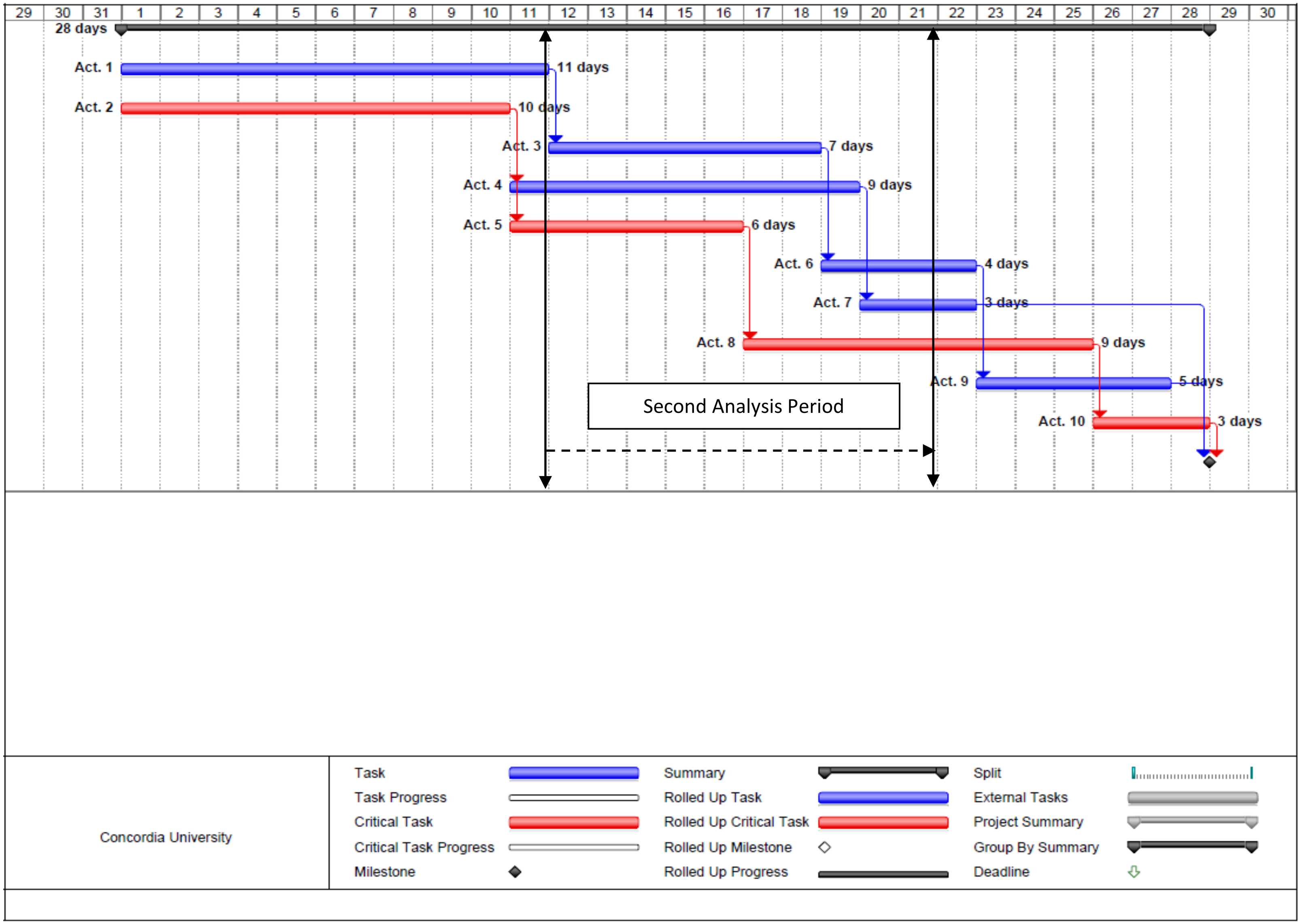
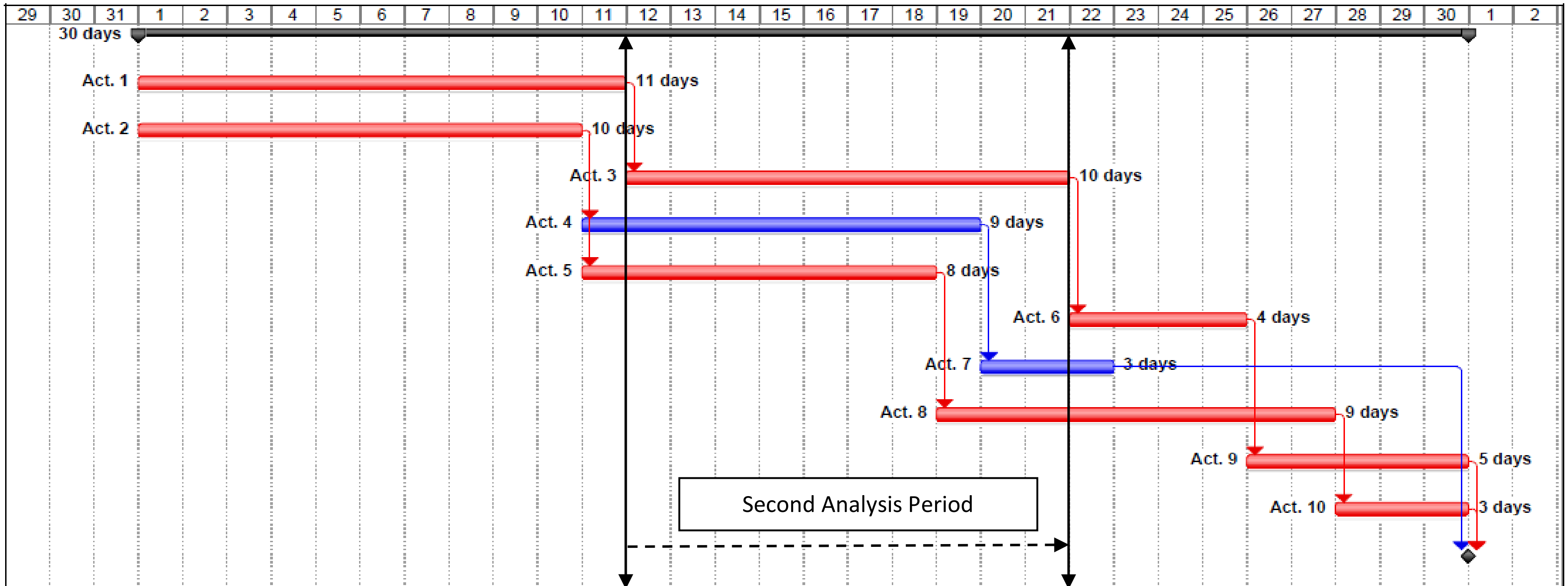


Figure 3.7: Baseline Schedule for Second Analysis Period (Owner's Point of View, NE Delays)



Baseline Duration (in days):	After incorporating NE and NE Concurrent delays (in days):	Contractor liability for the second analysis period (in days):
$BD_2 = PD + AD_{2-1}$	$ID_2^{NE} = D_2^b + NE$	$R_2^{Contractor} = D_2^{NE} - BD_2$
$BD_2 = 28$	$ID_2^{NE} = 30$	$R_2^{Contractor} = 30 - 28 =$
		$R_2^{Contractor} = 2$ days

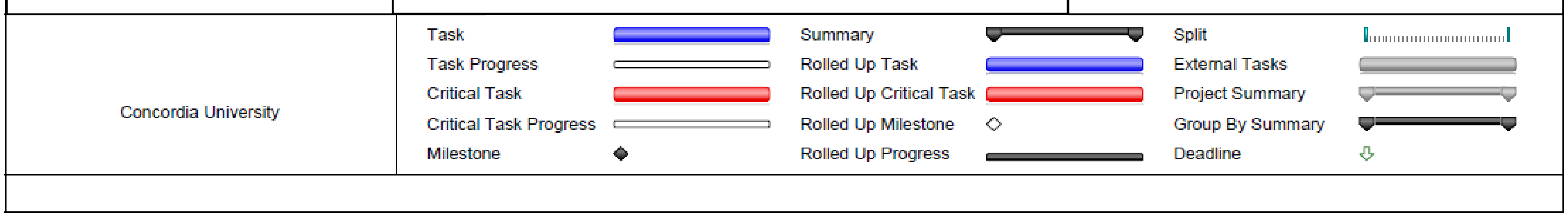


Figure 3.8: Impacted Schedule for the Second Analysis Period (Owner's Point of View, NE Delays)

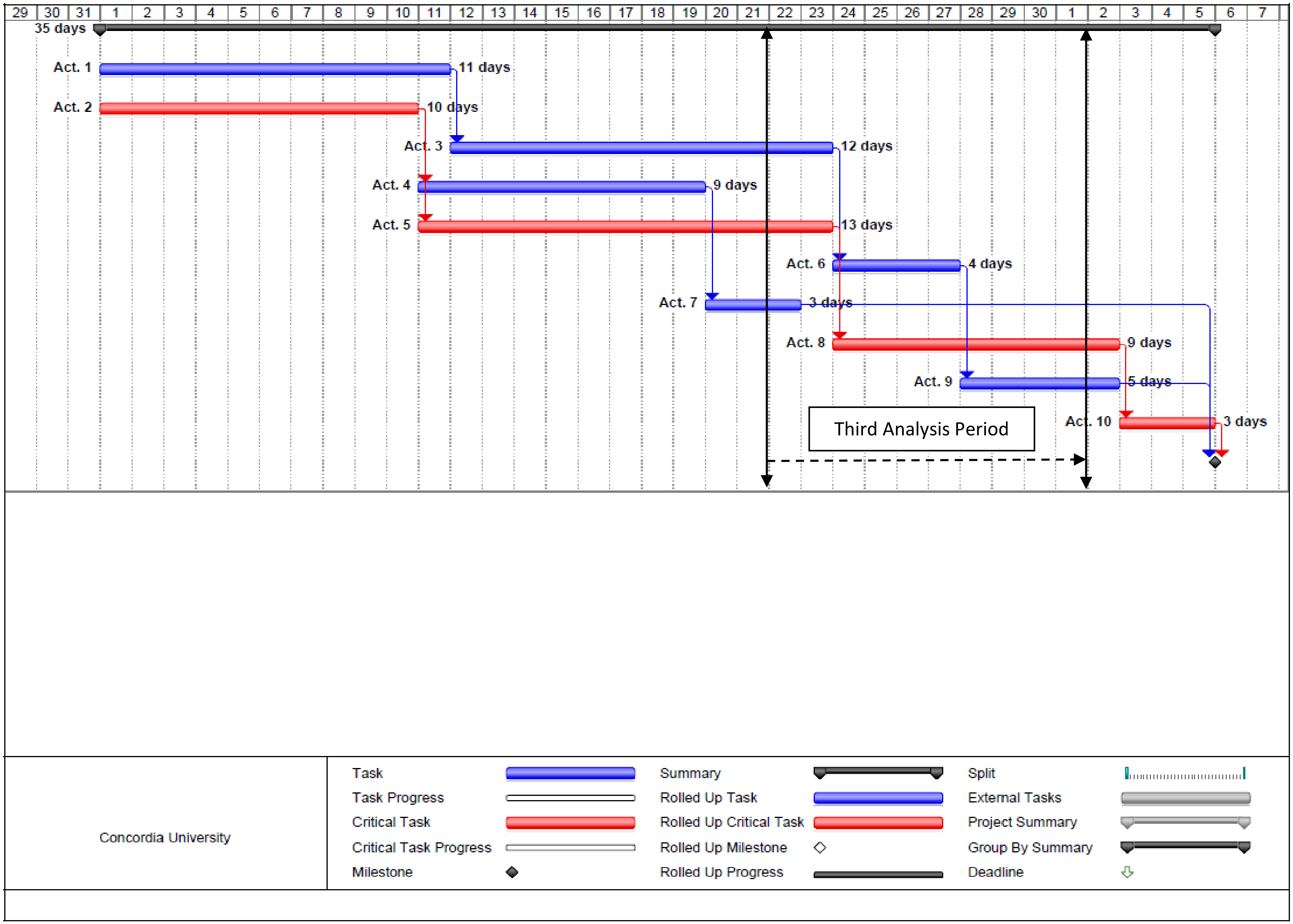
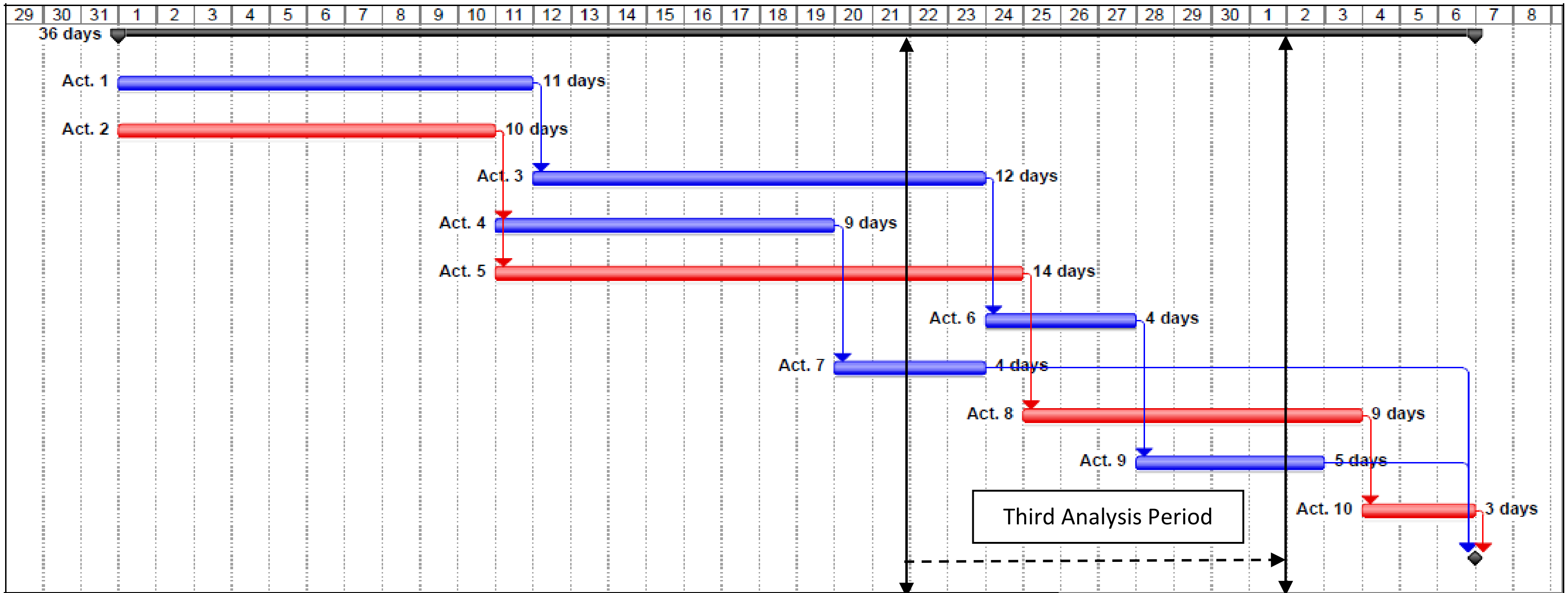


Figure 3.9: Baseline Schedule for the Third Analysis Period (Owner's Point of View, NE Delays)



Baseline Duration (in days):	After incorporating NE and NE Concurrent delays (in days):	Contractor liability for the third analysis period (in days):
$BD_3 = PD + AD_{3-1}$	$ID_3^{NE} = D_3^{b} + NE$	$R_3^{Contractor} = ID_3^{NE} - BD_3$
$BD_3 = 35$	$ID_3^{NE} = 35$	$R_3^{Contractor} = 35 - 35 =$
		$R_3^{Contractor} = 0$

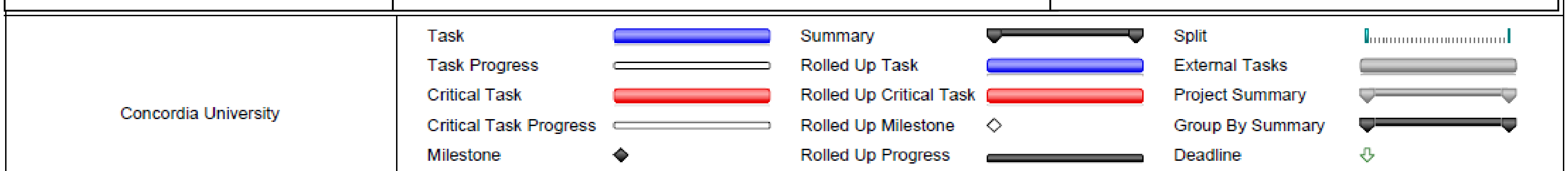


Figure 3.10: Impacted Schedule for the Third Analysis Period (Owner's Point of View, NE Delays)

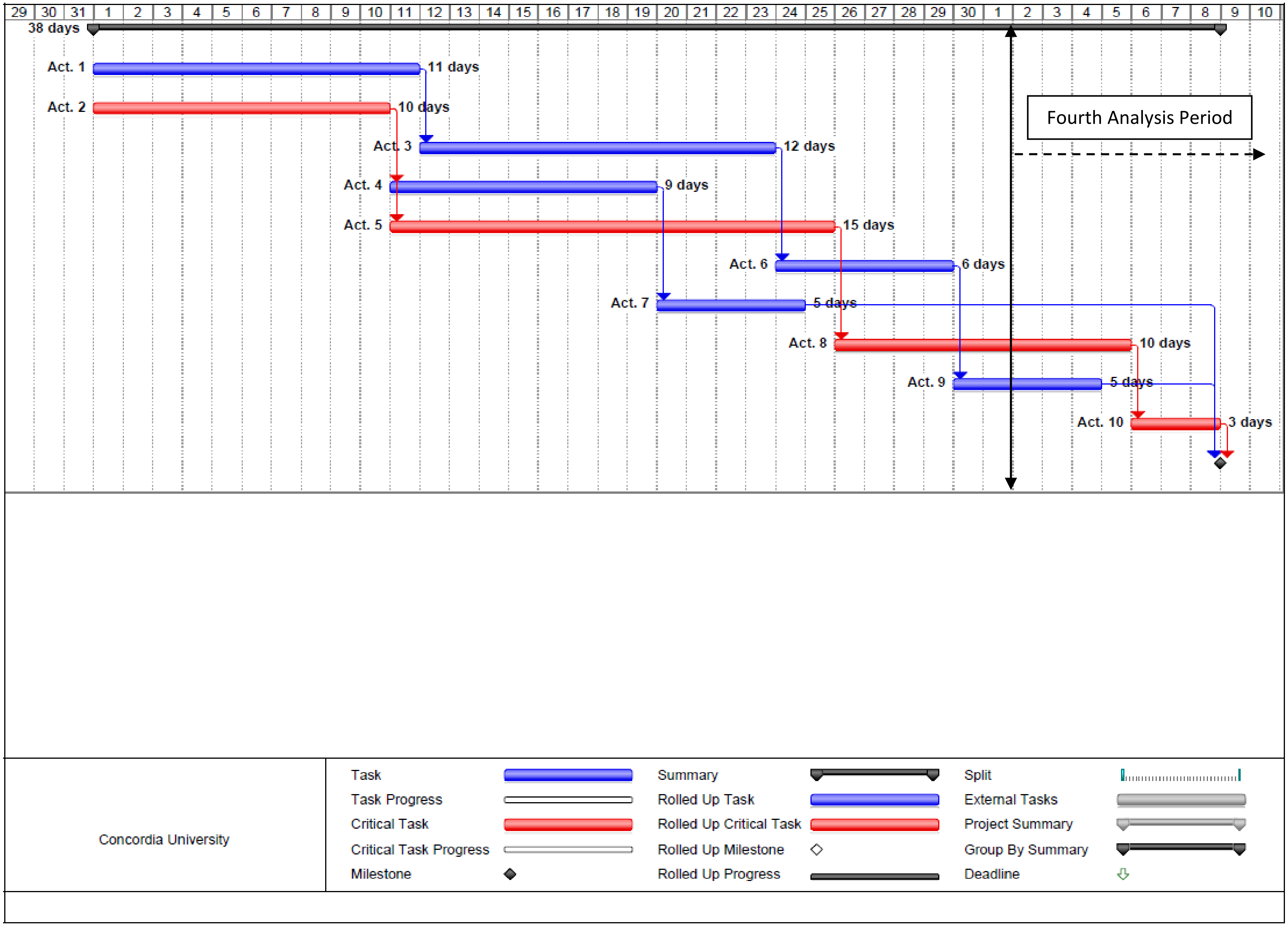
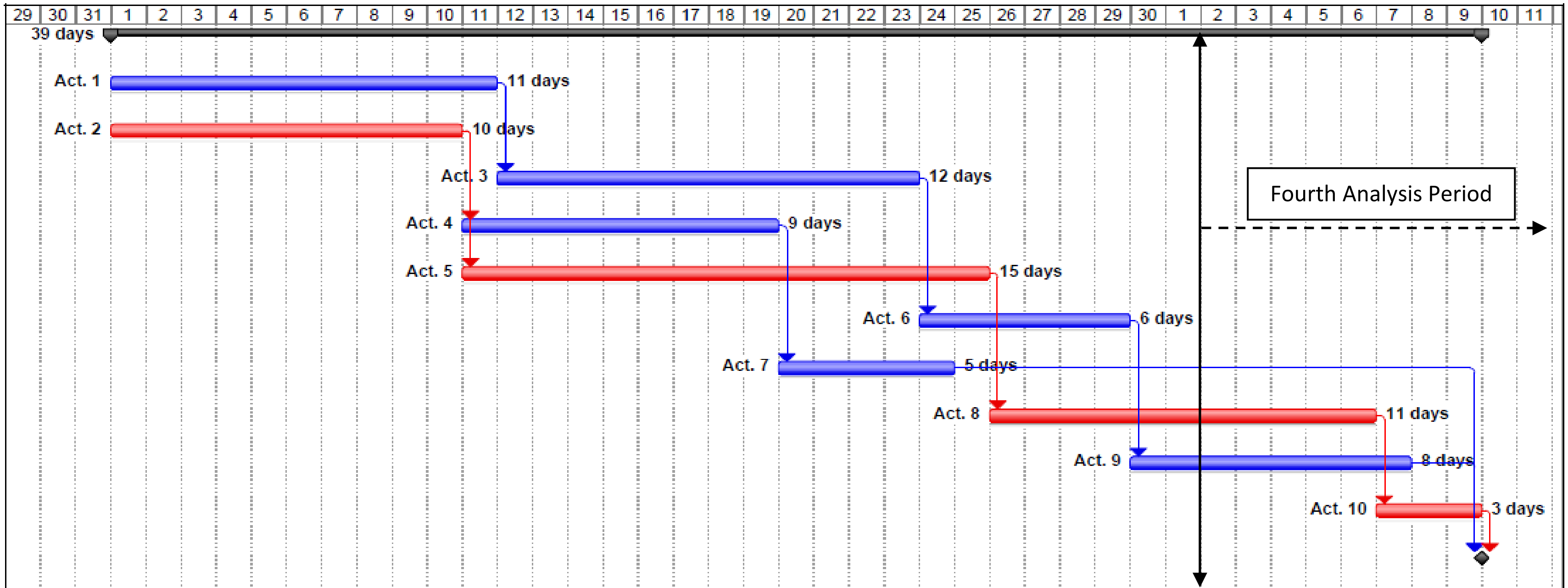


Figure 3.11: Baseline Schedule for the Fourth Analysis Period (Owner's Point of View, NE Delays)



Baseline Duration (in days):	After incorporating NE and NE Concurrent delays (in dayss):	Contractor liability for the fourth analysis period (in days):
$BD_4 = PD + AD_{4-1}$	$ID_4^{NE} = D_4^b + NE$	$R_4^{Contractor} = ID_4^{NE} + BD_4$
$BD_4 = 38$	$ID_4^{NE} = 38$	$R_4^{Contractor} = 38 - 38 =$
		$R_4^{Contractor} = 0$

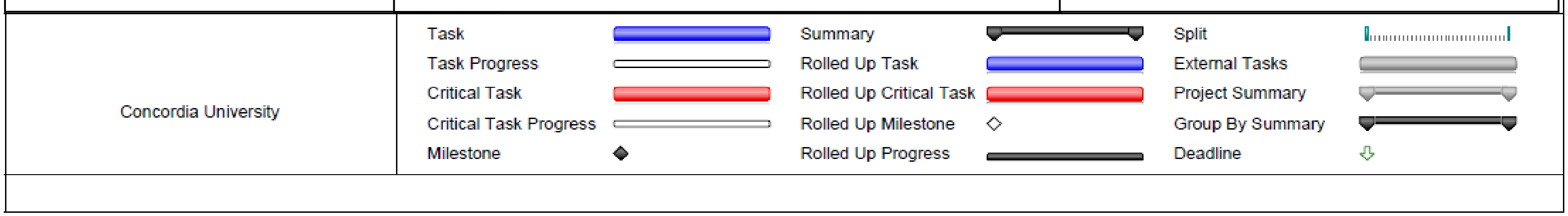


Figure 3.12: Impacted schedule for the Fourth Analysis Period (Owner's Point of View, NE Delays)

The MIDT analysis for the second period follows the same procedures as for the first analysis period. However, before incorporating the delaying events that occur in the second period, the analyst should modify the first analysis period by including all excusable and non-excusable delays. This step guarantees that the MIDT can properly track critical path(s). The second, third, and fourth analysis periods have a similar format to the first MIDT analysis period, and their analysis follows the above steps (Figs 3.7 to 3.12).

The results from the four analysis periods indicate that the project experienced a seven day delay caused by NE and concurrent delays that were classified as NE delays (3+2+0+0). This amount represents the number of days that the contractor is held responsible for delaying the project.

3.6.2 MIDT- Contractor's Viewpoint for EN delays

The MIDT analysis is performed twice from the contractor's viewpoint, once for excusable non-compensable delays and yet again for the excusable compensable delays. Thus, this approach provides a breakdown of all types of excusable delays for which the owner is held responsible.

To perform the MIDT analysis from the contractor's viewpoint, delaying events within the first analysis period, identified as EN delays (both independent and concurrent delays), were added to the first baseline schedule of this analysis period to generate the first impacted schedule. Due to the inclusion of the EN delays, the completion date was prolonged by four days (Figs .3.13 and 3.14).

Prior to moving to the next analysis period, a new baseline schedule is needed, so the first period is adjusted by adding all delays that occurred. This step ensures that any changes in critical path(s) are traceable, reflecting the actual project progress

Exactly the same procedures are repeated for the second, third, and fourth analysis periods. The EN delays are incorporated into each analysis period, and before proceeding to the next interval, the current period is adjusted by adding all delays or delaying events to reflect any changes in logic and duration (Fig3.15-3.20).

Summing up the outcome from each of the four MIDT analysis periods generates a total delay of eleven days (4+3+3+2). This value represents the number of days for which the contractor is entitled to claim as a time extension.

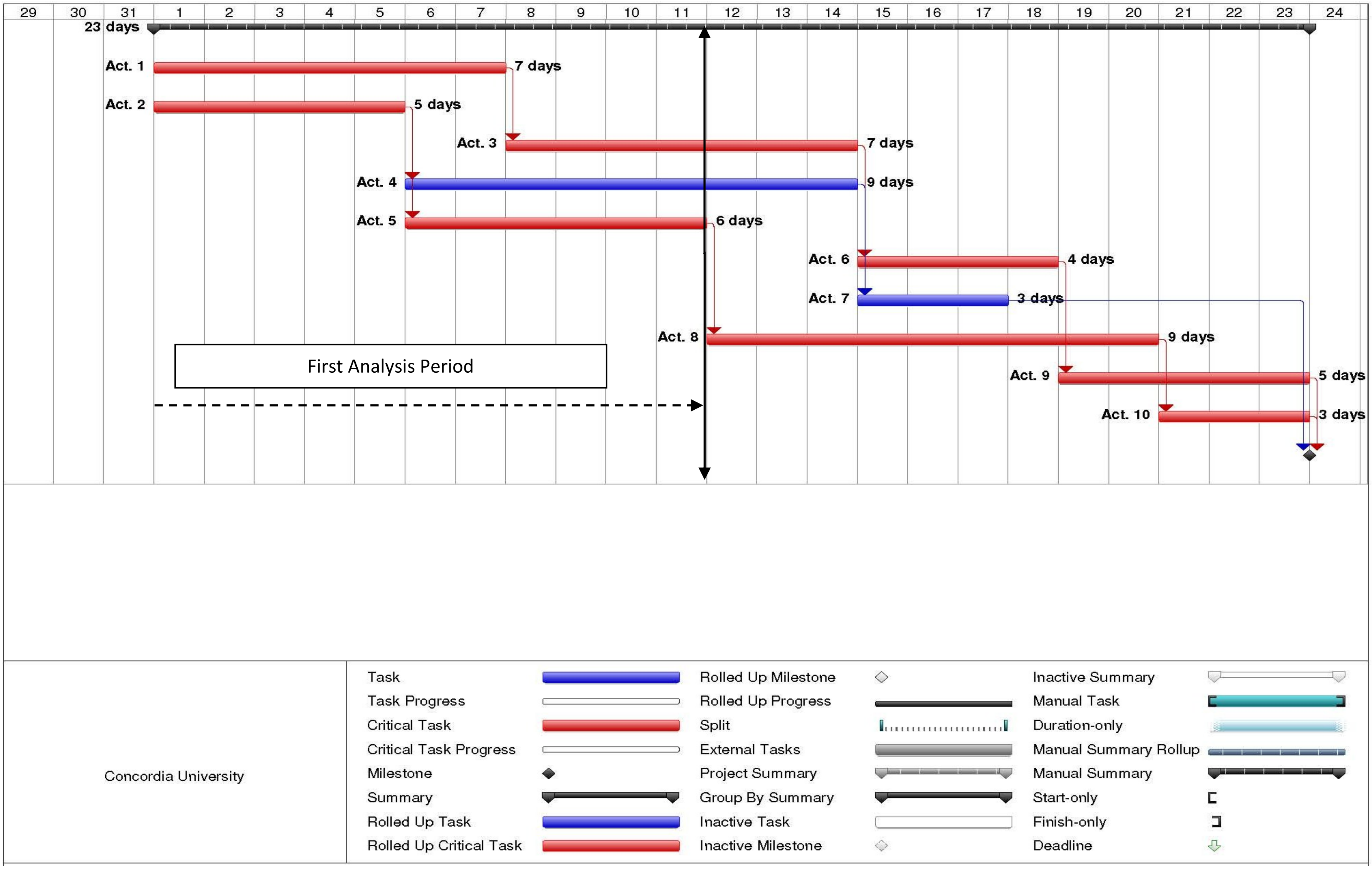
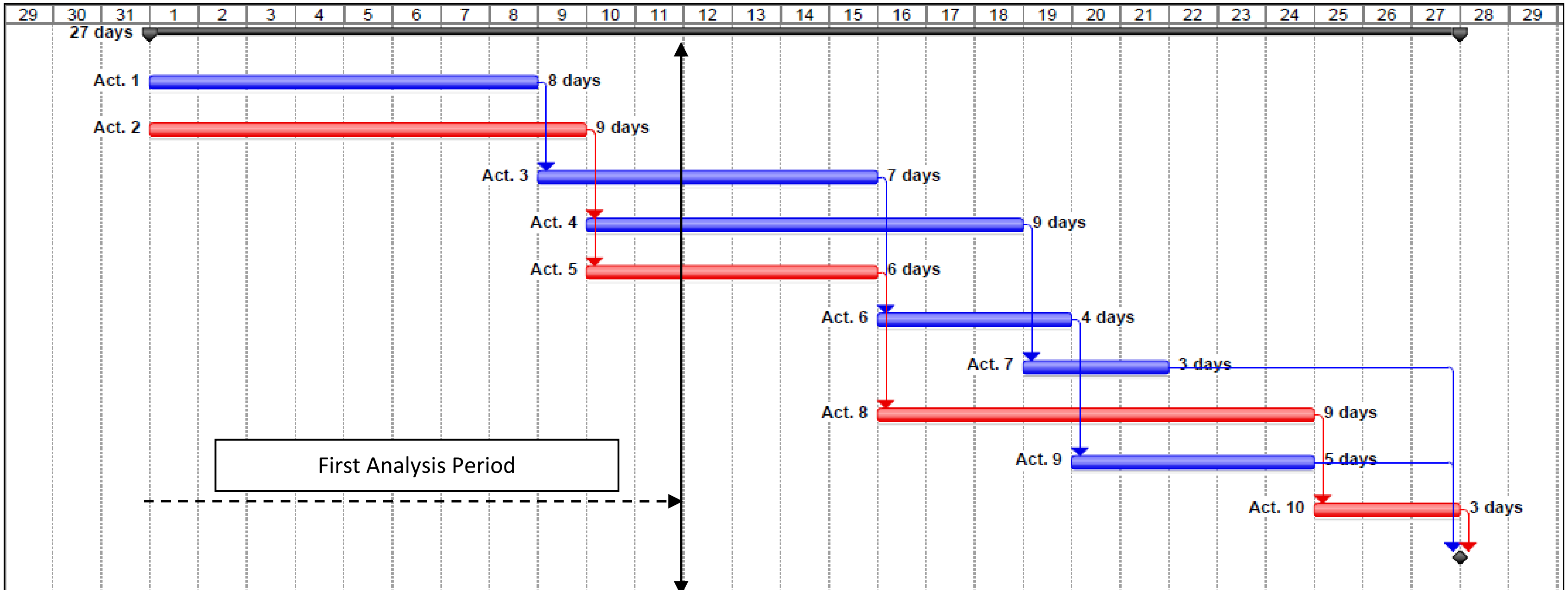


Figure 3.13: Baseline Schedule for the First Analysis Period (Contractor's point of View, EN Delays)



Baseline Duration (in days):	After incorporating EN and EN Concurrent delays (in days):	Owner liability for the first analysis period (in days):
$\mathrm{BD}_1 = \mathrm{PD} + \mathrm{AD}_{1-1}$	$\mathrm{ID}_1^{\mathrm{EN}} = \mathrm{BD}_1 + \mathrm{EN}$	$\mathrm{R}_1^{\mathrm{Owner(EN)}} = \mathrm{ID}_1^{\mathrm{EN}} - \mathrm{BD}_1$
$\mathrm{BD}_1 = 23$	$\mathrm{ID}_1^{\mathrm{EN}} = 27$	$\mathrm{R}_1^{\mathrm{Owner(EN)}} = 27 - 23 =$
		$\mathrm{R}_1^{\mathrm{Owner(EN)}} = 4$ days

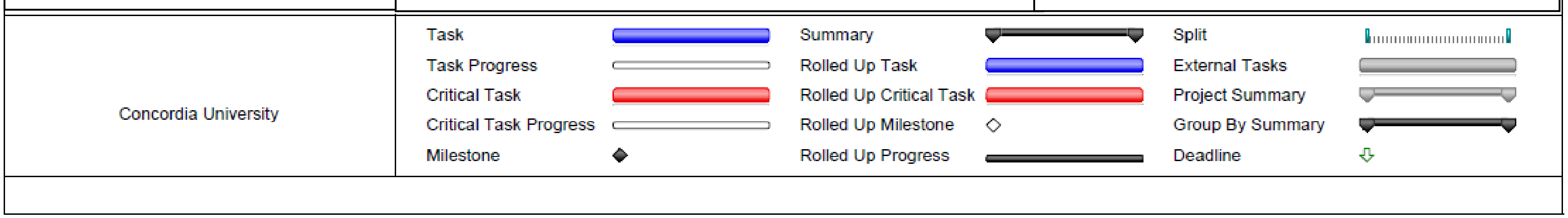


Figure 3.14: Impacted Schedule for the First Analysis Period (Contractor's Point of View, EN Delays)

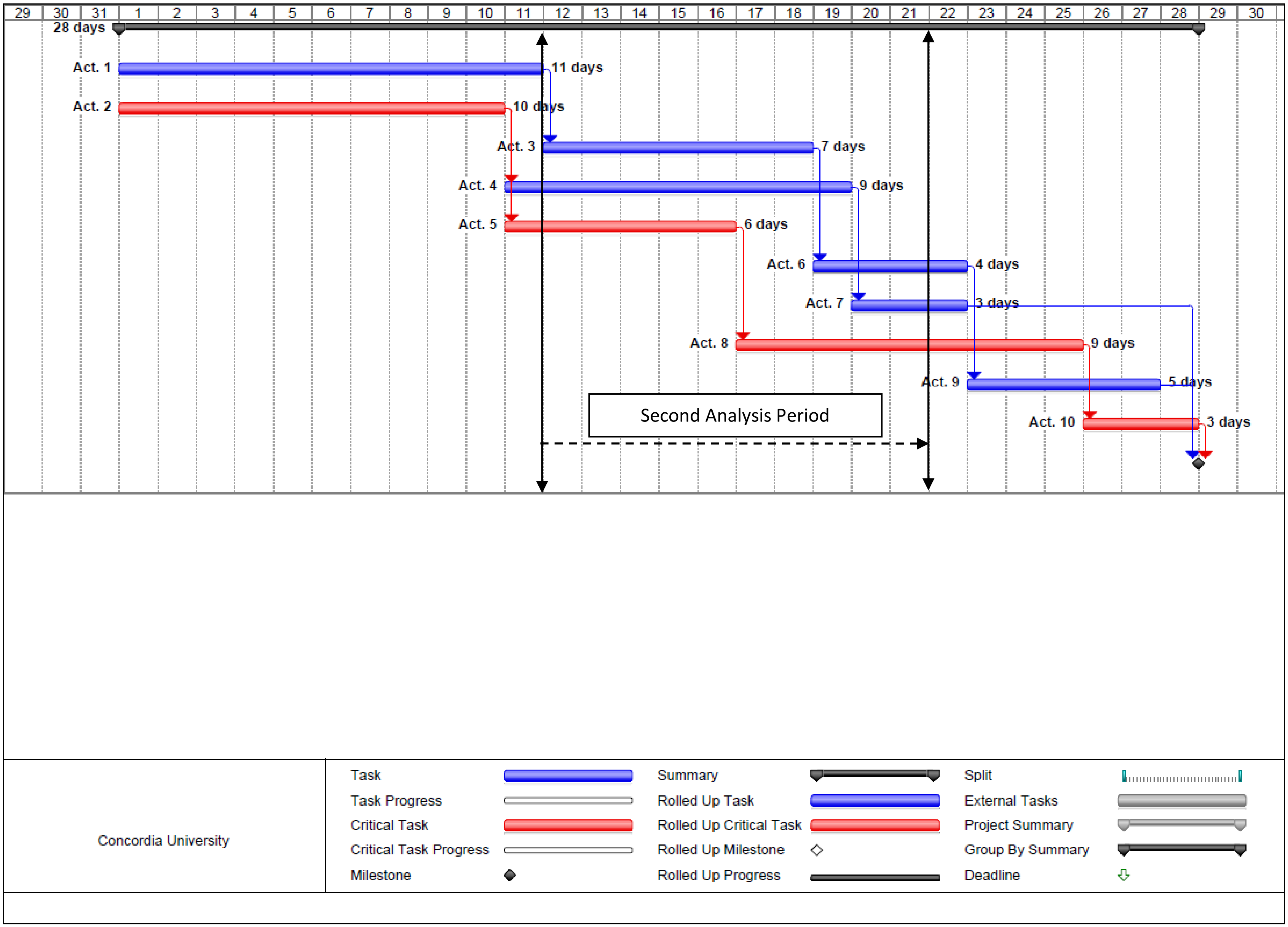
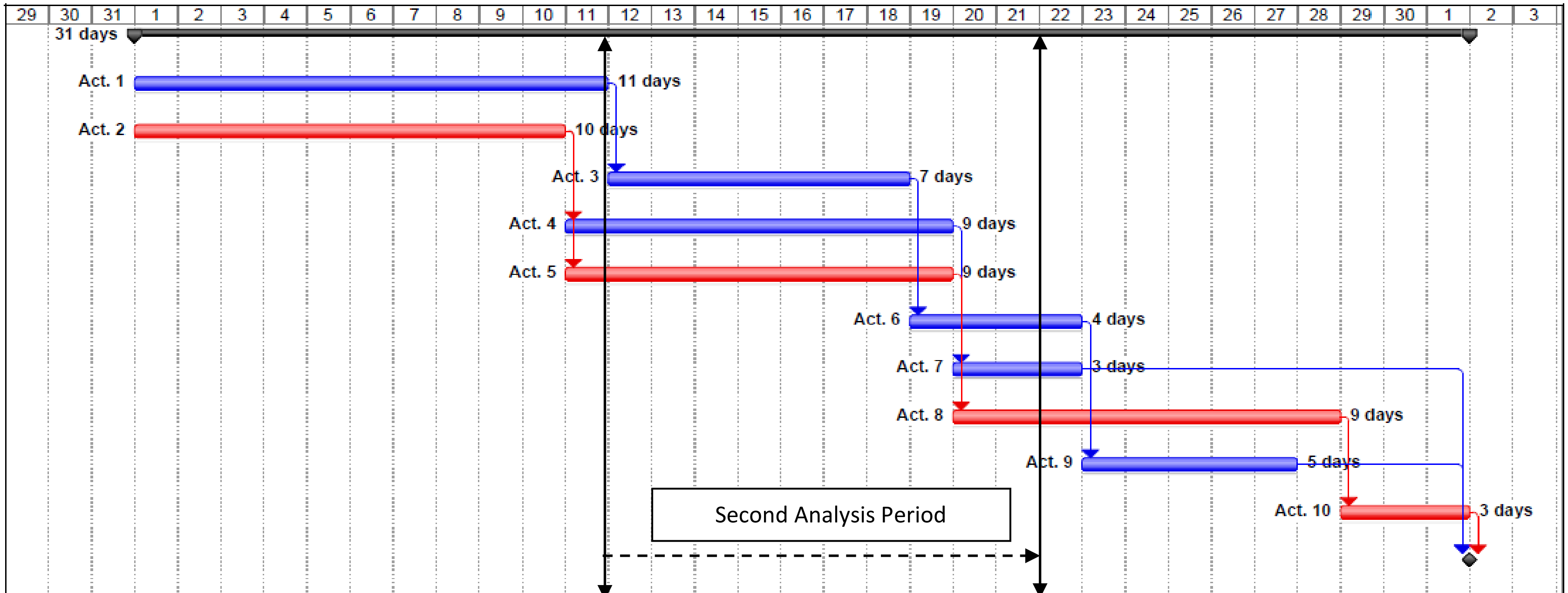


Figure 3.15: Baseline schedule for the Second Analysis Period (Contractor's Point of View, EN Delays)



Baseline Duration(in days):	After incorporating EN and EN Concurrent delays (in days):	Owner liability for the second analysis period (in days):
$BD_2 = PD + AD_{2-1}$	$ID_2^{EN} = BD_2 + EN$	$R_2^{Owner(EN)} = ID_2^{EN} - BD_2$
$BD_2 = 28$	$ID_2^{EN} = 31$	$R_2^{Owner(EN)} = 31 - 28 =$
		$R_2^{Owner(EN)} = 3 \text{ days}$

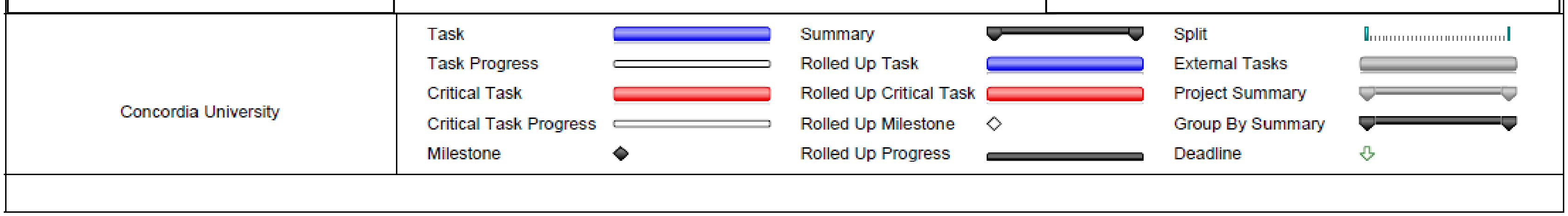


Figure 3.16: Impacted Schedule for the Second Analysis Period (Contractor's Point of View, EN Delays)

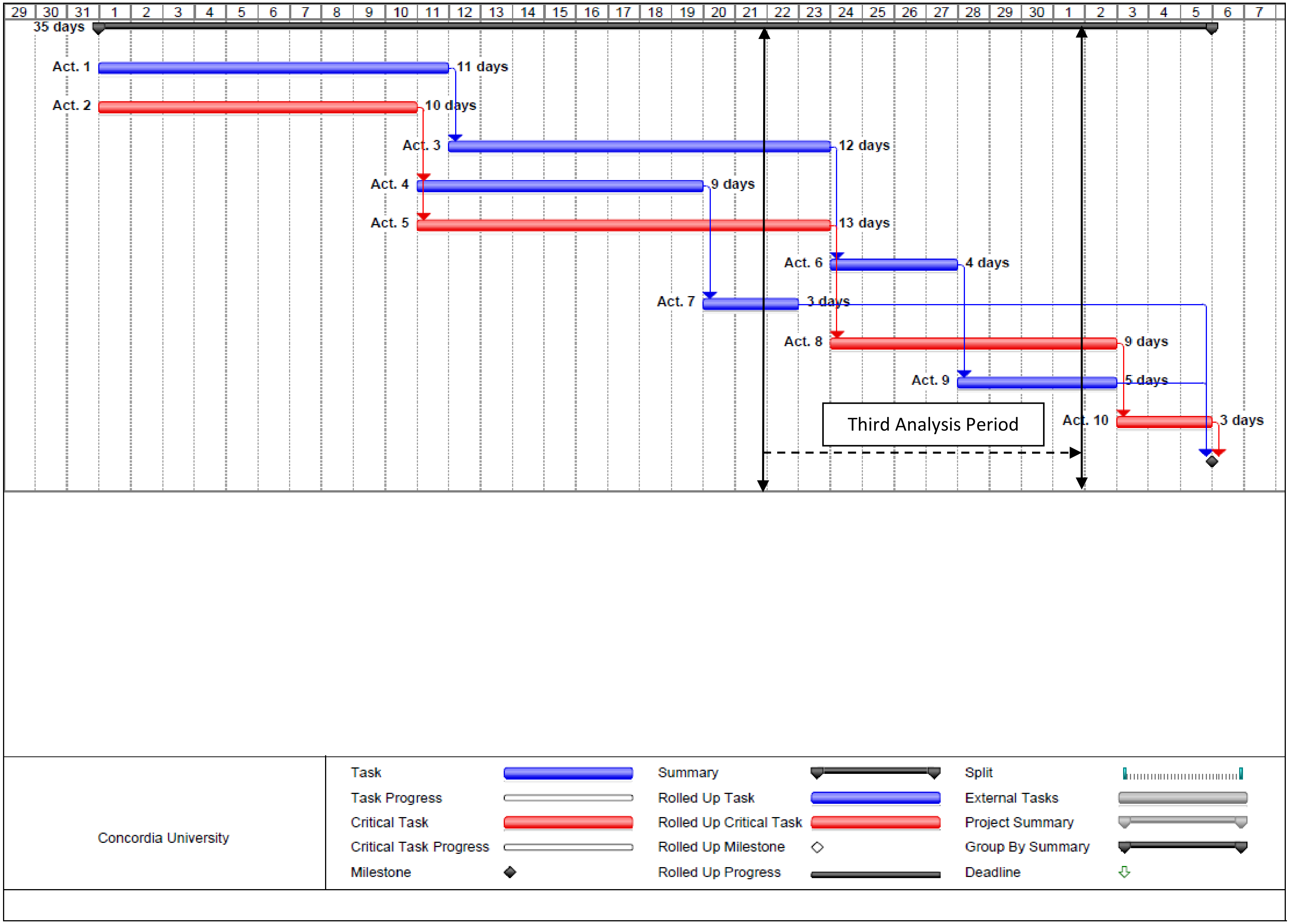
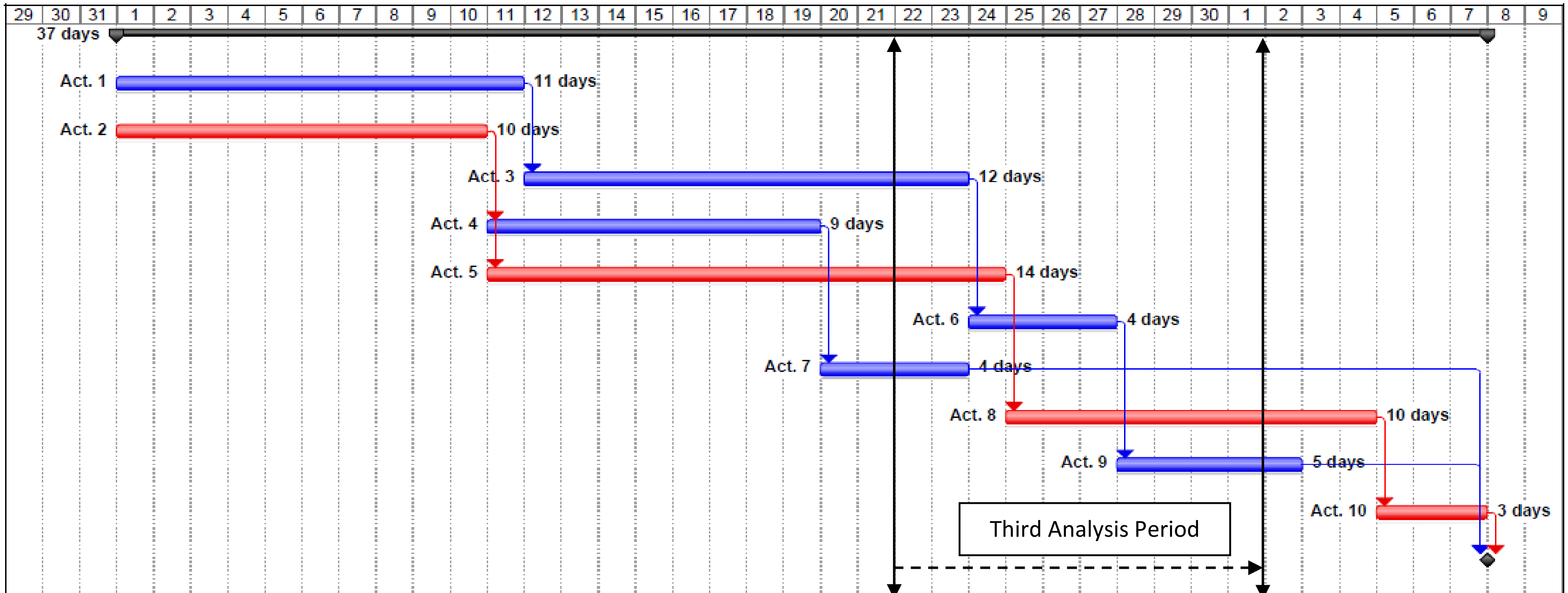


Figure 3.17: Baseline Schedule for the Third Analysis Period (Contractor's Point of View, EN Delays)



Baseline Duration (in days):	After incorporating EN and EN Concurrent delays (in days):	Owner liability for the third analysis period (in days) :
$BD_3 = PD + AD_{3-1}$	$ID_3^{EN} = BD_3 + EN$	$R_3^{Owner(EN)} = ID_3^{NE} - BD_3$
$BD_3 = 35$	$ID_3^{EN} = 38$	$R_3^{Owner(EN)} = 38 - 35 =$
		$R_3^{Owner(EN)} = 3$ days

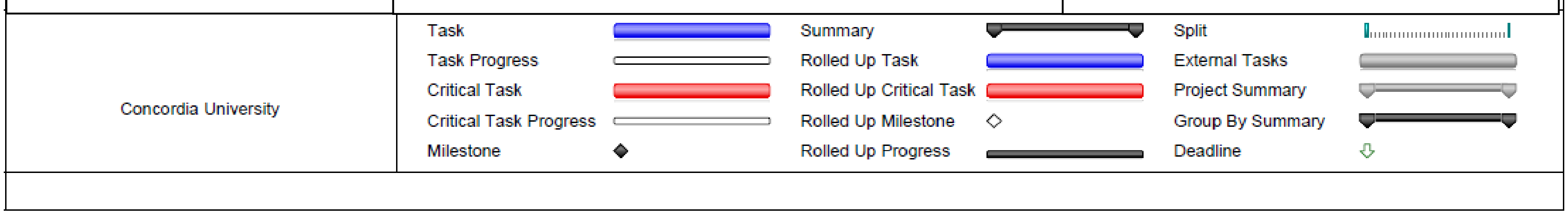


Figure 3.18: Impacted Schedule for the Third Analysis Period (Contractor's point of View, EN Delays)

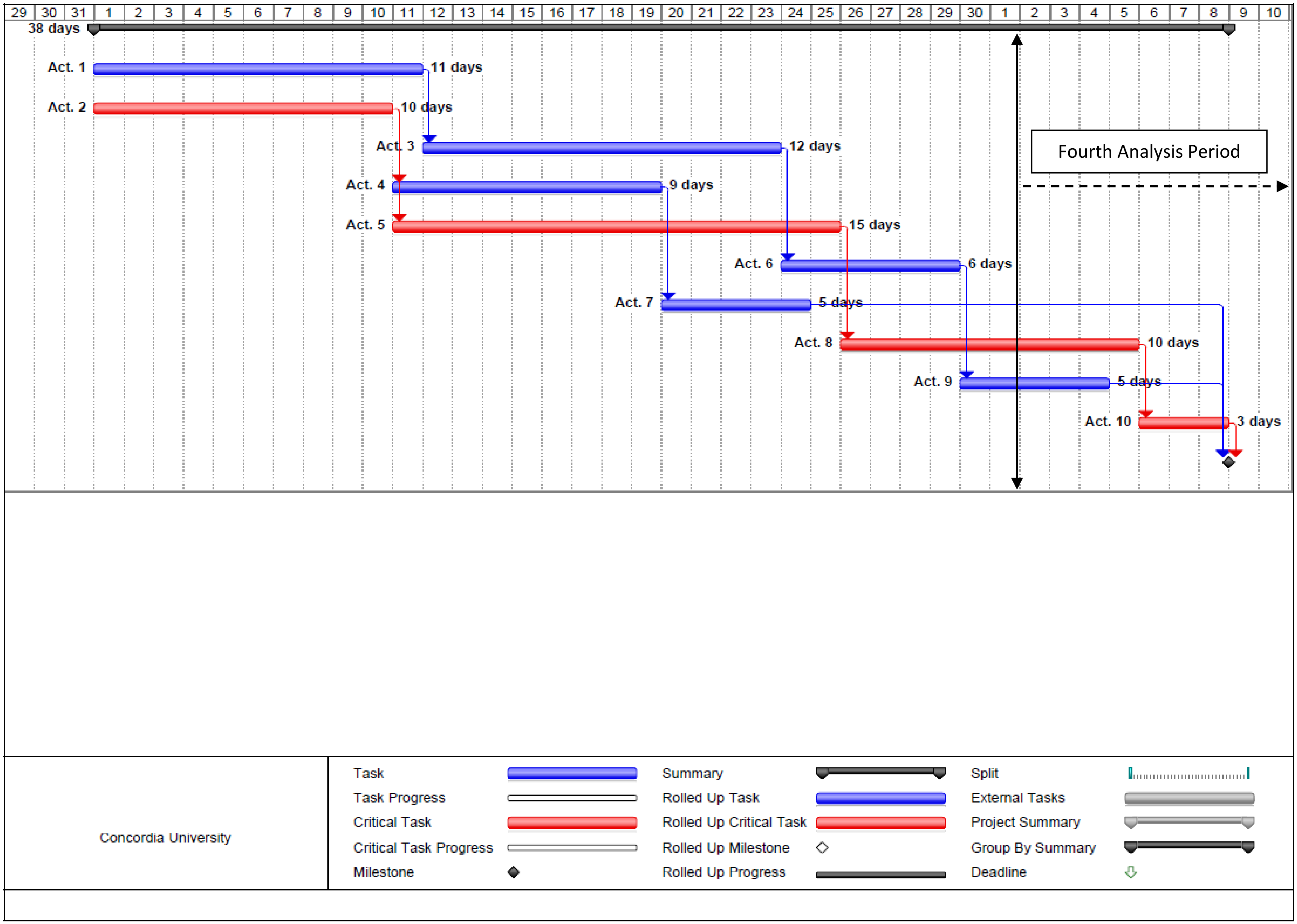
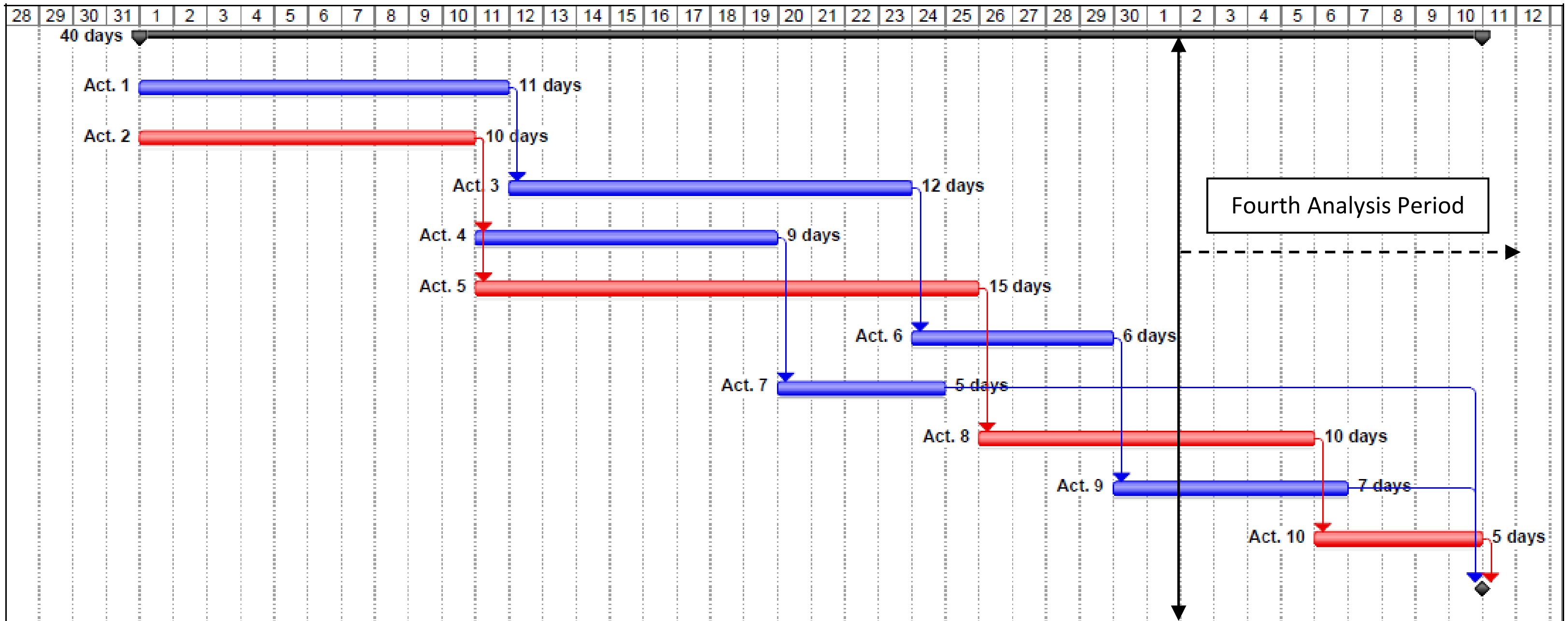


Figure 3.19: Baseline Schedule for the Fourth Analysis Period (Contractor's Point of View, EN Delays)



Baseline Duration(in days):

$$BD_4 = PD + AD_{4-1}$$

$$BD_4 = 38$$

After incorporating EN and EN Concurrent delays (in days):

$$ID_4^{EN} = BD_4 + EN$$

$$ID_4^{EN} = 40$$

Owner liability for the fourth analysis period (in days):

$$R_4^{Owner(EN)} = D_4^{EN} - BD_4$$

$$R_4^{Owner(EN)} = 40 - 38 =$$

$$R_4^{Owner(EN)} = 2 \text{ days}$$

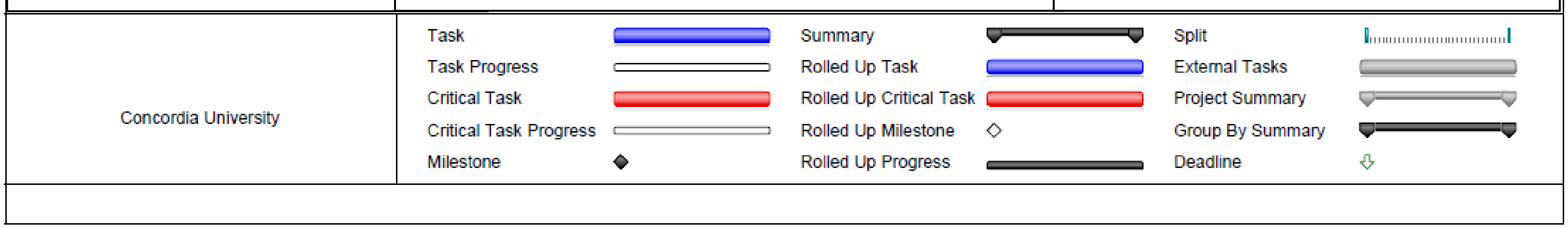


Figure 3.20: Impacted Schedule for the Fourth Analysis Period (Contractor's Point of view, EN Delays)

3.6.3 MIDT- Contractor's Viewpoint for EC delays

Evaluating EC delays is implemented similarly to the evaluation of EN delays. For the first analysis period, there were no EC delay(s) that needed to be incorporated into the baseline schedule. As a result, the schedule shows no changes to the completion date.

Before analyzing the second analysis period, the project duration must be recalculated based on all delays occurring in the first period. Incorporating the EC delays that occurred in the second analysis period and recalculating the schedule displays two days of delay, which prolonged the completion date.

After adding EC delays that occurred within the third analysis period and comparing its recalculated completion date (impacted schedule) to its related baseline, no deviation was observed. By following the procedures experienced in previous analysis periods, similar results are achieved for the last time interval. This means that EC delays occurring within the mentioned analysis periods had no effect on the critical path.

Adding up all deviations to the completion date inside those intervals, caused by EC delays, resulted in a total delay of 2 days for the project (0+3+0+1) (Fig. 3.21 to Fig. 3.28) where the contractor is entitled to claim for an extension of time and compensation. Therefore, the contractor can make a claim for a total number of 13 days (11 days for EN plus 2 days for EC delays).

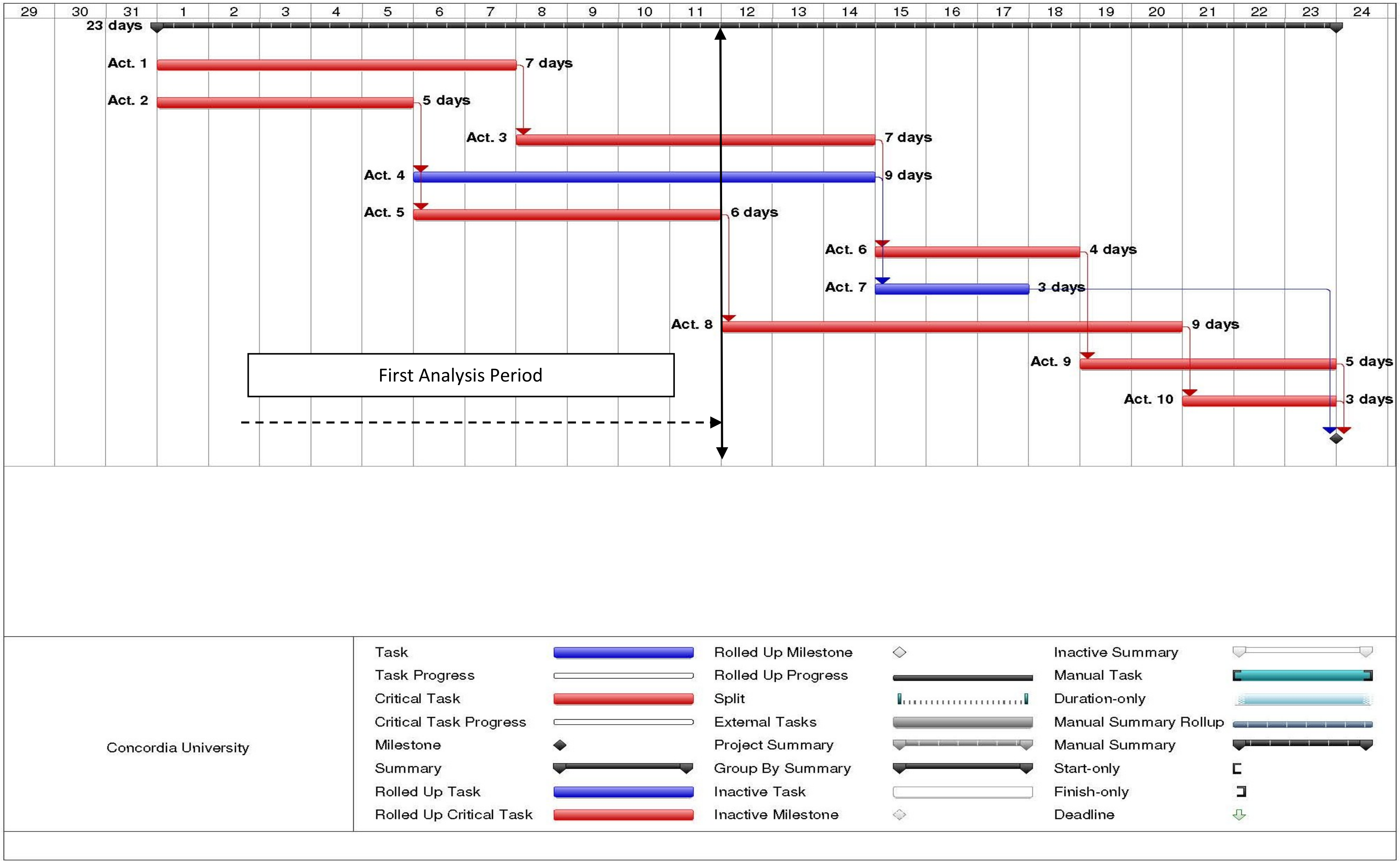
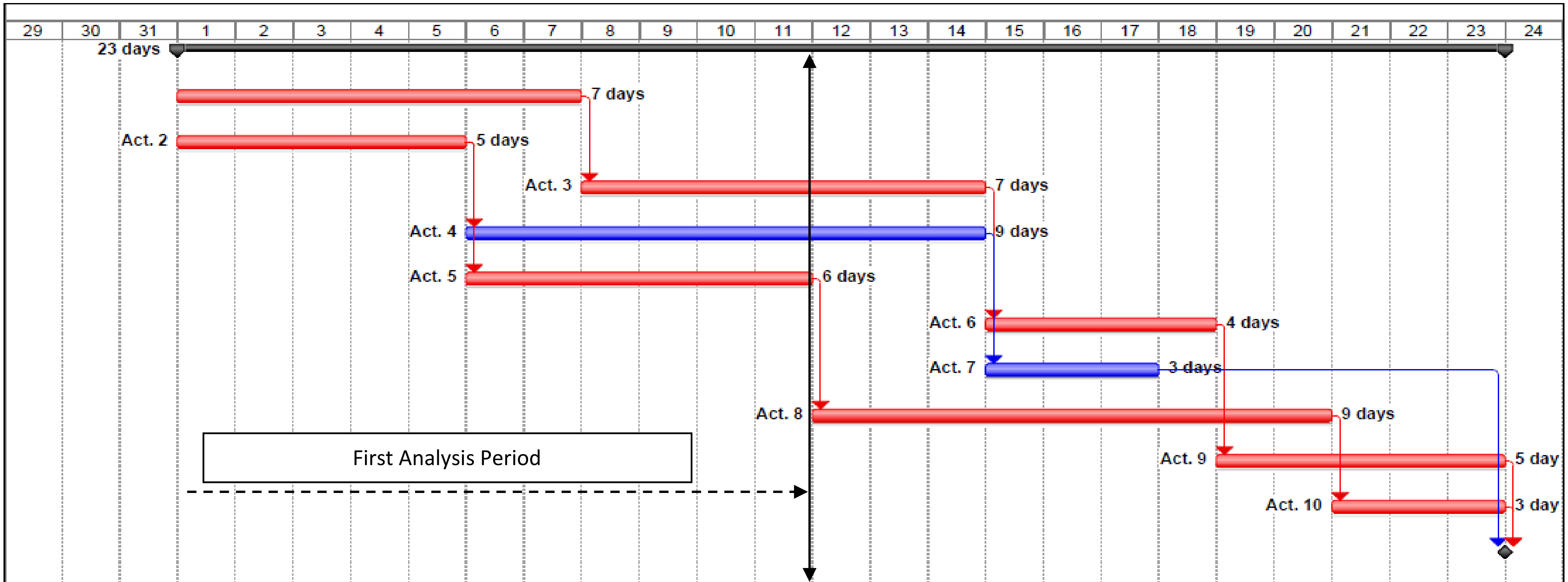


Figure 3.21: Baseline Schedule for the First Analysis Period (Contractor's Point of View, EC Delays)



Baseline Duration(in days):	After incorporating EC and EC Concurrent delays (in days):	Owner liability for the first analysis period (in days):
$BD_1 = PD + AD_{1-1}$	$ID_1^{EC} = BD_1 + EC$	$R_1^{Owner(EC)} = ID_1^{EC} - BD_1$
$BD_1 = 23$	$ID_1^{EC} = 23$	$R_1^{Owner(EC)} = 23 - 23 =$
		$R_1^{Owner(EC)} = 0$

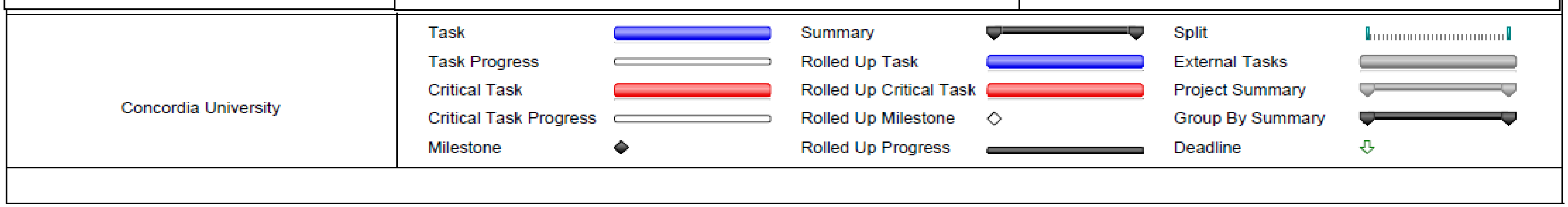


Figure 3.22: Impacted Schedule for the First Analysis Period (Contractor's Point of View, EC Delays)

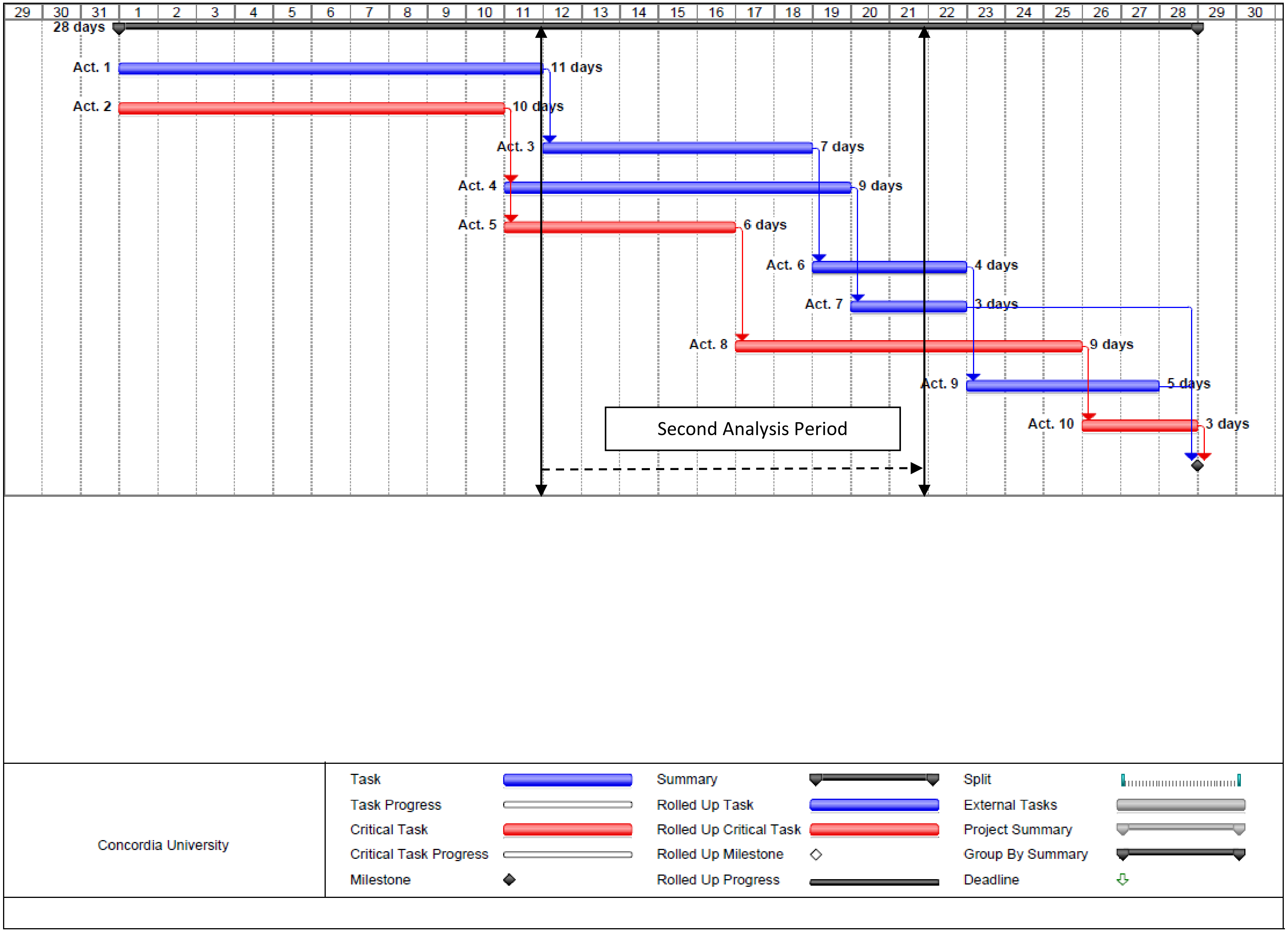
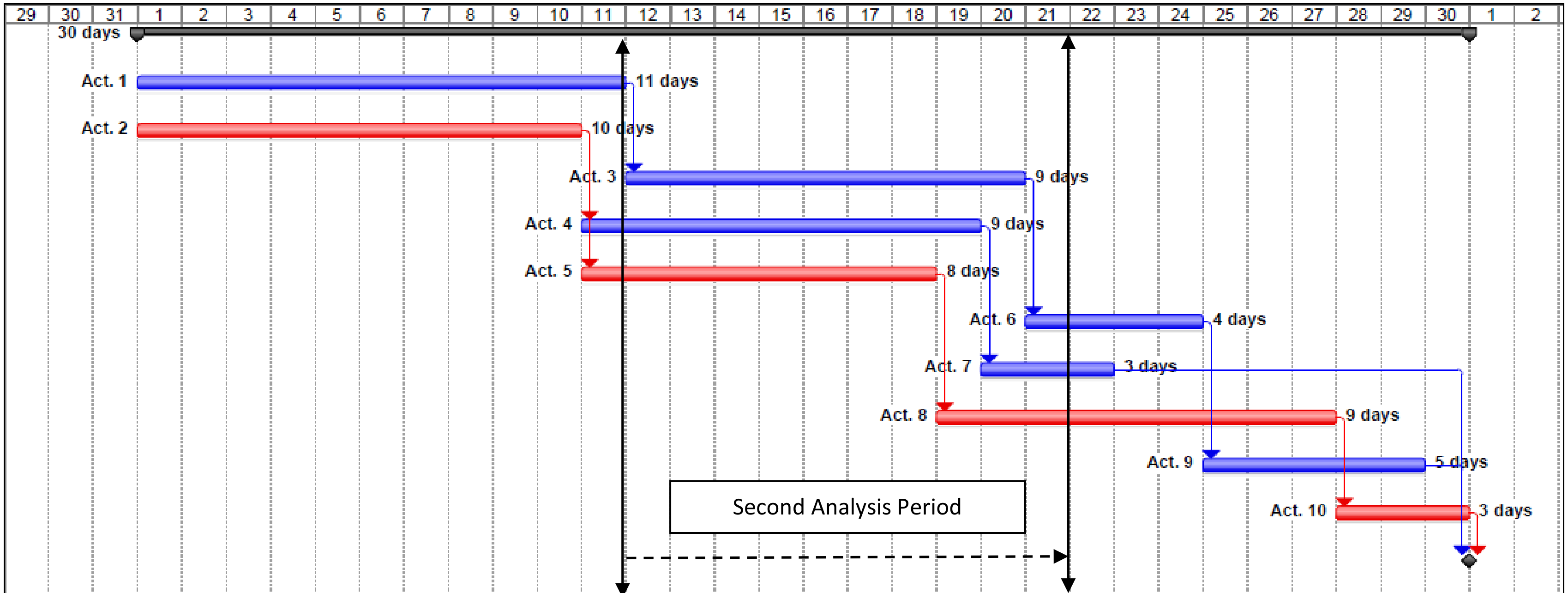


Figure 3.23: Baseline Schedule for the Second Analysis Period (Contractor's Point of View, EC Delays)



Baseline Duration(in days):

$$BD_2 = PD + AD_{2-1}$$

$$BD_2 = 28$$

After incorporating EC and EC Concurrent delays (in days):

$$ID_2^{EC} = BD_2 + EC$$

$$ID_2^{EC} = 31$$

Owner liability for the second analysis period(in days):

$$R_2^{Owner(EC)} = ID_2^{EC} - BD_2$$

$$R_2^{Owner(EC)} = 31 - 28 =$$

$$R_2^{Owner(EC)} = 3 \text{ days}$$

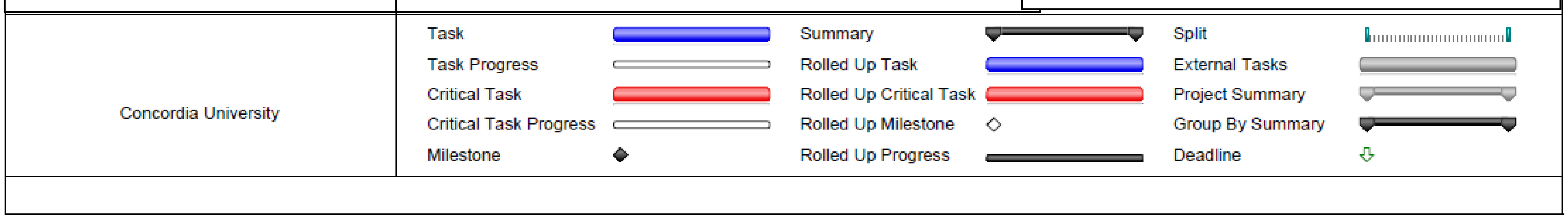


Figure 3.24: Impacted Schedule for the Second Analysis Period (Contractor's Point of View, EC Delays)

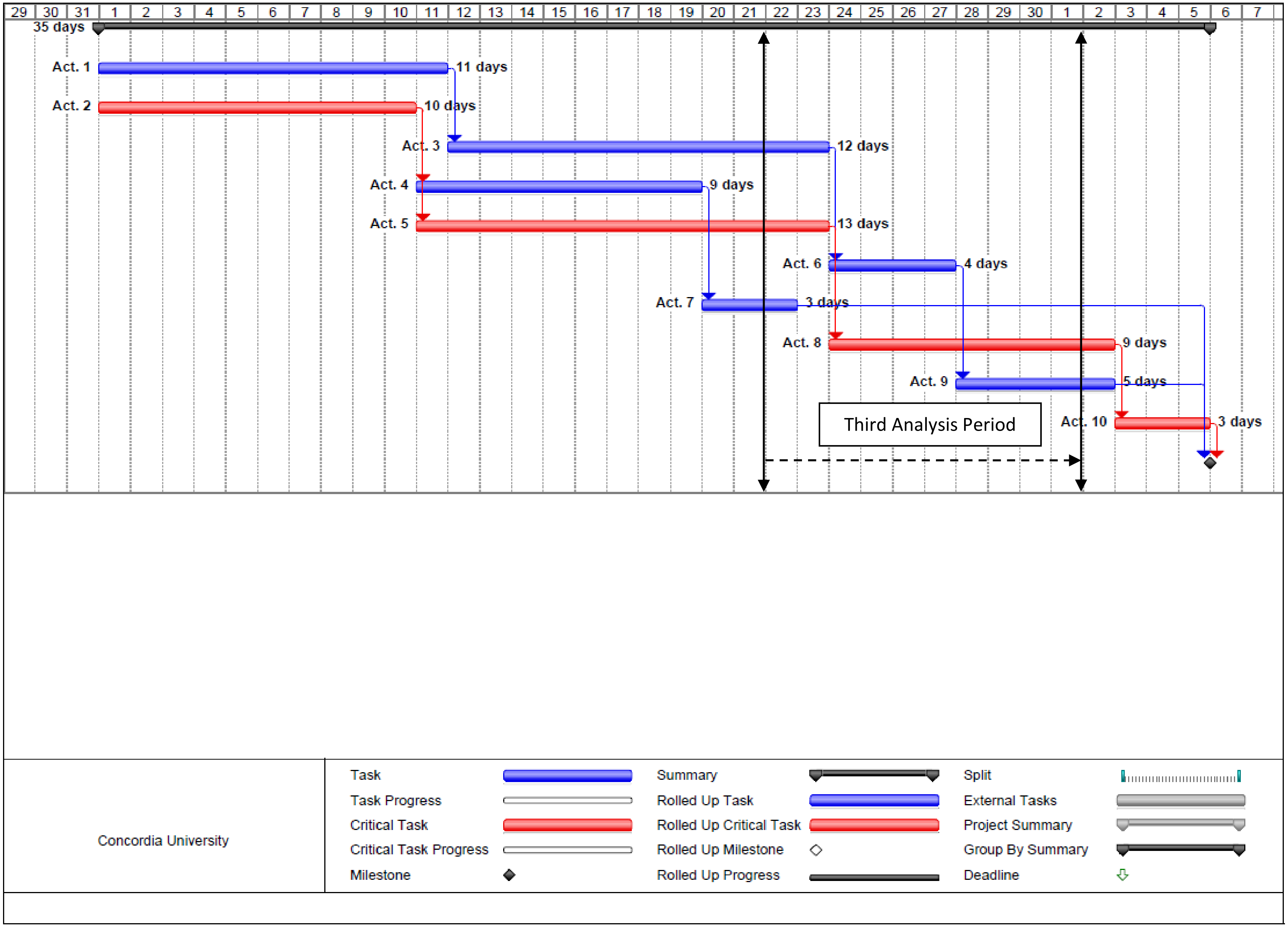
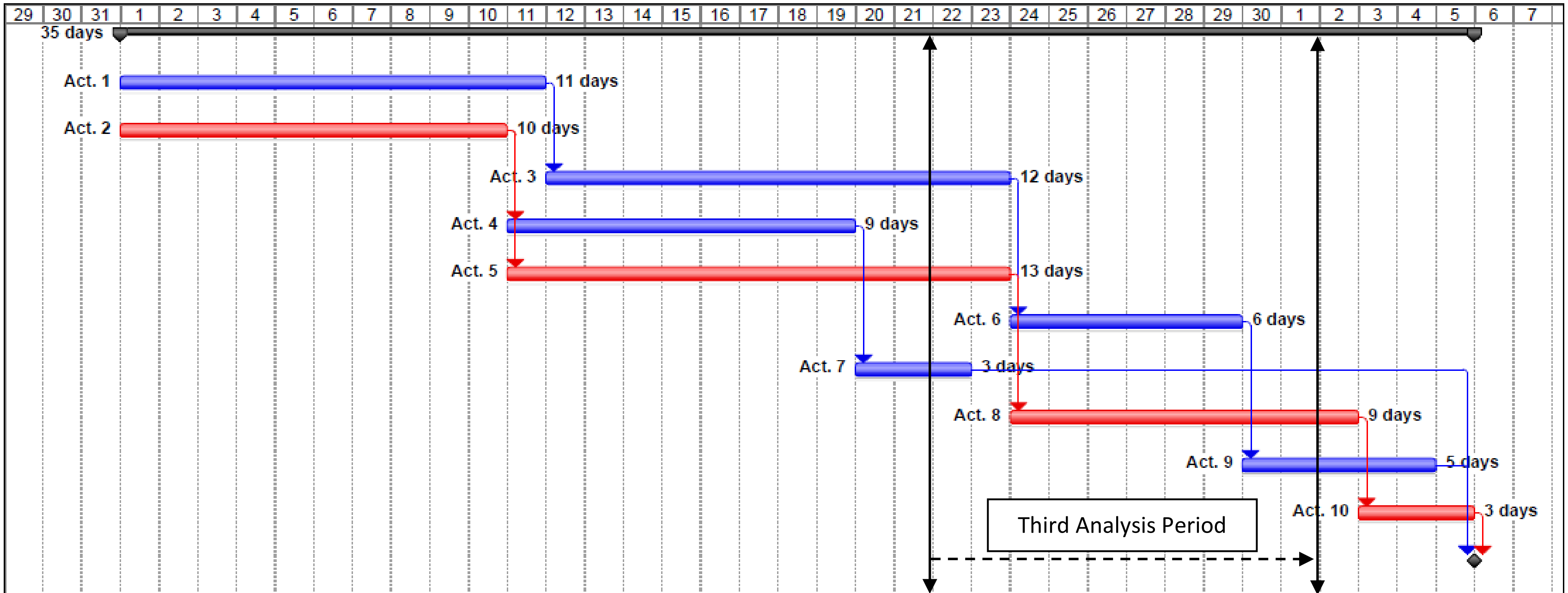


Figure 3.25: Baseline Schedule for the Third Analysis Period (Contractor's Point of View, EC Delays)



Baseline Duration(in days):	After incorporating EC and EC Concurrent delays (in days):	Owner liability for the third analysis period (in days):
$BD_3 = PD + AD_{3-1}$	$ID_3^{EC} = BD_3 + EC$	$R_3^{Owner(EC)} = D_3^{EC} - BD_3$
$BD_3 = 35$	$ID_3^{EC} = 35$	$R_3^{Owner(EC)} = 35 - 35 =$
		$R_3^{Owner(EC)} = 0$

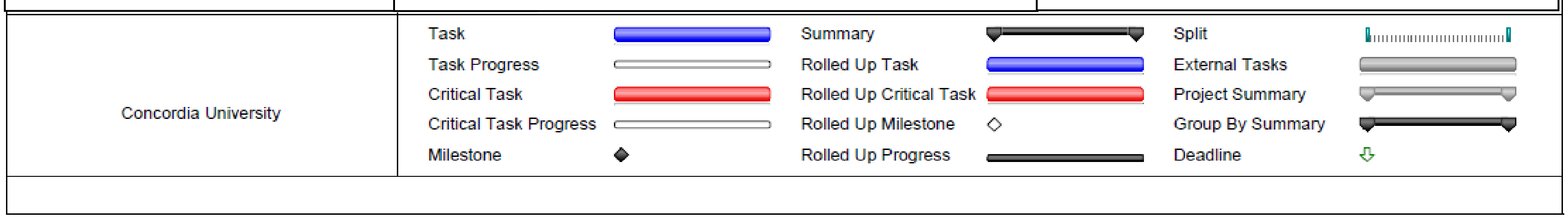


Figure 3.26: Impacted Schedule for the Third Analysis Period (Contractor's Point of View, EC Delays)

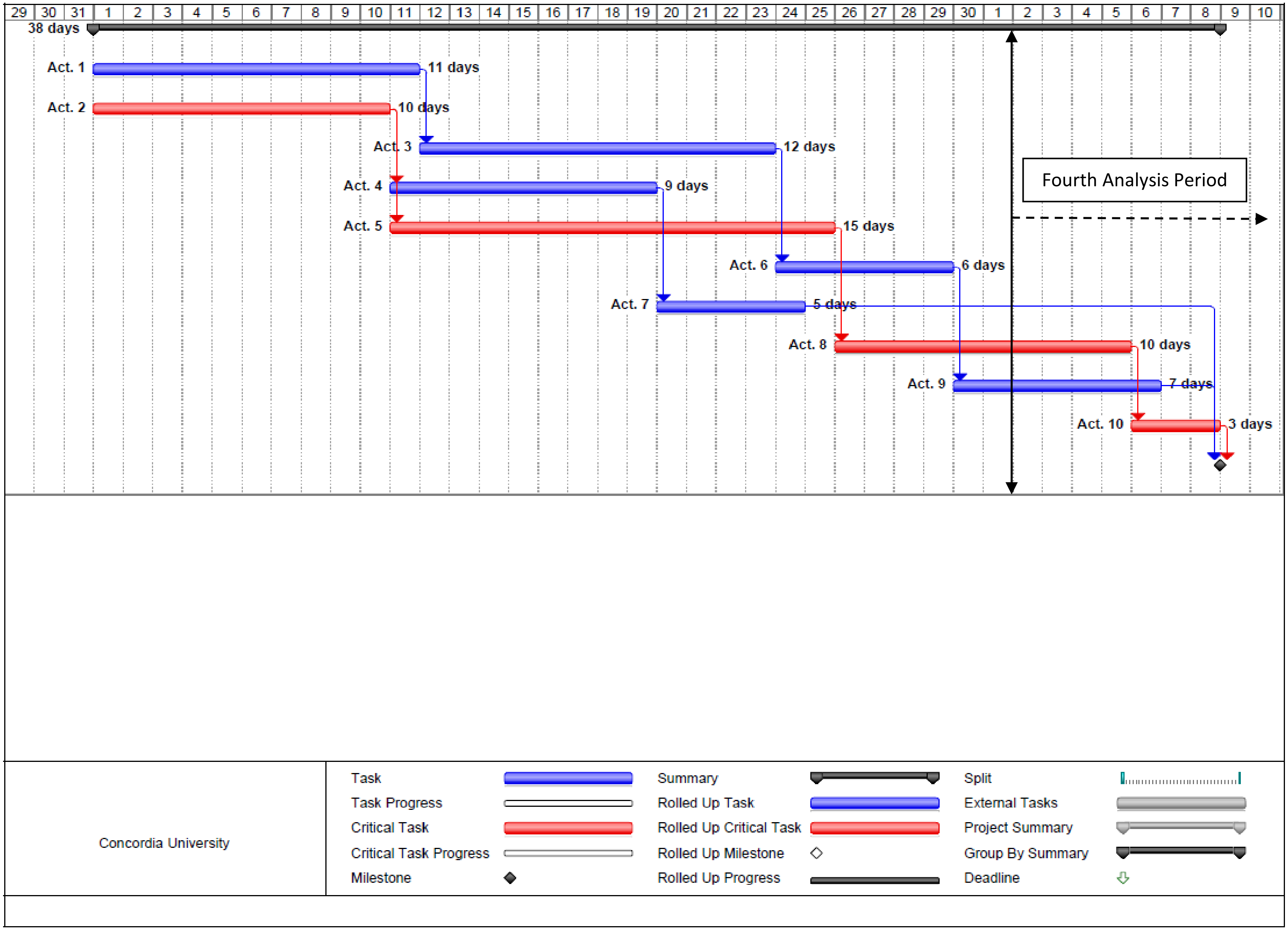
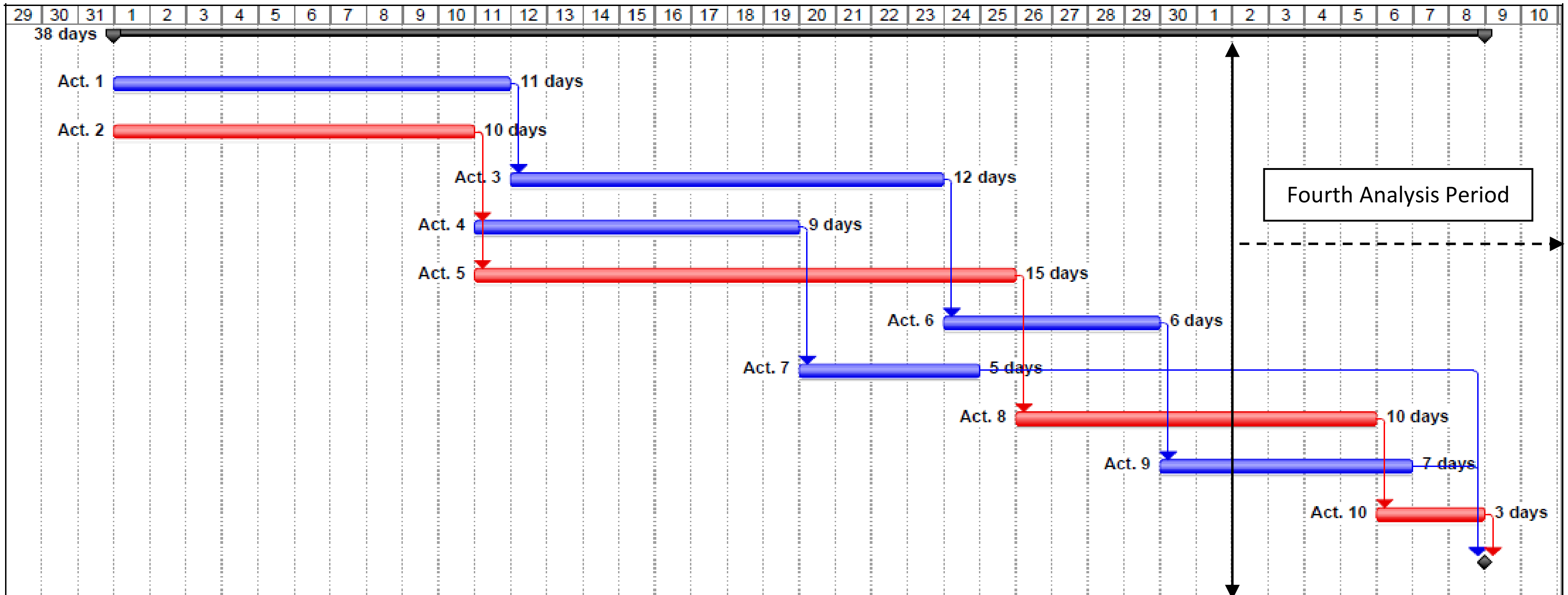


Figure 3.27: Baseline Schedule for the Fourth Analysis Period (Contractor's Point of View, EC Delays)



Baseline Duration(in days):	After incorporating EC and EC Concurrent delays (in days):	Owner liability for the fourth analysis period (in days):
$BD_4 = PD + AD_{4-1}$	$ID_4^{EC} = BD_4 + EC$	$R_4^{Owner(EC)} = ID_4^{EC} - BD_4$
$BD_4 = 38$	$ID_4^{EC} = 39$	$R_4^{Owner(EC)} = 39 - 38 =$
		$R_4^{Owner(EC)} = 1$ day

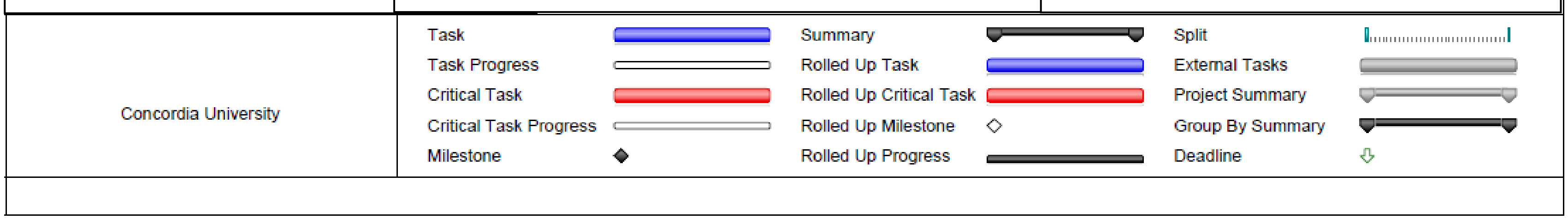


Figure 3.28: Impacted Schedule for the Fourth Analysis Period (Contractor's Point of View, EC Delays)

3.7 Comparison of the MIDT with Other Techniques

As indicated earlier, a variety of delay analysis techniques are available and have been used to obtain resolutions in delay claims. Thus far, no single “one-sized-fits-all” delay analysis technique to assess delay claims in different situations has come to the fore. The same case study was analyzed using MIDT and other techniques to highlight some differences. In the Global Impact technique, to calculate the total project delay, the duration of all delays are added together, resulting in a total of 38 days of delay (Table 3.3). However, the project completion date displays an 18-day time overrun. The contractor usually attempts to show that the difference between the 38 days of delay and actual time overrun of 18 days was caused by acceleration (Alkass et al., 1996).

Table3.3: Results of the Global Impact Technique

Activity	Delay Events Type	Delayed Days
Act.1	NE	3
Act.2	NE	1
Act.3	NE	3
Act.5	NE	1
Act.7	NE	1
Act.9	NE	3
Total Non-excusable Delay days		*12*
Act.2	EC	1
Act.3	EC	2
Act.5	EC	3
Act.6	EC	2
Act.7	EC	1
Act.8	EC	1
Act.9	EC	2
Total Excusable Compensable Delay days		*12*
Act.1	EN	1
Act.2	EN	3
Act.5	EN	5
Act.8	EN	1
Act.9	EN	2
Act.10	EN	2
Total Excusable Non-compensable Delay days		*14*
Total Delay Days		**38**

In the Net Impact analysis technique, the net effects of all delays are considered and the difference between as-planned and as-built is requested by the claimant. This technique attempts to take into account delay concurrence. The result is 18 days of delay, which is the difference between the as-planned schedule (23 days) and the as-built schedule (41 days). However, this value is cumulative and cannot be apportioned to either the contractor or the owner.

The Adjusted As-built technique is classified as a CPM technique. Delays or delaying events are considered as bars and are linked to their corresponding activities. The duration of the project is calculated twice: before and after incorporating delays. The difference between the as-planned schedule and the impacted schedule is the value of delay for which the claimant would seek compensation. This technique is similar to that of Net Impact analysis. Both techniques take into account the net effect of delays on the as-planned schedule. In this test case, the difference of 18 days between the as-built and impacted as-planned schedules would be the value of delays for which the claimant would seek compensation.

The But-For technique uses the CPM scheduling format, where the analyst incorporates those delays into the as-planned schedule that the claimant is willing to accept responsibility for. To determine the amount of delays that was beyond the claimant's control, the modified schedule is compared to the as-built schedule. This technique is applied twice, from the owner's and from the contractor's perspective.

By incorporating contractor- and owner-caused delays into the as-planned schedule, the project duration is 32 and 39 days, respectively. Therefore, the difference between the as-built completion date (41 days) and the modified as-planned date (39 days) is two days, which falls under the contractor's responsibility. By following the same procedure, the owner accounts for nine days delay. Table 3.4 summarizes the generated results of the But-For technique.

Table 3.4: Results of the But-For Technique

Responsibility	Project Completion Date of		Delay
	As-Built Schedule	Entitlement Schedule	
Owner	41	32	**9**
Contractor	41	39	**2**

Courts and construction industry practitioners broadly accept the Snapshot technique. The as-planned, as-built, and any revised schedules are necessary to implement this technique. The total as-planned duration is divided into a number of snapshots, or windows. The size of these snapshots is usually determined by considering major delay events, significant changes in a schedule, and periodic times.

In this case study, the as-planned schedule was divided into three snapshots. The corresponding as-built schedule snapshot substitutes the duration and logic of the as-planned schedule. The remaining activities after the current analysis period should maintain the relationships and durations of the as-planned schedule. The total duration of the adjusted as-planned schedule is compared to the completion date of the as-planned schedule prior to this procedure. Adding up all the results obtained from three snapshot analyses, a total 18 days of delay to the as-planned duration was determined (Table 3.5).

Table 3.5: Results of the Snapshot Technique

Window No.	*Beginning* of the Window Schedule	*Ending* of the Window Schedule	Project Completion Date	Delay
1	1	11	28	5
2	12	25	37	9
3	26	41	41	4
Total Delayed Days				**18**

Modified Windows Analysis originates from the Snapshot technique concept. Prior to determining the impacts of delays on the as-planned schedule, MWA attempts to reach an adequate resolution for delay liability events. MWA uses a systematic approach for calculating delay liability, which leads to an enhancement in its analytical procedures. This method was applied on the same case study by Kao and Yang (2009), where the as-planned schedule was divided into 17 analysis periods. They achieved the following results: NE delay for 5, EN delay for 9, and EC delay for 4 days.

The Delay Analysis Method Using Delay Section has been proposed to overcome the inadequate assessment of concurrent delays and time-shortened activities. As previously mentioned, two new concepts were proposed in this method, namely delay section and contractor's float. By applying the DAMUDS to the test case, the following result was obtained: NE delay for 4, EN delay for 9, and EC delay for 4 days (Kao and Yang, 2009).

Daily Windows Delay Analysis has been proposed to overcome the inherent limitations in traditional windows analysis technique. This technique considers one day as the length of each analysis period. Since DWDA is a real time analysis, accessibility to delay information records is simpler than in stated methods. Therefore, the outcome of the analysis is neither acceleration-sensitive nor deceleration-sensitive. This method is applied to the case study and the following result is obtained: NE delay for 4, EN delay for 9, and EC delay for 4 days (Kao and Yang, 2009).

Time Impact analysis is similar to the snapshot technique; it scrutinizes the consequences of delays or delaying events that occur in different periods of the project. This technique concentrates on delays or delaying events regardless of their occurrence periods.

In other words, this technique focuses on the individual delayed activities in a project. The analysis starts with the first delayed activity and progresses to the next one. It replaces the as-planned start and end dates of the first delayed activities with the as-built start and end dates. To determine the amount of delay of the project, the completion date must be compared before and after inserting an as-built duration for a delayed activity. Before evaluating subsequent delayed activities, the as-planned schedule should be revised to reflect the as-built schedule prior to the start of the next delayed activity. In this case study, nine out of ten activities had delay; thus, nine activities were analyzed. By summing the different completion dates produced by these nine delayed activities, a total delay of 30 days was achieved (table 3.6).

Table 3.6: Results of the Time Impact Analysis

Activity	Project Completion Date		Delay
	Before **the impact**	***After*** **the impact**	
Act. 1	23	27	4
Act. 2	23	28	5
Act. 3	28	32	4
Act. 5	28	37	9
Act. 6	37	37	0
Act. 7	37	37	0
Act. 8	37	39	2
Act. 9	37	41	4
Act.10	39	41	2
Total Delay Days			*30*

The Isolated Delay Type technique is a combination of the snapshot and but-for techniques. Similar to the snapshot technique, in IDT, the as-planned schedule is divided into several analysis periods. The same criteria as for the snapshot technique are employed to determine the size of each analysis period.

This technique is applied to the above test case from two independent perspectives, again the owner's and the contractor's. The as-planned schedule is used as the starting point for implementing the delay analysis. From one analysis perspective, delays caused by the other party are added to the as-planned schedule. Applying any required modification or changes in the as planned schedule must be reflected in each analysis period or window.

Comparing the total project's duration before and after substituting delays into the as-planned schedule gives the delay value for each analysis period. In the test case, three analysis periods are used to evaluate the effects of delays or delaying events on the project completion date. Summing the differences that appeared over these three analysis periods results in a total delay of six days (3+3+0) caused by the contractor and 16 days (4+8+4) by the owner (Table 3.7).

Table 3.7: The IDT Technique

Window No.	Project Completion Date at the		Delay	
	Start of the Window Schedule	*End* of the Window Schedule	Type	Days
1	1	11	EC/EN	4
2	12	25	EC/EN	8
3	26	41	EC/EN	4
Total of Excusable Delayed days				**16**
1	1	11	NE	3
2	12	25	NE	3
3	26	41	NE	0
Total of Non-excusable Delayed days				**6**

Table 3.8 summarizes the results of utilizing different delay analysis techniques for the mentioned case study. The net impact and the adjusted as-planned techniques produce the same results, because both techniques consider the net effects of delays; i.e., the project is delayed by 18 days. The snapshot and modified window analysis methods generated the same result, similar to that of the net impact and adjusted as-planned technique. However, there is no specific relationship between the snapshot technique and the modified window analysis and the other two methods; they just happened to achieve similar analysis results for this case. Although the daily windows delay analysis is an accurate technique, it requires a tremendous amount of effort. Furthermore, in the DAMUDS technique, to achieve an accurate result, it is required to implement a series of complicated analytical procedures.

Different methods provide different results and a variety of allocation delay liabilities for the owner and the contractor. There are several reasons for finding different results from these techniques. First, there is no common language between practitioners and the construction industry, which leads to different interpretations of delay claim issues such as concurrent delays. Second, several techniques are inconsistent and their procedures are arbitrary. Commercial scheduling programs such as MS Project are not designed to support these techniques. Finally, inaccurate project information leads to false analysis; information resource validity is required and essential to implement a sound analysis.

Table 3.8: Comparison of Different Techniques

No.	Delay Analysis Technique	Project Delays(in days)			
		EC	NE	EN	Total Delay
1	Global Impact	-	-	-	38
2	Net Impact	-	-	-	18
4	Adjusted As-Built	-	-	-	18
5	But-For (Owner's point of view)	-	-	-	2
6	But-For (Contractor's point of view)	-	-	-	9
7	Snapshot	-	-	-	18
8	Modified Windows Analysis	4	5	9	18
9	Delay Section	4	4	9	17
10	Daily Windows Analysis	4	4	9	17
11	Time Impact Analysis	-	-	-	30
12	IDT(Owner's point of view)	-	6	-	6
13	IDT(Contractor's point of view)	-	-	16	16
14	MIDT(Owner's point of view)	-	5	-	5
15	MIDT(Contractor's point of view)	4	-	12	16

3.8 Advantages and Limitations of the MIDT

Although numerous delay analysis techniques are available, there is no rule to determine which technique provides the most precise outcome in a particular situation. The MIDT shares similar positive aspects with the IDT, including:

1. Since the MIDT employs the same concept as the IDT, it is considered to be a systematic and dynamic analysis method, and both utilize the concepts of the snapshot and but-for techniques. MIDT is classified as a detailed technique, which is more reliable for assigning delay liability.
2. Before starting the analysis, the delays must be classified based on their compensability and the concurrency of classified delays needs to be identified and listed chronologically. Thus, the listed concurrent delays are utilized in MIDT calculation; thereby, the overestimation of delay distribution is prevented. This technique can be employed with both hindsight and foresight.
3. In the MIDT, project parties should agree on the combination results of concurrent delays prior to starting the analysis procedure: this helps assess concurrent delay fairly.
4. Any changes in critical path(s) are traceable because the analysis is performed within particular time periods. Therefore, the critical path(s) coincide with the actual critical path at the end of analysis.
5. To ensure the validity of the as-planned schedule, the MIDT mainly uses as-planned schedules. By imposing delays into the as-planned schedule within specific time periods, the as-built schedule should be generated at the end of the analysis. If not, then the as-planned schedule that was utilized was not realistic.

6. The float is distributed equally between the project parties. Both parties have a chance to utilize the floats because the effect of delays on the project is analyzed separately for each party.
7. The impact of compensable delays can be measured easily by evaluating the EC and EN delays individually, also considered the starting point for estimating damages.
8. An automated delay analysis can be developed based on the MIDT due to its uncomplicated procedures.
9. The MIDT can address the issue of pacing delays because these delays are classified based on project responsibility prior to the analysis phase being started.

Although the MIDT attempts to resolve most of the shortcomings of the existing delay analysis techniques, it fails to overcome the following:

1. Implementing the MIDT strongly depends on the as-planned and as-built schedules, and evidence obtained from the project. The MIDT is unable to evaluate delays without these documents.
2. The consistency of the MIDT is heavily dependent on the quality of the documents available, such as progress reports and meeting minutes.
3. The MIDT cannot address complicated delay situations such as acceleration, and effect of resources.
4. Determining the optimal length of the analysis period(s) is subjective, and the results can change by choosing different window sizes.

3.9 Conclusion

Construction projects are complex and time consuming in all their aspects, from design to the execution phase, and delivering a project on time is unpredictable due to the inherent uncertainty. Delays should be considered as an inseparable part of construction projects. Therefore, having an appropriate means to evaluate delay claims is essential for all projects.

This chapter has presented a delay analysis technique that considers concurrent delays and differentiates between different types of excusable delay to apportion delay responsibility between project parties. This approach is a windows-based technique; therefore, it can trace all changes in the critical path(s). Descriptive analysis procedures of this proposed delay analysis approach were explained in this chapter and supported by presenting a sample test case to illustrate its accuracy and effectiveness.

Chapter 4

Integrated System for Assessing Delay Claims

4.1 Introduction

Engineering skills and legal knowledge are essential for evaluating delay claims, and are crucial to developing a sound, precise, and realistic case for the claim. A convincing delay claim should be supported by a series of well-prepared information that can persuade a defendant or judge to view it as a valid claim. The information should illustrate the connection between delaying events and their impacts on the project. In other words, the cause and effect relationship of the delaying events must be reflected in the collected data. This cannot be possible unless all relevant details are readily accessible, including resource utilization, progress reports, change orders, and memos (Baram, 2000).

The claim management team faces a considerable challenge in extracting and establishing the required information related to delays from the considerable volume of assorted documents. The process is usually costly and time consuming. Therefore, utilizing a computerized integrated system would be desirable for practitioners, as it could provide valid, up to date, and readily retrievable information. The significant improvements in computer technology over the last decades has made the development of such a system realistic.

An integrated computer-based system is proposed and discussed in this chapter. The proposed system's objective is to facilitate and improve the preparation of delay-based claims within an integrated environment. The system has several interesting features. Firstly, for the practitioner's convenience, it integrates commercial project management software tools including databases, project scheduling software and an expert system tailored for the classification of delay. Secondly, it assesses delay claims in a systematic approach. Finally, it can be a useful means for training junior engineers by demonstrating the effects of their decisions on delaying events.

4.2 The Integrated System

Significant improvements in computer technology have made it possible to integrate the massive volumes of information obtained during the different phases of a project's life cycle (Parfitt et al., 1993). Furthermore, the construction industry has shown a growing trend towards utilizing computer software and high-tech technologies. These software packages cover a wide range of the construction industry, such as scheduling and database software (Mubarak, 2010).

However, these software packages are designed to be stand-alone elements rather than a part of an integrated system. As a result, an integrated system is required to connect these individual software packages around a common data core, with no inconsistent data conventions. One of the main purposes of a well-designed integrated system is to function efficiently to produce the required information in a user-friendly environment (Parfitt et al., 1993).

The developed integrated system is designed for four main functions, namely: detecting delayed activities, classifying delays, measuring delay impacts on project schedule, and calculating the cost of damages. The general framework of the system is shown in Fig. 4.1. At the beginning, the user must enter all related information of the project into the system, such as the as-planned and any revised schedules. The as-built schedule can be developed and entered as the project progresses. After utilizing the key functions, the user will be able to obtain results about delay liabilities and related costs.

Furthermore, the system generates reports on the stated main functions in a reasonable format for all parties involved in the possible claims. The purpose of the integrated system is to reduce the time and cost associated with claim preparation by facilitating the evaluation procedures. The automated system evaluates delay-based claims efficiently and retrieves the required data rapidly. The system was designed so that it can seamlessly compute, store, and retrieve information within its technical limitations.

The developed system can support management teams and claim analysts in delay-based claims evaluation, regardless of whether they are from the contractor's or the owner's organization. Before explaining the main functions of the proposed system, it is important to describe the function and capability of each component. The system consists of six components including the user, a unique graphical user interface, an expert system, a model and two commercially available software packages: Microsoft Access (2007) as the database, and Microsoft Project (2007) as the project scheduling software.

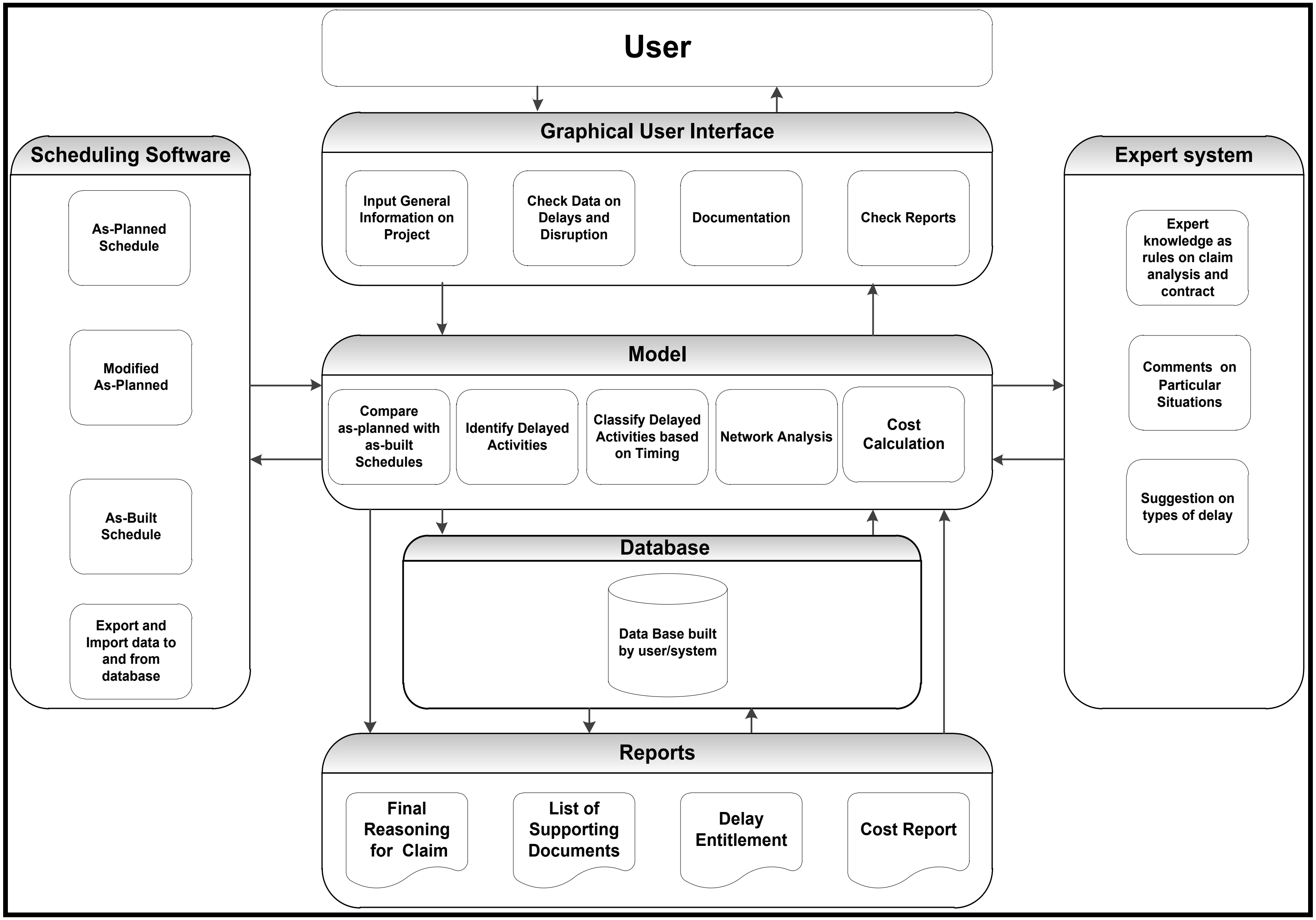


Figure 4.1: System Architecture

4.2.1 The User

The purpose of designing this interactive system, utilized by different project parties, is its simplicity in assessing delay analysis for claim management teams in which a user provides the system with specific data related to the project system, such as as-planned or as-built schedules, and relevant project documents. In addition to containing numerous supportive built-in features and its obvious utility for claim resolution, this system is also to be appreciated for its valuable historical data collection package that can be accessed for future projects' claim assessments. Users also have the responsibility of monitoring the generated reports to assure that they are arriving at accurate results based on the facts and delaying events.

4.2.2 The Graphical User Interface

User interaction with the system is very straightforward. By following user interface design principles such as employing appropriate visibility and pertinent consistency among various components, along with immediate feedback from the interface, all users will profit from a well-developed system in a robust, aesthetically designed framework that effectively controls all its modules.

4.2.3 The Expert System

An expert system is an intelligent computer program that acts as an expert in a specific domain. Typically, an expert system includes a knowledgebase containing facts, heuristics and rules of thumb regarding a particular field or area of expertise, along with a set of rules for manipulating and applying these elements (Diekmann and Kruppenbacher, 1984). Therefore, the expert system simulates human-like analysis in the form of a computer program (Iyer et al., 2008). According to Arditi and Patel (1989), expert systems solve problems by using a computer model of expert human reasoning. The result achieved by applying the expert system is to be the same as the conclusion that would be obtained from a human expert. Minkarah and Ahmad (1989) highlighted the reasons for applying expert systems in the construction industry:

1. In the construction industry, the project processes are always exposed to variances due to external and internal factors.
2. In this industry, the required set of input variables for supporting the decision making process varies from one project to another. This is the main problem behind situations where the manager is unable to apply a structured decision support system.
3. All projects are time and cost sensitive, in that the manager is under pressure to deliver the project on time and on budget. Thus, to follow the predefined safety practices and use the best possible resource allocation, management decisions need to be made simultaneously fast and accurate.
4. Managers mostly apply qualitative variables in their decision making process. In such situations, applying a rule of thumb approach is more appropriate and convenient, in comparison to a technical approach.
5. During any project, the conditions are continuously subjected to alterations. As a result, construction is always considered a dynamic process.
6. In the construction industry, as experienced managers retire or are replaced, thier skills and knowledge are typically lost. Employing an appropriate expert system is strongly recommended to overcome this problem.

A well-designed expert system for a construction project should (Arditi and Patel, 1989):

1. Ensure that uncertainties inherent in the construction project are taken into consideration;
2. Collect a large quantity of data and frequently update it; and
3. Incorporate an adequate connecting capability to other software packages, in order to allow the import and export of information for the decision-making process.

Mohan (1990) listed 37 expert systems in the field of construction management and engineering. The majority of these can be utilized on a microcomputer and are rule-based knowledge systems coded in commercial expert shell environments. Mohan also states that 60% of these expert systems have extracted knowledge from the literature and 40% from experts. These expert systems cover a variety of construction industry areas, such as project planning and scheduling, project control, earth moving operations, construction risk identification, claims management, and schedule analysis.

A knowledge-based expert system is designed to classify delays based on their compensability. It should be noted that classifying delays is a complicated task as delays are interdependent and auto-correlated; therefore, assigning delays to a single party is not a straightforward process (Ng *et al.*, 2004). The expert system developed here contains four components (Fig. 4.2):

- Knowledge base: a knowledge base is the accumulated information from historical data, literature, facts, and expert knowledge for formulating and solving the problem. This knowledge is formulated in “IF (situation), THEN (action)” rules. For example:

> IF there is any disclaimer clause in the contract that is related to a claim’s basis,
>
> THEN legal advice is recommended.

The knowledge-base for the expert system contains 250 rules built into the database that can easily be modified and expanded if needed.

- Inference engine: also known as a reasoning engine, the inference engine is the core of any expert system and includes a set of computer programs that attempt to achieve a solution by using the knowledge base. The developed expert system follows the forward chaining processing strategy that starts with the available data and reaches the final decision based on those data. Since the types of delay are unknown, applying forward chaining is the most appropriate technique for delay classification.
- Interface: all expert systems include a natural language processor (NLP) for user-friendly and problem-solving oriented communications between the user and the system.
- Database: the database is an essential component that retrieves the required information from the existing data stored in the permanent repository. MS Access is used here so that the expert system can take on the role of manipulating data from the user to solve a relevant problem.

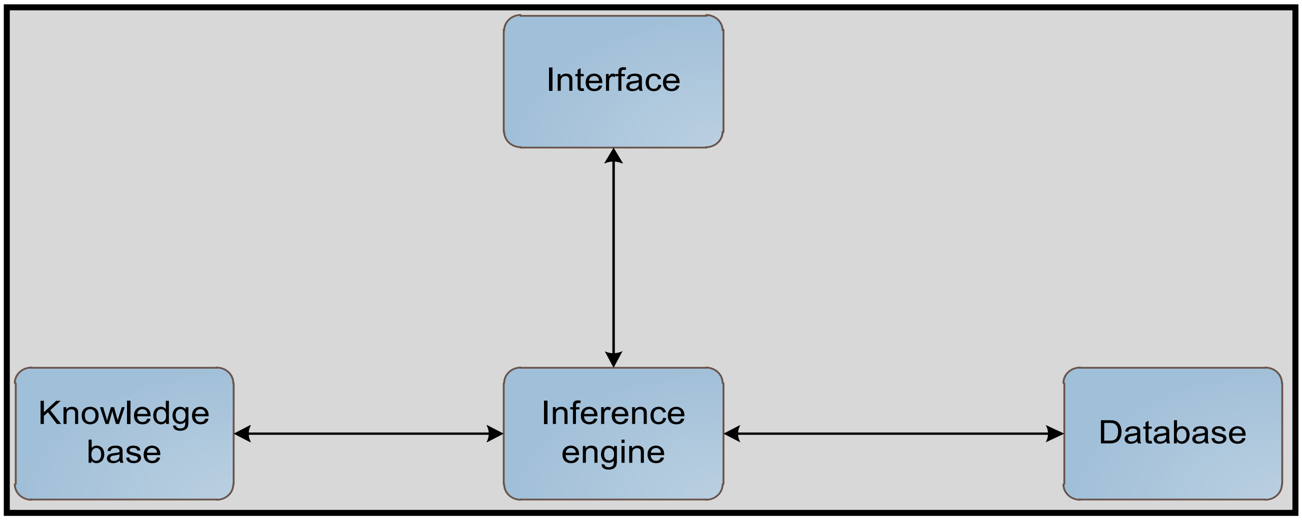


Figure 4.2: Structure of Expert System

A database management system (DBMS), utilized especially to control the expert system and built-in database, helps to manage the process of decision-making by using a “Decision Tree” approach, to support the decision-making itself as well as the ongoing knowledge base development of the expert system.

The DBMS makes it possible to keep a record of each delay as it takes place, including the responsible party, date of the delaying event, related costs, etc. By recoding all the relevant information, the data retrieving process can be carried out in a methodical and organized manner. The DBMS acts as a repository to accumulate expert knowledge, which is then developed by employing MS Access tools and the C# programming language.

The knowledge for the developed expert system is extracted from the claim procedures stated in the Intentional Standard Form of Civil Engineering of the Federation International des Ingenieurs-Conseils (FIDIC) and from the literature and experts in the field of construction management. The FIDIC contract was used because it is a unified form of contract used internationally. Because of the knowledge acquisition that has already been refined and engineered, delay claims are allocated to one of the following reasons:

1. Change orders;
2. Failure to give possession of site;
3. Unforeseeable physical conditions;
4. Ambiguity or discrepancy in the contract;
5. Failure to issue drawings or instructions;
6. Setting-out based on incorrect data;
7. Unanticipated requirement for exploratory excavations or boreholes;
8. Repairs required after an accident;
9. Discovery of items with geological or archaeological value;
10. Samples or tests were not clearly identified;
11. Uncovering or opening in the works;
12. Suspension order;
13. Efforts undertaken to search for the cause of any defect;
14. Contract frustrated;
15. Inefficiency caused by interference;
16. Owner's fault or negligence;
17. Events without fault from any party; or
18. Contractor's or a subcontractor's failure.

Figure 4.3 illustrates the programming logic, developed based on expert knowledge and literature, for reaching a decision that a delay has been caused by the failure to issue drawings or instructions.

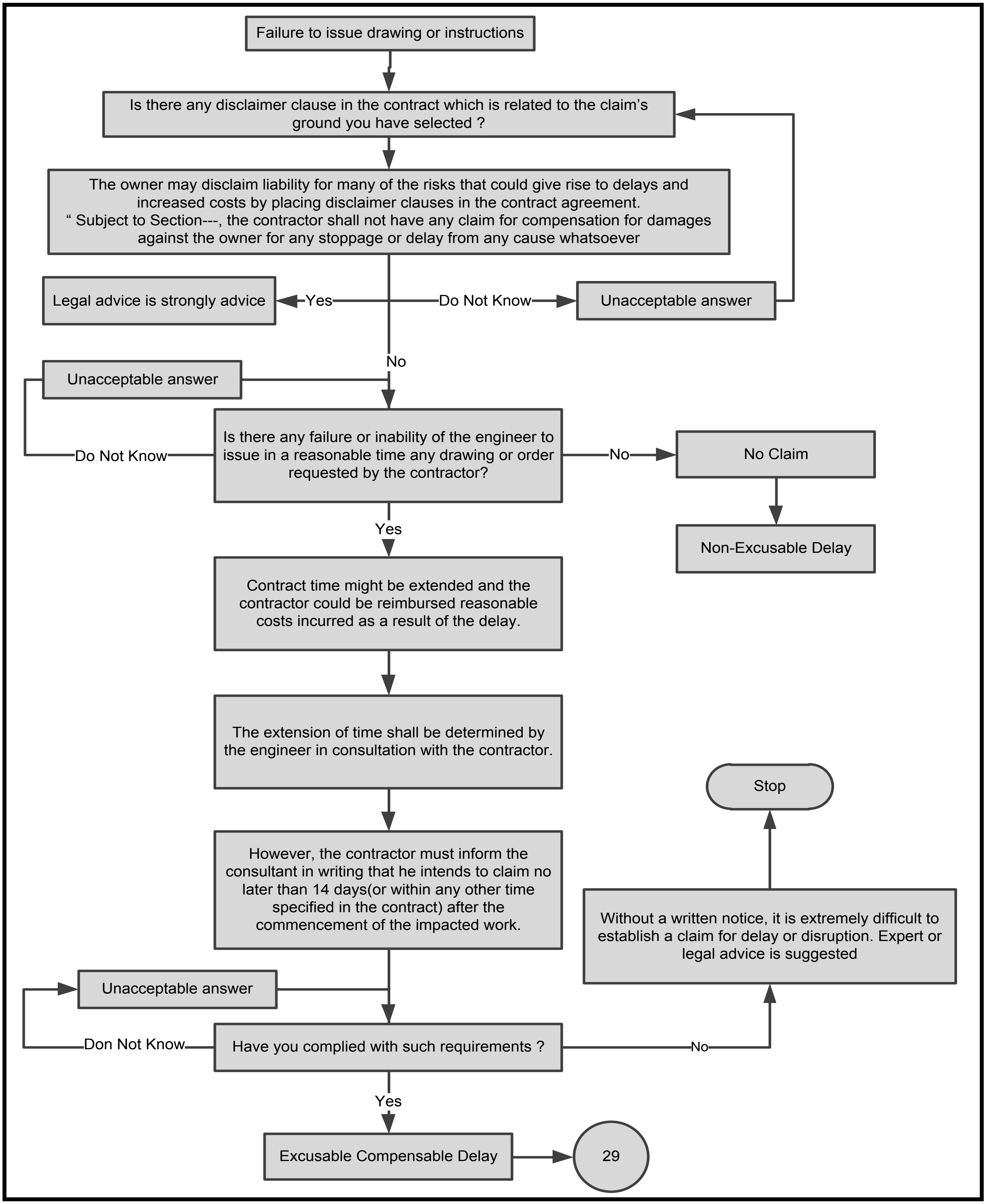


Figure 4.3: Decision Logic used in Expert system

4.2.4 The Model

Receiving all required input from the interface panel, the model section appears as a computational approximation, an analysis tool and calculator to handle the processing. This section is defined as a bridge between the front and back of our system. It also acts as a liaison between our expert system and the scheduling software. All raw data travels from the scheduling software to the model, which performs calculations on it before moving the ‘prepared’ data to the expert system for the delay classification process.

4.2.5 The Database

The database is created only once, and then it completes and updates itself progressively during the analysis process. By developing the database, the system’s capacity to process different projects’ delay claim assessments within a company is enhanced and continues to grow. This database includes all of the essential project data and the relevant information extracted from different types of documents. The accessibility of these document types and the capability to apply an appropriate delay analysis technique are two key factors in attaining delay claim resolution for any project. This type of database is built into the system specifically for a certain company performing one or a group of projects.

4.2.6 Project Scheduling Software

The project scheduling software is integrated with the system for the following reasons:

a) To allow it to connect to other commercial software packages, so that it can import and export project information;

b) To make it easy to use and capable of organizing graphical schedule presentations;

c) To ensure that it can support the CPM scheduling technique, the core of the delay analysis process; and

d) To keep its cost reasonable, since cost will affect its accessibility.

Thus, MS Project (2007) is employed to integrate the scheduling software into the system. MS Project is capable of importing and exporting essential information from and to other software. Different types of schedules can be provided by MS Project, a requirement to proceed with delay analysis. In addition, a major reason for employing MS Project is that the integrated system is developed in a Microsoft environment and thus is compatible with other Microsoft released products such as MS Access.

4.3 System Development

This section presents the development of an integrated system to aid the project parties in assessing delay claims. Figures 4.4 to 4.7 display the workflow (activity diagram) of the integrated system for delay-based claims. The Unified Modeling Language (UML) depicts the interaction process between the user and the system components, including the entire system from data acquisition to cost calculation modules.

The UML also displays the activities' processes that may occur in simple parallel and/or sequential paths. The activity diagram includes four phases that depict the user's action, from data acquisition (starting point) to the cost calculation phase (ending point) of the delay calculation. The user, however, does not need to complete all phases at once. Their work can be saved at the end of each module and resumed later.

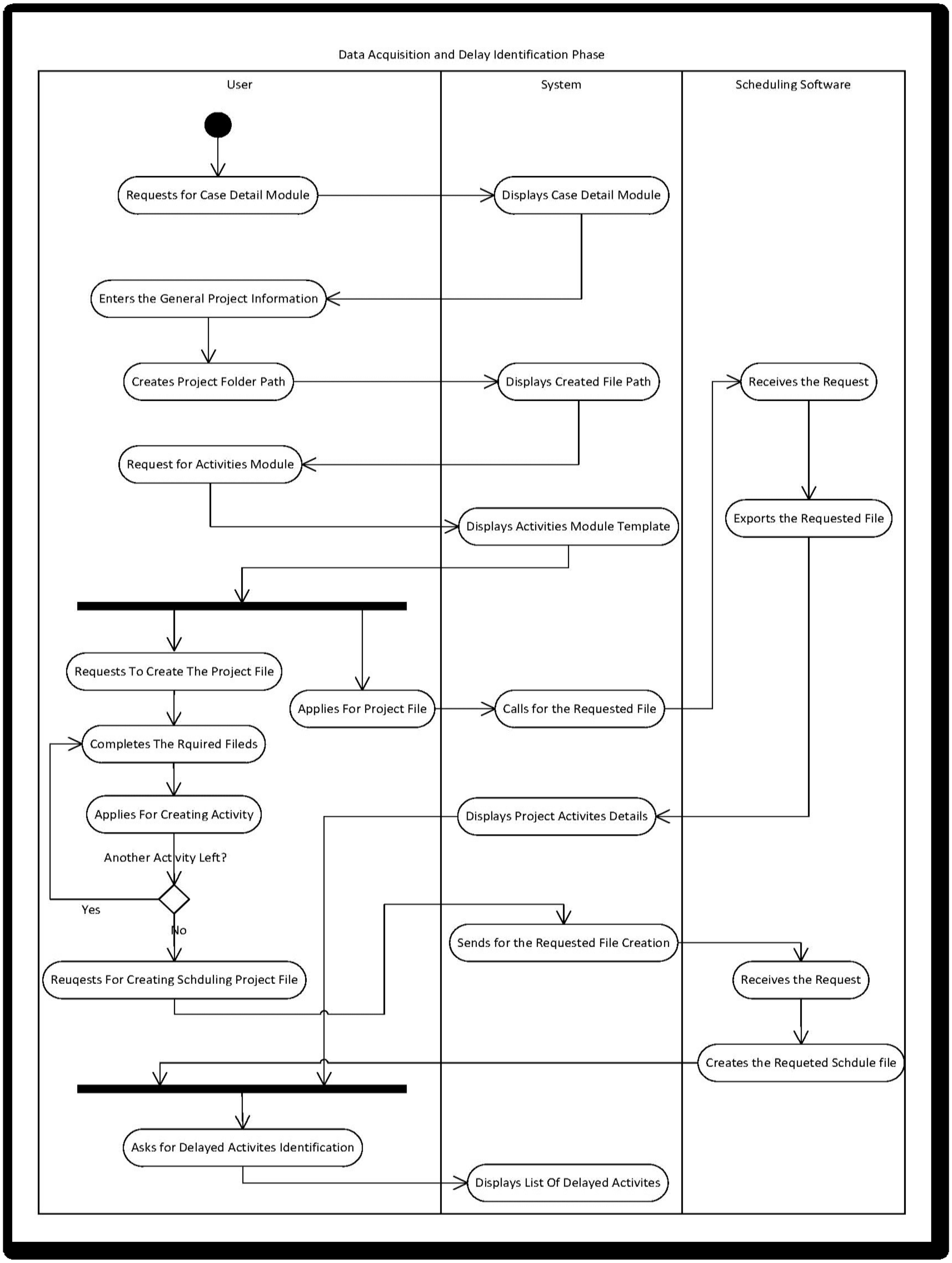


Figure 4.4: Activity Diagram for Data Acquisition Phase

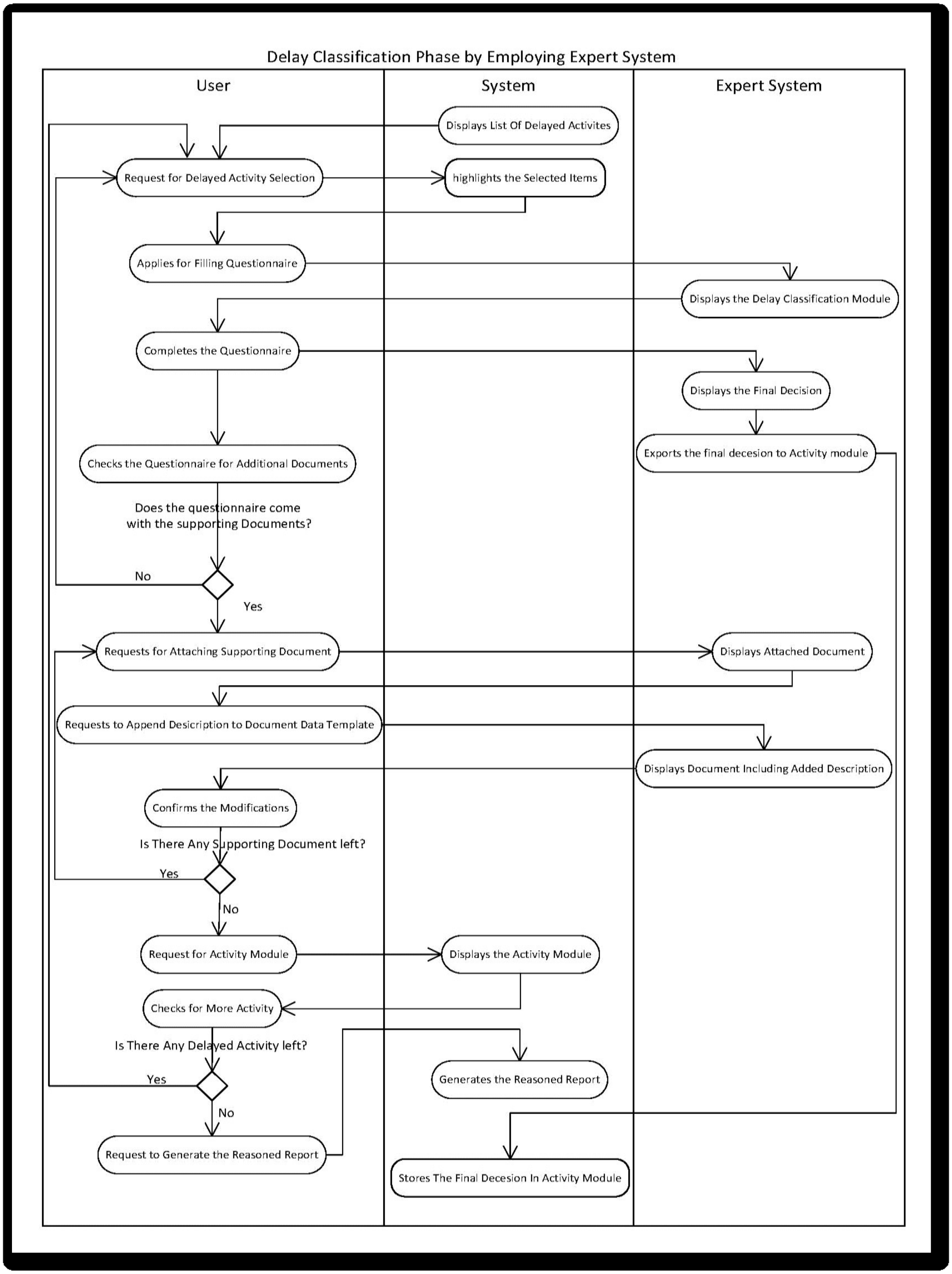


Figure 4.5: Activity Diagram for Delay Classification Phase

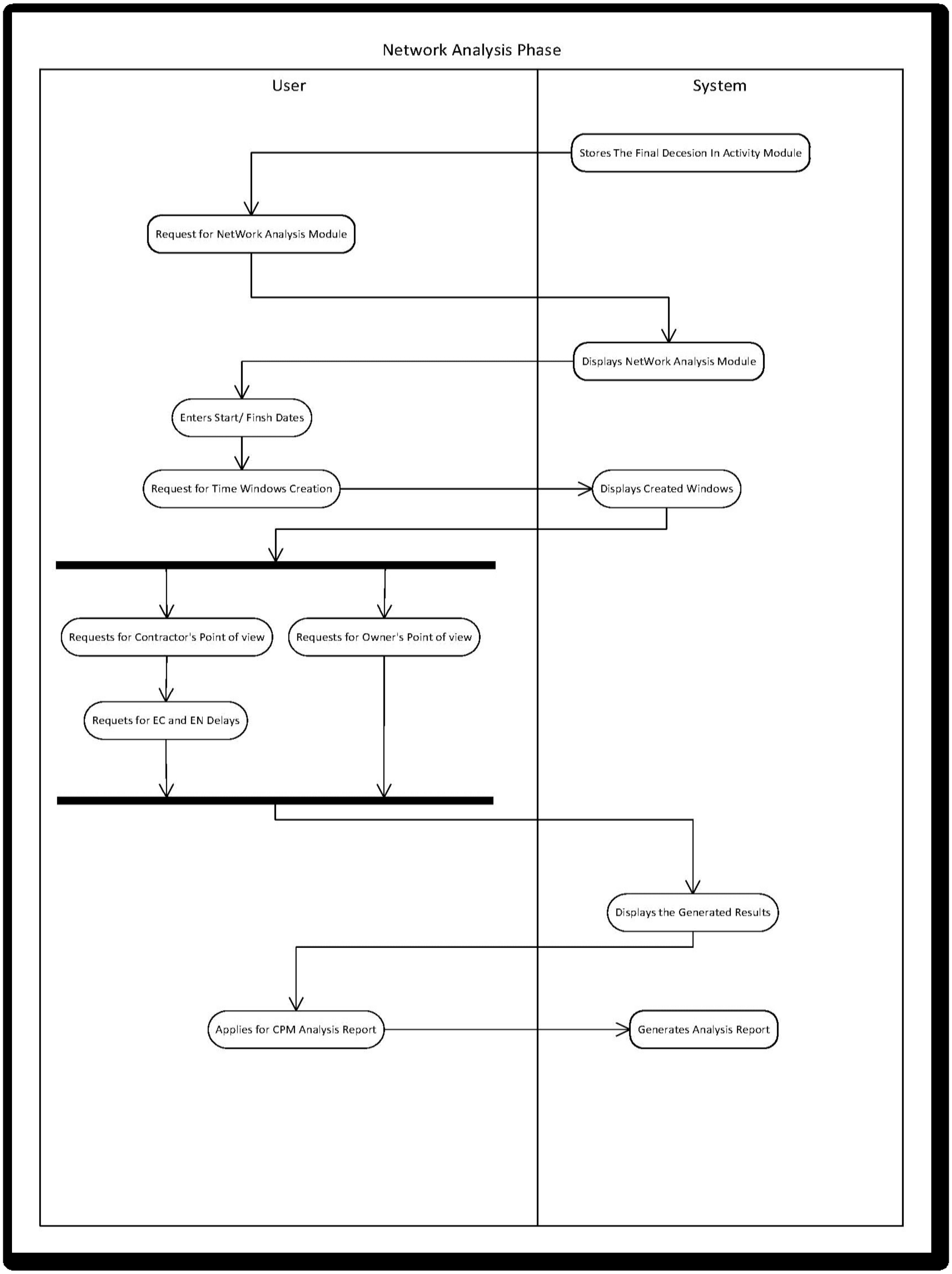


Figure 4.6: Activity Diagram for Network Analysis Phase

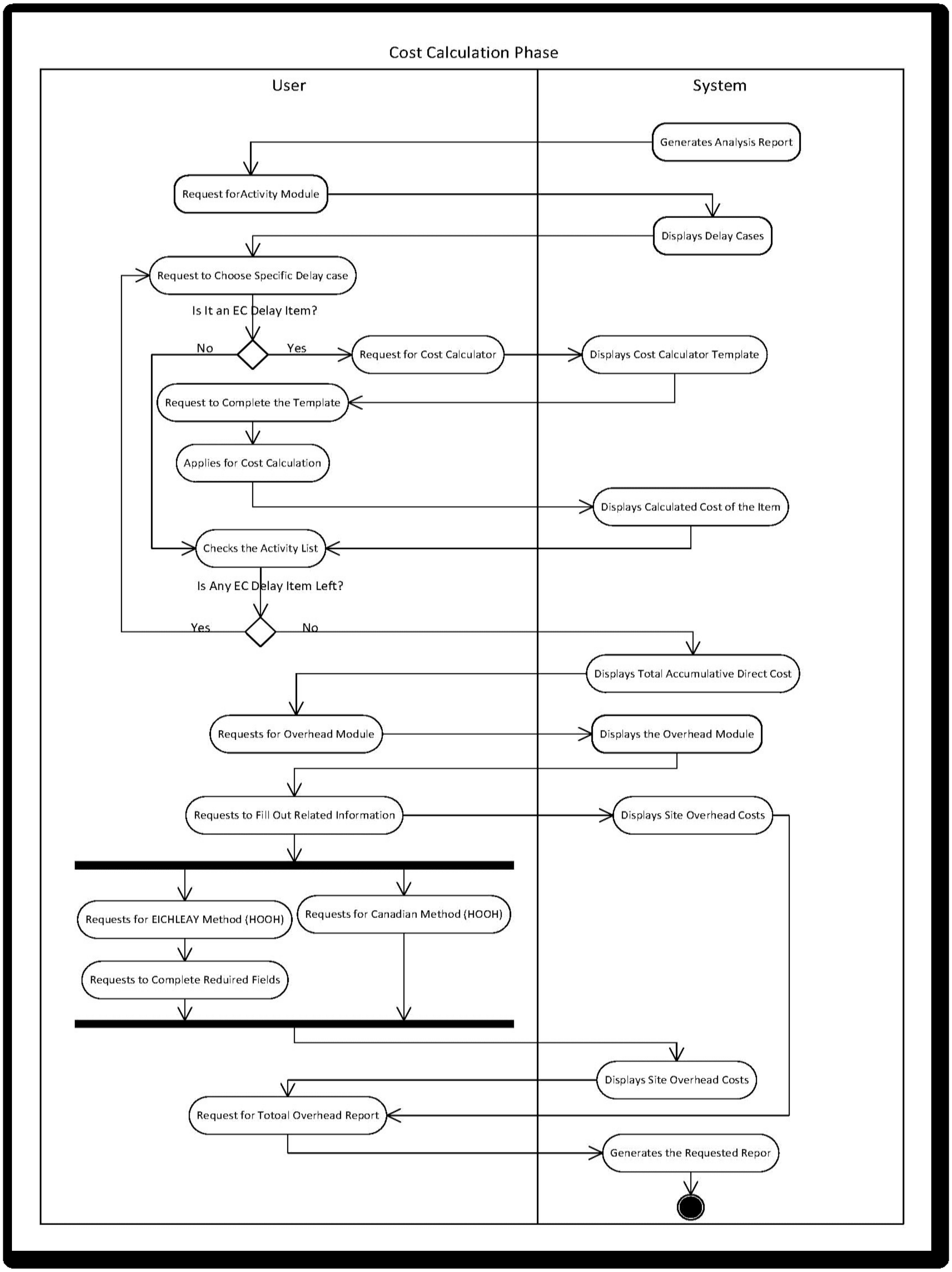


Figure 4.7: Activity Diagram for Cost Calculation Phase

Being user friendly is one the main concerns of the system. The system was developed using the C# programming language, which is much more effective than other object oriented languages like Java, and it runs faster. In addition, C# was especially designed for microcomputers with MS Windows operating system supports.

4.3.1 Data Acquisition Module

This phase is divided into two modules: the case detail module and the activities module. To start, the general information for the system should be provided by the user. This will be recorded and saved in the system for future reference, as indicated in Fig. 4.8. This information includes the project's name and location, the owner's name, contractor's name, engineer's name, project duration, etc. The user has to create a path file to store the information generated by the module, thereby making it easier to access data from previously completed cases. Meanwhile, through the built-in error-checking feature, the user's inputs will be validated.

After providing the requested information for the case detail module, the user can proceed to the activities module. The objective of this module is to identify delayed activities and list them in chronological order. The user has to specify the project schedule, either by selecting an MS Project file or by entering it manually (Fig. 4.9). If the user attempts to create the project schedule manually, the information for each activity should be entered into the system, including the activity's name, preceding activities, and as-planned and as-built dates. This feature is particularly useful when the project schedule is not accessible in the MS Project format. When creating a schedule manually, the user also has to define delays and working days for the system.

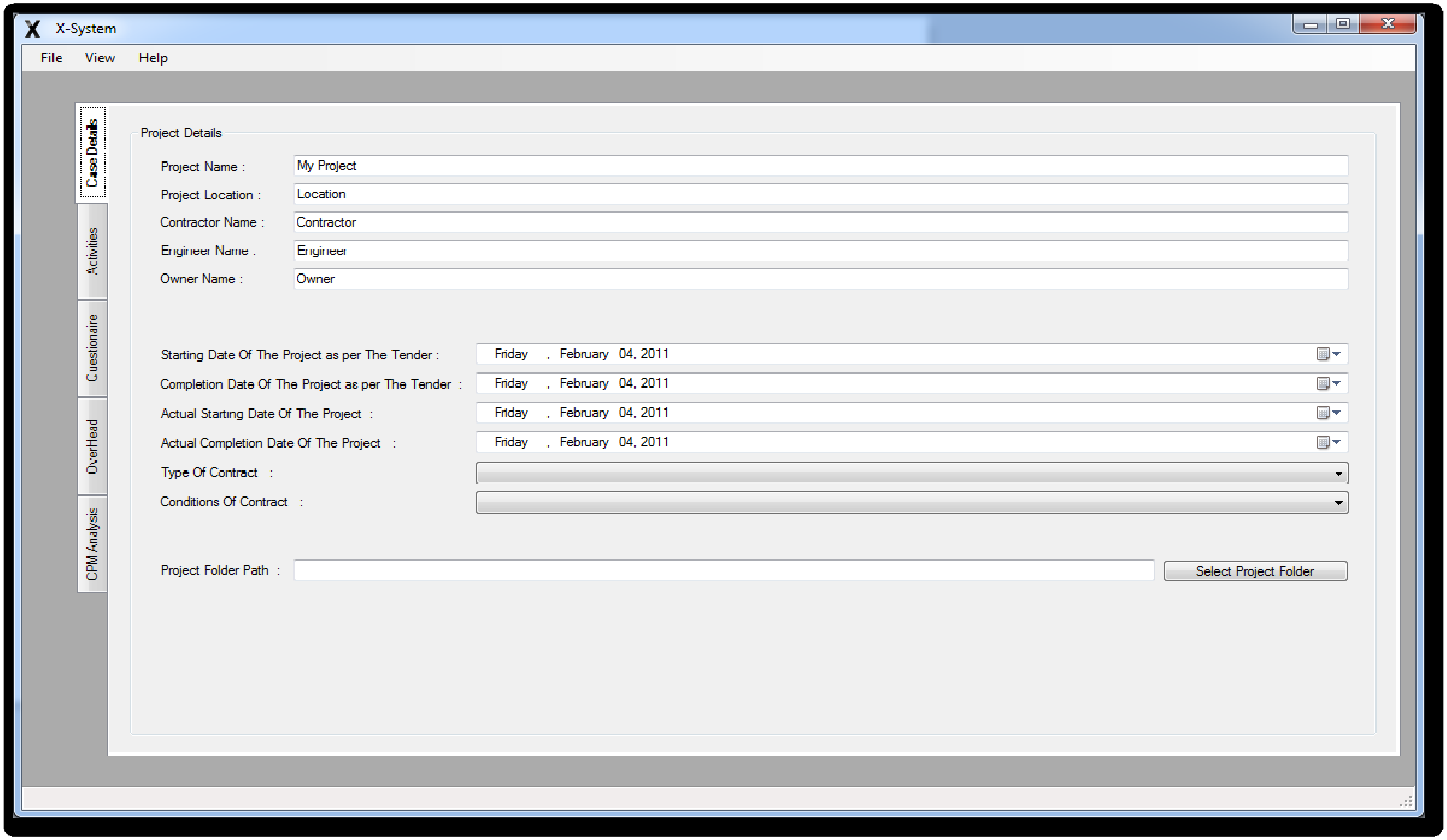


Figure 4.8: General Information Module

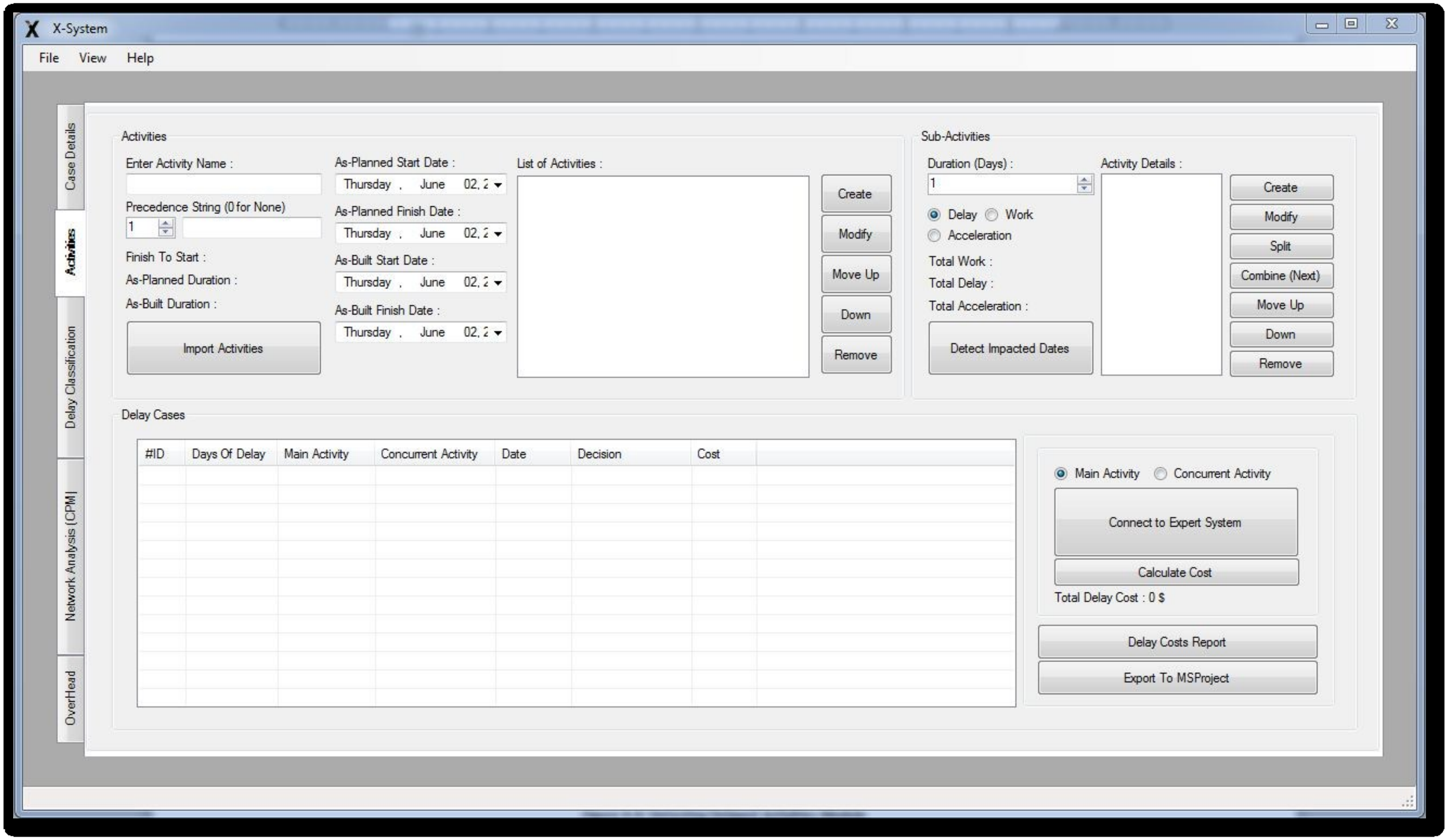


Figure 4.9: Detecting Delayed Activities Module

The system can also import the project schedule directly from MS project. It should be noted that the as-planned and as-built schedules should be created in a single MS Project file, in a format that is readable by the system. After importing the project schedule, the system automatically detects delayed activities and splits them into delays and working days (Fig.4.10). If there is any discrepancy between the actual and detected delayed activities, the system includes special features that can help the user modify the sequence and the amount of delays and working days for the delayed activities.

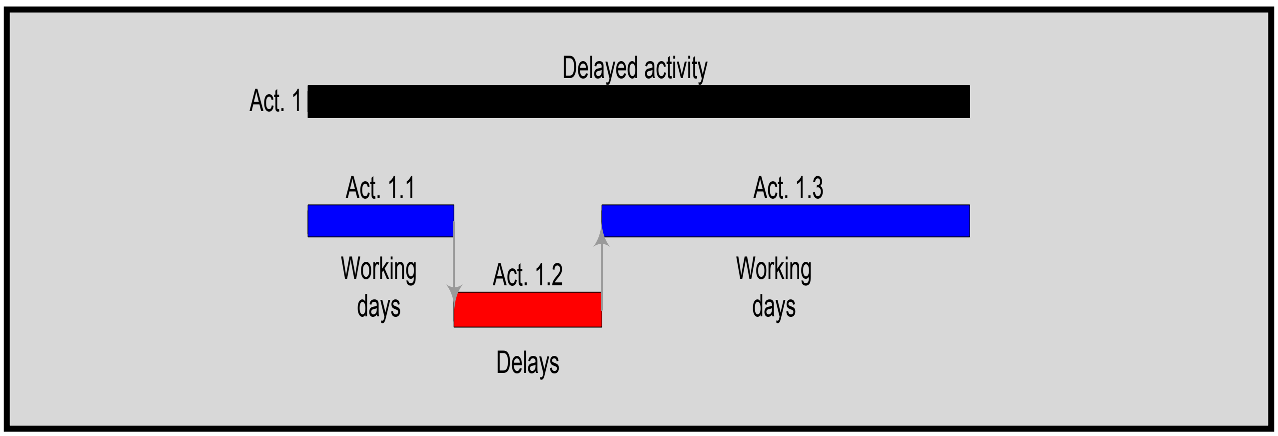


Figure 4.10: Representation of delayed activities

After identifying all delays that took place, the system classifies the delays into two categories: independent or concurrent delays. Figure 4.11 displays the As-Planned and As-Built schedule comparison, identifying delayed activities as well as classifying them according to the time of their occurrence in a brief flowchart diagram.

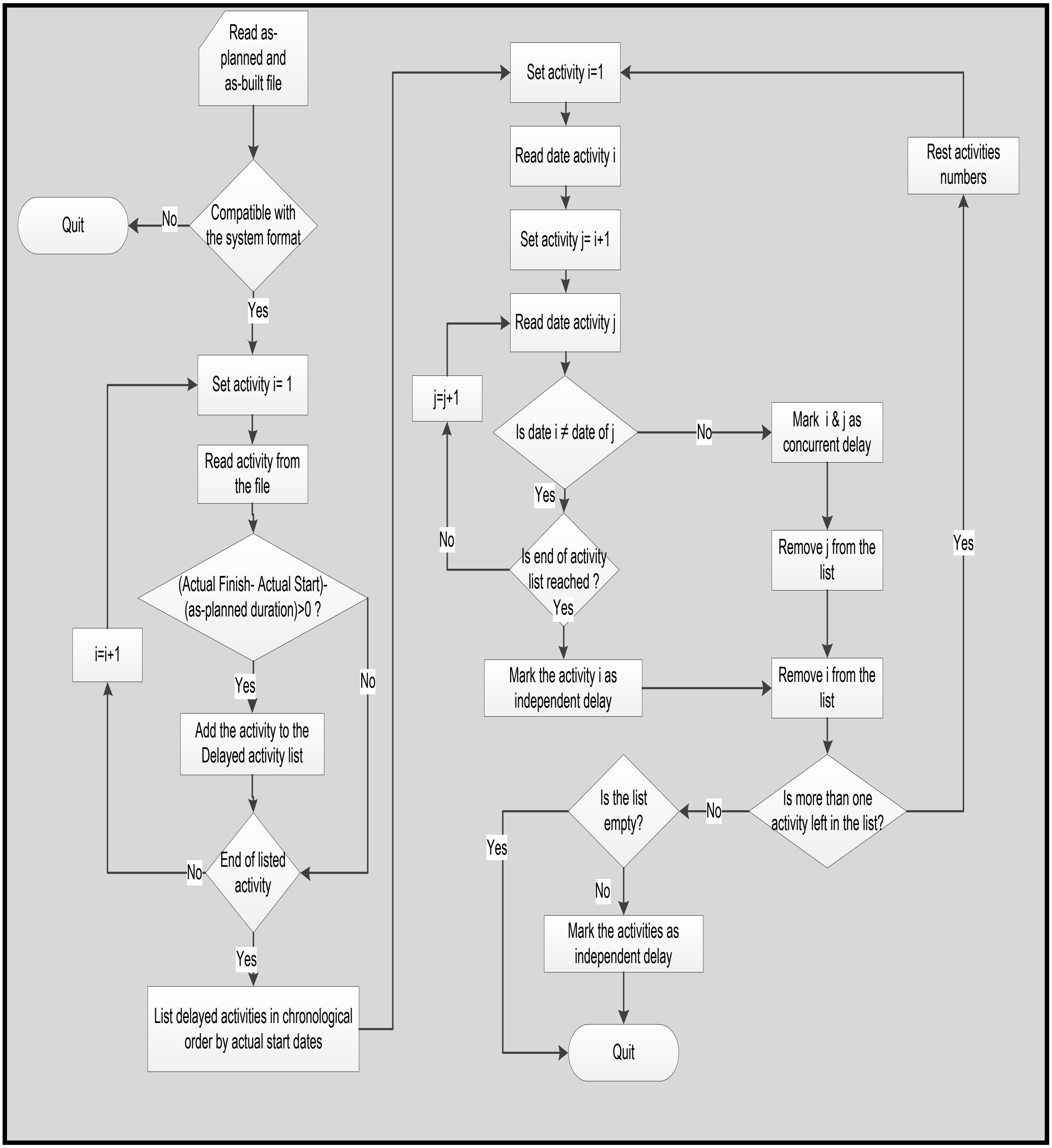


Figure 4.11: Logic Flow of Reading the MS Project File to Identify Delayed Activities

4.3.2 Delay classification Module (Expert System)

The expert system plays a key role in the proposed system by classifying delays as they occur over the course of the project. Delay classification requires a great deal of caution on the part of the analyst. The expert system is designed so that it simplifies the classification process and eliminates ambiguities. The expert system presents a series of most common reasons for a delay; the user chooses the most appropriate reason for a particular delay. It should be noted that the system restricts the user to select only one reason for making the claim. Then, the user is provided with a series of questions, which are the facts related to the selected reason of the claim. Based on the answers to each question, in the form of "Yes", "No", or "Do Not Know", the system leads the user to the next relevant question; all subsequent questions must necessarily be answered one after another. Finally, an appropriate decision is reached for the designated reason of the delay claim (Fig 4.12).

The most important step in assessing a delay claim is to collect all appropriate information about the delay to support a claim's validity. The unique built-in feature of this expert system is its capability to attach documents to the selected reason for a claim to support the decision-making process. During the analysis stage, knowing the type(s) of documents that are accessible, such as the contract, schedules, logs, photos, meeting minutes, cost reports, superintendent's daily reports, etc., is as important as choosing an appropriate delay analysis technique. In interacting with the expert system, as the user answers each question, any type of supporting document may be attached through the Questionnaire History (QH) section of this module. Meanwhile, the user can add any complementary information, including a description, a document type, as well as the issued and received dates of the attached document(s). The QH section also displays all questions answered thus far in the form of a decision tree to trace the decision making process. Furthermore, throughout this process, the user can modify the answer of any particular question; subsequently, all successive questions and the given answer pattern will be reset and the module forms a new decision tree (Figs. 4.13-4.14). Although the expert system provides possible explanations for some questions to facilitate the answering process, a minimum knowledge of construction contract language is required of the user.

Furthermore, the developed expert system is able to evaluate concurrent delays. After the initial classification of delays, these delays will be adjusted based on the concurrent delay entitlement, either in the contract clause or in an agreement between the project parties. For example, when an excusable compensable or an excusable non-compensable delay occur concurrently with a non-excusable delay, then the excusable compensable and excusable non-compensable delays would be considered as non-excusable delays. Similarly, if an excusable non-compensable delay and an excusable compensable delay happen at the same time, both would be changed to excusable non-compensable delays. The adjusted type of concurrent delay will be stored in the system so that it can be utilized to perform the proposed delay analysis technique.

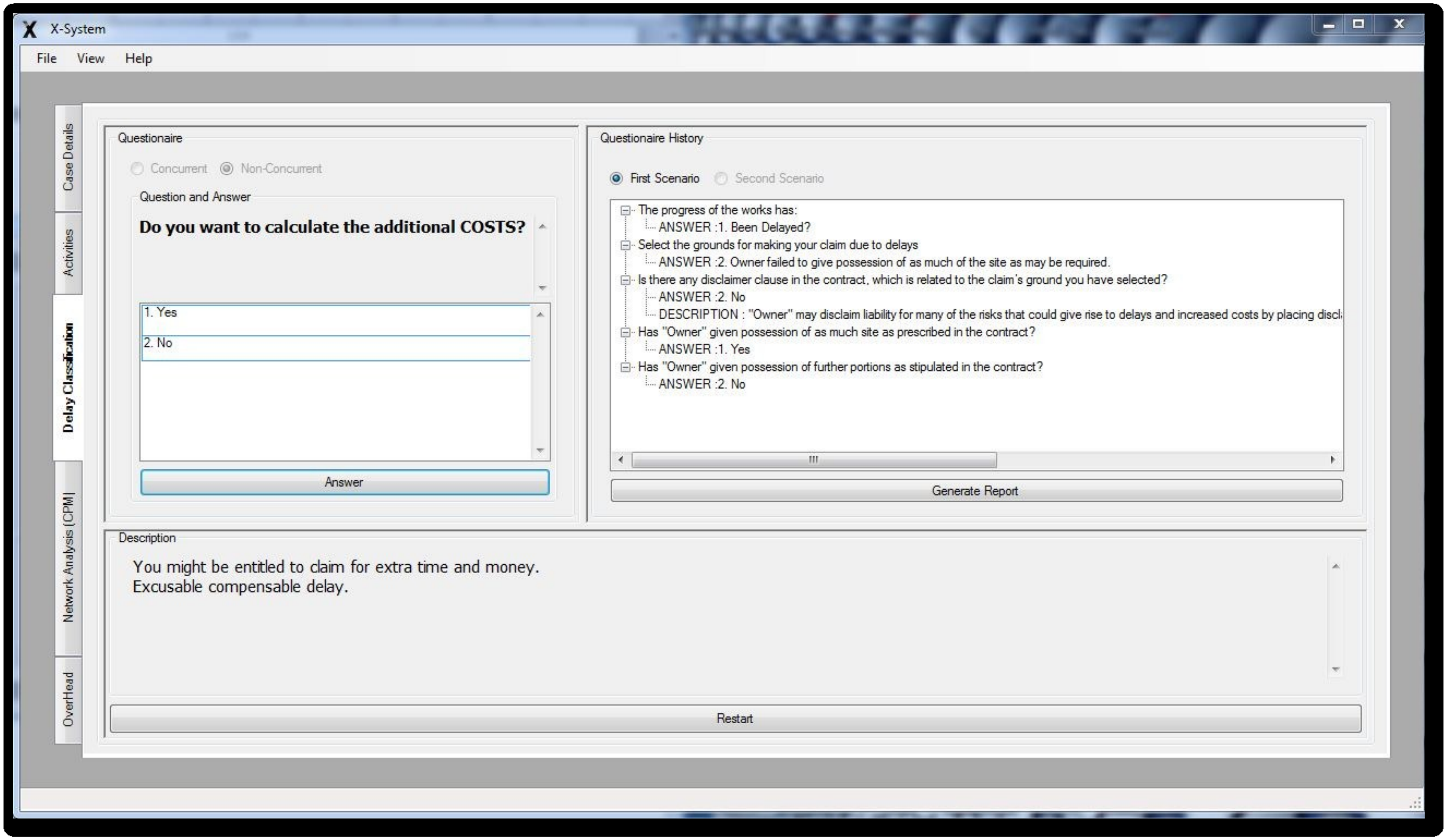


Figure 4.12: Delay Classification Module

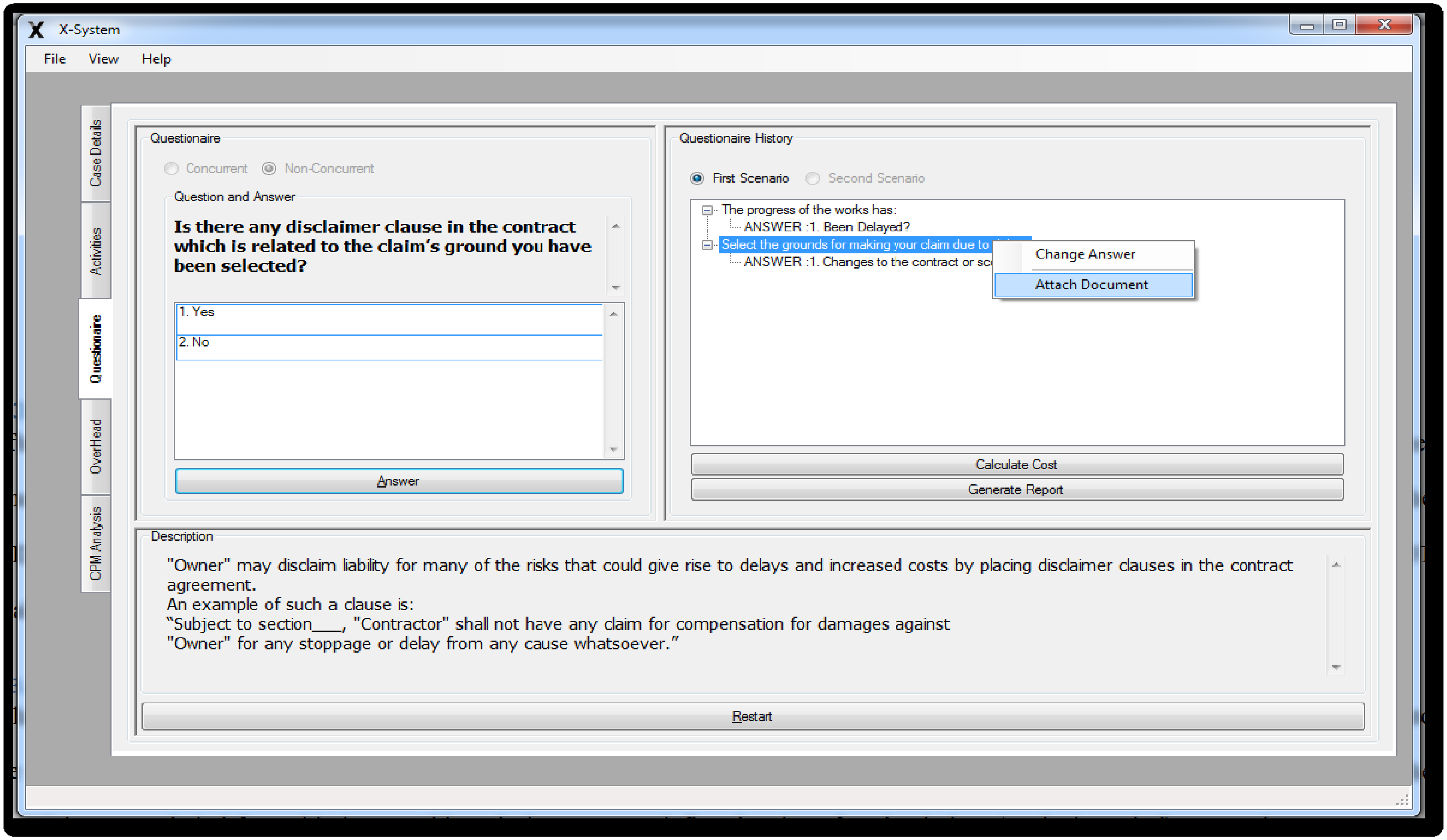


Figure 4.13: Document Management

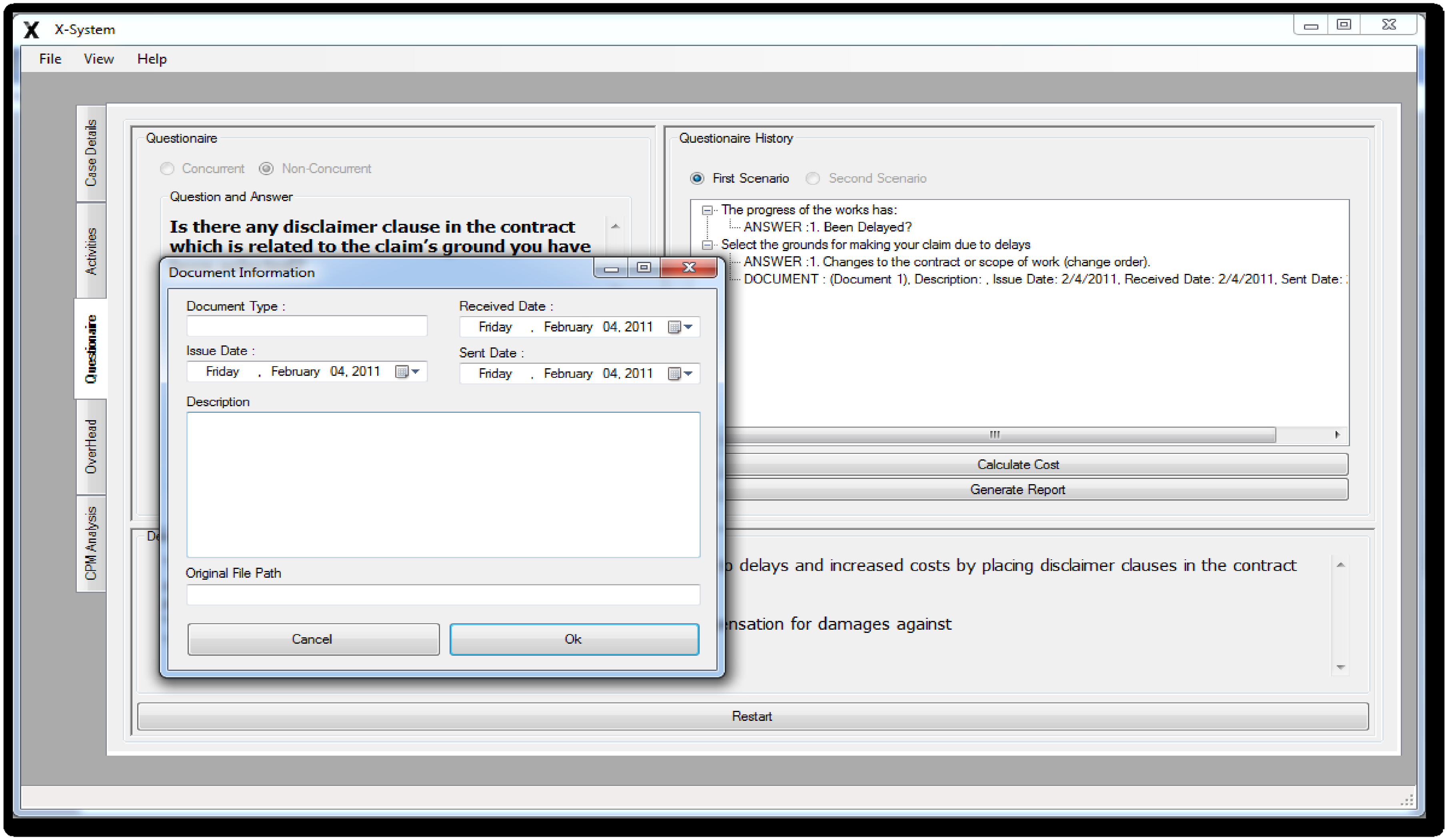


Figure 4.14: Document Management (Continued)

4.3.3 The Network Analysis Module

As the delays are classified, their results are sent directly to the network analysis module through an automated system. It should be noted that in the network analysis module, the system must be incorporated with some inputs to perform the MIDT analysis. The user follows the steps below to perform the proposed delay analysis (Fig. 4.15).

4.3.3.1 Determine the Analysis Period

The user must determine the size of the analysis period, also known as a snapshot, prior to implementing the MIDT. The size of these snapshots has a significant impact on the outcome of all windows-based techniques, and the MIDT is not excluded from this impact. However, the user does have the ability to define the size of each snapshot (analysis period) as one day to overcome this issue (Hegazy and Zhang, 2005). However, this is a time consuming solution and not recommended for the proposed analysis system. It is also recommended that the total number of snapshots not be less than the number of changes in the critical path. In the network analysis module, the process starts by entering the analysis periods start and finish dates. Then, the user requests to create the subsequent editable snapshots, one after the other.

4.3.3.2 Generate Analysis Results

This section begins by selecting either the owner's or the contractor's point of view. Then, for each snapshot, the network analysis module (MIDT) calculates the duration of the baseline and impacted schedules, which results in computing the delay(s) duration for each snapshot.

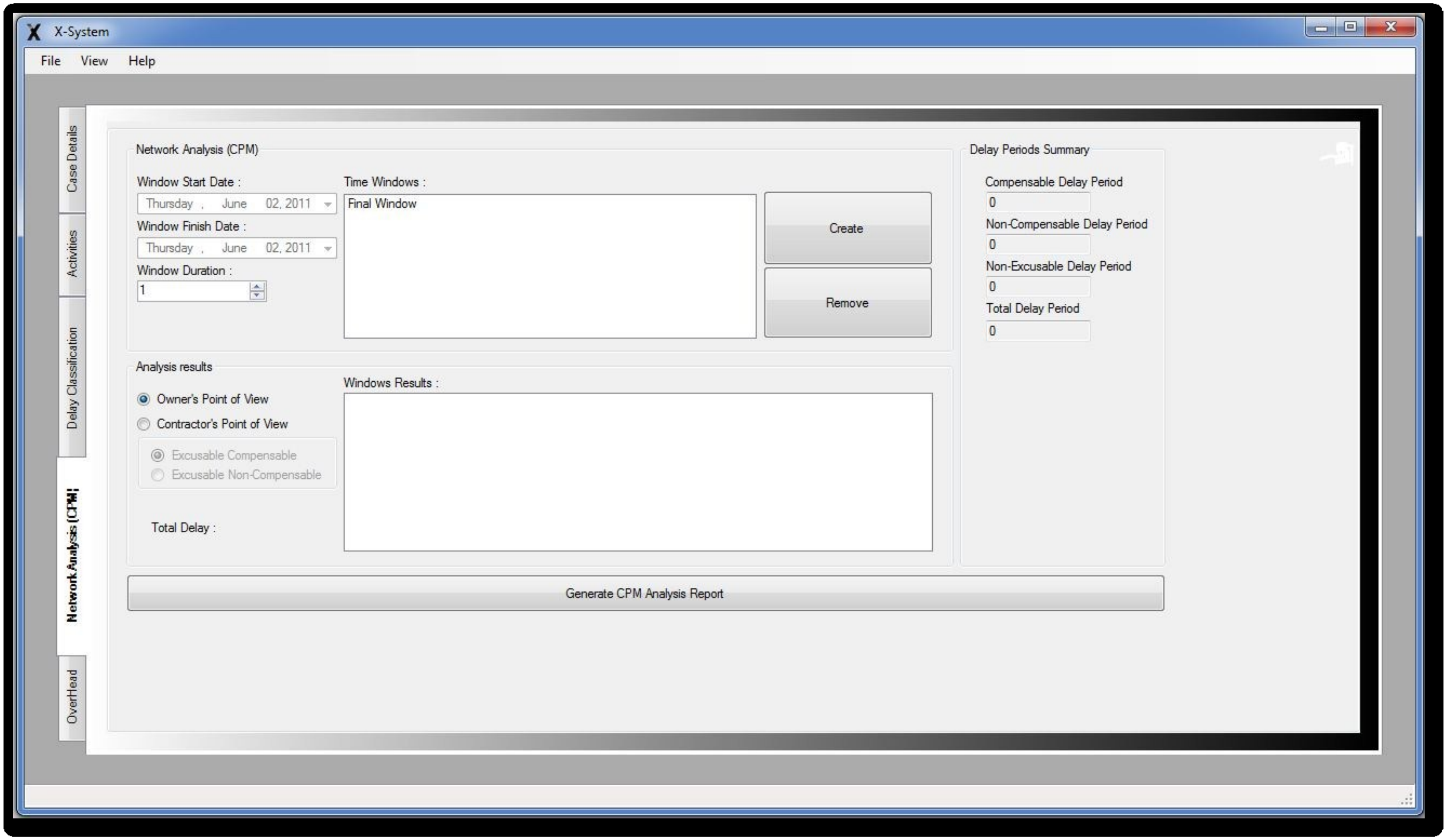


Figure 4.15: The MIDT Analysis Module

To accomplish this task, the system retrieves the as-planned schedule and the ordered delays from the activity module as the inputs. For the first snapshot, the system uses the as-planned schedule as a baseline; then, depending on the selected point of view, the ordered delays are added to the corresponding activity within this new baseline and thus the impacted schedule is generated. The difference between the baseline and the impacted schedules indicates the delay duration of this analysis period. Then, the system automatically creates the new baseline for the subsequent snapshot by reflecting all delays that occurred prior to the analysis period. This process is repeated for the all snapshots.

For validation purposes, the network analysis module (MIDT) has been tested against the same hypothetical case study used in the previous chapter. This case study consists of ten activities and it was selected because it contains different types of delays that have been already classified into excusable compensable, excusable non-compensable and non-excusable delays. As the data of this case study was input into the program, it identified nineteen delay scenarios: seven and twelve of which were classified as concurrent and independent delays, respectively. Similar to chapter three, four analysis periods (snapshots) were used. The first snapshot was assigned to have 11 days as its period, and 10 days were set for each of the remaining three snapshots. In conclusion, the delay entitlement results were calculated as follows, similar to those that appeared in chapter three:

- Owner’s point of view
    - 7 days of non-excusable delays
- Contractor’s point of view

- 11 days of excusable non-compensable delays
- 2 days of excusable compensable delays

4.3.4 Cost Calculation Modules

The process of calculating the total cost has been automated by establishing a set of C# codes to simplify the calculation and using a well-designed interface. To determine the total cost of excusable compensable delays, the direct and indirect costs of damages must be calculated. However, the system is unable to calculate the impact costs. Cost quantification is a must for delay claim assessment, which is why it was embedded into the system as an extra feature to provide the user with a way of conducting a preliminary cost analysis. It is imperative that this module not be considered a comprehensive and accurate cost estimator tool for delay claim assessment. Cost calculation is a major area of claims analysis and it is beyond the scope of this research.

The calculation process in the cost module is divided into two sections: direct and indirect costs.

I. Direct costs include labour, construction materials, subcontractors, insurance premiums, and equipment costs (Fig 4.16).
II. Indirect costs include head office and jobsite overhead costs (Fig. 4.17).

The user must select the delays classified as excusable compensable and input the requested information to create the cost components related to the delayed activities in the associated fields. The actual cost of each delayed activity will appear as the user presses the “Calculate Cost” button.

The proposed system finishes by computing the overhead costs in the "Overhead" module. As the user requests this module, the user may view the entire project data already retrieved from the network analysis unit. In calculating the overhead costs, the system applies two acceptable standard methods: "Canadian" and "Echileay". These two methods follow their own specific rules in computing the costs. The latter is more popular in the United States and exclusively applies to HOOH damages calculation. At the bottom of this module, the user can compute the jobsite overhead cost through applying the percentage method, which was covered in Chapter 2. This computation starts by using two default percentage values, 75 and 10, assigned to the time dependent and site overhead fields, respectively. The user may change these percentages according to the nature of the project.

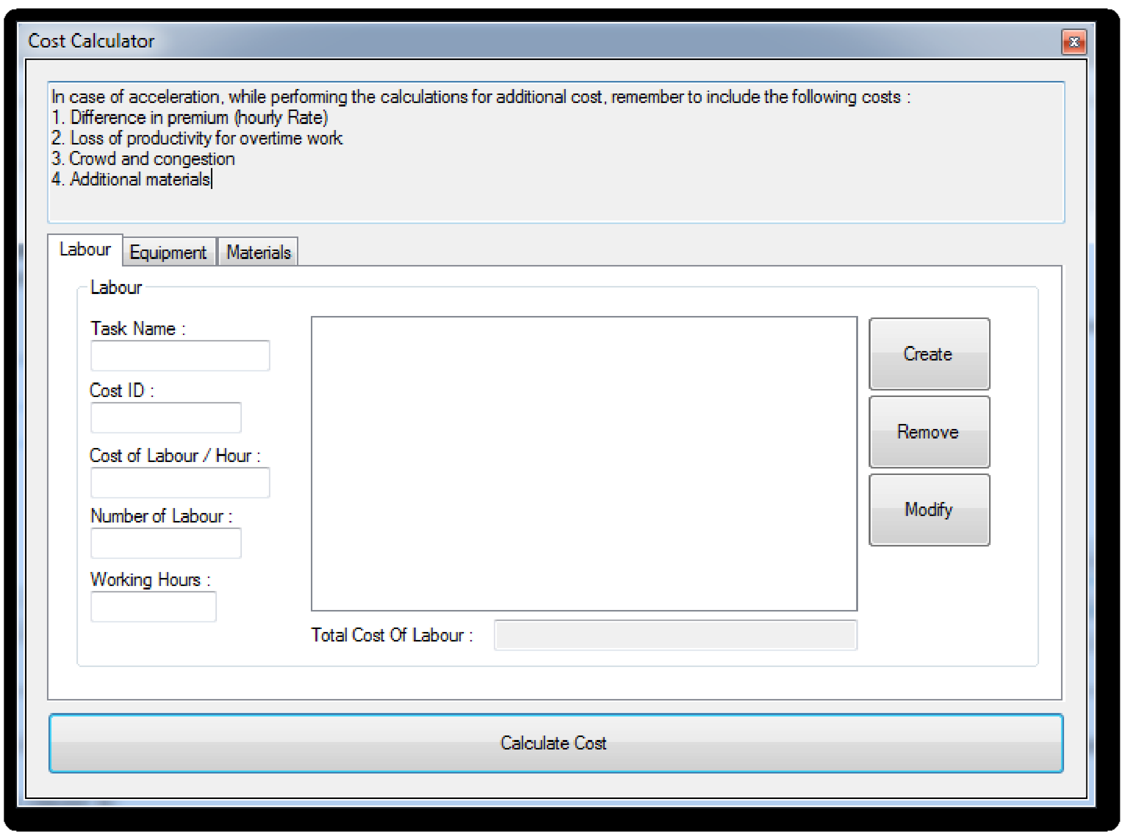


Figure 4.16: Direct Costs Calculator Module

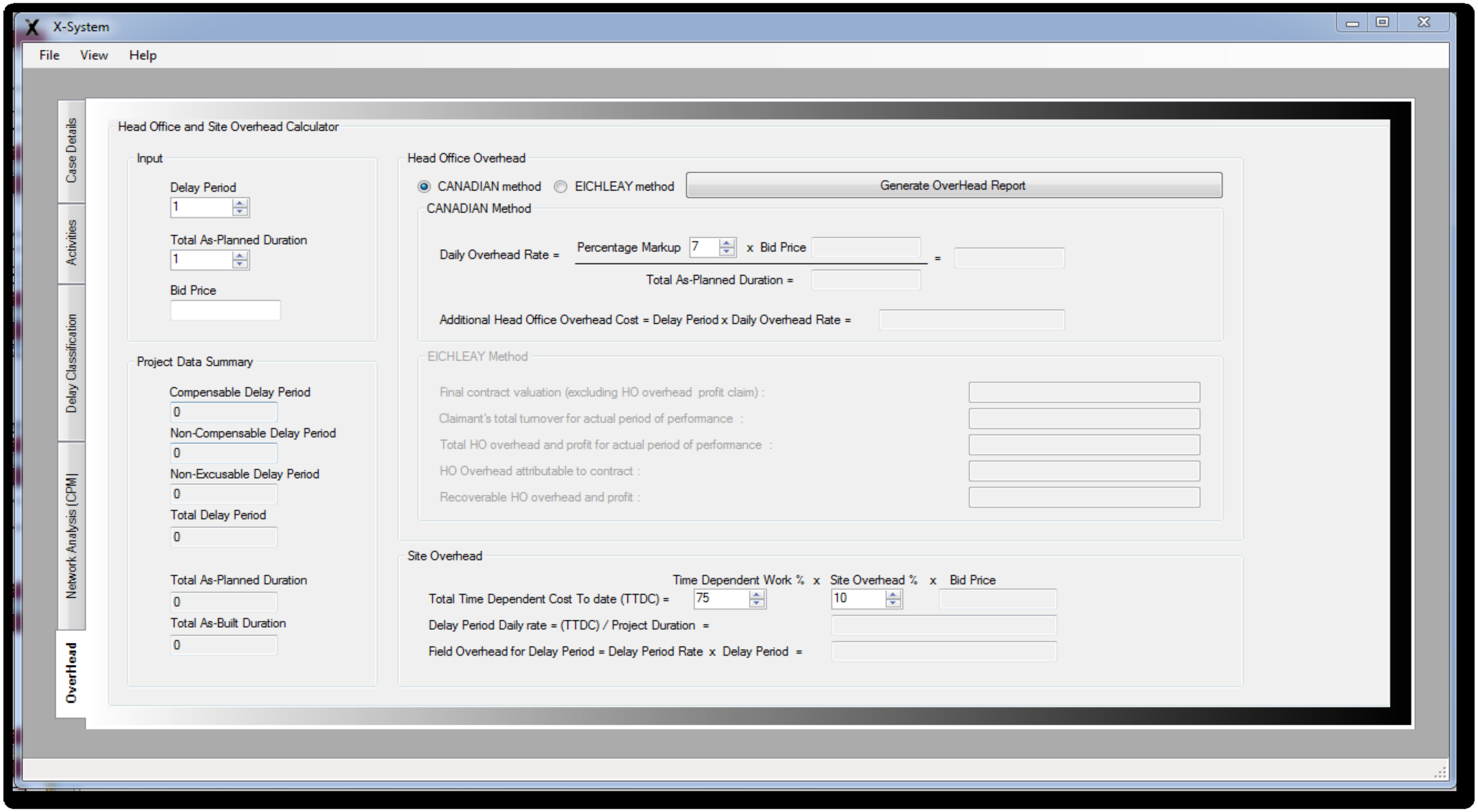


Figure 4.17: Overhead Calculator Module

4.4 Summary of the Procedures of the Integrated System

1. Collect and insert the project's general information.
2. Collect data from MS Project to identify delayed activities.
3. Check the delayed activities and modify them as shown in Fig 4.7.
4. Classify the delays into independent and concurrent delays.
5. Consult the expert system to classify delays based on their compensability.
6. Perform schedule analysis based on either the contractor's or the owner's point of view.
7. Calculate the costs of excusable compensable delays.
8. Calculate the head office and jobsite overheads.
9. Calculate the total costs of the delays, obtained by adding the results of steps 7 and 8.
10. Generate the reports for the claim.

4.5 Advantages and Limitations of the Proposed Integrated System

4.5.1 Advantages

1. The integrated system simplifies the process of claim analysis preparation in an automatic manner that saves time, effort and money.
2. The system transfers well-structured data that can be used for delay claim assessment.

3. The system is integrated with several low-cost and widely-used commercial computer application programs that are easily accessible to practitioners in the construction industry.
4. The system automates the proposed delay analysis technique and cost quantification. Thus, it greatly reduces the complex procedures required for delay claim assessment.
5. The user benefits from the system during the course of the project, as it evaluates delay(s) or delaying event(s) throughout a project.
6. The user can save the assessment process files of a delay claim at any level/module. This feature prevents data re-entry if the program needs to be closed for any reason.
7. Data obtained from the integrated system can be stored so that it can be easily retrieved at any time, to be used for other purposes or maintained as historical data for evaluating future cases.
8. The developed system can act on behalf of owners, contractors, or interested third parties.
9. The system can be used for educational purposes, from junior engineers to students, to help them better understand the concept of delay claims.
10. The expert system module can be employed as a valuable means of predicting a delay claim’s possible output and offering the appropriate recommendations to mitigate the negative effects of such problems on the project.

11. One of the main goals of developing the proposed system was to provide users with a friendly environment. The system demonstrates delay claim assessment in an easy-to-understand approach, including reports for each module.
12. The system generates the report for each module upon the user's request.

4.5.2 Limitations

1. The system can only read MS Project files created in a specific format; the user must include both the as-planned and as-built schedules in a single MS Project file.
2. The system is unable to calculate the impact costs for different types of delay; however, the outputs of this system may be used for additional and more accurate cost quantification.
3. The knowledge of the expert system is limited to 18 different types of delays common in construction. The system is unable to reach a conclusion outside of this scope.

4.6 Conclusion

Delays are an inherent part of construction projects, so performing an accurate assessment claim for those delays is a complicated and challenging task for all involved parties. In any delay claim evaluation, the legal and technical knowledge of the analyst are the two main factors affecting the accuracy of an assessment. All individuals involved in a project should have a comprehensive understanding of these techniques, otherwise, inaccurate results are inevitably. Due to the absence of sufficient legal and technical knowledge, hiring an employee as a delay claim consultant is usually recommended for any construction company during the course of a project; however, having this person as a team member is always costly. Furthermore, retrieving the pertinent information from the vast volume of a project's documents is considered to be an extremely time consuming and frustrating process.

The developed system's goal is to reduce the time and cost associated with the preparation of delay claims by storing and organizing project data in a well-structured format. The system consists of six major components: the user, the graphical interface, the expert system, the model, the database, and the scheduling software. The system was developed to help construction industry practitioners in delay classification, delay analysis, and cost calculation. The system imports the necessary data from the scheduling software to identify delayed activities, and then the system calls upon the expert system module to classify the identified delayed activities. The user can manipulate and export data to the scheduling software to create a new baseline at different stages of project execution. The system can definitely aid in the preparation of delay claims by saving time and money, while providing simple instructions that can be followed by a non-supervisory level employee.

Chapter 5

Case Study and Analysis

5.1 Introduction

System validation is considered a complex and critical task. According to Meseguer (1996), the main purpose of validation is to ensure that a program fulfills its requirements and satisfies its end user. Even though validation and verification are clearly different techniques, they have, however, been used interchangeably. Many researchers believe that validation embodies verification (Jagdev et al., 1995).

Validation is defined as developing the correct system, while verification is described as developing a system correctly (O’Keefe et al., 1993). The validation process usually occurs after verification, and varies from one industry to another, so that it is typically possible to find a general definition applicable to most industries. Since the expert system plays a key role in the system developed here, its validation is an essential task. Validating an expert system is a process to ensure that it accurately represents an expert’s knowledge in a particular problem domain (O’Leary et al. 1990).

This chapter consists of a sample validation of the developed system conducted by applying the information from a real case study. To validate the effectiveness of the proposed integrated system in delay claim preparation, a complete assessment will be performed for a case that utilizes all the embedded features of the designed system. The case study is a construction project that has been assessed by conventional means and whose results are available for comparison.

5.2 The Case Study

The case study is the construction of a concrete tunnel project in Canada that has been executed and assessed for delay claims. This project experienced various types of delays and also offers access to the related information as the source of inputs for the developed system; thus, it is a valuable practice case for delay claim assessment. Meanwhile, for confidentiality purposes, the source of the information and the parties engaged in this project are not revealed. According to the contract document, the project was supposed to be executed in 272 working days at a cost of 10,699,535 Canadian dollars (CAD). The project consists of four bid items, as shown in Fig. 5.1.

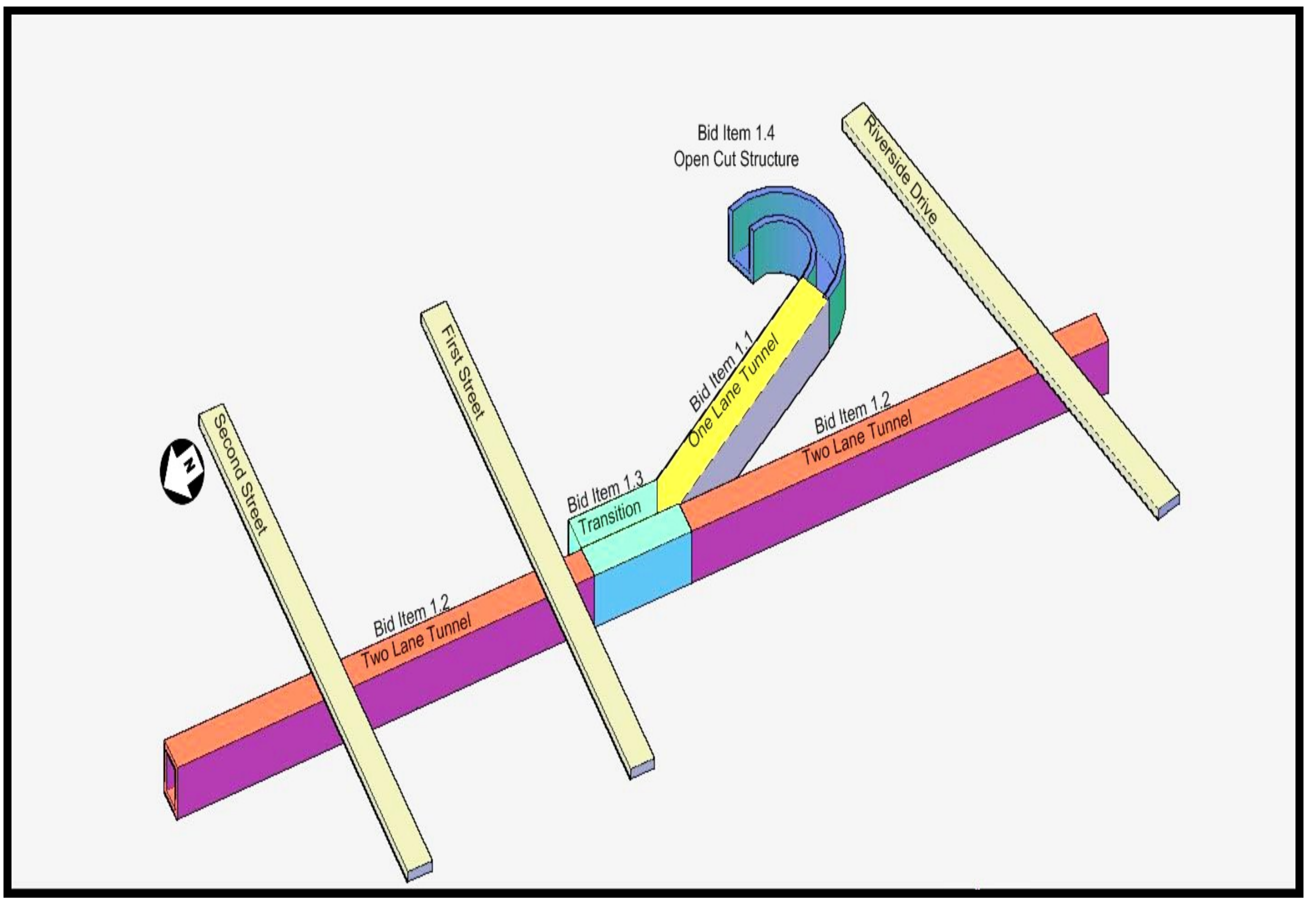


Figure 5.1: Key Plan (Bid Items)

The project was scheduled to start on March 7th, 2005, and be delivered by April 21st, 2006. During the course of the project, several delays were experienced by the contractor. Thus, it could not have been delivered on the agreed upon date. The project was delivered on July 27th, 2006, which represents a delay of 96 working days. The contractor claimed compensation to recover the damages due to the project time and cost overrun. Table 5.1 summaries the as-planned and as-built durations for this case study.

Table 5.1: Project As-planned Vs. As-built

Schedules	Project Date of		Total Duration
	Start	End	
As-planned	07-March-05	21-April-06	**272 DAYS**
As-built	07-March-05	27-July-06	**368 DAYS**
Difference			**96 Days**

This project consists of 18 activities falling into five major areas: start up, excavation, steel structure, concrete work, and demobilization. For a better understanding of the project, the work breakdown structure is shown in Fig. 5.2. In this case study, the project documents were used to recover the as-planned and as-built schedules, shown in Figs. 5.3 and 5.4. The delay assessment program based on the delaying events' information can be started.

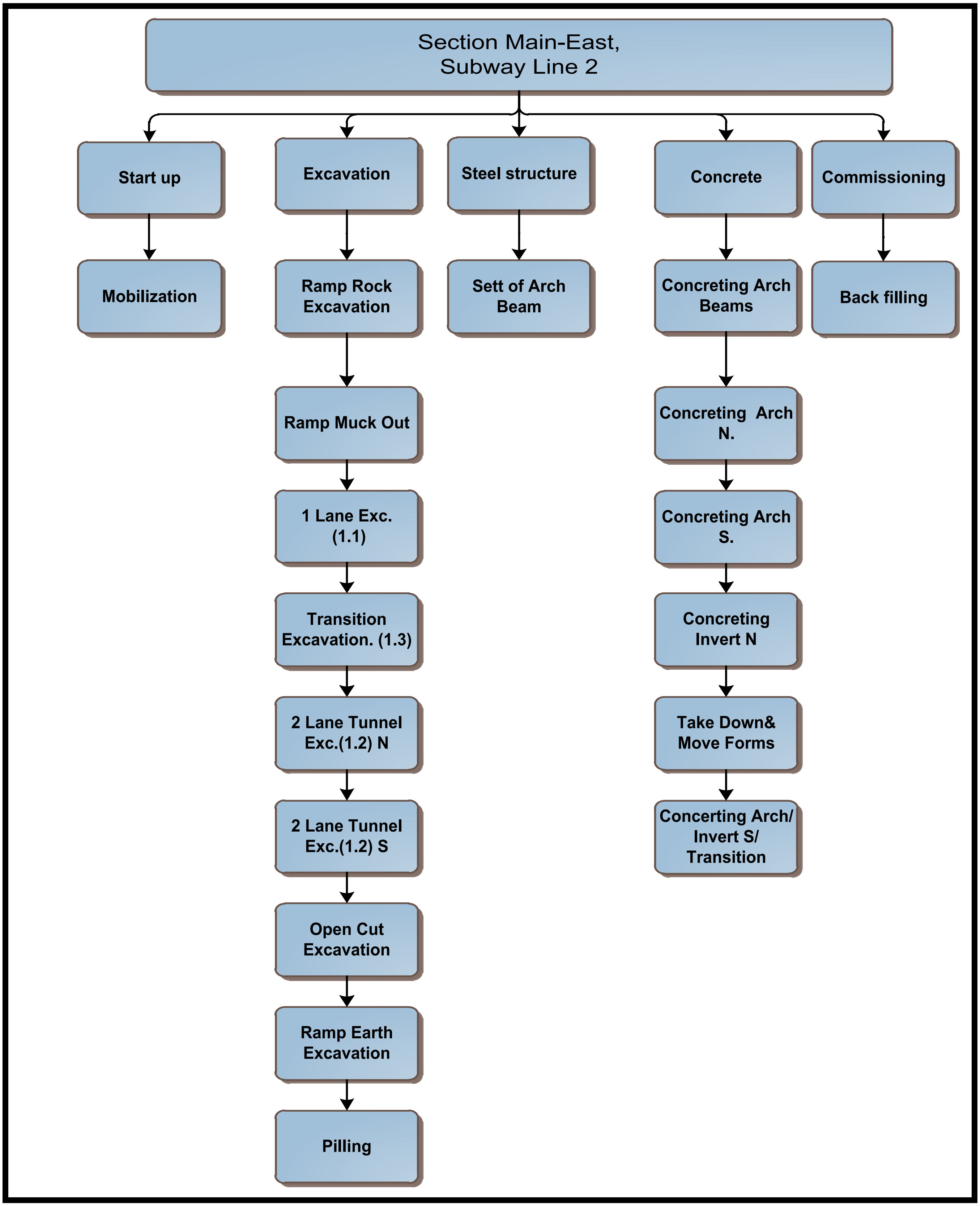


Figure 5.2: Work Breakdown Structure (WBS) of the Tunnel Project

The delays were grouped into four major cause categories: a) setting-out based on incorrect data supplied in writing by the engineer or his representative; b) Suspension order issued to ensure the security and safety of the work; c) Unforeseeable physical conditions; and d) force majeure. The delays were classified in the claim report as excusable compensable, excusable non-compensable, and non-excusable delays.

5.2.1 Summary of Major Delaying Events

As indicated above, the tunnel project experienced different delays. A brief explanation of the delays that occurred during the course of the project follow:

a) Setting-out was based on incorrect data supplied in writing by the engineer or his representative:

   - The engineer (consultant) used a soil classification system that is rarely used in the Canadian construction industry. Unfortunately, the engineer did not illustrate the applied system well. Therefore, the contractor misunderstood the soil classification system method, which resulted in poor anticipation of the ground water level, which was much higher than expected. Accordingly, excavation equipment could not operate at its maximum efficiency.

b) A suspension order was issued for the protection and security of work:

   - The excavation operation was suspended by the engineer for six weeks due to the flow of water into the excavation site; as the water surface reached the bottom of the excavation, the soil started to become "quick" (an unstable state). Therefore, the engineer requested the use of extra equipment such as sump and steel sheet piling to reduce the water level.

c) Unforeseeable physical conditions:

- The contractor experienced various rock cavity conditions in the two-lane tunnel, which were substantially different from what was anticipated in the geological soil report; hence, extensive ribbing was required. The contractor had to continuously install ribs for 200 *lf* (length feet). Unlike the geological soil report, this installation demonstrated the existence of a serious cavity in the two-lane tunnel, rather than a slight one.

d) Force majeure:

- The union called for a surprise walk-out that lasted two weeks.

5.2.2 Other Delays

Additional delays were experienced throughout the course of the project; however, the following delays did not have any significant effect on the work completion date:

i. Breakdown of the excavator equipment (jumbo) for one day;
ii. Breakdown of the excavator equipment again and a seriously injured worker: together, they caused the project to slow down for another four days.

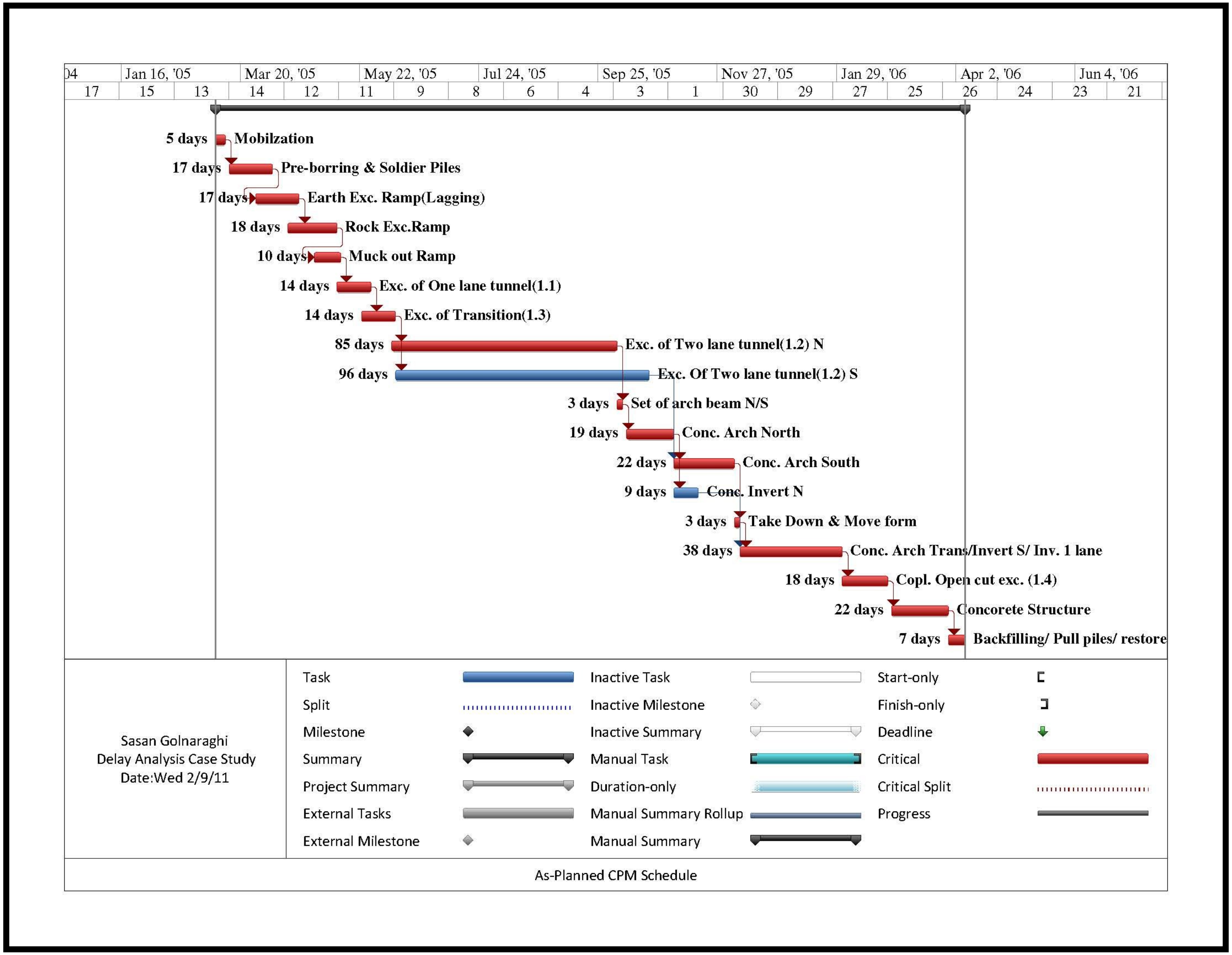


Figure 5.3: As-Planned CPM Schedule

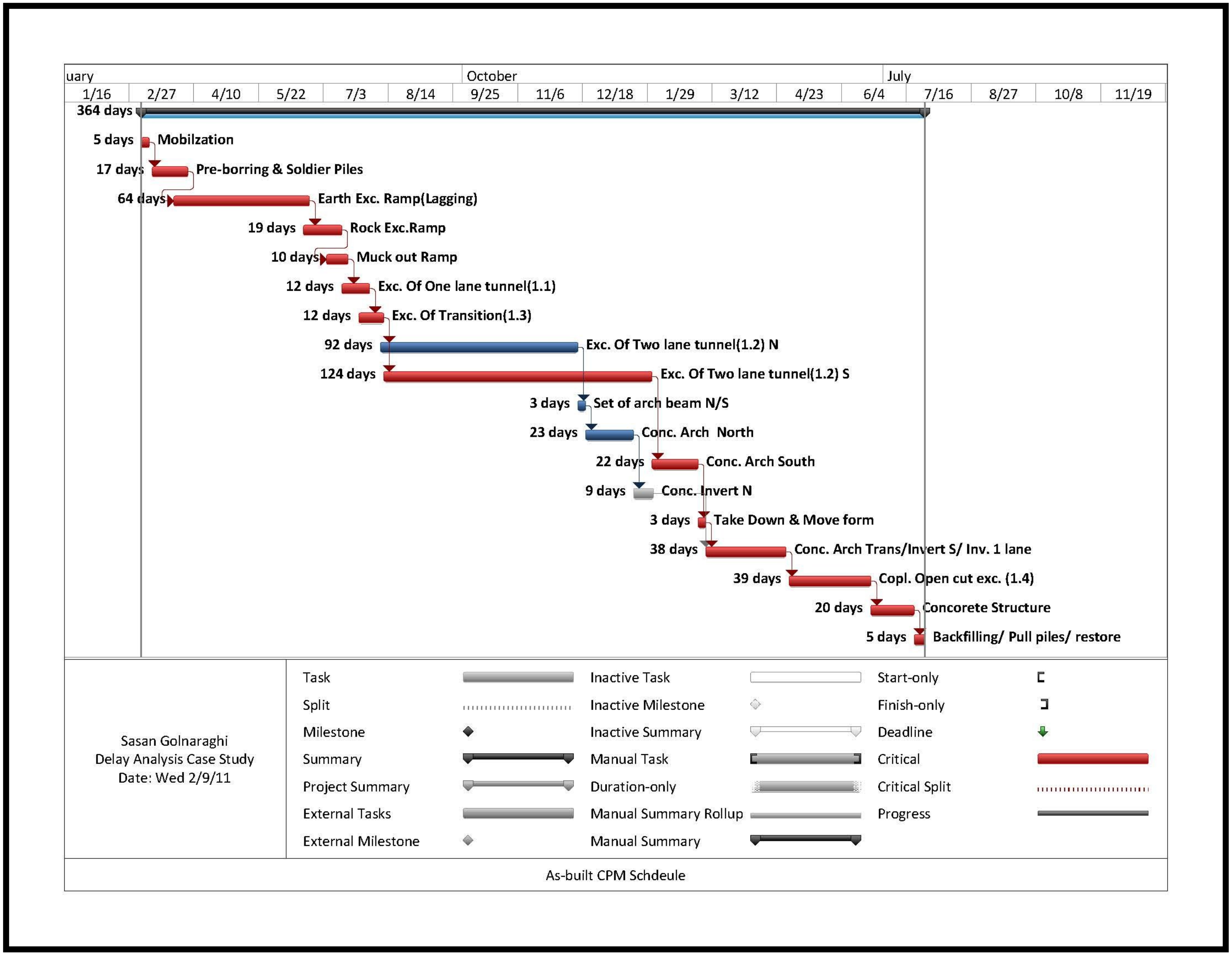


Figure 5.4: As-Built CPM Schedule

5.2.3 Delayed Activities

Table 5.2 summarizes the activities that experienced delays. The activities are listed in a chronological order with their related causes, durations and types of delays:

Table 5.2: Summary of Delayed Activities

Activities Affected	Major Problems	Duration of Delay	Type of Delays
Ramp Earth Excavation	Incorrect data supplied by the engineer	**15**	**EC**
Ramp Earth Excavation	Suspension order involving the protection and security of work	**30**	**EC**
Ramp Rock Excavation	Breakdown of the excavator equipment	**1**	**NE**
Excavation of 2 Lane Tunnel N	Deteriorated rock conditions (cavity problems)	**7**	**EC**
Excavation of 2 Lane Tunnel S	Deteriorated rock conditions (cavity problems)	**28**	**EC**
Concrete Arch N	Breakdown of the excavator equipment and a worker seriously injured	**4**	**NE**
Open Cut Excavation	Different soil condition Rock found on the site	**21**	**EC**
Concrete Structure	Labour Strike	**10**	**EN**

5.2.4 Assumptions

Although this case study contains a considerable amount of data in regards to the delaying events, some important information related to certain key major issues was not available. Since retrieving information is a time-consuming process and the project has already been completed, some assumptions were made:

1. The activities' relationship logic in the as-planned schedule were assumed to have remain unchanged over the course of the project;

2. Some non-delayed activities were merged together due to lack of detailed information;
3. Concurrent delays were evaluated based on the assumptions mentioned in Chapter 3 (section 3.7);
4. The method(s) statement for delivering the project were assumed to have remained the same throughout the execution phase; and
5. For confidentiality, the names of the real parties involved in this case study were replaced with fictitious names.

5.3 Recording General Project Information

According to the project contract signed by both parties, the City of Rowhill was assigned as the “Owner” and Drillco Inc. the “Contractor” to perform the project under the name of “Section Main-East, Subway Line 2”. This contract was prepared by TEB Consulting Inc., operating as the “Engineer” to accomplish its delegated tasks, as documented in the contract’s terms.

First, the above project information along with the as-planned and as-built dates were entered into the system (Fig. 5.5). This step allows the record of an evaluated project’s information to be available for future reference. The project’s folder path was created to store the user-processed data and includes a system that simplifies access to and the retrieval of information. To record the delays or delaying events information at the time of their occurrence, the developed system can be employed while the project is in progress. In other words, the analysis could be completed as soon as a project is delivered. However, this was impossible for this case study because the project was already completed; accordingly, the required data were extracted from the project's reports and documents, such as meeting minutes, progress reports, and cost reports. When the requested information was provided for the "Case Detail module", the system moved to the "Activities Module".

5.4 Detecting and Classifying Delayed Activities

The first step in performing the MIDT is to identify the delayed activities. Therefore, the project's as-planned and as-built schedules were entered into the system. As mentioned in the previous chapter, these two schedules must be developed as a single file in MS project format so that it can be readable by the system (Fig. 5.6). After the schedule file was entered into the system, the delayed activities were identified and listed in chronological order. Significantly, there was no discrepancy between the detected delayed activities and those mentioned in the claim report, demonstrating that this module has performed with acceptable accuracy (Fig. 5.7).

After identifying all delays that occurred over the course of the project, the developed expert system was employed to determine the type of a delay and its entitlement, simply by choosing the most appropriate reasons for the delay based on the actual events and by answering a series of questions. Figure 5.8 illustrates the classification process of a delayed activity.

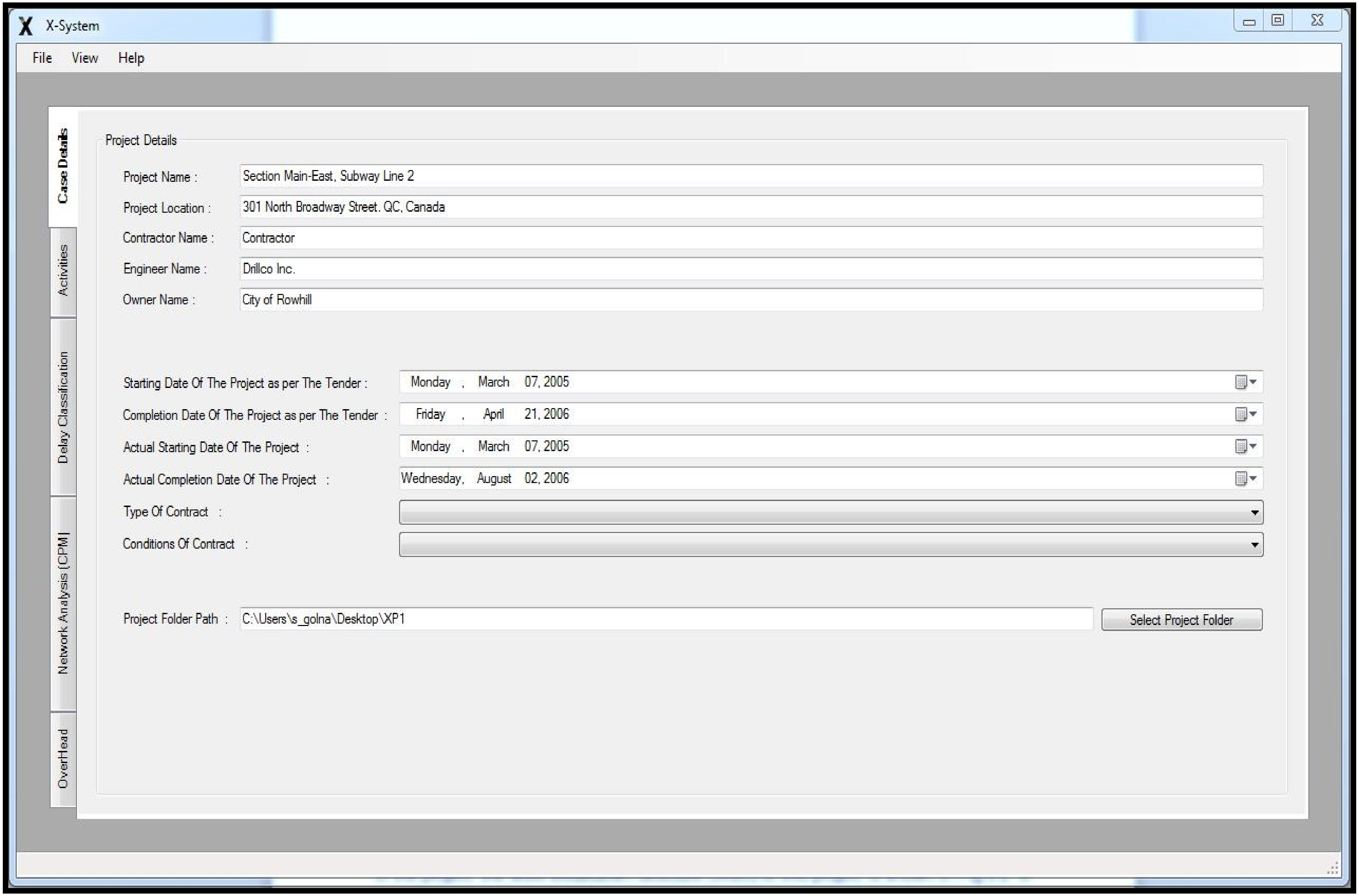


Figure 5.5: General Project Information (Case Details Module)

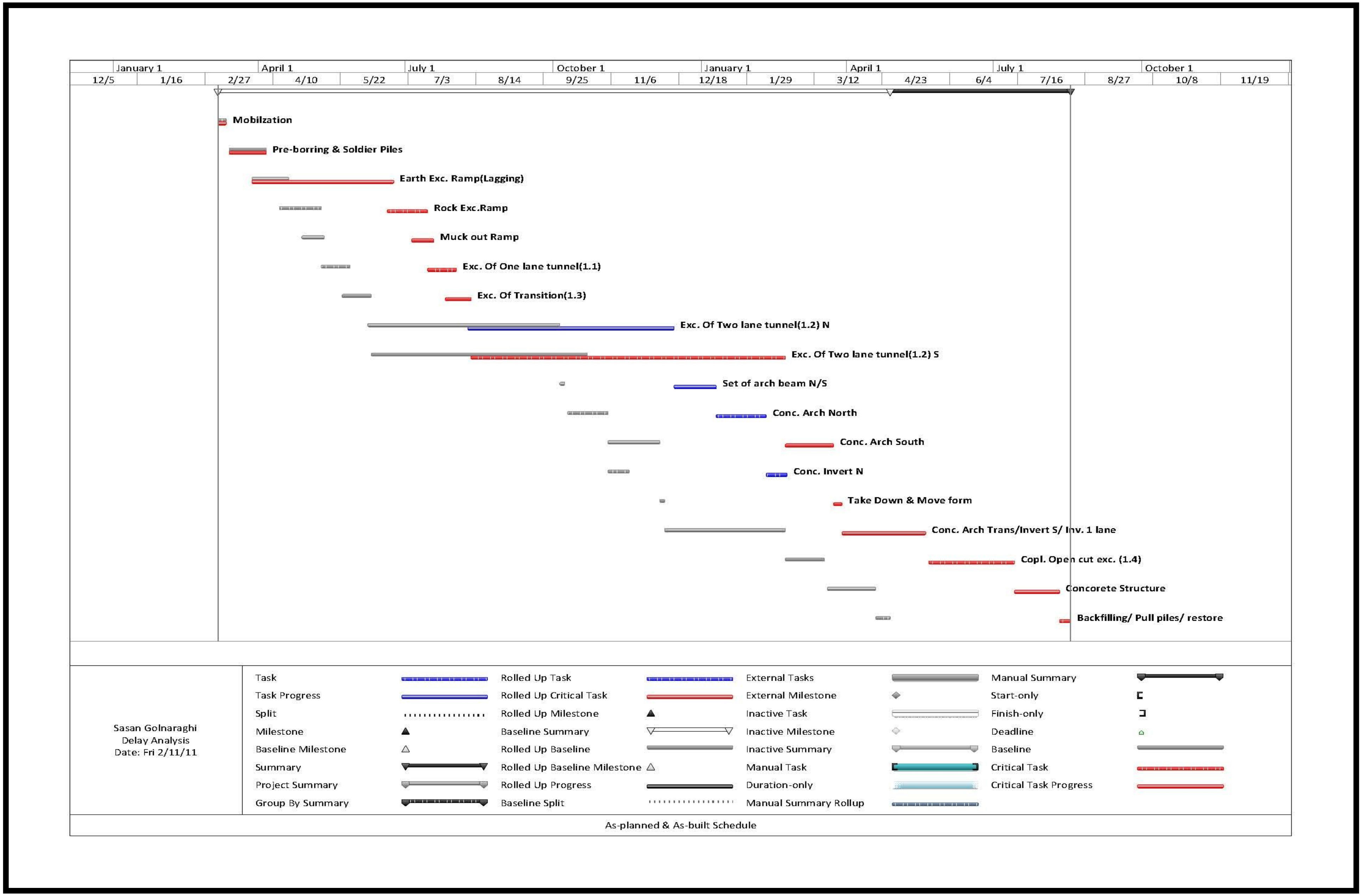


Figure 5.6: As-Planned vs. As-Built Schedules

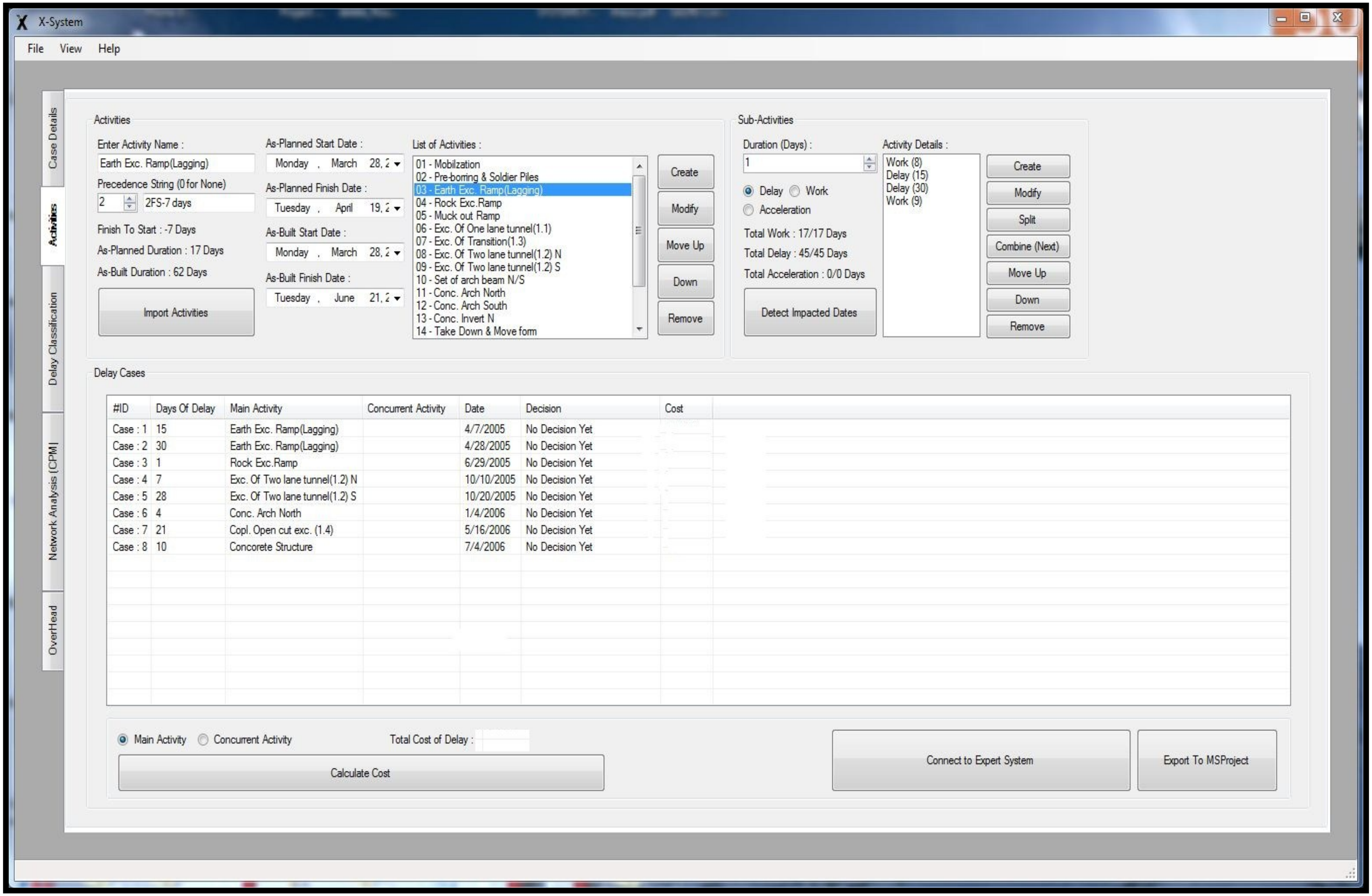


Figure 5.7: Identified Delayed Activities

When both the “Activities” and the “Expert System” modules have been applied, a brief list of independent and concurrent delays along with their types became available (Fig.5.8). Furthermore, by comparing the revealed results with those in the actual report of the project, the delays identified through the system and their corresponding classifications were similar to those documented in the actual claim reports of the case study. This approach verifies the accuracy of the “Expert System” module’s analysis.

5.5 Project Document

In this particular case, the as-planned schedule and relevant documents about the delays were available to begin evaluating the delay claim. The case study’s documents were used to simulate the actual events during the course of the project to generate the project’s as-built schedule (Fig.5.3). As mentioned above, the most critical stage in evaluating a delay claim is to collect all valid information needed for a successful assessment.

One of the exclusive embedded features of the developed system is its ability to attach the relevant documents while the delay classification is in progress (i.e. document type, issued date, received date, description of document). Thereafter, these data are exported to the user’s built-in database to keep a record of the information regarding the actual delaying events and thereby supporting the user’s decisions. Figure 5.9 demonstrates the process of attaching supporting documents that was used to make rational decisions for the delay events as they occurred during the earth excavation process. This information can be printed in the delay claim report (Figures 5.10-5.11).

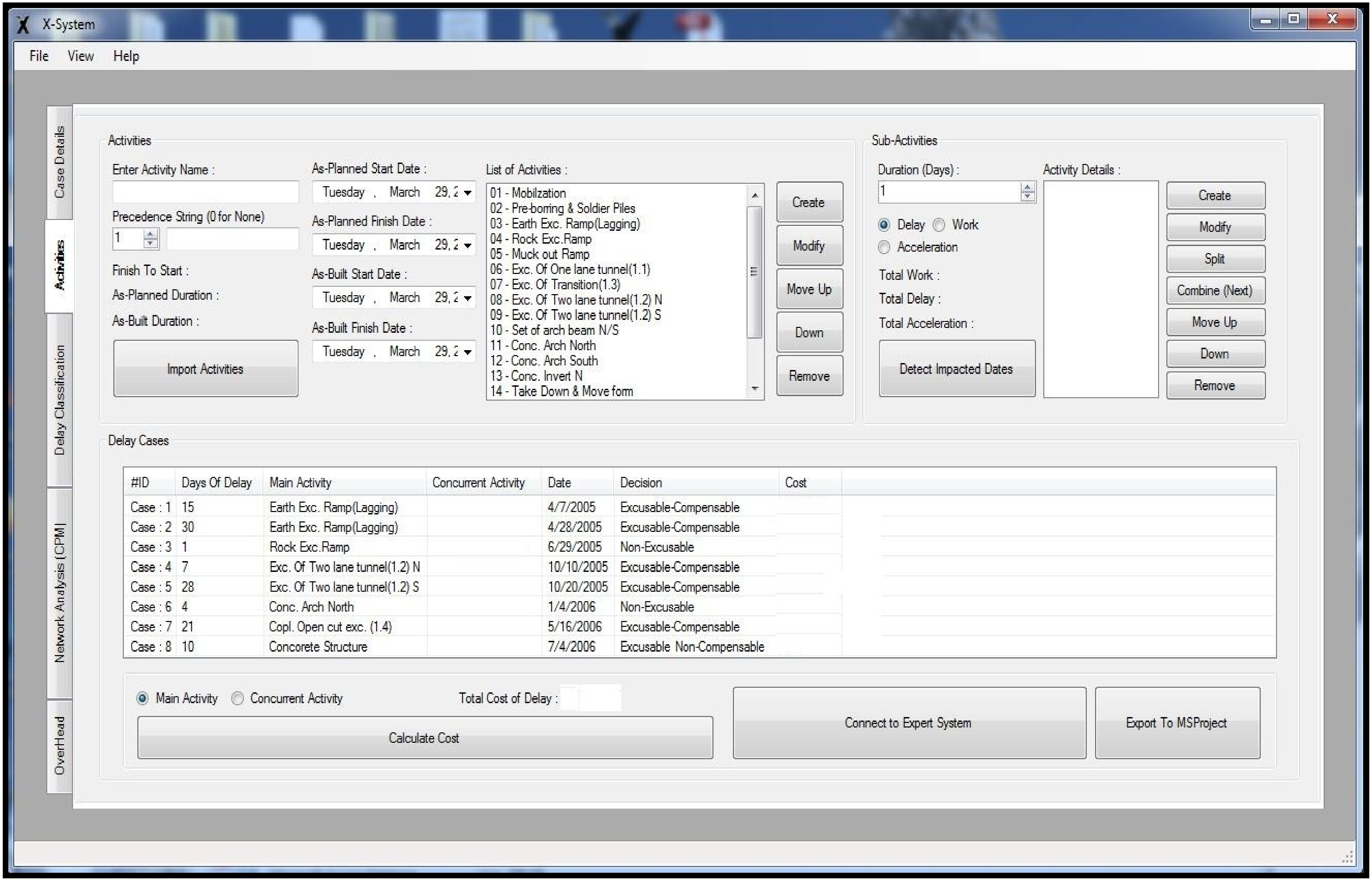


Figure 5.8: List of Classified Delayed Activities

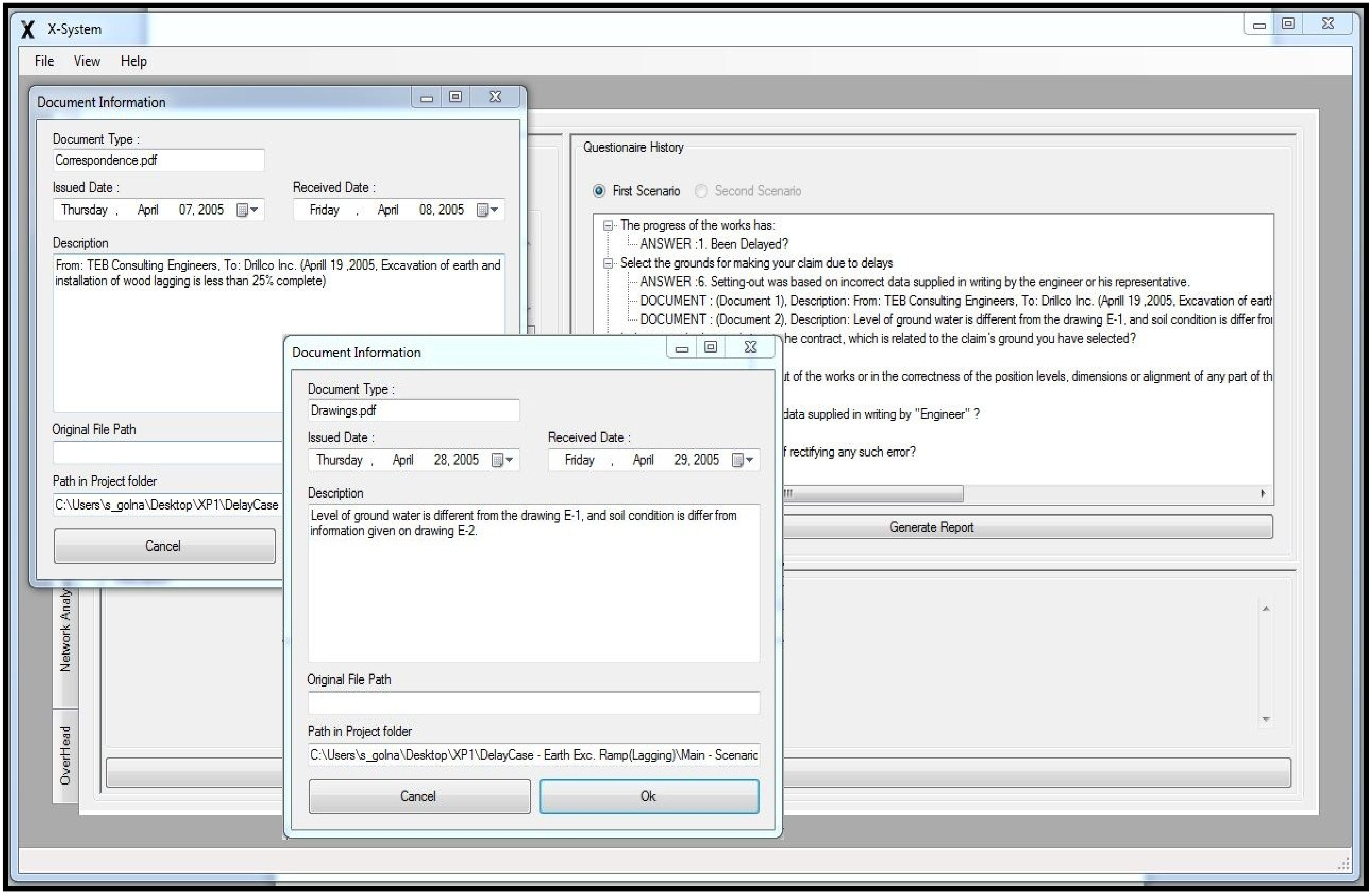


Figure 5.9: Attaching Supporting Documents for the Claim

Project : Section Main-East, Subway Line 2
Project Location : 301 North Broadway Ave. QC. Canada
Owner : City of Rowhill
Contractor : Drillco Inc.
Engineer : TEB Consulting

Main Scenario:

Activity:

Name : Earth Exc. Ramp (Lagging)
As-Planned Start : 3/28/2005
As-Planned Finish : 4/19/2005
As-Built Start : 3/28/2005
As-Built Finish : 6/21/2005
Days of Delay : 15 EC days

Question:
The progress of the works has:
Answer:
1. Been Delayed?

Question:
Select the grounds for making your claim due to delays
Answer:
6. Setting-out was based on incorrect data supplied in writing by the engineer or his representative.

Question:
Is there any disclaimer clause in the contract, which is related to the claim's ground you have selected?
Answer:
2. No

Question:
Is there any error in the setting out of the works or in the correctness of the position levels, dimensions or alignment of any part of the works?
Answer:
1. Yes

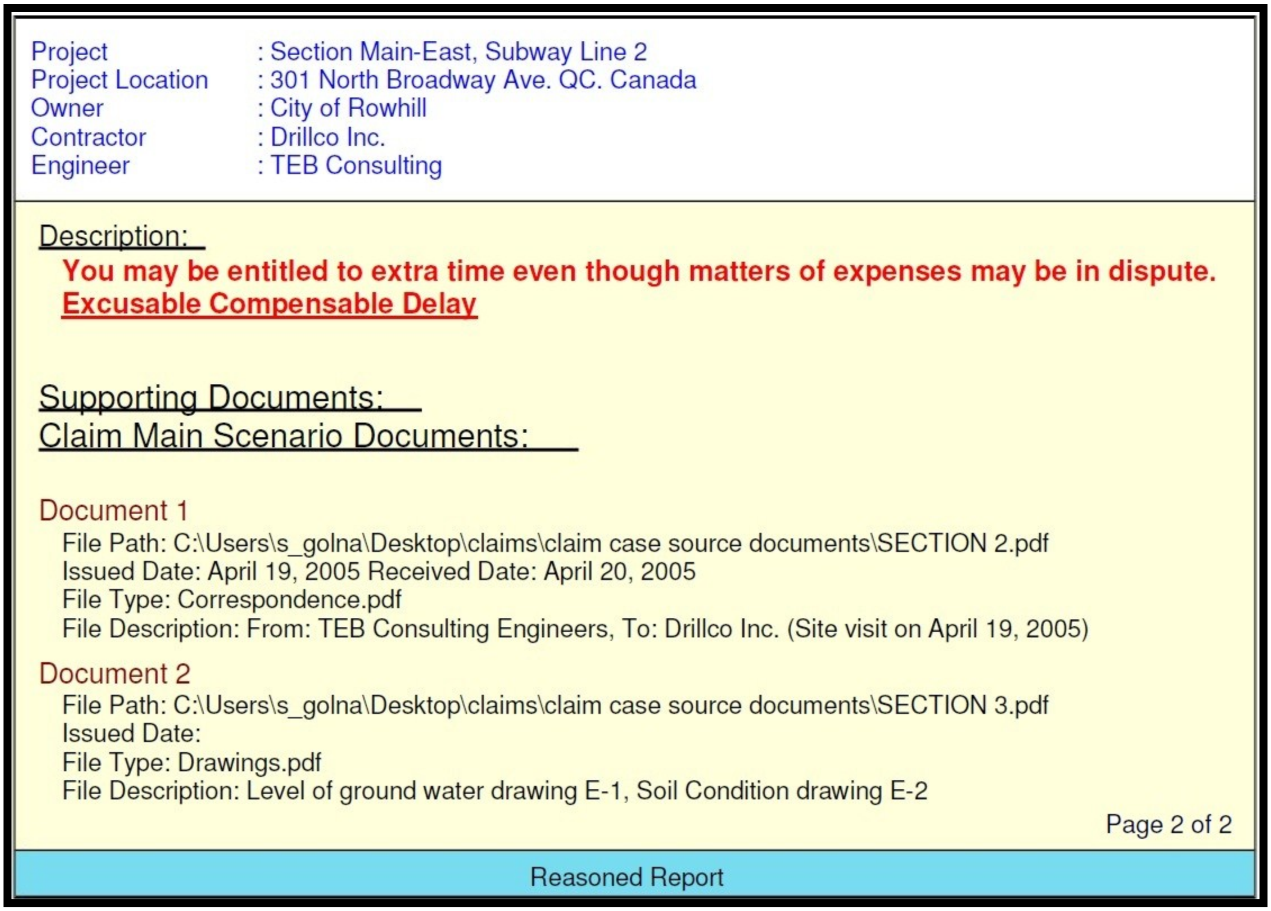
Question:
Such error is based on incorrect data supplied in writing by "TEB Consulting"?
Answer:
1. Yes

Question:
Did "City of Rowhill" bear the expense of rectifying any such error?
Answer:
2. No

Page 1 of 2

Reasoned Report

Figure 5.10: Delay Classification Report with a List of Supporting Documents


Project : Section Main-East, Subway Line 2
Project Location : 301 North Broadway Ave. QC. Canada
Owner : City of Rowhill
Contractor : Drillco Inc.
Engineer : TEB Consulting

Description:

You may be entitled to extra time even though matters of expenses may be in dispute.
Excusable Compensable Delay

Supporting Documents:
Claim Main Scenario Documents:

Document 1
File Path: C:\Users\s_golna\Desktop\claims\claim case source documents\SECTION 2.pdf
Issued Date: April 19, 2005 Received Date: April 20, 2005
File Type: Correspondence.pdf
File Description: From: TEB Consulting Engineers, To: Drillco Inc. (Site visit on April 19, 2005)

Document 2
File Path: C:\Users\s_golna\Desktop\claims\claim case source documents\SECTION 3.pdf
Issued Date:
File Type: Drawings.pdf
File Description: Level of ground water drawing E-1, Soil Condition drawing E-2

Page 2 of 2

Reasoned Report

Figure 5.11: Delay Classification Report with a List of Supporting Documents (cont.)

5.6 Schedule Analysis

In the "Activity Module", the delays were listed in chronological order and classified as EC, EN, or NE. It should be noted that concurrent delay situations were not reported in this particular case study, since there was only one critical path. For this analysis, the "Network analysis Module" was requested, then five analysis intervals were created based on the occurrence of major delay events, followed by the generation of the two required schedules for each interval. These intervals were: from March 7th 2005 to June 17th 2005; from June 20th 2005 to October 30th 2005; from October 3rd 2005 to January

13th 2006; from January 15th 2006 to April 28th 2006; and from May 2ed 2006 to July 27th 2006.

The delay analysis procedures were completely automated in the developed system, and the system is capable of exporting the information needed to generate the required schedules to MS project, namely as baseline and impacted schedules for each analysis interval. In the first interval, the as-planned schedule (Fig. 5.3) was considered as the baseline for performing the MIDT analysis. After choosing the "Contractor's point of view" option, the module started to measure the effect of these delays on the project completion date as the EN and EC delays that were inserted separately into their corresponding baseline schedules.

The EC delays falling within the first analysis interval were entered into the first baseline to generate the impacted schedule. The first delay took place from March 18th, 2005, to April 7th, 2005, taking 15 working days, and the second EC delay occurred from April 8th, 2005, to May 19th, 2005, due to a suspension order for the 30 days. By entering these delays into the baseline schedule, the original project completion date of the first baseline, April 21st, 2006, was compared to the impacted schedule completion date, indicating that the total project completion date was prolonged by 45 working days due to these EC delays (Fig. 5.12). Prior to moving to the next analysis interval, the new baseline duration for the second analysis period was calculated by inserting all delays that had occurred up to the beginning of the second analysis interval into the first baseline schedule. The second analysis period started from June 20th, 2005, to October 30th, 2005. However, there were no EC delays within the second analysis period, and thus, the project completion date was not affected.

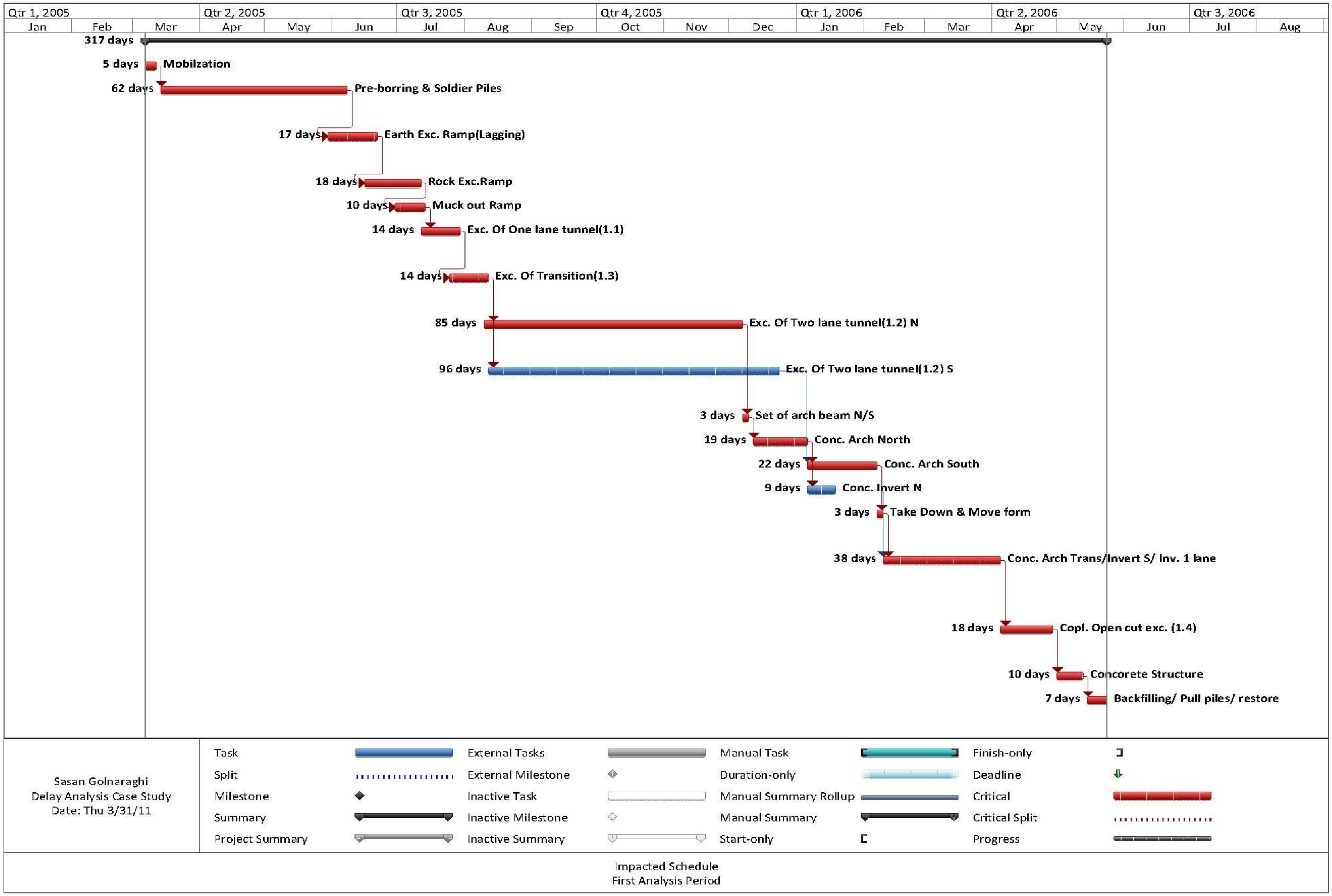


Figure 5.12: Impacted Schedule for the First Analysis Period

The third analysis period was from October 3rd, 2005, to January 13th, 2006, and the total duration of the baseline for the stated analysis interval was 318 working days (Fig. 5.13). At this point, by incorporating the EC delays into the third analysis period baseline schedule and comparing the predicted completion date with the impacted schedule, a delay of 19 working days was obtained (Fig. 5.14).

Since in the fourth analysis period, the developed system could not identify any EC delays from January 15th, 2006, to April 28th, 2006, the project completion date did not show any changes for the fourth analysis period.

The last analysis period, from May 1st, 2006, to July 27th, 2006, experienced delays of 21 working days in the open-cut excavation operation that were classified as EC delays. When this amount was inserted into its corresponding activity, the project completion date changed and an additional 21 working days appeared, altering the total project duration to 358 working days (Figs 5.15, 5.16).

Adding all the differences in completion date from the five analysis periods, a total of 85 working days (45+0+19+0+21) due to EC delays were identified. Thus, the contractor was entitled to claim compensation for 85 days.

The same procedures were repeated for the EN delays that had caused the project to be delayed for another 10 days (0+0+0+0+10). The contractor was thus entitled to ask for a time extension of 95 days to complete the project. The MIDT analysis performed from the owner's point of view resulted in a delay of 5 working days due to the contractor's action or inaction. Figure 5.17 illustrates the MIDT analysis results generated by the system for this case study.

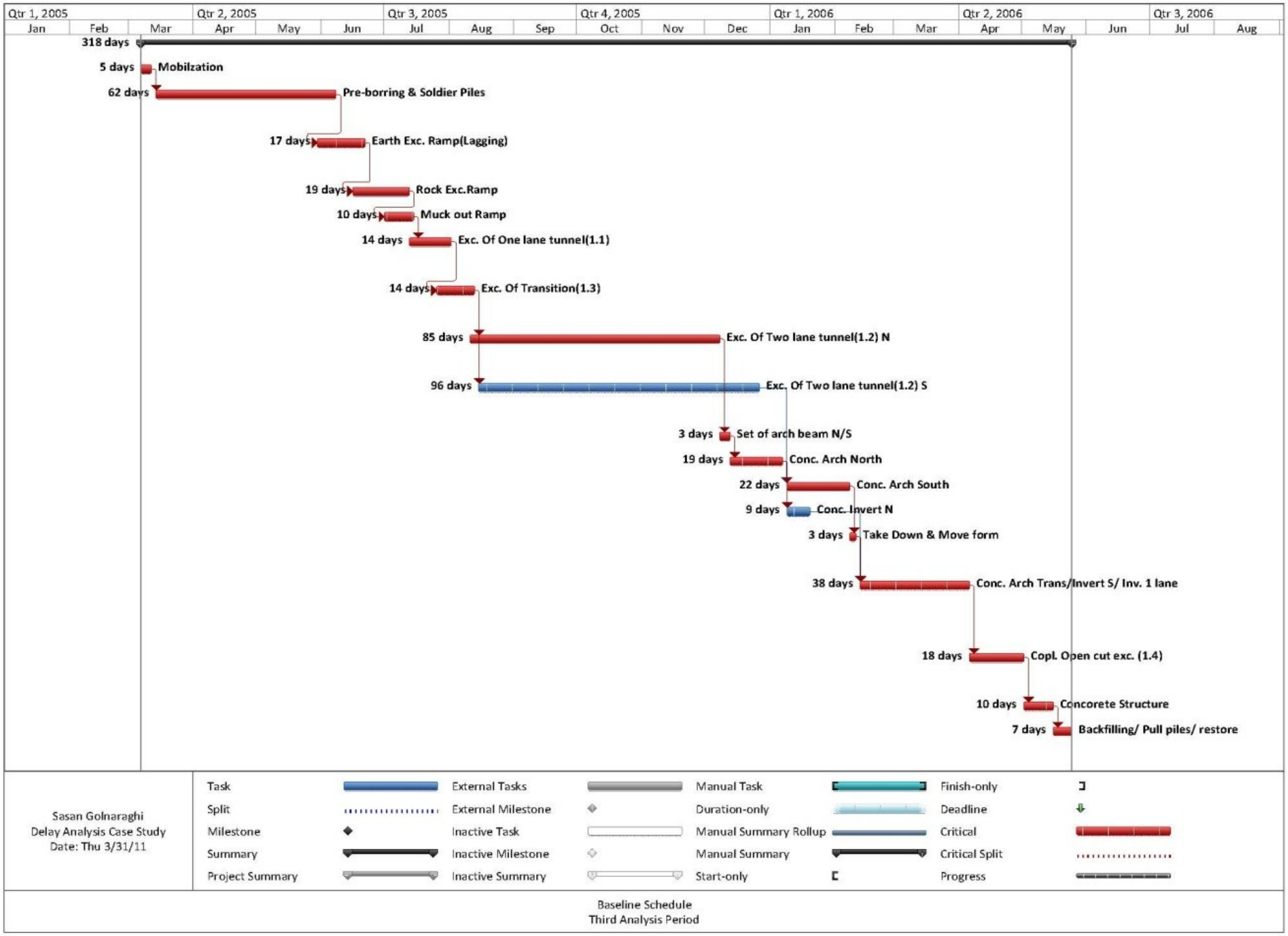


Figure 5.13: Baseline Schedule for the Third Analysis Period

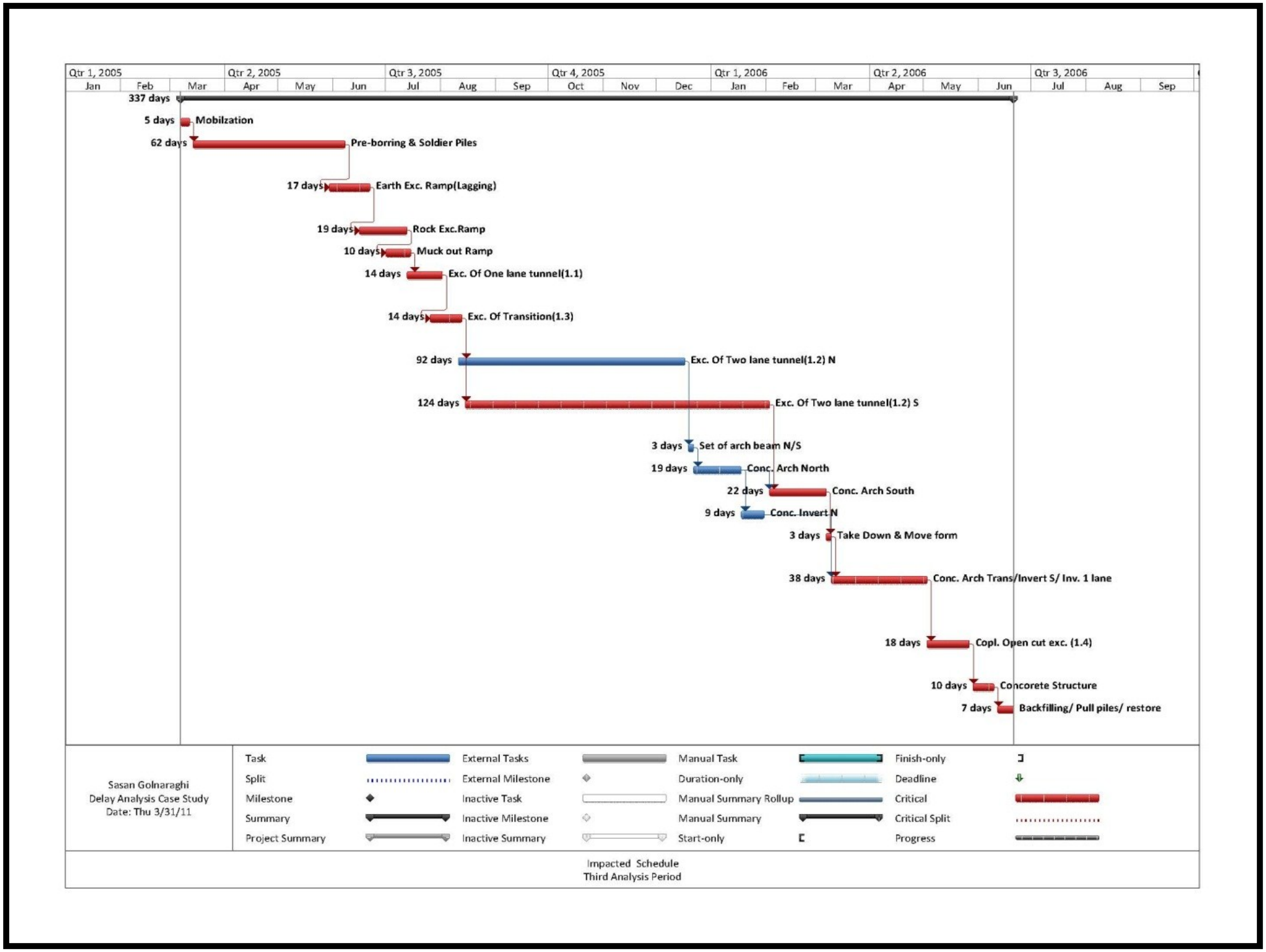


Figure 5.14: Impacted Schedule for the Third Analysis Period

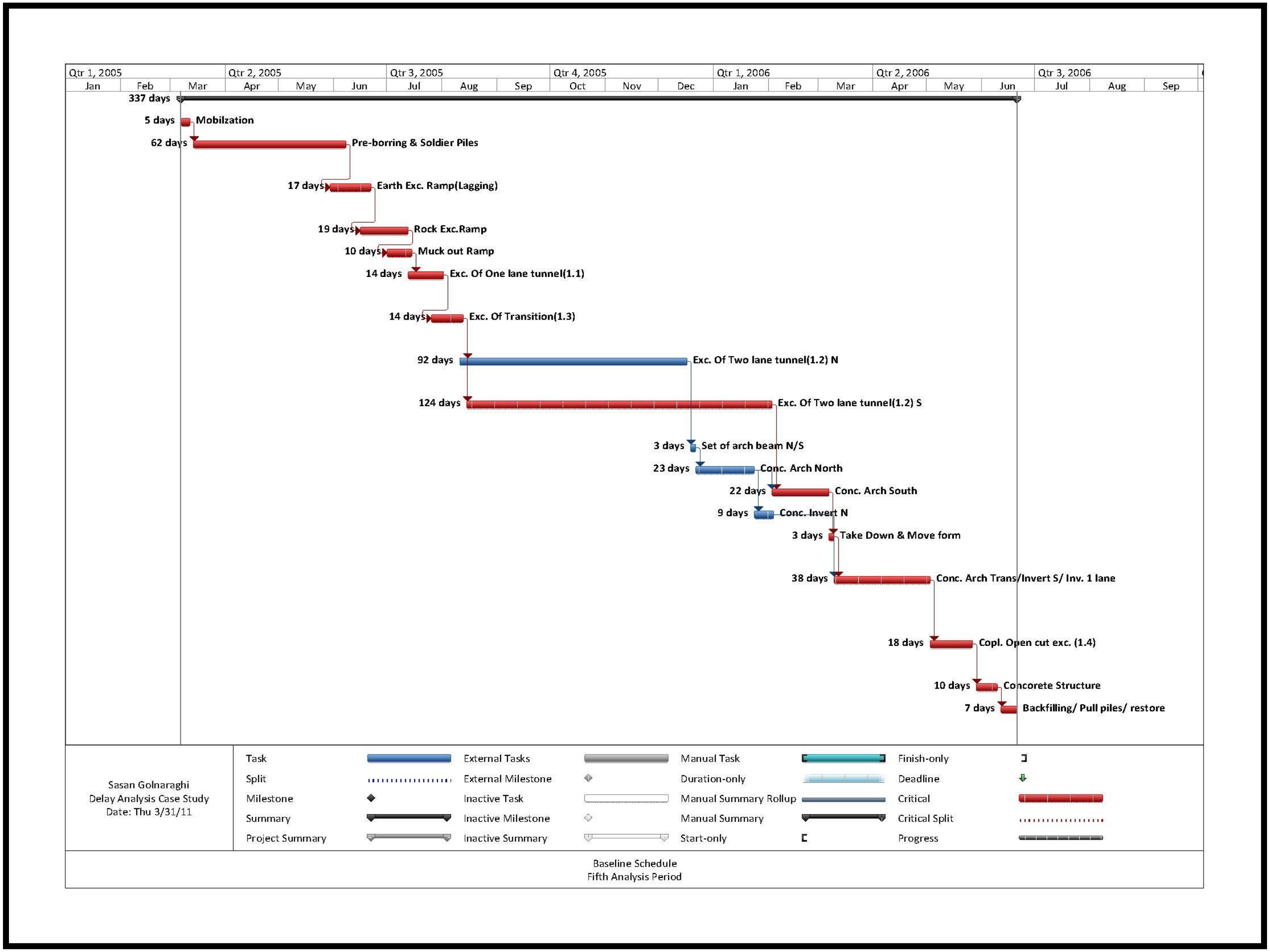


Figure 5.15: Baseline Schedule for the Fifth Analysis Period

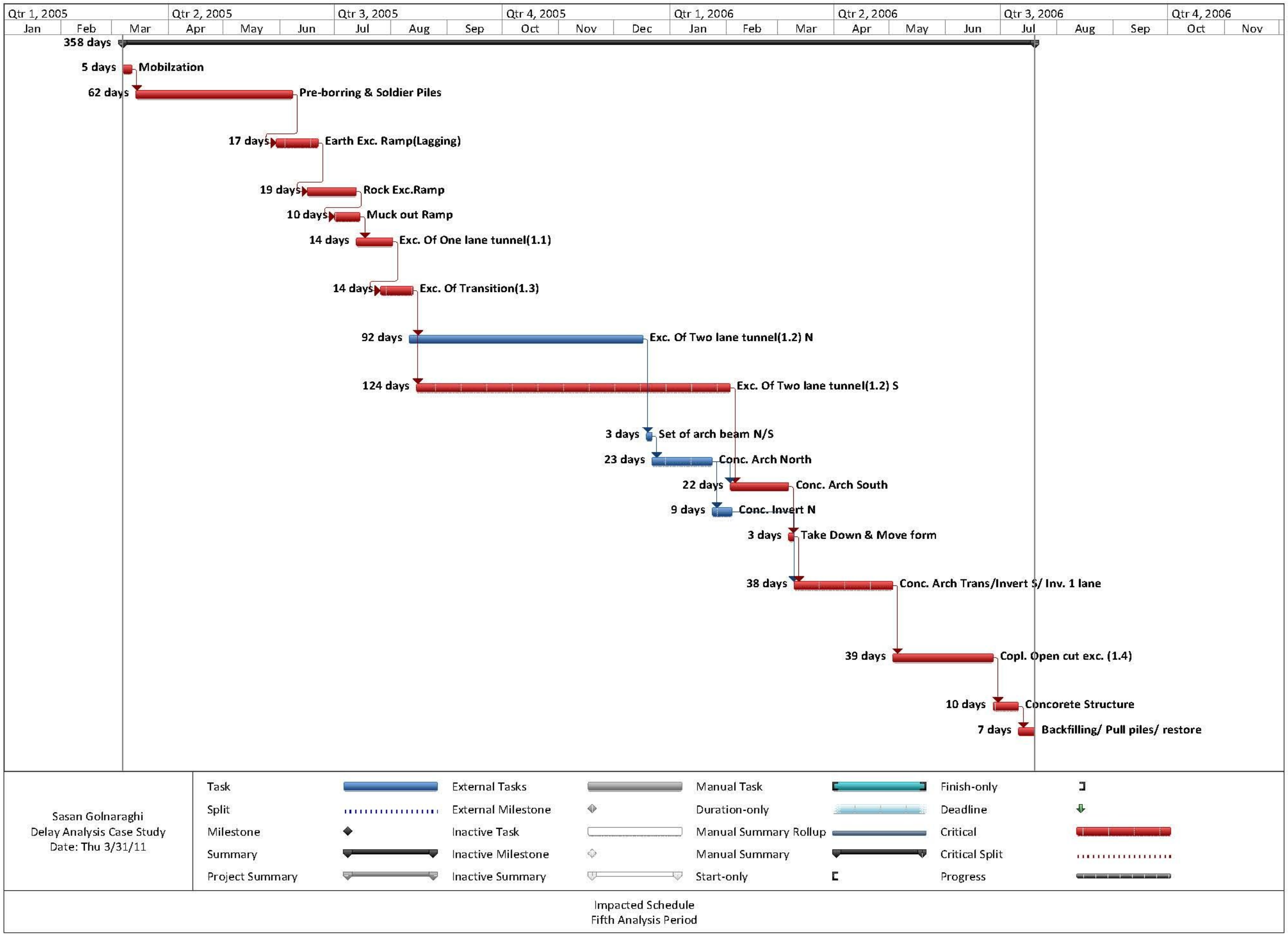


Figure 5.16: Impacted Schedule for the Fifth Analysis Period

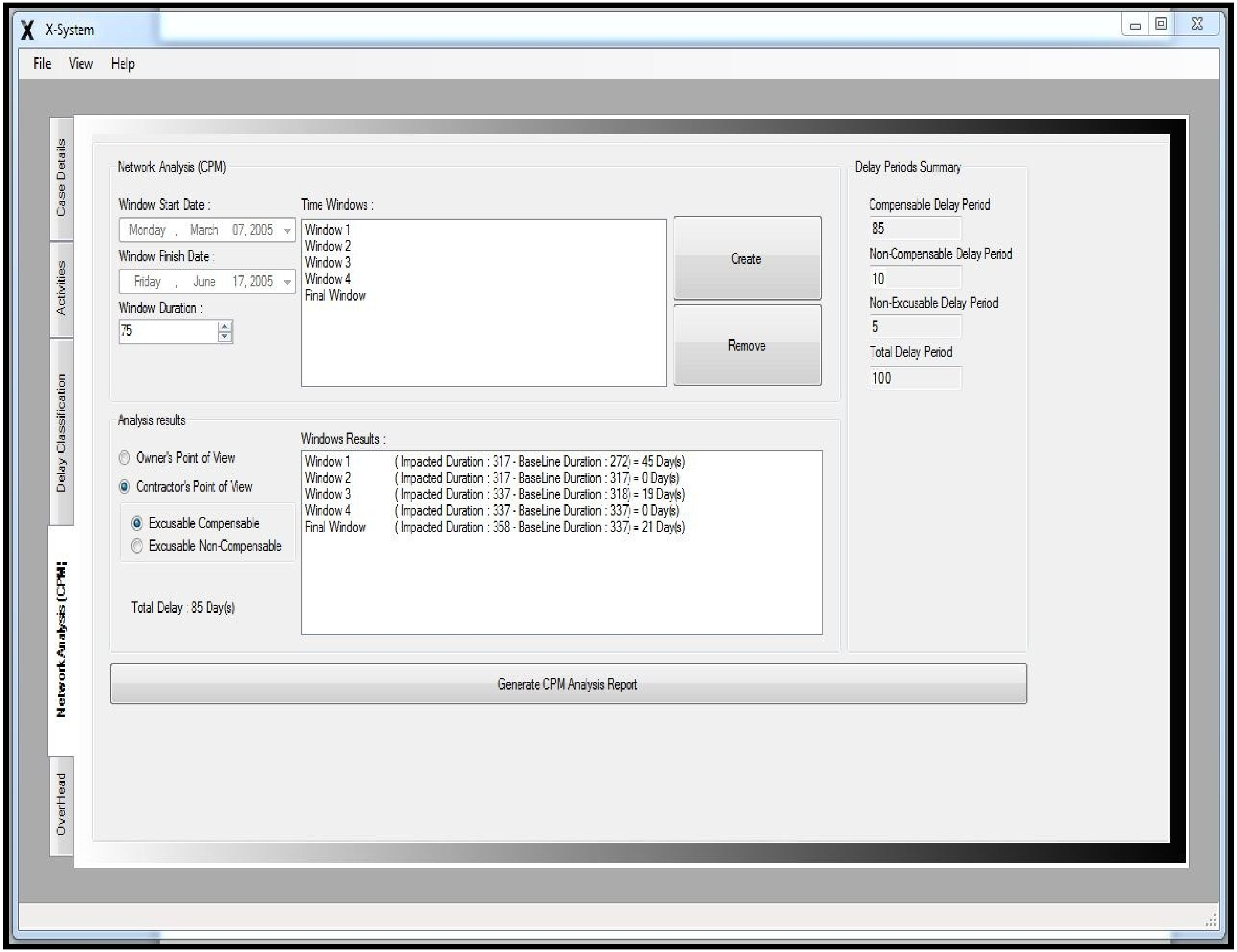


Figure 5.17: MIDT Analysis for Contractor's Point of view

Adding the corresponding delays for each party, the total delay of $85_{EC}+10_{EN}+5_{NE}=100$ working days was obtained, which is 6 days more than the total actual delay of the project. Furthermore, the windows analysis technique was performed for this claim previously, coming to a total delay of $99_{(EC+EN)} + 5_{NE} =104$. The MIDT generated result was thus more accurate than that of the windows analysis technique. Figures 5.18 to 5.20 show the delay entitlement reports generated by the system for the above-mentioned procedures.

5.7 Costs Quantification and Analysis

After identifying the number of excusable compensable delays, their associated costs were calculated by using the cost calculator module. It should be noted that in calculating impact costs, a tremendous amount of information regarding labour and equipment productivity is required. For the current case study, this information was not available and further performance of this computation is beyond the scope of this research. Therefore, direct and indirect costs for the delayed activities were considered, which were obtained by consulting experts in the construction industry.

The effect of each EC delay on the project completion date was determined by employing the “Network Analysis” module, and consequently the changes in the project cost were calculated based on the effect of each individual EC delay on the project completion date. For instance, the excavation of the two-lane tunnel was delayed for 28 working days; as this delay was added to the corresponding baseline schedule, the total project duration was extended for 12 working days. Thus, these 12 days would be considered as the time for calculating the project's cost increase related to this particular activity. A similar practice was applied for the remaining EC delay activities.

The first delayed activity experienced 15 days of delay due to incorrect information provided by the engineer and another 30 days due to a suspension order. The direct cost of the first portion of delay was calculated using the "Cost Calculator" module. Because of the suspension order rules, the contractor was entitled to recover the idle costs for the labour and equipment, present at the site but unable to perform the work. Furthermore, the engineer ordered a reduction of the ground water level during the six-week suspension, which entitles the contractor to be paid for the extra work involved, including: extra sump pit, extra sump pump, and sheet pilling. The direct costs for the remaining delayed activities were calculated by following the same procedures. For instance, Fig. 5.21 illustrates the cost calculation process for the excavation of the two-lane tunnel (1.2) South. The total amount of 794,175 CAD was calculated by summing all the direct costs associated to EC delays.

The total overhead costs (indirect cost) for the project was $434,668, which was divided into head office overhead and jobsite overhead. The "Canadian method" and the "Precentage method" were utilized for calculating head office overhead and site overhead, as shown in Fig. 5.22.

For the Canadian method, the percentage mark-up was 7% as per the contractor bid documents. This percentage was multiplied by the contract price of the project ($10,699,535) and then divided by the as-planned duration (272 days) to get the daily rate of head office overhead.

Project : Section Main-East, Subway Line 2
Project Location : 301 North Broadway Ave. QC. Canada
Owner : City of Rowhill
Contractor : Drillco Inc.
Engineer : TEB Consulting

Delay Entitlement (Network Analysis)

Analysis Period 1 :

Start Date : 3/7/2005
Finish Date : 6/17/2005
Duration : 75 Day(s)

From the Owner's Point of view (Non-Excusable delays) :
Baseline Schedule Duration : 272 Day(s)
Impacted Schedule Duration : 272 Day(s)
Non-Excusable Delays : 0 Day(s)

From the Contractor's Point of view (Excusable Compensable delays) :
Baseline Schedule Duration : 272 Day(s)
Impacted Schedule Duration : 317 Day(s)
Excusable Compensable Delays : 45 Day(s)

From the Contractor's Point of view (Excusable Non-Compensable delays) :
Baseline Schedule Duration : 272 Day(s)
Impacted Schedule Duration : 272 Day(s)
Excusable Non-Compensable Delays : 0 Day(s)

Analysis Period 2 :

Start Date : 6/20/2005
Finish Date : 9/30/2005
Duration : 75 Day(s)

From the Owner's Point of view (Non-Excusable delays) :
Baseline Schedule Duration : 317 Day(s)
Impacted Schedule Duration : 318 Day(s)
Non-Excusable Delays : 1 Day(s)

From the Contractor's Point of view (Excusable Compensable delays) :
Baseline Schedule Duration : 317 Day(s)
Impacted Schedule Duration : 317 Day(s)
Excusable Compensable Delays : 0 Day(s)

From the Contractor's Point of view (Excusable Non-Compensable delays) :
Baseline Schedule Duration : 317 Day(s)
Impacted Schedule Duration : 317 Day(s)
Excusable Non-Compensable Delays : 0 Day(s)

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Network Analysis Report

Figure 5.18: Generated Network Analysis Report by Developed System

Project	: Section Main-East, Subway Line 2
Project Location	: 301 North Broadway Ave. QC. Canada
Owner	: City of Rowhill
Contractor	: Drillco Inc.
Engineer	: TEB Consulting

Analysis Period 3 :

Start Date : 10/3/2005
Finish Date : 1/13/2006
Duration : 75 Day(s)

From the Owner's Point of view (Non-Excusable delays) :
Baseline Schedule Duration : 318 Day(s)
Impacted Schedule Duration : 322 Day(s)
Non-Excusable Delays : 4 Day(s)

From the Contractor's Point of view (Excusable Compensable delays) :
Baseline Schedule Duration : 318 Day(s)
Impacted Schedule Duration : 337 Day(s)
Excusable Compensable Delays : 19 Day(s)

From the Contractor's Point of view (Excusable Non-Compensable delays) :
Baseline Schedule Duration : 318 Day(s)
Impacted Schedule Duration : 318 Day(s)
Excusable Non-Compensable Delays : 0 Day(s)

Analysis Period 4 :

Start Date : 1/16/2006
Finish Date : 4/28/2006
Duration : 75 Day(s)

From the Owner's Point of view (Non-Excusable delays) :
Baseline Schedule Duration : 337 Day(s)
Impacted Schedule Duration : 337 Day(s)
Non-Excusable Delays : 0 Day(s)

From the Contractor's Point of view (Excusable Compensable delays) :
Baseline Schedule Duration : 337 Day(s)
Impacted Schedule Duration : 337 Day(s)
Excusable Compensable Delays : 0 Day(s)

From the Contractor's Point of view (Excusable Non-Compensable delays) :
Baseline Schedule Duration : 337 Day(s)
Impacted Schedule Duration : 337 Day(s)
Excusable Non-Compensable Delays : 0 Day(s)

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Network Analysis Report

Figure 5.19: Generated Network Analysis Report by Developed System (cont.)

Project : Section Main-East, Subway Line 2
Project Location : 301 North Broadway Ave. QC. Canada
Owner : City of Rowhill
Contractor : Drillco Inc.
Engineer : TEB Consulting

Analysis Period 5 :

Start Date : 5/2/2006
Finish Date : 7/27/2006
Duration : 73 Day(s)

From the Owner's Point of view (Non-Excusable delays) :
Baseline Schedule Duration : 337 Day(s)
Impacted Schedule Duration : 337 Day(s)
Non-Excusable Delays : 0 Day(s)

From the Contractor's Point of view (Excusable Compensable delays) :
Baseline Schedule Duration : 337 Day(s)
Impacted Schedule Duration : 358 Day(s)
Excusable Compensable Delays : 21 Day(s)

From the Contractor's Point of view (Excusable Non-Compensable delays) :
Baseline Schedule Duration : 358 Day(s)
Impacted Schedule Duration : 368 Day(s)
Excusable Non-Compensable Delays : 10 Day(s)

Total Delay :
Total Non-Excusable Delays : 5 Day(s)
Total Excusable Compensable Delays : 85 Day(s)
Total Excusable Non-Compensable Delays : 10 Day(s)

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Network Analysis Report

Figure 5.20: Generated Network Analysis Report by Developed System (cont.)

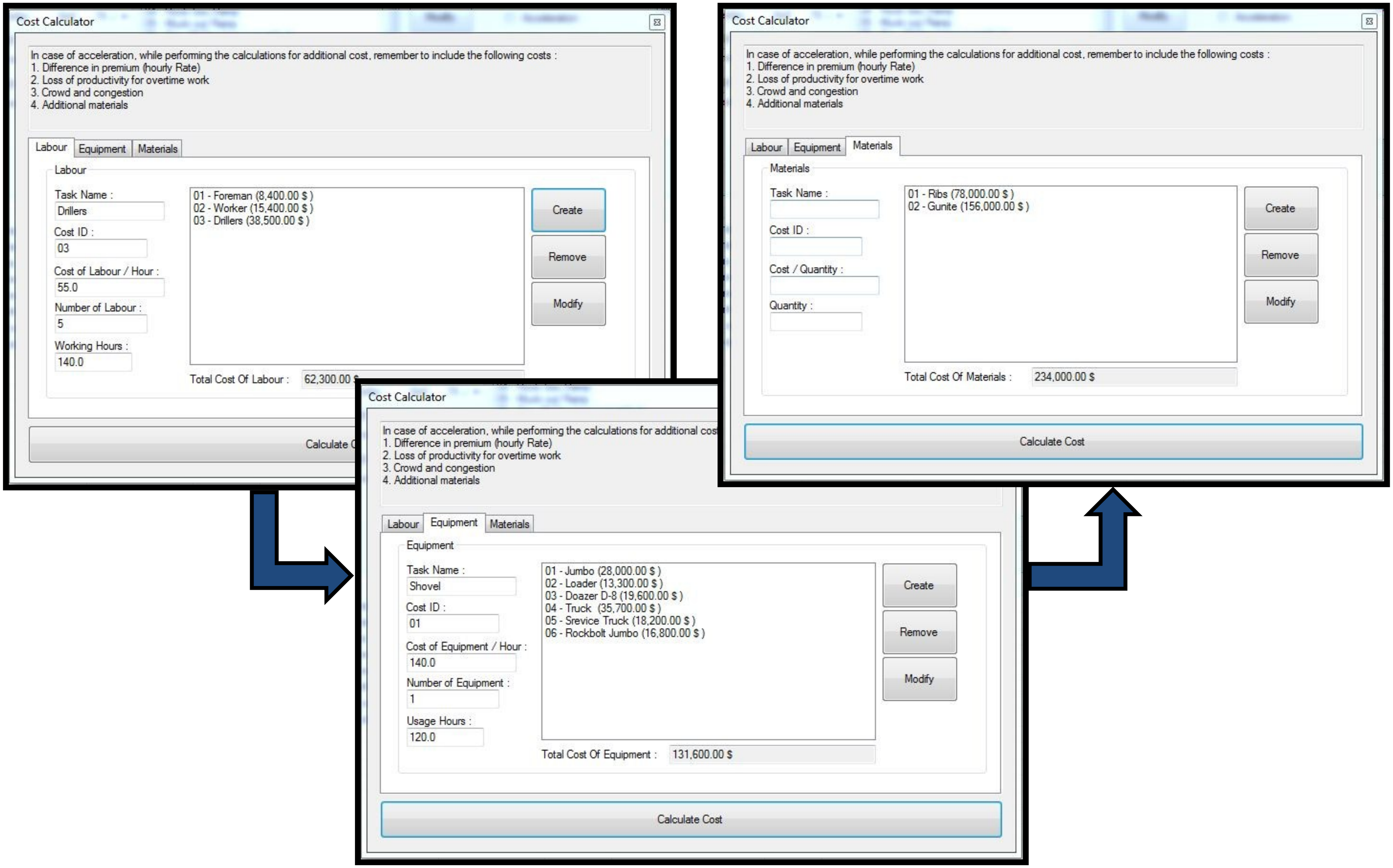

Figure 5.21: Direct Cost Calculation for the Two Lane (1.2) South

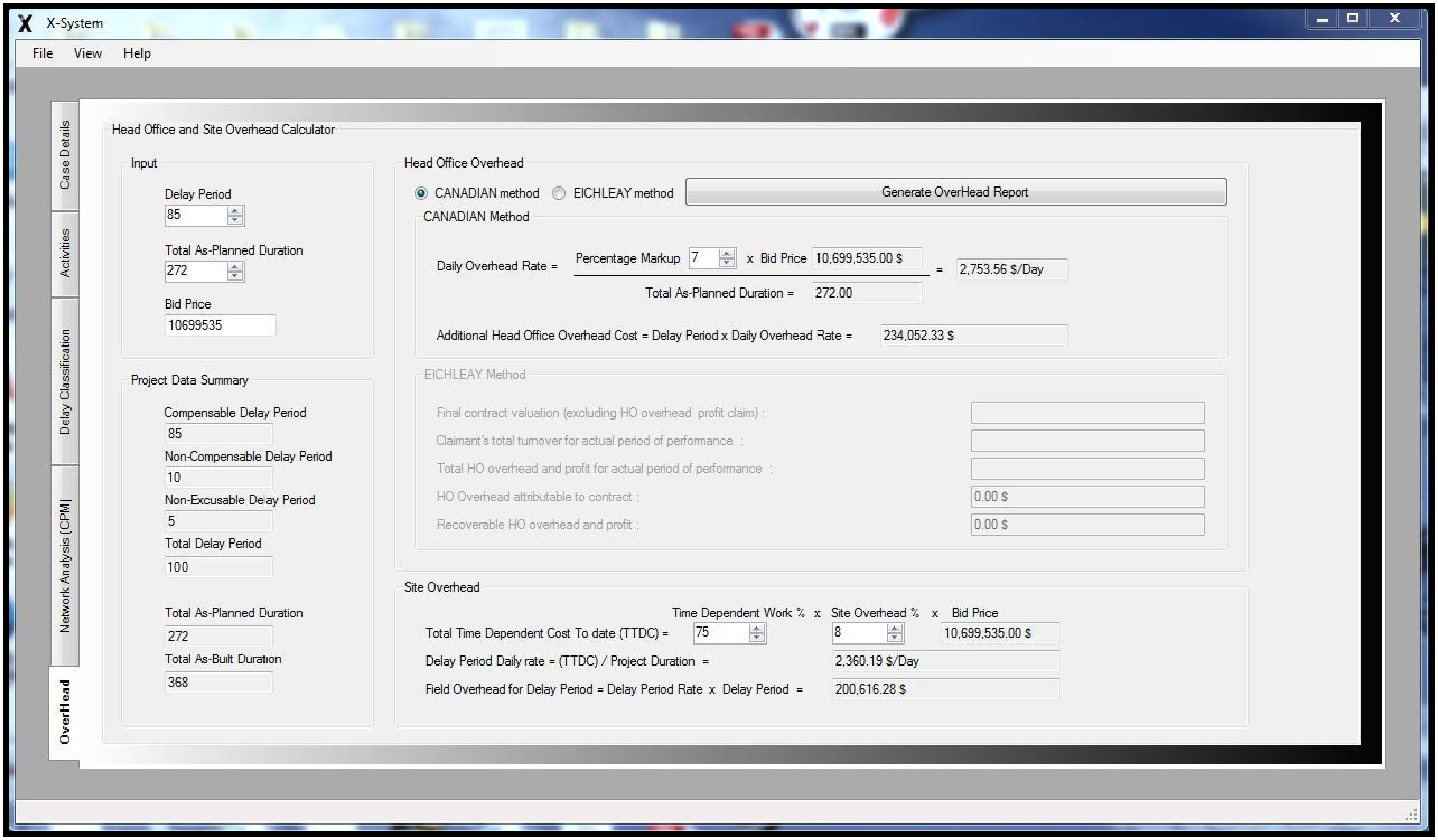

Figure 5.22: Head office and Site Overhead Costs

The daily rate of head office overhead was multiplied by the 85 days of excusable compensable delays, which came to 234,052 CAD in total head office overhead.

For calculating the site overhead, the percentage of time dependent on the project was assumed to be 75% and the percentage of site overhead 8%. These percentages were multiplied by the total project price and divided by the as-planned duration to get the daily rate of site overhead of $2360/day. The daily rate of delay was multiplied by the length of the excusable compensable delay to get the total site overhead cost: $200,616.

Therefore, the total amount of the claim was 1,228,843 CAD, determined by adding up the actual costs (direct and indirect) of the EC delays, and the related site and head office overhead. The complete cost calculation is shown in Appendix A.

5.8 Conclusion

A real case study from the construction industry was used to validate the proposed system. This case study has already been evaluated for delay claims. The as-planned and as-built schedules were used to start assessing this case, along with the extracted information about delaying events from the project documents. Delayed activities were listed in chronological order to identify independent and concurrent delays. Next, those delays were classified as excusable compensable, excusable non-compensable and non-excusable delays by consulting the developed expert system. The proposed system solidly accomplished all its intended purposes, including identifying delays, evaluating concurrent delays, delay analysis, and calculation of the actual costs for the case study. The discrepancies between the results obtained from the system and the documented figures were insignificant, and thus the system worked very effectively throughout the validation procedure. The system can also facilitate the delay analysis and claim preparation procedures; however, the accuracy of the generated results depends on the accuracy of the information resources, which is monitored by the user. Finally, it should be noted that the current developed system must be utilized as a supplementary tool, not as a comprehensive substitution for a qualified expert.

Chapter Six

Conclusions and Recommendations

6.1 Conclusions

This chapter concludes this research by outlining the research findings and contributions, and discusses the limitations and some future research and development areas. A summary of these aspects follows, beginning with the research problem.

The effect of concurrent delays in assessing a delay claim can change the overall result of a delay analysis technique. Some techniques attempt to overcome this issue, but it is clear that more research is required in the area of assessing concurrent delays. This thesis shows that overlooking concurrent delays may lead to unrealistic results. It also proposes a delay analysis technique to overcome concurrent delays, based on the currently available schedule analysis technique. The essential steps for this proposed technique were embedded in the isolated delay type (IDT) analysis technique to account for the effect of concurrent delays. A hypothetical case study was adapted and evaluated to compare the results obtained from the current and the modified isolated delay type (MIDT) analysis methods.

The reasons for adapting the IDT as a foundation block of the proposed MIDT is that it assigns classified delays before performing any analysis, and it gives both parties a fair chance to consume float. Furthermore, the analyst does not need to become familiar with a completely new technique in order to enhance the accuracy of the delay claim. However, the IDT overlooks concurrent delays and it is not able to track the fluctuation of the critical path throughout the delay analysis process. These factors should be addressed in delay analysis techniques to achieve more accurate and reliable results.

The MIDT solves the above-mentioned issues in delay analysis by addressing concurrent delays, the changes in critical path(s), and by promoting the fair consumption of total float. It can also be used for both real-time and after-the-fact delay analysis techniques. In other words, MIDT can be employed either while a project is in progress or after a project has been completed.

The MIDT relies on the as-planned schedule and on project documents, since inappropriate project data input results in inaccurate outcomes. Inputs are inaccurate when they do not reflect the actual events and when the documents and schedule updating are not done on a regular basis. In addition, the MIDT cannot address the effects of acceleration and resource allocation on the analysis outcomes. These issues require more study.

As mentioned earlier, prior to launching the MIDT, delays should be classified based on their compensability. Therefore, a knowledge-based expert system was created to classify and provide recommendation(s) on delay(s) or delaying event(s). This expert system was developed in the C# object-oriented programming language and consists of an inference engine, a database, a graphical user interface and a knowledge base.

The knowledge base for the expert system was extracted from the literature and was embedded into the system as a series of “IF, THEN” logic questions. The user responds to the questions in the form of “yes”, “no”, or “do not know”. The system uses the responses to these questions to lead the user to a specific decision or course of action to address and solve the problem. The expert system helps claim analysts to properly classify delay types, and it is also able to evaluate concurrent delays.

The MIDT and the developed expert system were integrated with scheduling software, and combined with a database for retrieving system data. The purpose of developing an integrated system is to facilitate the procedures of delay claim preparation. For validation purposes, the developed system was tested against a real case study that had already undergone a claim delay analysis.

The validation process of the developed integrated system included expert system classification, delay entitlements and cost calculation procedures. The developed system performed all its tasks precisely, while it reduced the time and cost associated with claim preparation. The system can also be used by all parties involved in a claim situation, such as the owner, contractor, or their representatives, or even by a third party. Meanwhile, the system can be used as a forecasting tool, enabling managers to determine the outcome of potential delaying events that occur during the course of a project. Another advantage of this developed system is its compatibility with most commercial Microsoft software, another aspect of how it provides accessibility to practitioners in different areas of the construction industry.

To conclude, time and cost are key indicators that show if a project may not be delivered successfully. Construction projects are often completed above the allocated time and budget. Various interrelated factors give rise to these circumstances and make it very complicated to identify the main causes for these delayed and/or over-budget deliverables. Since delays are costly, it is vital to accurately assign delays between project participants. The process of scrutinizing delaying events to determine the financial accountabilities for the project participants is known as delay analysis. The goal of this research was to assist the delay claim evaluation process by proposing a new, reliable delay analysis technique that is integrated into the developed computer system. The developed system can be used to:

- Assess a delay claim in a consistent and precise manner, thereby saving time and cost.
- Classify delays and provide recommendations for delayed activities using expert system technology.
- Assign delay responsibility to project parties based on a reasonable and consistent manner for all parties.
- Calculate the associated cost of compensable delays and quantify head office and site overhead in a practical manner.

6.2 Future Research and Development

This work may serve as a solid base for researchers who wish to carry out additional studies of delay analysis techniques and integrated systems for delay claim preparation.

Some of the specific aspects of the proposed delay analysis technique and integrated system that could be improved upon are:

1. The proposed delay analysis technique requires further improvement in order to address the effect of resource allocation and acceleration.
2. The proposed delay analysis technique should be tested by practitioners in a variety of delay claims scenarios for complex projects to ensure that the technique is robust and to increase its creditability.
3. The designed expert system requires further exploration and study in different claims areas so that more features can be added, including dealing with breach of contract and poor work quality. Moreover, the ability to include the legal aspects of a delay claim should be developed, which may be possible by providing more description.
4. The automated delay analysis, built into the integrated system, is based exclusively on “Finish to Start” relationships. It should also be possible to include other types of activity relationships, such as “Start to Start”, “Finish to Finish”, and Start to finish”. It should be noted that the above-mentioned relationships can be applied by using lag and lead time.
5. The developed system could be integrated with commercial cost estimating software in order to calculate the corresponding costs of delays.
6. The impact costs should be considered for future research. The impact costs include loss of productivity cost, weather effects, acceleration, deceleration, and loss of opportunities.

7. It may be possible to integrate 3D and 4D technical software with the current system to promote a better understanding of complex scenarios by different users.

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Appendix A:

Cost Report

Project : Section Main-East, Subway Line 2
Project Location : 301 North Broadway Street. QC Canada
Owner : City of Rowhill
Contractor : Drillco Inc.
Engineer : TEB Consulting

Delay Costs

Case 1 :

Main Scenario :

Activity Name : Earth Exc. Ramp(Lagging)
As-Planned Duration : 17
As-Built Duration : 62
Delay Duration : 15 EC

Delay Costs :

Labour Costs:
Labour Unit : Forman
Number of Labour : 1
Number of Hours : 120 hours
Cost per Hour : 60 $/hour

Labour Unit : Worker
Number of Labour : 2
Number of Hours : 120 hours
Cost per Hour : 50 $/hour

Total Labour Cost : 19200 $

Equipment Costs:
Equipment Unit : Shovel
Number of Equipment : 1
Number of Hours : 120 hours
Cost per Hour : 140 $/hour

Equipment Unit : Loader
Number of Equipment : 1
Number of Hours : 120 hours
Cost per Hour : 95 $/hour

Equipment Unit : Truck
Number of Equipment : 1
Number of Hours : 120 hours
Cost per Hour : 85 $/hour

Project : Section Main-East, Subway Line 2
Project Location : 301 North Broadway Street. QC Canada
Owner : City of Rowhill
Contractor : Drillco Inc.
Engineer : TEB Consulting

Total Labour Cost : 38400 $

Total Material Cost : 0 $

Case 2 :

Main Scenario :

Activity Name : Earth Exc. Ramp(Lagging)
As-Planned Duration : 17
As-Built Duration : 62
Delay Duration : 30 EC

Delay Costs :

Labour Costs:
Labour Unit : Foreman
Number of Labour : 1
Number of Hours : 240 hours
Cost per Hour : 60 $/hour

Labour Unit : Worker
Number of Labour : 2
Number of Hours : 240 hours
Cost per Hour : 50 $/hour

Total Labour Cost : 38400 $

Equipment Costs:
Equipment Unit : Shovel
Number of Equipment : 1
Number of Hours : 240 hours
Cost per Hour : 140 $/hour

Equipment Unit : Loader
Number of Equipment : 1
Number of Hours : 240 hours
Cost per Hour : 95 $/hour

Equipment Unit : Truck
Number of Equipment : 3
Number of Hours : 240 hours
Cost per Hour : 85 $/hour

Cost Report

Project : Section Main-East, Subway Line 2
Project Location : 301 North Broadway Street. QC Canada
Owner : City of Rowhill
Contractor : Drillco Inc.
Engineer : TEB Consulting

Equipment Unit : Hammer
Number of Equipment : 1
Number of Hours : 240 hours
Cost per Hour : 150 $/hour

Total Labour Cost : 153600 $

Total Material Cost : 0 $

Case 3 :

Main Scenario :

Activity Name : Rock Exc.Ramp
As-Planned Duration : 18
As-Built Duration : 19
Delay Duration : 1 NE

Delay Costs:

Total Labour Cost : 0 $

Total Labour Cost : 0 $

Total Material Cost : 0 $

Case 4 :

Main Scenario :

Activity Name : Exc. Of Two lane tunnel(1.2) N
As-Planned Duration : 85
As-Built Duration : 92
Delay Duration : 7 EC

Contractor Delay Costs :

Labour Costs :
Labour Unit : Foreman
Number of Labour : 1
Number of Hours : 35 hours

Cost Report

Project : Section Main-East, Subway Line 2
Project Location : 301 North Broadway Street. QC Canada
Owner : City of Rowhill
Contractor : Drillco Inc.
Engineer : TEB Consulting

Cost per Hour : 60 $/hour

Labour Unit : Worker
Number of Labour : 2
Number of Hours : 35 hours
Cost per Hour : 55 $/hour

Labour Unit : Drillers
Number of Labour : 5
Number of Hours : 55 hours
Cost per Hour : 65 $/hour

Total Labour Cost : 23825 $

Equipment Cost:
Equipment Unit : Jumbo
Number of Equipment : 1
Number of Hours : 35 hours
Cost per Hour : 200 $/hour

Equipment Unit : Loader
Number of Equipment : 1
Number of Hours : 35 hours
Cost per Hour : 95 $/hour

Equipment Unit : Dozer D-8
Number of Equipment : 1
Number of Hours : 35 hours
Cost per Hour : 140 $/hour

Equipment Unit : Truck
Number of Equipment : 3
Number of Hours : 35 hours
Cost per Hour : 85 $/hour

Equipment Unit : Rockbolt Jumbo
Number of Equipment : 1
Number of Hours : 120 hours
Cost per Hour : 85 $/hour

Total Labour Cost : 34350 $

Total Material Cost : 0 $

Cost Report

Project : Section Main-East, Subway Line 2
Project Location : 301 North Broadway Street. QC Canada
Owner : City of Rowhill
Contractor : Drillco Inc.
Engineer : TEB Consulting

Case 5 :

Main Scenario :

Activity Name : Exc. Of Two lane tunnel(1.2) S
As-Planned Duration : 96
As-Built Duration : 124
Delay Duration : 28 EC

Contractor Delay Costs :

Labour Costs:
Labour Unit : Foreman
Number of Labour : 1
Number of Hours : 140 hours
Cost per Hour : 65 $/hour

Labour Unit : Worker
Number of Labour : 2
Number of Hours : 140 hours
Cost per Hour : 55 $/hour

Labour Unit : Drillers
Number of Labour : 5
Number of Hours : 140 hours
Cost per Hour : 65 $/hour

Total Labour Cost : 70000 $

Equipment Costs:
Equipment Unit : Jumbo
Number of Equipment : 1
Number of Hours : 140 hours
Cost per Hour : 200 $/hour

Equipment Unit : Loader
Number of Equipment : 1
Number of Hours : 140 hours
Cost per Hour : 95 $/hour

Equipment Unit : Doazer D-8
Number of Equipment : 1
Number of Hours : 140 hours

Cost Report

Project : Section Main-East, Subway Line 2
Project Location : 301 North Broadway Street. QC Canada
Owner : City of Rowhill
Contractor : Drillco Inc.
Engineer : TEB Consulting

Cost per Hour : 140 $/hour

Equipment Unit : Truck
Number of Equipment : 3
Number of Hours : 140 hours
Cost per Hour : 85 $/hour

Equipment Unit : Rockboly Jumbo
Number of Equipment : 1
Number of Hours : 120 hours
Cost per Hour : 85 $/hour

Total Labour Cost : 106800 $

Material Costs:
Material Unit : Ribs
Quantity : 120
Cost per Quantity : 650 $

Material Unit : Gunite
Quantity : 5200
Cost per Quantity : 30 $

Total Material Cost : 234000 $

Case 6 :

Main Scenario :

Activity Name : Conc. Arch North
As-Planned Duration : 19
As-Built Duration : 23
Delay Duration : 4 NE

Delay Costs :

Total Labour Cost : 0 $

Total Labour Cost : 0 $

Total Material Cost : 0 $

Case 7 :

Cost Report

Project : Section Main-East, Subway Line 2
Project Location : 301 North Broadway Street. QC Canada
Owner : City of Rowhill
Contractor : Drillco Inc.
Engineer : TEB Consulting

Main Scenario :

Activity Name : Copl. Open cut exc. (1.4)
As-Planned Duration : 18
As-Built Duration : 39
Delay Duration : 21 EC

Delay Costs :

Labour Costs:
Labour Unit : Foreman
Number of Labour : 1
Number of Hours : 105 hours
Cost per Hour : 60 $/hour

Labour Unit : Worker
Number of Labour : 2
Number of Hours : 50 hours
Cost per Hour : 105 $/hour

Total Labour Cost : 16800 $

Equipment Costs:
Equipment Unit : Shovel
Number of Equipment : 1
Number of Hours : 120 hours
Cost per Hour : 140 $/hour

Equipment Unit : Loader
Number of Equipment : 1
Number of Hours : 120 hours
Cost per Hour : 95 $/hour

Equipment Unit : Truck
Number of Equipment : 3
Number of Hours : 120 hours
Cost per Hour : 85 $/hour

Total Labour Cost : 58800 $

Total Material Cost : 0 $

Cost Report

Page 7 of 8

Project : Section Main-East, Subway Line 2
Project Location : 301 North Broadway Street. QC Canada
Owner : City of Rowhill
Contractor : Drillco Inc.
Engineer : TEB Consulting

Case 8 :

Main Scenario :

Activity Name : Concorete Structure
As-Planned Duration : 10
As-Built Duration : 20
Delay Duration : 10 EN

Delay Costs :

Total Labour Cost : 0 $

Total Labour Cost : 0 $

Total Material Cost : 0 $

Project Total Delay Costs :

794175 $

Cost Report