Integrated Forensic Delay Analysis Framework for Construction Projects –Time and Cost Perspectives

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ABSTRACT

Integrated Forensic Delay Analysis Framework for Construction Projects - Time and Cost Perspectives

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Claims resulting from delays and acceleration on construction projects are inevitable. To prepare a delay/acceleration claim, a forensic schedule analysis needs to be performed. In this analysis, the impacts of different delays/accelerations are assessed and the responsibility of each party is calculated. The analysis usually involves CPM schedule calculations using a number of methods adopted by the industry. Although some of these methods are more accurate than others, they usually produce different results depending on the available data and the user's point of view.

There is a need for an integrated framework that enhances the documentation of progress data, and that performs forensic schedule analysis and damage quantification in a more timely, accurate, and cost effective manner. There is also a need to integrate the forensic schedule analysis function with the more routinely performed scheduling and monitoring functions. From this perspective, the present research introduces an integrated framework for progress data documentation, forensic schedule analysis, and damage quantification.

The main objectives of this research are to: i) Identify delays/accelerations and document their related information as they emerge; ii) Determine the impact of delays/accelerations on the project duration and determine responsibilities; iii) Quantify damages for contractors and owners; and iv) Integrate and automate the process of schedule analysis and damage quantification to help minimize time, cost and errors. The methodology adopted for this research includes a review of the literature, the design and implementation of a delay/acceleration and cost database, a schedule analysis module, a direct cost module, an impact cost module, an overhead cost module, and a liquidated cost module.

The event identity concept (EIC) and the equal liability method (ELM) were introduced to document delays and apportion concurrency entitlements, respectively. An Isolated Daily Window Analysis Technique (IDWAT) was also introduced and used as part of the framework. The framework assists in the creation of the as-built, as-planned, and of any adjusted schedule at any day of a project's life. It also facilitates forensic schedule analysis using essentially any analysis technique.

MS Project, Access, and VBA were used to implement the framework; MS project was used as both a scheduling tool and as an interface for the user, while Access was used to create the database. Using MS Project as an interface made the forensic schedule analysis function totally integrated with the more routinely performed scheduling and monitoring functions. The VBA was used to implement the schedule analysis and cost calculation modules as well as to integrate the different components of the framework.

The framework was tested using manually calculated cases and by comparing its results with those of previous studies. The results of the framework were reasonable and always resulted in a total delay equal to the sum of the parties' shares of the delay.

Acknowledgement

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Finally, I would like to dedicate this thesis to my beloved mother for her unconditional love, prayers and sacrifices.

Contents

List of Figures

List of Tables

ABBREVIATIONS

CPM: Critical Path Method

EIC: Event Identity Concept

ELM: Equal Liability Method

IDWAT: Isolated Daily Window Analysis Technique

EC: Excusable Compensable (Owner Delay)

NE: Non Excusable (Contractor Delay)

EN: Excusable Non compensable (Third-Party Delay)

EOT: Extension of Time

OA: Owner Acceleration

CA: Contractor Acceleration

OAD: Owner Adjusted Duration

CAD: Contractor Adjusted Duration

TAD: Third-party Adjusted Duration

AAD: All-events Adjusted Duration

SCR: Scheduled Cost Rate (scheduled cost per 1% of activity work)

ACR: Actual Cost Rate (Actual cost per 1% of activity work)

OH: Overhead Cost (Cost due to EC delays)

LD: Liquidated damages (Cost due to NE delays)

NSI: Net Saving Impact

LD max: Maximum Liquidated Damages (Without Acceleration)

LD x: Liquidated Damages for scenario X

AC x: Acceleration Cost for scenario X

SP: Scheduled production (Scheduled production per activity day)

AP: Actual production (Actual production per activity day)

AC: Actual Cost of the activity

SC: Scheduled Cost of the activity

ACD: Actual cost of the activity day

ASD: Activity-start delay (in days)

EXC: Extra cost of the activity

DIC: Daily impact cost

AIC (EC): Activity Impact cost due to EC delay in its predecessors.

DDC: Daily Direct Cost

DDC (EC): Daily Direct Cost due to EC delay

ADC (EC): Activity Direct Cost due to EC delay

Chapter 1

INTRODUCTION

1.1 General

The construction industry is a major sector of the economy of almost every country. According to Statistics Canada (2011), the value of building permits for the last five years were from **66,265.8** to **72,445.5** billion dollars per year. The GDP in the construction sector increased from $55.5 billion in 2001 to $69.1 billion in 2009 (Industry Canada, 2010).

Most construction projects include the participation of multiple parties, and these relationships are usually regulated by contract agreements. Contract agreements typically contain clauses designating the completion time, liquidated damages, and other related clauses as well as the contract documents themselves (Clough, 1981).

Completing construction projects within the planned timeframe and budget has always been a big challenge to the main parties involved, as most projects are affected by a multitude of changes, disruptions and delays.

Despite the developments in construction management tools and recent innovations for managing disputes, construction projects continue to suffer disruptions and so have disputes and claims that must be resolved (Gardiner P. D. et al, 1995). In fact, the management of construction claims is considered to be the greatest challenge that contractors face in today's business environment (Kululanga G. K. et al, 2001).

Delays are a very common occurrence in construction projects, and they are the cause of many of the disputes and claims. Cushman et al. (2001) described delay in its basic form to "involve an increase in the time necessary to complete the project beyond that which was contemplated at the time the contract was signed". Delays can take place as a result of many events (reasons) caused by different parties or conditions. By their very definition, as mentioned above, delays lead to time overrun, which in many cases leads to cost overrun. Time and cost overruns are the main reasons for construction claims.

A study conducted in western Canada (Semple et al., 1994) revealed that out of 24 claims reports investigated, the large majority of claims involved some delay. In many cases the delay exceeded the original duration by more than 100%, as shown in Figure 1.1. Also, in more than half of the cases, the claim value was at least 30% of the original contract value. In some cases, the claim value reached up to 60% of the contract value, as indicated in Figure 1.2.

Claims management is not normally treated as a management function like estimating, planning, scheduling, and cost control. Most of the time, it is inadequately resourced and performed in an unplanned manner (Vidogah et al., 1997; Gardiner P.D. et al, 1995).

Delay analysis and claim preparation is a costly and time-consuming process, since it involves a thorough search through numerous (and varied) documents to determine the relevant delays encountered during a project (Alkass et al, 1995).

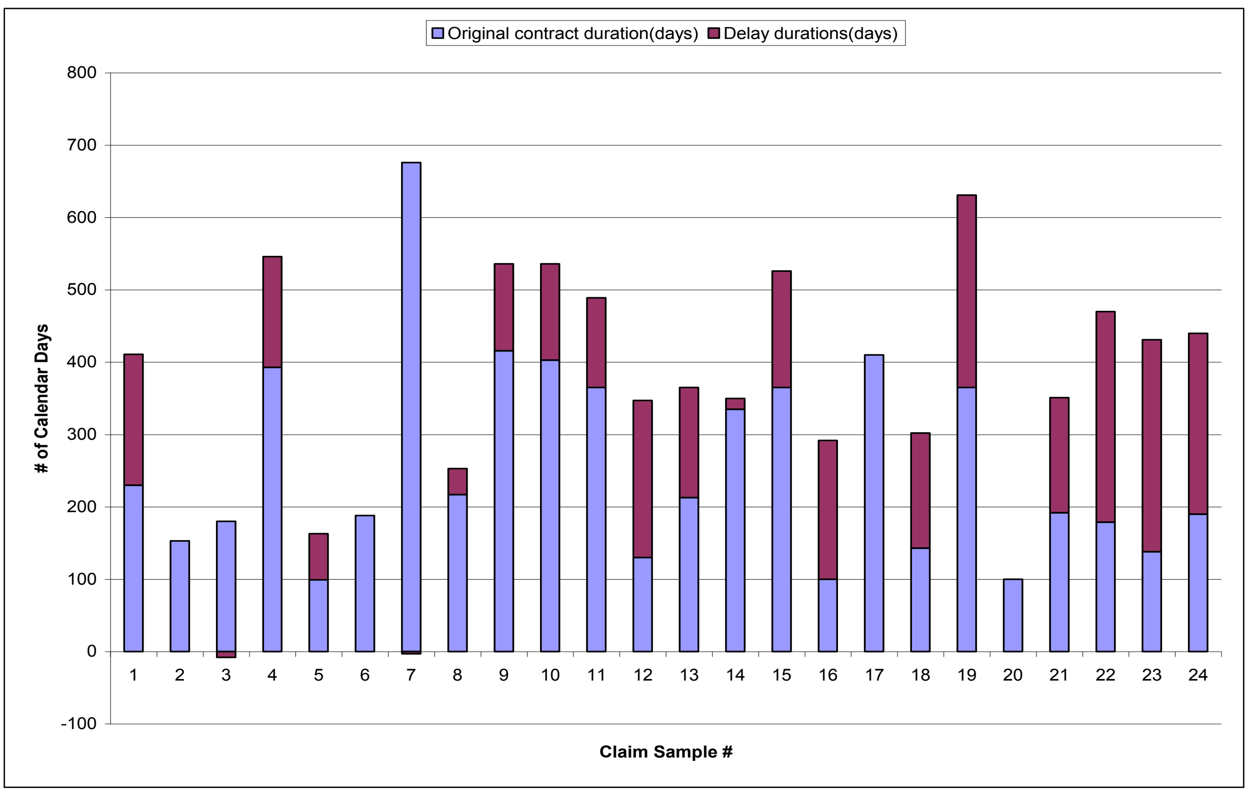


Figure 1-1 project duration (Semple, 1994)

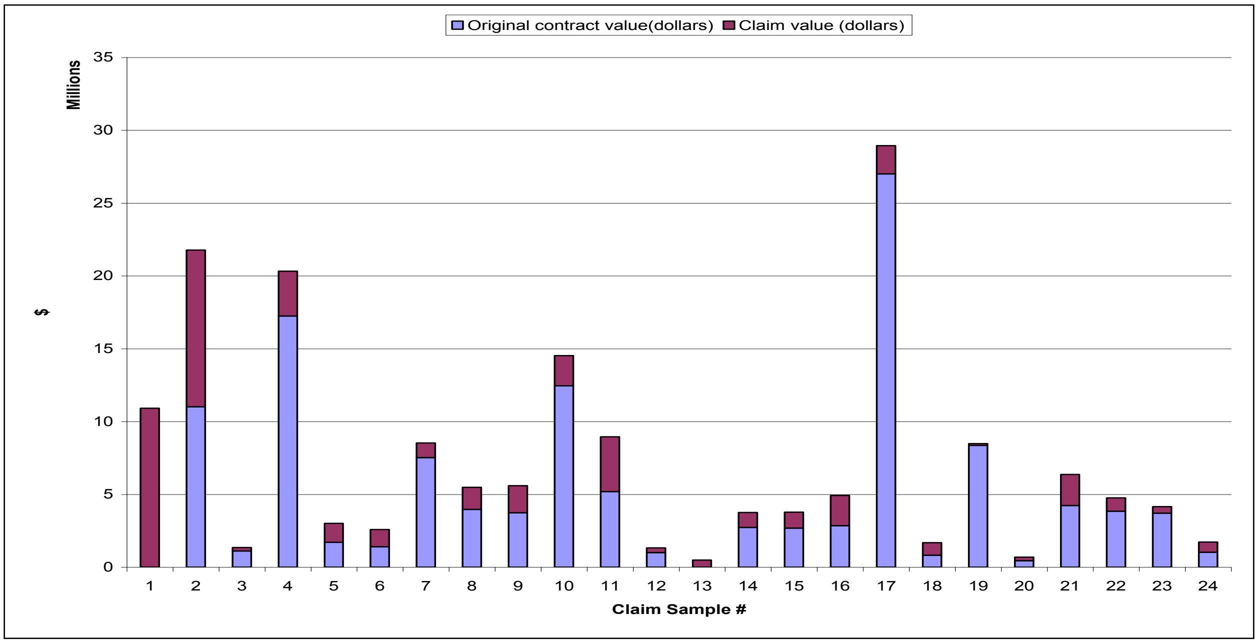


Figure 1-2 Contract and claim values (Semple, 1994)

In claim cases involving delays, delay data has to be documented and analyzed. A schedule analysis must be performed to determine the impact, if any, of delay(s) on the total project duration. Eventually, total project delay is apportioned among the parties and the damages are calculated accordingly.

The process of preparing delay claims starts by identifying the causes and effects of delays/changes. Based on the cause and effect analysis, the responsibilities for delays are determined (Delays are classified) and the entitlements of different parties to time and cost are established. Apportioning project delay among different parties and quantifying damages incurred by each party are then performed.

Assigning responsibilities for the project delay and determining shares of that delay for different parties, referred to hereafter as delay/schedule analysis is a complicated and time-consuming process. Quantifying delay-related damages is also time-consuming and entails the use of actual as well as budgeted costs and production rates. In addition, some types of cost are directly related to the delay analysis output which requires an integration of both the delay/schedule analysis and damage quantification.

This research mainly covers the delay/schedule analysis and damage quantification parts of the process of preparing delay-related claims for construction projects.

1.2 Research Objectives

The main objective of this research is to develop a methodology for analyzing schedule delays in construction projects in a timely and automated manner. This methodology integrates the time and cost perspective of delay analysis. This main objective can be accomplished via the following secondary objectives:

1. Identify construction delays and document their related information as they emerge;

2. Determine the impact of delays on the project duration and determine the responsibility (ies) of the project's major parties;

3. Quantify the delay damages for both the contractor and the owner; and

4. Integrate and automate the process of delay analysis and damage quantification to help minimize the time, cost and errors in delay claims preparation.

1.3 Research Methodology

To develop an integrated and automated methodology for documenting and analyzing schedule delays and to quantify delay damages, i.e., to achieve the aforementioned objectives, the following actions are performed:

1.3.1 Literature Review

A complete literature review is conducted in the areas of construction claims, construction delays, construction delay damages, management information frameworks and in the automation of delay analysis.

1.3.2 Event Identity Concept (EIC)

An event identification concept is introduced to help document events (delays and accelerations) in the most basic format. This format is flexible and is used in a new delay analysis technique.

1.3.3 Equal liability Method (ELM)

A new method of determining the entitlements for extensions of time and damages, in the case of concurrent delays, is introduced. This method is called the equal liability method (ELM) and is based on the suggestion that all parties are equally liable in the case of concurrent delays.

1.3.4 Isolated Daily Window Analysis Technique (IDWAT)

Using the event identity concept, an isolated daily window analysis technique is proposed. In the case of concurrency, this technique is used with either the aforementioned equal liability method (ELM) or with what Kraiem (1987) described as the "Easy Rule", called the "regular method" in this thesis.

1.3.5 Validation of the Isolated Daily Window Analysis Technique (IDWAT)

The Isolated daily window analysis technique is validated through the use of a test case and by comparing it with other techniques.

1.3.6 Delay and Progress Database

A relational database is designed and developed to store delay and progress data as it is produced. The event identity concept is used to document the delay data. The database is used along with a project management program to create schedules, analyze delays, quantify damages and generate reports.

1.3.7 Delay Analysis Module

A delay analysis module is designed and implemented to calculate the impact of different types of delays on the project duration and to apportion responsibility between different parties. Both the But-for and the Isolated daily window analysis techniques are used in this module.

1.3.8 Direct Cost Module

A module to calculate the direct cost of delays is designed and implemented. The direct cost of delays is calculated at the activity-day level.

1.3.9 Impact Cost Module

A module to calculate the impact cost of delays is designed and implemented. The impact cost of delays is calculated at the activity level.

1.3.10 Overhead Cost Module

A module to calculate the office and site overhead cost of delays is designed and implemented. The office and site overhead costs of delays are time-dependent and will be calculated at the project level.

1.3.11 Visual Basic for Applications (VBA) Module

A Visual basic for applications module is designed and implemented to help integrate the database with the project management program. This module also integrates all the delay analysis and delay cost modules into one framework. It makes the integrated framework fully automated, which reduces the time and cost of analysis and minimizes errors. A special menu is created within the project management software (MS Project) to allow access to all of the framework's steps and modules.

1.3.12 Validation

Using a test case, the framework will be validated by comparing its output with manually obtained results.

1.4 Thesis Organization

This thesis is comprised of seven chapters. Chapter Two contains a literature review that covers matters related to forensic delay analysis, including types of delays, types of schedules, CPM role in delay analysis, delay analysis techniques, delay damages and other delay-related issues such as critical path dynamics, delay classification, float ownership, and acceleration. It also covers the use of computer applications in delay analysis.

Chapter Three introduces the Isolated Daily Window Analysis Technique (IDWAT) for analyzing delays and accelerations, the Event Identity concept (EIC) for documenting delays and accelerations and the Equal Liability Method (ELM) for concurrent-delays entitlements.

Chapter Four presents the framework development methodology, including framework features, framework components such as the database, the MS Project and the modules of data documentation, delay analysis, direct cost, impact cost, overhead cost and liquidated damages. It also describes how the framework functions and presents the framework outcomes.

The framework implementation process is explained in Chapter Five. This explanation depicts the implementation of different framework features and components such as progress documentation, delay analysis and cost quantification modules.

Chapter Six is devoted to validating the framework's performance. Manually calculated case studies, some of which were used in previous studies, are used to validate the performance of the

IDWAT technique, the delay/acceleration analysis modules and the delay/acceleration cost modules.

Finally, Chapter Seven presents the conclusion, including a summary of the main research contributions, an overview of the limitations and suggestions for future work.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

Delay is defined by the Recommended Practice for forensic schedule analysis (RP) of the AACEI (2007) as: “Delay simply means a state of extended duration of an activity, or a state of prevention of an activity from starting or finishing on time, relative to its predecessor.”

The SCL protocol (2002) defines delay to completion as “delay to the date when the contractor planned to complete its works, or delay to the contract completion date.” It also defines Delay to Progress as “delay which will merely cause delay to the contractor’s progress without causing a contract completion date not to be met.”

Disruption, on the other hand, is defined by the SCL protocol (2002) as “Disturbance, hindrance or interruption of a Contractor’s normal work progress, resulting in lower efficiency or lower productivity than would otherwise be achieved. Disruption does not necessarily result in a Delay to Progress or Delay to Completion.”

For the purpose of this research, Activity Delays describe either a total stop of work or a slowdown of work at the activity level. Activity delays may eventually cause a delay to the project completion date.

2.2 Causes of Delays

There are many causes of delays that are usually encountered in construction projects. The most frequently encountered causes are documented in the literature. They are grouped in categories as follows:

Category	**Delay Cause**
Engineering	Inaccurate drawings Incomplete drawings Late engineering
Equipment	Equipment breakdowns Equipment delivery Improper equipment Shortage of equipment
External delays	Environmental issues Later than planned start Regulatory changes Permit approval
Labour	Craft shortages Labour productivity Labour strike Rework
Management	Construction methods More work than planned Quality assurance/quality control Schedule too optimistic Not working on critical tasks
Materials	Damaged goods Improper tools Material delivery Material quality

Owner	Change orders Design modifications Inaccurate estimates Owner interference
Subcontractor	Bankruptcy Subcontractor delay Subcontractor interference
weather	Freezing Heat and humidity Rain Snow

{Yates, J of CEM, June, 1993, 226-244(originally extracted from Project control for construction, publication 6-5. ,1987, Construction Industry Institute , Austin, Tex); Assaf S. et al,1995; Al-Khalil M. et al,1999.}

There are other delay-causing factors mentioned in the literature. Some of these factors are: unforeseen ground conditions, material shortages, inadequate construction planning, financial difficulties, poor site management, impractical design, poor communication, inappropriate type of contract, and inaccurate estimating (Chan et al, 2002; Assaf S. et al, 1995; Alkhalil M. et al, 1999). Equipment productivity, sample material approval, joint ownership of projects and accidents during construction were too mentioned as potential delay causes (Assaf S. et al, 1995). Also, work in congested areas and overcrowding, Unbalanced bidding and underestimation (Jergeas G. F et al,1994), restricted site access (Semple C. et al, 1994; Wilson R. L.,1982)

2.3 Types of Delays

Types of delays differ based on the criteria used to classify them. As shown in Figure 2.1 (Kartam, S., 1999), delays can be classified according to origin, timing, and compensability.

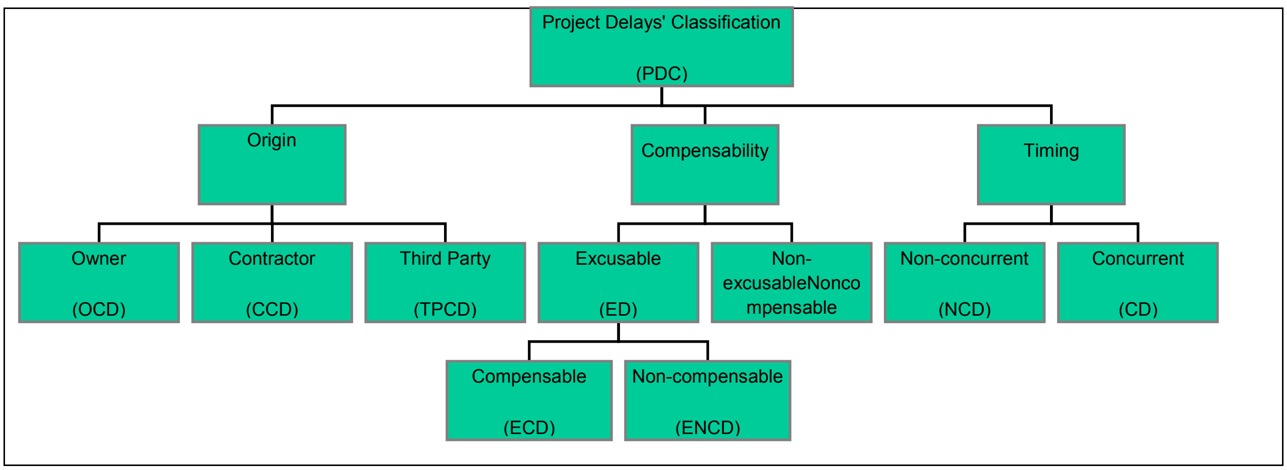


Figure 2-1 Types of delays (Kartam,1999)

Based on who is the responsible party, delays can be classified as owner-caused delays (OCD), contractor-caused delays (CCD), and third party-caused delays (TPCD).

The timing of delays is classified as either concurrent (CD) or non-concurrent (NCD). Concurrent delays are when delays caused by more than one party coincide. Non-concurrent delays occur as single, isolated events.

For two or more delays to be concurrent and cause delay in the overall project, they must occur within the same period and they each must have the ability to affect the overall project duration independently of the other (Arditi, 1995). This implies that only concurrent delays affecting critical activities are considered.

For the purpose of this research, the concept of concurrency is used in a wider perspective. It covers all of the delays that happen at the same time, regardless of the criticality of their respective activities and regardless of their effect on the project duration at the date of their occurrence.

Scott S. (1993) described three scenarios of concurrent delays:

concurrent delays to one critical activity;

concurrent delays to parallel critical activities; and

a combination of the first two scenarios.

There are also what are called parallel delays; in which the delay causes are under the control of the same party (Revay, 1991)

From a liability perspective, delays are either excusable (ED) or non-excusable delays (NED) (Alkass et al., 1996). ***Excusable*** delays are those that are not attributed to a contractor's actions or inactions. These are further divided into excusable compensable delays and excusable non-compensable delays.

Excusable compensable *delays* are caused by an owner's actions or inactions. An example of this type is when an owner denies a contractor access to the site after the notice to proceed has been given. In this case, the contractor is entitled to both time extension and cost compensation (Alkass et al., 1996; Bordoli et al., 1998). This type of delay will be referred to hereafter as **EC** delay.

Excusable non-compensable *delays* are caused by a third party, where neither the contractor nor the owner is responsible for the delay. In this case, only a time extension can be given to the contractor. An example of this type is when an unprovoked strike or severe weather occurs (Alkass et al., 1996; Bordoli et al., 1998). This type of delay will be referred to hereafter as **EN** delay

Non-excusable *delays* are caused by a contractor's actions or inactions. The contractor is not entitled to time extension or to monetary compensation, while the owner may be entitled to liquidated damages (Alkass et al., 1996; Bordoli et al., 1998). This type of delay will be referred to hereafter as **NE** delay.

There are other terms (types) in the literature that have been used to describe specific delay situations. Bordoli and Baldwin (1998) list several different types of delay. '**Date** delays', where an activity cannot start (or finish) until a specific date irrespective of when the preceding activities were carried out or were planned to be carried out; '**Total** delays', where a complete work stoppage occurs; and '**Extended** delays', when the duration of an activity is increased. There may be occasions where it is necessary to add construction activities to the planned work, which will result in '**Additional delays**'. '**Sequence** delays' occur when activities cannot be carried out in the sequence they were originally planned. '**Progress** delays' are those that result from a lack of progress in the construction work.

Independent *delays* occur in isolation or without coincident or consecutive delays. The effect of such a delay on the total project duration can be calculated by analyzing the network schedule. ***Serial*** *delays,* on the other hand, are sequences of consecutive non-overlapping delays on a particular network path. In this case, individual delays do not conflict, and the apportionment of the overall project delay is relatively easy to be determined (Arditi, 1995).

Pacing delays can best be described in the context of a project situation. When a contractor is involved in a project and realizes that there is or there will be an owner-caused delay to the critical path, the contractor may decide to slow down non-critical work activities in an effort to keep pace with the owner's delay. The attitude usually expressed by the contractor is, "Why hurry up and wait?" (Zack Jr., 2000).

Since the entitlement for extension of time or damages is ultimately connected to liability, the liability-based EC; EN and NE types will be adopted in this research.

2.4 CPM and Delay Analysis

Critical Path Method (CPM) scheduling has gained approval in the construction industry as the preferred method of scheduling for simple as well as complex projects (Schumacher, 1995). By the year 1994, it was used by some 88% of contractors in the UK and in the USA (Aouad and

Price, 1994). CPM schedules make it possible to determine the critical path and the earliest completion of a project. They are very useful if all the project parties are committed to the schedule. The project will only be delayed if a critical activity on the critical path is delayed, or if a non-critical activity goes beyond its duration and its float time.

The CPM helps in evaluating the cumulative effect of delays on the total project duration (Riad et al., 1994; Schumacher, 1995).While the effects of concurrent delays are clearly easier to assess using CPM, delays to non-critical activities are also easier to assess using CPM (Householder et al., 1990).

The CPM has become an excellent tool for negotiating a timely settlement of the changes, disputes, and delays that occur throughout the life of a project (Bubshait et al., 1998). Courts and boards of appeals have begun to emphasize the importance of CPM scheduling and time impact analysis, which identifies main elements of delay that are not possible by using simple scheduling techniques like Bar Charts (Singh, 2002; Kallo, 1996).

In the United States, recognized procedures have been developed to adopt the CPM in the area of delay claims (Scott S., 1997). The situation in the U.K. is not as clear, but in a survey conducted in the U.K. some years ago, both contractors and supervisors recognized that CPM will be useful in dealing with delay claims (Scott S., 1997).

In order for a CPM schedule to be reliable in the analysis and evaluation of delay claims, it has to be updated, realistic and reasonable. It must be updated to reflect the dynamic nature of the critical path. It has to be assembled following a sound logic with realistic, reasonable activity duration estimates. An as-built CPM schedule should show the actual sequence and duration of project activities. This can be accomplished by using pertinent data such as project records, daily diaries, workforce reports and progress payment estimates. (Kallo G., 1996)

2.5 Types of schedules

Schedules based on CPM networks are usually the basis for any delay analysis effort. The CPM schedule is normally modified and updated throughout the project as change orders are issued and delays occur. The critical path(s) may shift, so that critical activities may become non-critical and vice-versa.

a) As-planned schedule

This schedule is usually prepared by the contractor to represent his/her work plan for executing the project according to the contract documents. To be accepted as a baseline for any later schedule analysis, it should satisfy the following conditions. To effectively determine the activity relationships, the schedule should have a sound logical basis. Second, its activity durations should be accurate and realistic. Third, resource utilization should be properly assessed and any additional constraints and contingencies accounted for. As-planned schedules that meet these conditions are generally approved by the respective owners and can serve as the starting points for schedule variance analysis (Arditi, 1989; Alkass, 1993; Finke, 1999; Barrie, 1992; Riad, 1994).

b) As-built schedule

As suggested by the name, an as-built schedule defines how a contractor actually executed a project. It shows the actual starts and completions, as well as the work performed. This schedule includes the impacts of all of the changes and delays that were encountered and therefore may serve as the starting point for the development of entitlement schedules. It is developed based on project records, inspection reports, minutes of meetings...etc. (Arditi, 1989; Alkass, 1993; Finke, 1999; Riad, 1994). Conlin et al (1997) mentioned three ways to prepare as-built schedules. One is to use the actual start and finish dates for planned activities to calculate the extended project duration, based on the original planned sequence. Another way is to compare the last monthly update to the initial schedule, assuming regular schedule updates. A third way is to prepare an as-built schedule that includes actual dates, while sequencing all of the activities, whether or not they were included in the planned schedule. The choice of method depends on which activities have been delayed or what kind of delay must be measured, what information is available, and how economical a method can be to use. Baram (1994) showed how constructing the as-built schedule from the available sources was the most difficult and time consuming exercise in any analysis.

c) Adjusted schedule

Adjusted schedules are prepared to explain how the schedule is impacted by different changes, delays, and accelerations. Starting with the as-planned schedule, the changes are incorporated into the schedule and a new adjusted schedule is created. This adjusted schedule is then considered as a benchmark for further analysis to create subsequent adjusted schedules (Riad et al., 1994).

d) Entitlement schedule

Entitlement schedules are used to show how original completion dates have been affected due to excusable delays. They also illustrate the projected completion dates given the remaining work and depict the difference between the adjusted and the projected completion dates (Alkass, 1996; Finke, 1999; and Battikha, 1994).

2.6 Delay analysis issues

2.6.1 Concurrency

Concurrency is one of the major challenges and is a controversial issue confronted by delay analysts. The main reason for this situation is the different definitions of concurrency and the different methods of calculating entitlements for the extension of time (EOT) and for calculating damages.

As per the SCL delay protocol (2002), “the term ‘Concurrent delay’ is often used to describe the situation where two or more delay events arise at different times, but their effects are felt (in whole or in part) at the same time. To avoid confusion, this is more correctly termed the ‘concurrent effect’ of sequential delay events.”

The AACEI RP (2007) mentions Literal Concurrency vs. Functional Concurrency to describe delays that are literally concurrent in time vs. those whose impacts are concurrent.

In order to come up with an accurate and fair analysis outcome, the concurrency issue has to be addressed. Many of the traditional analysis techniques ignore this aspect. Addressing the concurrency issue accurately requires a day by day analysis of delays and their impacts on a project's critical path dynamics.

Documenting delays in a basic format using the event identity concept (EIC), as will be explained in the next chapter, coupled with using a wider perspective of concurrency that includes all activities regardless of their criticality, will help to cover the concurrency issue. This addressing of the concurrency issue can best be achieved by using the Isolated daily window analysis technique (IDWAT), as will be explained in chapter 3.

2.6.2 Critical path dynamics (real-time analysis)

A critical path is defined as a chain of interrelated work activities with the longest path duration. "That longest path determines the earliest date that the project will finish" (Trauner, et al, 2009).

Critical paths in CPM-based schedules usually change as the project proceeds. Delays and other changes may cause noncritical activities to become critical and critical activities to become noncritical. Therefore, the critical path has to be evaluated on a day by day basis to get a full picture of the continuously changing status of the critical paths. This is especially important when evaluating delay impacts on schedules, because the criticality status of the impacted activity plays an essential role in the outcome of the analysis.

2.6.3 Delay Classification

To adequately apportion delays, the delay types have to be determined from a liability perspective (based on identifying the responsible party). Determining the three delay types: Owner delays (EC), Contractor delays (NE), and Third-party delays (EN) in a timely manner is a prerequisite of this analysis. With the types of delay defined, measuring the effect of each type on the overall project duration becomes a more reasonable task and the apportionment of the project delay can be more accurate.

The language in a contract plays a crucial role in defining the type of delay at hand. Based on different types of contracts, delay types may differ for similar delaying events. The expertise of the construction manager or of the analyst plays an important role in this regard. Expert frameworks especially tailored for specific types of contracts are used to help in classifying delays (Tribaldos, 1994).

2.6.4 Float Ownership

Trauner, et al. (2009) define float as "the amount of time an activity can be delayed before it begins to delay the project." In other words, when an activity's float is consumed by a delay, that delay then becomes critical, as it will affect the project's completion date. In a CPM calculation, an activity's float equals the difference between the late start and the early start or the difference between the late finish and the early finish of that activity. The early start and finish dates are the outcomes of the forward pass calculation of the CPM network, while the late start and finish dates are the outcomes of the backward pass calculation of the CPM network.

"Who owns the float?" has been a controversial question in CPM schedule analysis. Many approaches to sharing the float between owners and contractors have been suggested. Al-Gahtani (2009) introduced the latest method to allocate float, based on the risk assumed by each party. According to this approach, each party will be credited or debited based on the amount of total float change they induce as a result of delaying the critical or noncritical paths.

The most commonly used approach to float ownership is the project approach, the approach used in this research. According to the project approach, the float belongs to the project and both parties are entitled to consume it on a first-come, first-serve basis (Al-Gahtani, 2009). Trauner, et al. (2009) specified that either party can use the float, as long as "there is no adverse financial effect to the other party."

2.6.5 Acceleration

Acceleration occurs when the contractor performs the work earlier than the contracted project completion time. The acceleration is classified as one of the following:

1. Owner-directed acceleration, where the owner forces the contractor to finish the project ahead of the originally scheduled duration. In this case, the owner will be charged the costs of acceleration; or
2. Contractor-initiated acceleration, where the contractor accelerates the work and finishes earlier for his/her own benefit and motives. In this case, the contractor will not be compensated for the acceleration cost; or
3. Constructive acceleration, where the contractor has a justified claim for an extension of time and the owner refuses to extend the project duration and forces the contractor to finish as per the original duration. In this case the contractor may be compensated if the following conditions are met:
   A) The contractor experienced an excusable delay;
   B) The owner was informed about the delay and a request for time extension was submitted;
   C) The time extension request was refused or delayed;
   D) An order to finish the work within the original duration was issued; and
   E) Actual efforts were exerted by the contractor to accelerate the work and there is proof of extra cost (Cushman, et al., 2001).

2.7 Delay Analysis Techniques

In an attempt to have a standardized classification method, the RP of the AACEI (2007) employs a hierarchical classification framework comprised of five layers to classify CPM-based forensic schedule analysis methods. Table 2.1 shows the commonly-associated names for each of the taxonomic classifications, while Figure 2.2 depicts the taxonomy classes. The taxonomy layers are:

1. Timing: Prospective or Retrospective
2. Basic Methods: Observational or Modeled
3. Specific Methods: Observational Methods (Static Logic Observation, Dynamic Logic Observation) or Modeled Methods (Additive Modeling, Subtractive Modeling)
4. Basic Implementation:

a) Static logic observational methods that can be implemented in a gross mode or periodic mode.
b) Dynamic logic observational methods that can be implemented in contemporaneous/as-is or contemporaneous/split formats. They can also be implemented as modified or recreated.
c) The additive and subtractive modeling methods can be implemented as single-base or multi-base simulations.

5. Specific Implementation:

a) Fixed Periods vs. Variable Periods/Grouped Periods: These two choices of segmentation come with all of the usual specific implementations, except for the single mode and single base.
b) Global (Insertion or Extraction) vs. Stepped (Insertion or Extraction): This specific implementation takes place with the single base implementation that comes (sequentially) with the additive and subtractive modeling methods.

Most of the commonly-used techniques fit somewhere under one of the classes of this taxonomy, while some other methods may come under more than one class.

Taxonomy	Level													
	1	RETROSPECTIVE												
	2	OBSERVATIONAL							MODELED					
	3	Static Logic			Dynamic Logic				Additive				Subtractive	
	4	3.1 Gross	3.2 Periodic		Contemporaneous Updates (3.3 As-Is or 3.4 Split)		3.5 Modified / Reconstructed Updates		3.6 Single Base		3.7 Multi Base[1]		3.8 Single Simulation	
	5		Fixed Periods	Variable Windows	All Periods	Grouped Periods	Fixed Periods	Variable Windows	Global Insertion	Stepped Insertion	Fixed Periods	Variable Windows or Grouped	Global Extraction	Stepped Extraction
Common Names		As-Planned vs As-Built	Window Analysis		Contemporaneous Period Analysis, Time Impact Analysis, Window	Contemporaneous Period Analysis, Time Impact Analysis, Window Analysis	Contemporaneous Period Analysis, Time Impact Analysis	Window Analysis, Time Impact Analysis	Impacted As-Planned, What-If	Time Impact Analysis, Impacted As-Planned	Time Impact Analysis	Window Analysis, Impacted As-Planned	Collapsed As-Built	Time Impact Analysis, Collapsed As-Built

Table 2-1 nomenclature Correspondence (AACEI, 2007)

Footnotes
1. Contemporaneous or Modified / Reconstructed.
2. The single base can be the original baseline or an update.

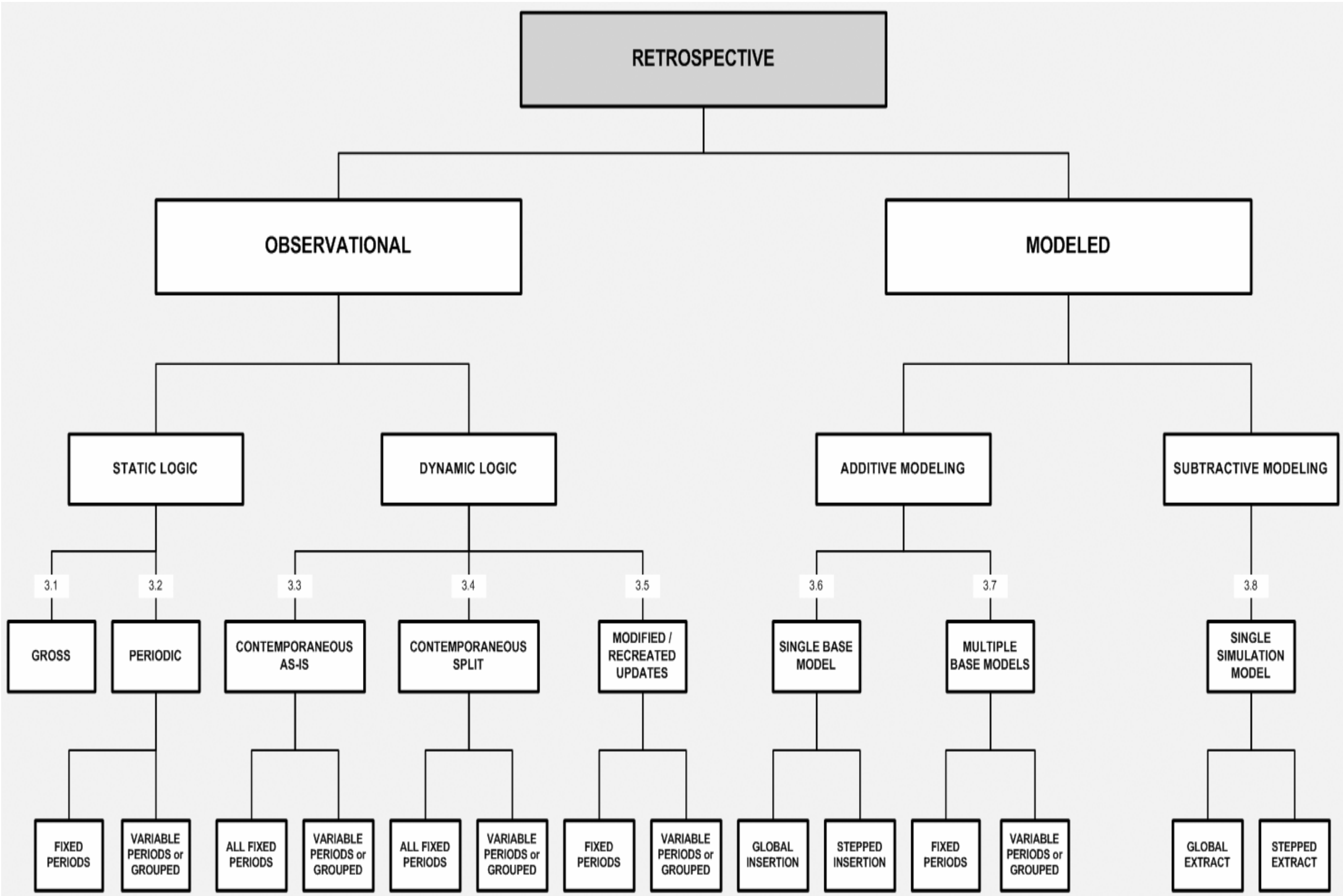


Figure 2-2 Taxonomy of Forensic Schedule Analysis (AACEI, 2007)

2.7.1 Global Impact Technique

The global impact technique is a simplistic way to show the impact of delays. In this technique; all delays are plotted on a bar chart. The start and finish dates of each delay are determined, and then the total project delay is the sum of all the delay durations.

There are many problems with this technique. It ignores the effects of concurrent delays, does not distinguish delay types, and it assumes that every delay has an equal impact on the project duration. These lacunae lead to exaggeration in determining the entitlement due to delays (Alkass et al., 1996).

2.7.2 Net Impact Technique

This technique depicts the net impact of all of the claimed delays on a bar chart. All delays are plotted on an as-built schedule and the net effect of all of the delays is calculated. The requested time extension is the difference between the as-built and the as-planned completion dates.

While it does attempt to deal with concurrent delays, this method does not examine delay types. Also, because a network is not used, the true impact of a delay on the overall project completion date is difficult to assess (Alkass et al., 1996). This technique uses what Bordoli (1998) calls the as-built bar chart.

2.7.3 Scatter Diagram

The scatter diagram method is a simplistic one, where the timing of irrelevant events is indicated throughout a project. The diagram is based on the as-planned bar chart, which is footnoted with the incidence of events affecting the project: variations in instructions, dates of information issue, etc. By supporting the scatter diagram with a detailed breakdown of each of the identified events, the negotiator is able to provide extensive information on each event and argue its impact on the overall schedule. Although the scatter diagram has little evidential value, it has a powerful visual impact in negotiations (Bordoli and Baldwin, 1998).

2.7.4 Adjusted As-built CPM Technique

This technique uses the CPM format to develop an as-built schedule. Delays are shown as activities and tied to specific work actions. The critical path is spotted twice, once in the as-planned schedule and once in the as-built schedule. The difference between the as-planned completion date and the adjusted as-built completion date is the amount of time the claimant would demand a compensation for.

This technique does not examine delay types. It is very much like the net impact technique except it uses the CPM, which makes it appear to be more sophisticated (Alkass et al., 1996). This method is called the ***as-built*** method by Conlin J. et al., (1997) and the ***as-built network*** by Bordoli and Baldwin (1998).

2.7.5 But-for (collapsing) Technique

The "but-for" technique uses the CPM format. It requires each party to inject all the delays that he/she is ready to accept responsibility for into the as-planned schedule. The updated schedule yields a revised project completion date which is compared to the as-built schedule completion date. The difference between the aforementioned dates is considered to be due to delays that were beyond the claimant's control. The "but-for" technique is also called the as-planned technique by some authors (Alkass et al., 1996; Conlin et al., 1997; and Zack Jr., 1999).

If a contractor were to use this technique to ask for a time extension, he/she would inject the non-excusable delays into the as-planned schedule. An adjusted schedule, with a revised completion date, will be produced. The difference between the revised completion date and the as-built completion date is considered to be due to delays that are the owner's fault (including third-party delays). If the contractor were to use this technique to ask for damages, he/she would inject the non-excusable delays and the excusable non-compensable delays into the as-planned schedule.

An adjusted schedule, with a revised completion date, would then be produced. The difference between the revised completion date and the as-built completion date is then assumed to be due to delays that are the fault of the owner (excluding third-party delays).

This technique does examine the delay types and it takes concurrent delays into consideration. However, it does not account for any changes in the CPM schedule during construction. Delays are injected into the as-planned schedule in a one-shot process without evaluating and accounting for the change in critical path that may occur.

Mbabazi and Hejazy (2005) introduced a Modified But-For delay analysis technique (MBF). A Venn diagram was used to represent concurrent critical delays to reconcile the varying results of different parties' perspectives.

2.7.6 Snapshot Technique (Windows)

In this technique, the project duration is divided into time periods or snapshots. The dates of these snapshots generally match project milestones or major changes or delays. The amount of delay to a project caused by a particular delay is determined by imposing the relationships and the durations of the as-built schedule within the snapshot period upon the as-planned schedule, while maintaining the relationships and durations of the as-planned schedule for the activities after the snapshot period. The amount of delay due to the delaying event during the snapshot is the difference between the extended project completion date (after the snapshot) and the as-planned project completion date before the snapshot.

This method is an objective and systematic way of measuring delays in a progressive manner. As more snapshots are applied, the more accurate the attained results will be. The snapshot technique accounts for concurrent delays and real-time CPM, but it fails to classify delays prior to the analysis, which necessitates additional investigation to apportion the entitlement (Alkass et al., 1996). This is called the window method by some authors (Bordoli and Baldwin, 1998; Finke, 1999; and Zack Jr, 1999), and the time impact approach (TIA) by others (Baram, 1994). It is also referred to as contemporaneous period analysis (Zack Jr., 1999). Baram went further, stating that almost every schedule analyst would agree that the use of the TIA/snapshot technique is the most desirable way to handle a delay claim, as long as data and source documents are available in the required format and in the required time frame.

A form of window analysis based on analyzing a delaying event or events (if within a reasonably short time frame) is also known as time impact analysis (TIA). With TIA, the analysis would be restricted to pre-identified causing events (Baram, 2000).

2.7.7 Time Impact Technique

The time impact technique focuses on a particular delay, and not on a time period containing delays. The concept is to compare the schedule just before a delay occurs with the adjusted schedule right after that delay. The difference between the completion dates is the effect of inserting a specific delay into the schedule. Although this technique considers the real time CPM, it fails to classify delays before the analysis and it does not address concurrent delays (Alkass et al., 1996 & Conlin et al., 1997). It is also known as baseline adding impacts (Bordoli and Baldwin, 1998).

2.7.8 Isolated Delay Type (IDT) Technique

The IDT technique combines the systematic approach of the time impact and snapshot techniques with the delay scrutinizing ability of the “but for” technique. It addresses classes of delays where delays are scrutinized in advance. It also addresses the real time CPM issues by systematically running the analysis within specified time periods. Although it covers the concurrency issue, the assessment of concurrent delays has to be performed manually prior to the analysis (Alkass et al., 1996).

2.7.9 As-built Subtracting Impacts

This method uses the as-built network as a basis, and then subtracts the delaying events to produce a 'no disruptions' program. This method produces a schedule revealing what would have occurred if no delays had happened. The impact of disruptions may then be evaluated (Bordoli and Baldwin, 1998).

2.7.10 FLORA (float, logic and resource allocation)

Nguyen and Ibbs (2008) presented FLORA, which addresses the effect of change in float, logic, and resource allocation on delay analysis. It deals with such changes simultaneously by using a predefined set of rules which are agreed upon by the project parties. Although it works for real-time and after-the-fact analysis, it is demanding, complicated and requires more records and information than other methods.

2.7.11 Daily Delay Measure

Livengood and Laush (2003) presented a tool called the daily delay measure. It allows an analyst to track activities on a regular basis (daily) and calculate the difference between the actual and planned activity data over the span of the activity duration. It is not a replacement of traditional analysis techniques, but rather an auxiliary tool to help to identify and represent delays.

2.7.12 Continuous Delay Measurement

Seals (2004) presented Continuous delay measurement (CDM), a tool to measure schedule variance. It draws attention to areas that need additional exploration. It does not determine causation or liability for measured delays.

2.8 delay Damages

Damages in construction delay claims are classified as either direct or consequential. Direct damages occur when specific project costs increase as a result of certain events, such as a delay. Consequential damages usually have an indirect link to project events, such as delays (Cushman, 2001).

As Cushman (2001) states, "construction costs are a function of three primary drivers: activity-related, time-related and combined activity, and time-related". Activity-related costs are the direct costs of labor and material. Time-related costs increase with time, as in the case of a project manager's salary. The cost of equipment has both activity-related and time-related components. The rent of equipment is time-related while the maintenance cost is usage-related, or in other words, activity-related.

For the purpose of this research, the equipment costs will be treated as direct costs like labor and material. These costs are usually recorded in the job cost reports. Although some authors differentiate between damages and costs, the two terms are used interchangeably in this research.

There are a number of damage pricing methodologies. The discrete cost approaches are the most effective. These approaches try to directly link events, such as owner caused delays, to an increase in activity-related or time-related costs. The total cost approach, the modified total cost approach, and the jury verdict method are among the other less effective damage pricing methods (Cushman, 2001). For the purpose of this research, costs and delays/accelerations are recorded on a daily basis which made it possible to use the discrete cost approach where increases in costs are directly linked to delays caused by the owner.

2.8.1 Contractor Damages

For the purpose of this research, the delay damages for a contractor are divided into direct cost, indirect cost (overhead cost), and impact cost (disruption cost). The three types of costs are explained in more detail below.

2.8.1.1 Direct Cost

Direct costs are the costs that are associated with specific tasks and could include costs for labor, materials and equipment. An increase of these specific project costs as a result of a certain event, such as a project delay is referred to here as a direct cost (Cushman, 2001). For example, the cost of idle equipment or labourers as a result of a delay is considered a direct cost.

2.8.1.2 Indirect cost (Overhead Cost)

Indirect costs are time related and are mainly the home office overhead cost and the site overhead cost. The site overhead cost is also referred to as a general conditions cost.

a) <u>Head Office Overhead:</u>

Head office overhead consists of a contractor's fixed costs of operating their principal or head office. It is in the head office that executive and administrative functions are performed on behalf of the contractor's entire organization. Head office overhead costs in a delay situation can represent a significant percentage of the overall delay damages.

The auditing or accounting standards employed by the owner can further restrict the definition of head office overhead. For example, under contracts governed by Federal Acquisition Regulation (FAR) cost principles, certain costs, such as those expended on marketing and entertainment may not be recovered as head office overhead. Under FAR, the contractor can only recover such costs through profit markup.

Normally, the contractor includes head office overhead costs in some part of the bid price for each project. Usually, the contractor calculates the final bid price by adding a percentage for this markup to the direct cost bid amount. The exact markup depends on the amount of home office overhead costs the contractor incurs in a given period, usually one year. The number of projects the contractor has under construction at any one time also affects the markup. There are various formulae to measure the effect of delay on head office overhead cost, including:

1. The Eichleay formula:

The Eichleay formula is a three-step formula to calculate (estimate) the head office overhead delay damages at the end of a project, after all the work and delays have been completed.

$$\textbf{Allocable Overhead} = \left(\frac{Total\ \ project\ billing}{Total\ company\ billing}\right)\text{(Total Head office Overhead)}$$

$$\textbf{Daily allocable overhead rate} = \frac{\text{Allocable overhead}}{\text{Number of days of contract performance (including delays)}}$$

$$\textbf{Head office overhead damages} = \text{Daily allocable overhead rate x Number of days of compensable delay}$$

The most commonly used argument against the Eichleay formula is that the contractor receives compensation for head office overhead by virtue of the markup on a change. The obvious problem with this argument is that the contractor receives this same markup whether or not the change causes a delay. Unless the markup clearly contains an allocation for the head office overhead, the argument that Eichleay should not be used may not be a valid one.

2. The Canadian Method:

The Canadian method uses the contractor's actual markup for overhead in its calculation. This markup is based on either the project bid documents or on an audit of the contractor's records. An audit would reveal the historical percentage markup for head office overhead as applied to each project. The Canadian method is depicted in the following formula:

$$\textbf{Daily overhead rate} = \frac{\text{Percentage markup} \times \text{Original contract sum}}{\text{Original number of days in the contract}}$$

$$\textbf{Compensation for home office overhead} = \text{Daily overhead rate} \times \text{Number of days of compensable delay}$$

b) <u>Site overhead cost:</u>

Site overhead costs, known also as general conditions costs or jobsite support costs, are time-related costs. These costs may be charged directly to the job but are not associated with any specific activity. In addition, these costs may be incurred throughout the project period. Examples of such costs are the salaries for the project manager, superintendent, engineers, and clerks. There are other jobsite costs related to trailers, vehicles, radios, temporary toilets, and other items (Cushman, 2001).

2.8.1.3 Impact Cost (disruption cost)

The impact cost refers to the cost incurred by the contractor as a result of inefficiency or loss of productivity. This loss of productivity may take place because of a disruption of the work sequence or a change of methods as a result of delays. In a disruption situation, the work may still be performed within time but at a higher cost.

There are many methods to quantify disruption damages; the following is a partial list:

1. Measured mile: In this method, actual hours and outputs (productivity) achieved during a period unaffected by disruption events are compared with those achieved in a period affected by one or more disruption events. The production achieved during the unaffected period is considered the measured mile. The difference between the hours required during the measured mile and those required during the affected period is said to be the loss due to the disruption factors. This method is accepted in the courts and endorsed by the SCL (Keane and Caletka, 2008).
2. Total cost approach: In this approach, the claimant quantifies the total costs incurred in a project and subtracts that amount from the estimated costs as per the bid. The damages

are the excess of actual over expected costs. Courts are reticent to allow a total cost approach. However, it has been allowed when the following conditions exist:

- The nature of the claim did not allow the use of other methods;
- The contractor’s estimate was reasonable;
- The contractor’s actual costs were reasonable and accurately documented;
- The overruns were not the responsibility of the contractor (Cushman, 2001).

3. Modified total cost approach: Under this approach, the claimant also subtracts the planned project cost from the actual costs; however, it then adjusts the difference for any increase in costs that are its own fault and adjusts the bid for errors, if appropriate. Although this approach is tighter than the total cost approach, in that the contractor is willing to accept responsibility for their own overruns, the approach still provides minimal links between the costs and specific claim issues (Cushman, 2001).
4. Jury verdict: this method may be available when no other approach is feasible. Under this method, the contractor must show that it incurred actual cost, there was not a reliable method available to calculate the damages, and that there was sufficient information to allow the court to fairly approximate the costs (Cushman, 2001).
5. Discrete cost approaches: These approaches are the most effective methodologies. They attempt to directly link the claim issues with increases in costs. For activity-related costs, the discrete approach links a causal event or action by the owner to an increase in activity-related costs. For time-related costs, the discrete approach links an increase in the duration of the project caused by the owner to an increase in time-related costs (Cushman, 2001).
6. Industry standards and handbooks: Many industry bodies have published standards and manuals that include some benchmark values of productivity for different trades and situations. The Mechanical Contractors’ Association of America (MCAA), the National Electrical Contractors Association (NECA), the Business Roundtable and R.S. Means are examples of these sources. However, caution should be exercised when using these manuals because of job-specific situations. An effort should be made to ensure that the activities identified in industry sources are truly identical to the work actually performed (Cushman, 2001).

2.8.2 Owner Damages

If a project is not finished on time, the owner may be subjected to many direct and indirect costs. The direct costs may contain extended costs such as personnel, cost of storage, interest fees for extending a construction loan, rental of a substitute facility and lost revenue. The indirect cost, referred to by Cushman et al. (2001) as “consequential damages”, may contain lost profit and the decrease of a business’s assessed value.

2.8.2.1 Liquidated Damages

Determining owner damages may not be an easy calculation, which is why many contracts typically include a liquidated damages clause. This clause entitles the owner to recover a certain amount of damages per day of project completion delay (Schwartzkopf, 2001). In order for this clause to be enforceable, the liquidated damages must be a reasonable estimate of the damages that will be sustained by the owner in the case of a contractor-caused delay.

2.8.2.2 Real Damages

The absence of a liquidated damages clause may lead to the need to calculate the actual damages incurred by the owner as the result of a delay in a project’s completion. These actual damages can be substantial and may include many direct and consequential damages, as mentioned above.

2.9 Delay and claim documents

Construction projects generate a substantial amount of data. This data is usually documented in either a paper form (hard copy) or an electronic form. Depending on the size and complexity of the project, the number of documents generated may reach tens of thousands. Some types of documents are more related to the delay and claims management -- these will serve as the data source for the database that will be developed at a later stage as part of this research. In a survey conducted by Elnajar and Yates (1997), the indicators for delays (documents) were ranked in order of their occurrence. The top seven documents for all sectors of the economy are: Schedules, Correspondence, Change order logs, Requests for information, Daily construction reports, Progress curves and Drawing logs. A total of 43 indicators were mentioned. The highest-ranking indicator had 733 occurrences, and the lowest-ranking ones only had one occurrence each.

Other types of records include personal diaries, minutes of progress meetings, photographs and weekly progress reports (Scott, 1990). Bu-Bshait (1990) mentioned memos, manpower curves, material procurement, purchase orders and delivery receipts along with some of the aforementioned records. In addition to some of the items mentioned earlier, Baram (1994) named cost and progress payments reports.

2.10 Databases

A database is a collection of persistent data that can be shared and interrelated (Mannino,2001). It is used to store, retrieve, and manipulate data. Database management systems (DBMS), which are commercially available, are usually used to create databases.

For the purpose of this research, data related to delays/accelerations, project tasks, resource costs, and supporting documents will be recorded in a database for further use during the schedule analysis and cost calculations.

Some of the records that are important to be included in a delay and claim database are: correspondence, minutes of meetings, daily progress reports, clarification memos, status logs, and photographs (Wilson R. L., 1982).

2.11 Delay analysis and computer applications

To deal with the vast amount of data encountered in construction projects, computers are being utilized in an ever-increasing manner. Their use involves on-site data collection (Russell, 1993; McCullouch, 1993) and comprises a variety of project management applications, including those related to claims processing.

There have been many efforts aimed at developing computer applications for delay analysis and claim preparation. This section will briefly summarize the previous works in this field.

Tribaldos (1994) developed an expert framework to classify delays and determine the costs associated with them. The framework deals with delays after the fact and does not analyze delays. Tribaldos' framework was developed as a stand-alone module.

Cooper (1994) incorporated the claims-related provisions of the A.I.A. A201 general conditions document into an expert framework that provides specific advice to contractors for the evaluation and processing of construction claims. His framework evaluates the general strength of the contractor's claim but does not address delay issues specifically. It deals with the problem after the fact and does not analyze delays or apportion responsibility.

Diekmann (1984) developed a framework using AI techniques called the differing site conditions analysis framework. This framework was patterned after the Federal Government Standard Form General Conditions (23-A, GP-4). It provides contract analysis from a legal point of view. It only deals with differing site conditions; one of the more common reasons behind delays. It also deals with claims after the fact and does not analyze delays or apportion responsibility.

Moselhi and El-Rayes (2002) developed a decision support framework that is designed to facilitate the analysis of weather-related construction claims. It quantifies the extent of delays due to weather by considering weather-sensitive tasks such as earthmoving, masonry and paving operations. This framework only analyzes delays associated with weather-related activities.

A hypertext information framework to assist in claims analysis was presented by Bubbers and Christian (1992). It provides a precise hypertext guide to contract wording, which in turn is linked to the relevant sections of various reference texts and descriptions of cases in which similar issues were determined. It only works for after-the-fact cases and has no delay analysis or damage quantification capability.

Some studies focused on integrating an expert knowledge base framework with existing control software to help in determining the causes of delays and suggesting actions to reduce them (Yates, 1993). This type of framework serves more as a project control tool and has no delay-impact calculation or apportioning of responsibility capability.

Spread sheets have been used to document site data on a daily basis and to construct as-built schedules (Hejazy, 2005a). They have also been used to introduce a daily windows delay analysis approach (Hejazy, 2005b). The spread sheets cells were used to construct a bar chart, where each cell represents one time unit of the activity duration and is used to record progress data. This approach cannot be used for large projects.

Alkass et al. (1995) introduced a system that integrates an expert system, a database and a project management system. The Isolated delay type (IDT) technique (Alkass and Mazerolle 1993; Mazerolle, 1993) was utilized in this framework. However, it is not a fully integrated framework and it requires frequent user interaction.

A database management system was developed to document and analyze construction claims in Kuwait (Al-Sabah et al., 2003). This management system deals with claims from an owner's perspective and from a statistical point of view and does not explore any delay analysis or damage quantification issues.

Evrenosoglu (2008) suggested using relational databases in forensic delay analysis. This relational database imports the as-planned and as-built activity data from *primavera,* after the fact. It cannot classify delays nor establish causation, and it involves a significant amount of data entry.

Conlin and Retik (1997) evaluated 16 different project management software packages. By conducting a survey, they evaluated the general, technical, and specialist features of these packages to assess their relevance to delay and claim management. Consequently, the packages were classified into four groups: base level, mass market, advanced and sophisticated. Data input, project tracking, reports, macros and data integration were rated as among the features to be considered when choosing the right software for claim and delay management. Table 2.2 summarizes the results of their evaluation

This literature review has indicated that there is a need for an integrated delay analysis framework in which delay issues can be tackled in a timely manner. These delay issues include documenting delays, quantifying delay impacts on project duration, apportioning project delay responsibility/costs between parties, and quantifying delay-associated damages.

Table 2-2Features of project management software (Conlin, 1997)

Table 1 Package features of project management software*

Product	Vendor	Tasks per project	Resources per project	Multiple calenders	Materials and costs	No. of views	Resource loading reports	Shows resource loading conflict	Resource levelling	Marks critical path	Macros	Dependencies	Operating system	Minimum memory	LAN	Minimum hardware	Issue disks	Additional languages	Price ‡	Category
Powerproject Horizon	ASTA Development Corp.	200,000	10,000	Y	N	5	Y	Y	N	Y	N	Y	DOS/W	2 MB	Y	80286	3.5&5.25	3	£845	MM
CA-Superproject	CA Ltd	Unlimited†	Unlimited	Y	Y	7	Y	Y	Y	Y	Y	Y	DOS/W	2 MB	Y	80386	3.5&5.25	9	£795	MM
Hornet 5000i	Claremont Controls Ltd	5000	128	Y	Y	0	Y	Y	Y	Y	Y	Y	DOS	640 kB	Y	80286	3.5&5.25	Fr&Sp	£3800	A
Hornet XK	Claremont Controls Ltd	5000	128	Y	N	5	Y	Y	Y	Y	N	Y	DOS	640 kB	Y	80286	3.5&5.25	Y	£2300	MM
Instalplan	Deepak Sareen Associates	Unlimited	Unlimited	Y	Y	7	Y	Y	Y	Y	N	Y	DOS	425 kB	Y	HD	3.5&5.25	Fr	£195	MM
Primavera (P3) 5.1	Forgetrack Ltd	Unlimited	Unlimited	Y	Y	0	Y	Y	Y	Y	Y	Y	DOS	640 kB	Y	HD	3.5&5.25	5	£3600	A
Artemis 7000	Lucas Management Systems	999,999	999,999	Y	Y	0	Y	Y	Y	Y	Y	Y	DOS/W	1 MB	Y	80386	3.5	Y	£5000	So
Artemis Schedule Publisher	Lucas Management Systems	12,000	Unlimited	Y	Y	0	Y	Y	Y	Y	N	Y	DOS/W	1 MB	Y	80386	3.5	Y	£995	MM
Microplanner V6	Micro Planning Ltd	1364	26	Y	Y	0	Y	Y	Y	Y	Y	Y	DOS/W	1 MB	Y	80286	3.5&5.25	Fr&G	£2956	A
Microplanner Profession	Micro Planning Ltd	Unlimited	26	Y	Y	0	Y	Y	Y	Y	Y	Y	DOS	640 kB	Y	HD	3.5&5.25	None	£1500	A
Pertmaster Advanced 2.4	Project Management Shop	Unlimited	Unlimited	Y	Y	0	Y	Y	Y	Y	N	Y	DOS	640 kB	Y	HD	3.5&5.25	None	£1250	MM
Project/2 Series X	PSDI Inc.	Unlimited	Unlimited	Y	Y	0	Y	Y	Y	Y	Y	Y	DOS	4 MB	Y	HD	3.5&5.25	Y	£3500	A
On Target v.1	Symantec (UK) Ltd	1500	Unlimited	Y	Y	0	Y	Y	Y	Y	N	Y	DOS/W	1 MB	Y	80286	3.5&5.25	4	£299	MM
Time Line v.5	Symantec (UK) Ltd	1500	300	N	Y	0	Y	Y	Y	Y	Y	Y	DOS	640 kB	Y	80286	3.5&5.25	5	£599	MM
Project Scheduler 5	Tekware Limited	2000	500	Y	Y	0	Y	Y	Y	Y	N	Y	DOS	640 kB	Y	80286	3.5&5.25	Fr&G	£550	MM
Open Plan	Welcome Software	Unlimited	1430	Y	Y	0	Y	Y	Y	Y	Y	Y	DOS	640 kB	Y	80386	3.5&5.25	Fr,G&M	£3250	So

HD, Hard Disk; W, Windows; LAN, Local Area Network. Fr, French; Sp, Spanish; G, German; and M, Mandarin. MM, mass market level; A, advanced level; and So, sophisticated level.
*All data contained in this table have been abstracted from the manufacturers' specifications obtained in the vendors survey.
†Unlimited in this instance means theoretically unlimited.
‡The figures denoting the price are the listed retail price for single user purchases without any discount. For further information and clarification the software house should be contacted. Prices have been sourced from reference 11. (Some price updates are available from *PC Magazine*'s survey, November 1995, published after the review of this paper.)

Table 2.2 features of project management software(Conlin,1997)

Chapter 3

ISOLATED DAILY WINDOW ANALYSIS TECHNIQUE (IDWAT)

3.1 Introduction

There are several delay analysis techniques out there, as elaborated in chapter two. Some of these techniques are more accurate than others, but most give different results, and sometimes the same technique gives different results depending on the user's choices (for example, window analysis results may differ based on the number of windows). Some techniques exaggerate certain parties' shares and others allocate shares that do not add up to the total project delay. Many of these delay analysis techniques do not consider the delays acting on non-critical activities, which may cause a distortion to the final results by failing to address the changes in critical paths due to the consumption of float.

As explained in section 2.5, there are a number of delay issues, such as concurrency, critical path dynamics, delay classification, and float ownership. For a delay analysis technique to produce accurate results, it has to address all these issues simultaneously.

An event identity concept is introduced in the following sections. This concept breaks delays down into micro levels where one can ensure that no delay will go undocumented while, at the same time, be sure that every delay is accounted for only once. This will help in avoiding the overestimation and under-estimation of delay impacts, producing results that are much more exact.

To analyze any concurrency situation, the different parties' entitlement to time and damages has to be addressed. The standard method for concurrency entitlements (hereafter called the Regular method) suggests that in a case of concurrency that involves contractors' and owner's delays, the contractor will only be granted an extension of time, which essentially treats it like a third-party delay (Kraiem,1987). The same method also suggests that whenever there is a concurrency that involves a third-party delay, the third-party responsibility will prevail and the contractor will also only be entitled to a time extension.

As an alternative to the standard method, an equal liability method (ELM) is introduced in the following sections. This method assumes equal responsibility for all of the parties participating in a delay, and hence apportions the entitlement accordingly. It also considers the fact that contractor and owner absorbed costs are not necessarily equal. This method is expected to give more accurate and fair results for all parties.

An isolated daily window analysis technique that considers the aforementioned delay issues and employs the delay identity concept in documenting delays is introduced in this chapter. This technique can be used with both the ELM and the regular method of concurrency entitlements. By extending the delay identity concept to include accelerations, the isolated daily window analysis technique can cover both accelerations and delays.

3.2 Activity level delays

Based on the responsible party, delay types can be designated as follows:

Owner-caused delay: O

Contractor-caused delay: C

Third-party caused delay: T

There are seven scenarios (combinations) of delay types that may occur during any activity at any given date. These combinations and the responsibility shares are represented in table 3.1, which depicts an activity with a nine-day duration, seven of which are delay days:

Day	1	2	3	4	5	6	7	8	9
Delay Type Combination	No delay	**O**	**C**	**T**	**O** **C**	**O** **T**	**C** **T**	**O** **C** **T**	No delay
Delay responsibility share on the activity level (days)		**O** = 1	**C** =1	T = 1	**O** = 1/2 **C** = 1/2	**O** = 1/2 **T** = 1/2	**C** = 1/2 **T** = 1/2	**O** = 1/3 **C** = 1/3 **T** = 1/3	

Table 3-1 delay type combinations and responsibility shares

3.3 Event Identity Concept (EIC)

For the purpose of this research, an event identity concept is introduced in which 'event' refers to a delay or an acceleration. Based on this concept, events are defined by assigning a unique identity for each event. This identity is accomplished by breaking down events into easily manageable time units. A day is usually the basic time unit used in scheduling construction projects.

In the case of delays and in order for a delay's identity to be unique, each delay is solely defined as the time unit delay (day) that is associated with a specific party (type of delay), and a specific activity at a specific time (date). In other words, the three determinants of a delay are:

1. The responsible party or the type of delay (O: EC,C: NE & T: EN);
2. The activity associated with the delay; and
3. The date (the day) of the delay.

In the case of a delay that affects a specific activity and has a duration of many time units (days), the delay is initially classified and then broken down into time units (days). Each delay day is recorded in the database (DB) as a delay that is associated with a specific activity on a specific date.

If two parties delayed an activity on the same date (day), two different delays will be recorded in the DB for that day, one for each party. Likewise, if the same party is responsible for a delay that has affected two activities in two parallel paths on the same date (day); there will be two delays recorded, one for each activity. Similarly, if the same party delayed the same activity for two consecutive days there will be two delays recorded, one for each date (day).

An ideal example for the last scenario is shown in Table. 3.2, where

Activity B has an original duration of 6 days and was affected by a work stoppage for two consecutive days due to bad weather (third-party (EN)). This work stoppage (the delay) occurred on days 3 and 4 of the activity. Two separate delays will be recorded for this activity:

1. Delay 1: A one-day third-party (EN) delay for activity B on day 3 of the activity duration.
2. Delay 2: A one-day third-party (EN) delay for activity B on day 4 of the activity duration.

Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8
		Delay 1	Delay 2				

Table 3-2 Activity B

For the purpose of this research, only full days of delay (work stoppage) will be considered, and only at their exact date of occurrence. If the work encountered a delay as a result of a slowdown (disruption), the assumption is that the work has stopped for as many time units (days) as the activity duration was extended.

Unless there is a complete stop of work with a specific date, the days of delay resulting from a slowdown (disruption) will be added at the end of the activity.

Based on this concept, for each project day (date x) and for any parallel number of activities (K activities), the number of delays stored in the database can be calculated based on the following equation:

$$\text{No. of delays at date x of the project} = \sum_{k=1}^{k=n}(\text{No. of delay types at date x of the activity K})$$

Where k = the number of activities at date x of the project.

The same concept can be extended to cover accelerations. However, concurrency of acceleration with other accelerations or delays at the same activity day is not allowed. For the purpose of this research, only full days of acceleration will be considered. Accelerations are either owner-directed (OA) or contractor-initiated (CA).

3.4 Equal Liability Method (ELM)

When owner and contractor delays happen concurrently, the resulting project delay is considered as a third-party delay, where the contractor is only entitled to an extension of time (EOT) (Kraiem, 2011). This implies that each party will absorb their own costs (extra direct, impact and overhead costs for the contractor and liquidated damages or actual delay damages for the owner).

With the classification and definition of delay on a daily basis, and by extending the concurrency to the activity day level, a new method of assessing concurrency can be introduced. This method is based on the concept of the equal liability of the three different parties; the owner, contractor and the third party are jointly responsible and equally liable for delays. For example, if both the contractor and the owner are responsible for delays on the same activity day, with EC and NE types acting on the same day, then the responsibility for the delay of that specific day should be shared jointly (50% for each party). This joint responsibility will allow a contractor to claim 50% of the entitled EOT and 50% of the encountered cost. The same is true for the owner when it comes to liquidated damages (LDs), where he/she will be able to claim 50% of those damages. This approach appears to be more accurate and fair for all parties because the costs to each party are usually not equal. Based on this method, four different scenarios of concurrency and entitlements are depicted in tables 3.3- 3.6 as follows:

Table 3-3 Owner and contractor delays acting on the same activity day

Party	**Share** of Responsibility	**Entitlement** To Extension of **time** (EOT)	**Entitlement** to delay **damages** (direct, impact and OH cost)	**Entitlement** to **LDs** or actual delay damages
Owner	1/2	N/A	N/A	1/2 (for the contractor's share)
Contractor	1/2	1/2 of the duration related to the delay day (for the owner's share of the delay)	1/2 of the cost related to the delay day (for the owner's share of the delay)	N/A

Table 3-4 Owner, contractor and third-party delays acting on the same activity day

Party	**Share** of Responsibility	**Entitlement** To Extension of **time** (EOT)	**Entitlement** to delay **damages** (direct, impact and OH cost))	**Entitlement** to **LDs** or actual delay damages
Owner	1/3	N/A	N/A	1/3 (for the contractor's share)
Contractor	1/3	2/3 of the duration related to the delay day (for both the owner's and the third-party's shares)	1/3 (for the owner's share)	N/A
Third party	1/3	N/A	N/A	N/A

Table 3-5 Owner and third-party delays acting on the same activity day

Party	**Share** of Responsibility	**Entitlement** To Extension of **time** (EOT)	**Entitlement** to delay **damages** (direct, impact and OH cost)	**Entitlement** to **LDs** or actual delay damages
Owner	1/2	N/A	N/A	N/A
Contractor	0	1 unit of the duration related to the delay day (for both the owner's and the third-party's shares)	1/2 (for the owner's share)	N/A
Third party	1/2	N/A	N/A	N/A

Table 3-6 Contractor and third-party delays acting on the same activity day

Party	**Share** of Responsibility	**Entitlement** To Extension of **time** (EOT)	**Entitlement** to delay **damages** (direct, impact and OH cost)	**Entitlement** to **LDs** or actual delay damages
Owner	0	N/A	N/A	1/2 (for the contractor's share)
Contractor	1/2	1/2 of the duration related to the delay day (for the third-party's share)	N/A	N/A
Third party	1/2	N/A	N/A	N/A

Based on the equal liability concept, the entitlements for single types of delay, acting alone, are depicted in Tables 3.7 – 3.9 as follows:

Table 3-7 Owner delay, acting alone

Party	**Share** of Responsibility	**Entitlement** To Extension of **time** (EOT)	**Entitlement** to delay **damages** (direct, impact and OH cost)	**Entitlement** to **LDs** or actual delay damages
Owner	1	N/A	N/A	N/A
Contractor	0	1 unit of the duration related to the delay day (for the owner's share)	Full cost related to the delay day (the full responsibility of the owner)	N/A
Third party	0	N/A	N/A	N/A

Table 3-8 Contractor delay, acting alone

Party	**Share** of Responsibility	**Entitlement** To Extension of **time** (EOT)	**Entitlement** to delay **damages** (direct, impact and OH cost)	**Entitlement** to **LDs** or actual delay damages
Owner	0	N/A	N/A	Full cost related to the delay day (the full responsibility of the contractor)
Contractor	1	N/A	N/A	N/A
Third party	0	N/A	N/A	N/A

Table 3-9 Third-party delay, acting alone

Party	**Share** of Responsibility	**Entitlement** to Extension of time (EOT)	**Entitlement** to delay **damages** (direct, impact and OH cost)	**Entitlement** to **LDs** or actual delay damages
Owner	0	N/A	N/A	N/A
Contractor	0	1 unit of the duration related to the delay day (for the third-party share)	N/A	N/A
Third party	1	N/A	N/A	N/A

3.5 Acceleration Rules

1. Accelerations are either Owner-directed (OA) or Contractor-initiated (CA).
2. Accelerations cannot coincide with delays on the same activity day. However, they can act on parallel activities on the same day (date).
3. Owner acceleration cannot coincide with contractor acceleration on the same activity day. However, they can be acting on parallel activities on the same day (date).

As demonstrated above, concurrency of accelerations and concurrency of accelerations and delays can only happen on parallel activities and not on the same activity. In order for the project to be accelerated on a specific day (date), all the critical path(s) should be accelerated on that day. On the other hand, it only takes one delay in one critical path to delay a project.

By using the IDWAT, as the next section explains in detail, delays/accelerations are inserted in the as-planned or in the current schedule of window n for each party individually to calculate the impact of each party's events (delays/accelerations) on the project duration. By calculating the impact of each party's events for a specific window, a number of scenarios may be detected, as follows:

<u>Acceleration/Delay scenarios for window n (day n)</u>:

1. The impact of either the owner or the contractor events for window n is a net acceleration of the project by 1 day. This scenario implies that there are no delays of any type acting on critical activities on that same day n.
2. The impact of one party's events for window n is a net delay of the project by 1 day. This scenario implies that there is no net project acceleration associated with either the owner or the contractor. It also leaves the door open for other net delay impacts of 1 day caused by either one of the other two parties. In the case of other net delay impacts, the delay has to be apportioned between the parties as per the Regular or the ELM methods.
3. The impact of each one of the three parties' events is zero days. This implies that there are no delays of any type acting on critical activities on that day. However, it leaves the door open for the existence of accelerations associated with the owner and/or the contractor that may be acting on critical activities on the same day (day n). These

accelerations, when inserted together, may result in a net acceleration of 1 day for the project, which will have to be apportioned between the owner and the contractor (- 0.5 days for each one, where the negative sign indicates acceleration in the project duration).

3.6 Acceleration-Delay Scenarios

When delays are encountered during construction projects, contractors are, in many cases, forced to make decisions to accelerate the pace of their work to mitigate a delay's effects and to avoid liquidated damages. The decision to accelerate or not depends, for the most part, on the comparison of the damages that would be incurred if the delays are allowed to occur versus the damages that would be incurred to accelerate the project.

As per the rules for acceleration, explained in section 3.5, accelerating a project requires accelerating all the critical paths, and delaying a project requires delaying at least one critical path. Hence, a comparison of the damages that would be incurred in acceleration and delay scenarios will concentrate on critical activities only. Based on this comparison, the decision can be made to accelerate or not.

One of the possible scenarios for examining this issue is to compare the cost of the total acceleration period with that of the total delay period. This scenario is relatively simple and entails an acceleration equivalent to the delay (encountered and/or to be encountered). Other scenarios could be investigated as well. One such scenario is to look at the cost of delays and accelerations on a daily basis. Because the critical paths are dynamic and because the costs incurred on critical paths are of concern in the comparison, the cost of acceleration and delays may differ on a daily basis. This will help the contractor to decide to accelerate some segments of the project and let other segments be delayed. Hence, it can be possible to make an optimum decision regarding the delay/acceleration-cost trade off.

An example of the latter scenario would be a project that has multiple critical paths that keep changing over the life of a project. In some segments of the project one critical path (one critical activity) may exist, while other segments may have multiple critical paths (multiple critical activities). These fluctuating critical paths will affect the daily cost that would be incurred in the case of delays/accelerations. In some segments, the daily cost of acceleration may be less than the daily cost of delay, which makes an acceleration in that segment justified. In other segments, the cost of acceleration may be more than the cost of the delays to be incurred, which means that the acceleration is not justified and the contractor would rather let the project be delayed in this segment.

Eliminating the total delay of a project (by acceleration) may be justified, but choosing which segment of a project to accelerate and which not to accelerate may even lead to additional savings (although not to eliminating all delays). In other words, the optimum scenario (from a cost perspective) may not necessarily be to eliminate all of the project delays (although eliminating all delays may lead to a net savings). The optimal situation may very well be to eliminate part of the delay (accelerating some segments and letting other segments get delayed). Also, the optimum scenario may be to let the project get delayed because it is simply less costly overall.

3.7 Isolated Daily Window Analysis Technique (IDWAT)

Delay analysis techniques differ in their accuracy and sophistication, depending on the details and on the amount of information available. Window analysis is one of the techniques that have gained credibility in the industry (Baram, 2000). The accuracy of this technique is very dependent upon the number of windows considered in the analysis; as the number of windows increases, the more that consideration will be given to the critical path dynamics and to the concurrency of delays.

If a window is relatively big, a shift in the critical path within that window is always a real possibility. This shift will go unnoticed and will not be considered in the delay calculations. The same applies to the concurrency issue and its relation to the critical path(s) within a window. The most accurate scenario of window analysis is to run the analysis based on the basic scheduling time unit (the day, for example), which will require updating information and making calculations on a daily basis. This daily analysis allows the full coverage of the critical path dynamics and of the concurrency of delay issues.

To get the most out of the window analysis technique, delays and accelerations (Events) must be identified on a daily basis, as they occur, based on the above-mentioned event identity concept. Defining event types before the analysis begins, along with breaking down the analysis windows to the basic scheduling time unit (day), will cover the following three aspects of schedule analysis:

1. Isolate event types as they happen (covering delay and acceleration types).
2. Account for changes to the critical path (covering critical path dynamics).
3. Account for changes to concurrent events (covering concurrency).

The window analysis (window schedule calculation) may need to be run many times for each project day, because in each project day, for a specific activity or parallel activities, a number of event-type combinations (including events acting on non-critical activities) may be encountered.

In addition to the regular method, the aforementioned equal liability method will be adopted in the isolated daily window analysis technique to apportion the responsibility for project time extension due to concurrent delays; thereby providing a means for the damages for each party to be determined. Fig. 3.1 shows a flow chart for the isolated daily window analysis technique.

As per the AACEI taxonomy (section 2.6), the isolated daily window analysis technique fits within the retrospective category of techniques. It can also be considered to be in the prospective category because it can be used to evaluate the impact of events before they happen. In addition, it also falls under the variable window, multi-base, additive, and modeled subcategories of techniques. Furthermore, it can be considered a dynamic logic technique, because the analysis is run on a daily basis that permits the consideration of logic change at any point in the schedule.

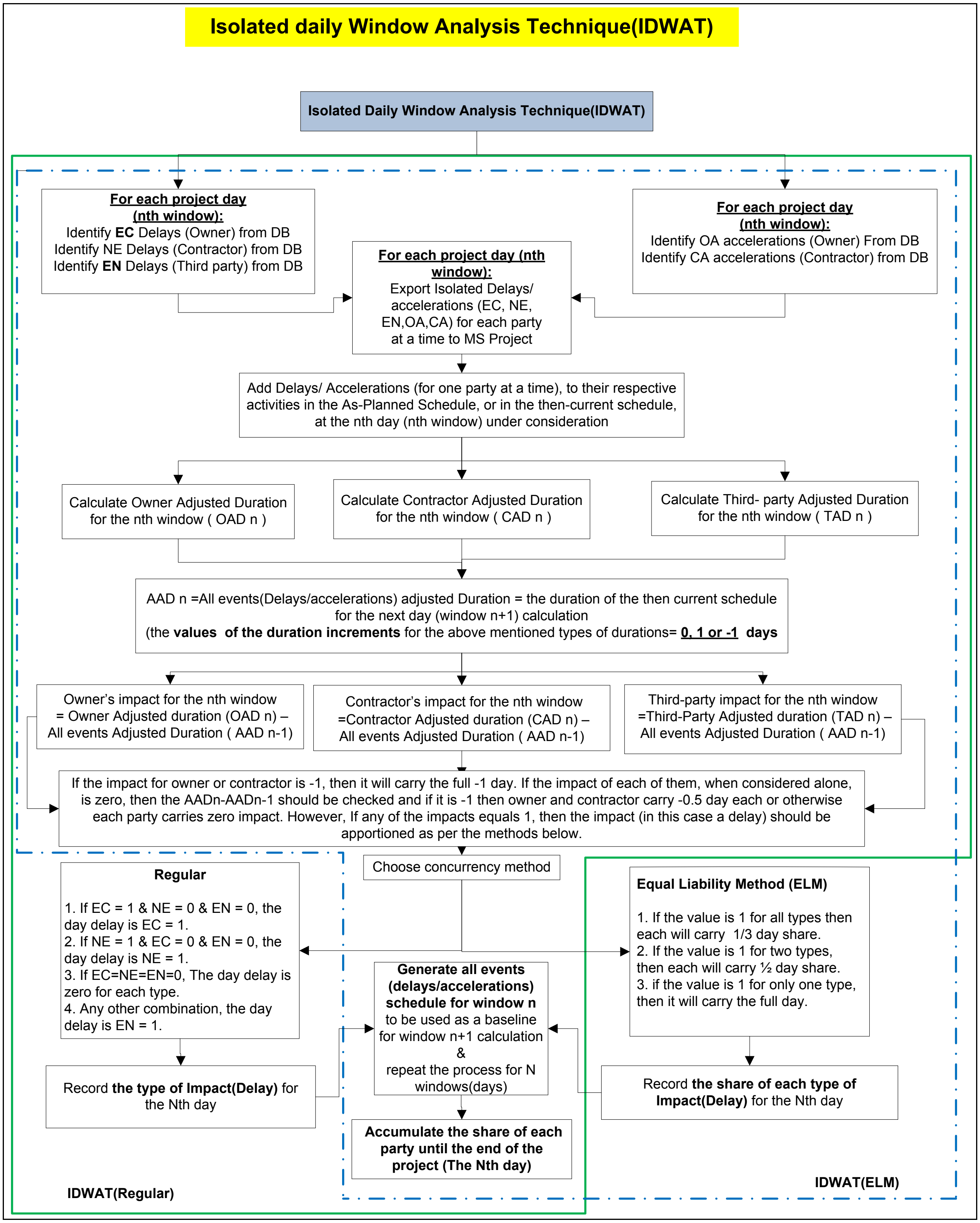


Figure 3-1 Isolated Daily Window Analysis Technique (IDWAT)

As can be seen from Figure 3.2, the technique starts by identifying the events for each project day (the nth daily window) and restores them from the database according to the responsible party (EC, NE, EN, OA and CA). These events were previously stored in the database based on the event identity concept, which uniquely identifies events by three determinants: activity, responsible party (Type), and date. So, by definition, each of these restored events has a duration of one day, is classified (EC, NE, EN, OA or CA) and associated with a specific activity and a specific date.

For the first daily window, the technique adds these events to their respective activities in the as-planned schedule, one party's events at a time. After adding the first party's events from the first window to their respective activities (EC delays and/or OA, for example), the CPM schedule is calculated to determine the impact of these events on the project duration. If a delay is inserted in an activity, its duration will be extended by one day. However, if an acceleration is inserted in an activity, its duration will be shortened by one day.

The newly-calculated schedule is called an adjusted schedule and its duration is called the adjusted duration. For each day, four adjusted schedules and four adjusted durations are calculated, one for each of the three parties and one for all the parties combined.

The maximums of the owner adjusted duration (OAD) n, the contractor adjusted duration (CAD) n, and the third-party adjusted duration (TAD) n are equal to the all-events adjusted duration (AAD) (the duration of the adjusted schedule generated by injecting all the parties' events), which is considered as a baseline or as the current schedule for the next window, n+1. The impact of each party for the nth window is calculated as follows:

Owner's impact for the nth window

= Owner Adjusted Duration (OAD n) – All-events Adjusted Duration (AAD n-1) (3.1)

Contractor’s impact for the nth window

= Contractor Adjusted Duration (CAD n) – All-events Adjusted Duration (AAD n-1) (3.2)

Third-party impact for the nth window

= Third-Party Adjusted Duration (TAD n) – All-events Adjusted Duration (AAD n-1) (3.3)

Although EC, NE and EN stand for delays caused by owners, contractors and third-parties, respectively, this definition will be extended to describe the impact caused by all three parties. A negative EC will indicate owner-caused project acceleration, while a positive EC will indicate an owner-caused project delay. A negative NE will indicate contractor-caused project acceleration and a positive NE will indicate a contractor-caused project delay. However, the EN can only take a positive sign, indicating a third-party-caused project delay, because third-party acceleration is excluded.

Since the duration of each of the events restored from the database is 1 day, the values of the delay impact of each of the parties for the nth window of the project will be 0, 1 or -1.

For each project day, the total impact of any number of concurrent events of one-day duration is 0, 1 or -1. The (-1) indicates a compression of one day in the project duration while the (1) indicates an extension of one day in the project duration. The impact of (1) day also indicates that there is a delay or there are delays acting on critical path(s) on that day. This one-day impact (delay) on the project duration will be apportioned between the parties, according to either the equal liability method (ELM) or the regular method. As per the ELM, the delay will be apportioned as follows:

1. If the value is 1 for all types, then each will carry a 1/3 day share;
2. If the value is 1 for two types, then each will carry a 1/2 day share; and
3. If the value is 1 for only one type, then it will carry the full day.

A delay share will be assigned for each party for that day.

According to the regular method for concurrency entitlements, the following rules will control the apportionment of the delay day:

1. If the EC impact = 1 day and the other two types have zero impact, the EC will carry the full day of delay;
2. If the NE impact = 1 day and the other two types have zero impact, the NE will carry the full day of delay; and
3. All other combinations of impacts, including the concurrency between EC & NE delays, will be considered as a third-party delay and the third party will carry the full day of delay.

An impact of -1 indicates that there are only acceleration(s) acting on the critical path(s) on that day. Hence, the impact will be allocated to the responsible party or apportioned between the owner and the contractor if both of them have accelerated parallel critical activities; thus a - 0.5 day for each.

This process will be repeated for all project days, one window for each day. The schedule that will be used for the next window (window n+1) calculation is the all-events schedule for window n. This schedule allows for the inclusion of all the events acting on window n regardless of the criticality of their respective activities at that window (date). Shares of the values of daily impact on project duration will be accumulated at the end of the project as EC, NE, and EN values (Owner, Contractor, and third-party impacts)

For both methods, the summation of the EC, NE, and EN impact shares will be equal to the total impact on project duration. However, individual shares of impact for different parties may differ, because the rules apportioning delays are different and because ELM allows the allocation of fractions of delay-days while the regular method assigns the full day of delay to one party at a time. For each method, a summary of the following values will be attained at the end of the analysis:

EC (OWNER) Impact

NE (CONTRACTOR) Impact

EN (THIRD-PARTY) Impact

TOTAL project Impact = EC (owner impact) + NE (Contractor impact) + EN (third-party impact)

Chapter 4

FRAMEWORK DEVELOPMENT METHODOLOGY

4.1 Introduction

The methodology and the process of developing an integrated framework for analyzing schedules and quantifying delay/acceleration damages in construction projects is presented and discussed. The framework consists of eight main components: a delay/acceleration database, a project scheduling system, data documentation module, schedule analysis module, direct cost module, impact cost module, overhead cost module, and liquidated damages module. The implementation of the framework will be elaborated in chapter five. The methodology of the framework development is divided into the following stages:

- Stage one involves designing the framework's relational databases for delays, accelerations, tasks, actual costs and documents.
- Stage two consists of designing and customizing new menus in the scheduling software to cover the delay analysis process.
- Stage three involves designing the framework's progress documentation forms to enter progress data concerning delays, accelerations, costs, and production rates.
- Stage four covers the design of schedule analysis modules based on the "but-for" technique and the previously-introduced isolated daily window analysis technique (IDWAT). The IDWAT-based module accounts for delays and accelerations.
- Stage five is where a module to calculate the direct cost encountered by contractors due to excusable compensable (EC) delays and/or due to OA accelerations is designed.
- Stage six covers the creation of a module to calculate the impact cost of delays on activities as a result of EC delays that occur in their predecessors.
- Stage seven consists of designing a module to calculate the overhead costs encountered by contractors as a result of EC delays.
- Stage eight consists of designing a module to calculate the liquidated damages encountered by owners as a result of NE delays.

- Stage nine is where an overall module that integrates the aforementioned stages and modules which target different levels of the project (project, activity, and activity day levels) is designed. This integrated module permits the transfer of project data between the database and the scheduling software and covers different framework modules.

4.2 Framework Features

Analyzing delays/accelerations and quantifying damages involves a significant amount of data gathering and entails the documentation of event details. It also requires the classification of delays/accelerations, calculation of the impact of different events on the total project duration and the apportionment of the total project delay/acceleration based on the respective responsibilities. In addition, it involves calculating the costs associated with delays/accelerations. These functions are usually performed by different applications, and some functions are still done manually. The framework integrates different applications and modules in order to perform a timely, reliable, automated, and economic schedule analysis and damage quantification. The steps utilized to develop this integrated framework are:

1. Designing and implementing relational databases for delays/accelerations, tasks, actual costs and documents.
2. Designing and customizing new menus in MS Project to cover the schedule analysis process.
3. Designing and implementing data documentation forms within the project scheduling system. These forms are used to enter the delay/acceleration and the actual cost and production data into the database on a daily basis.
4. Linking the scheduling system with the databases to facilitate data transfer for documentation, schedule analysis and cost calculation purposes.
5. Introducing an event identity concept to help document delay and acceleration data in a very basic form that covers all of the delay/acceleration scenarios.
6. Introducing and implementing an isolated daily window analysis technique (IDWAT) to help quantify delay/acceleration impacts and apportion project delay based on both the

suggested Equal Liability method (ELM) and the Regular method of concurrency entitlements.

7. Designing and implementing modules for calculating direct costs, impact costs, overhead costs, and liquidated damages.
8. Automating schedule analysis procedures.
9. Generating schedule analysis and costs reports.

4.3 Framework Components

The framework consists of the following components and modules: the database, scheduling software, a data documentation module, schedule analysis modules, a direct cost module, an impact cost module, an overhead cost module and a liquidated damages module. Figure 4.1 depicts a flow chart of the framework's components.

The cost calculation modules are based on different levels of the project and are interrelated with other components of the framework in different ways. The direct cost module, for example, is based on the activity-day level, while the impact cost is based on the activity level, and the overhead and liquidated damages modules are based on the project level. Also, while the overhead cost and liquidated damages modules make use of the schedule analysis module, the direct cost module does not. Figure 4.2 shows a detailed flowchart of the framework where the targeted levels of the project and the relation with other components are presented for all modules. Figures 4.5, 4.6, 4.7, 4.8 and 4.9, presented in the following sections, show detailed flowcharts of the different components of the framework.

4.3.1 Database

A relational database was created to accommodate task information and delay/acceleration-related data such as delay/acceleration type, date, description, documents, and associated actual costs and production percentages. Detailed forms that make daily data entry possible as the project execution progresses were created within the scheduling software.

The database serves as a documentation tool for the storage and retrieval of project progress information concerning delays, accelerations, actual costs and production. This information can easily be accessed, retrieved and transferred to and from the scheduling software for schedule analysis and delay/acceleration damage calculations. Schedule analysis and damage reports are also generated via this database.

The user can find delay/acceleration-related data to support any claim that may arise as a result of delays/accelerations in an easily accessible and organized format. This obviously makes for time and cost savings. Microsoft Access is used as the database management system to create the database. Figure 4.3 shows the database's tables' relationships diagram.

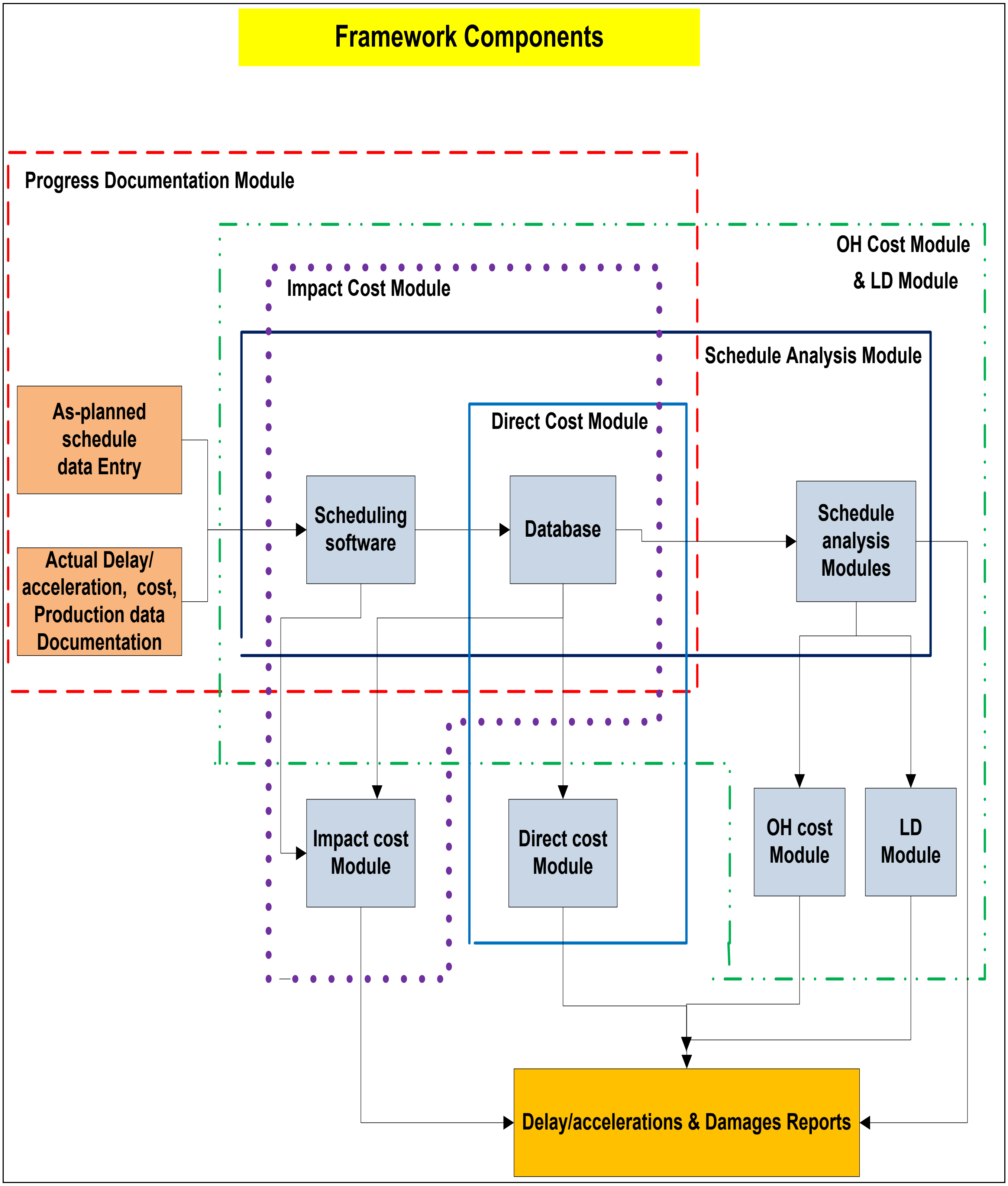


Figure 4-1 Framework components

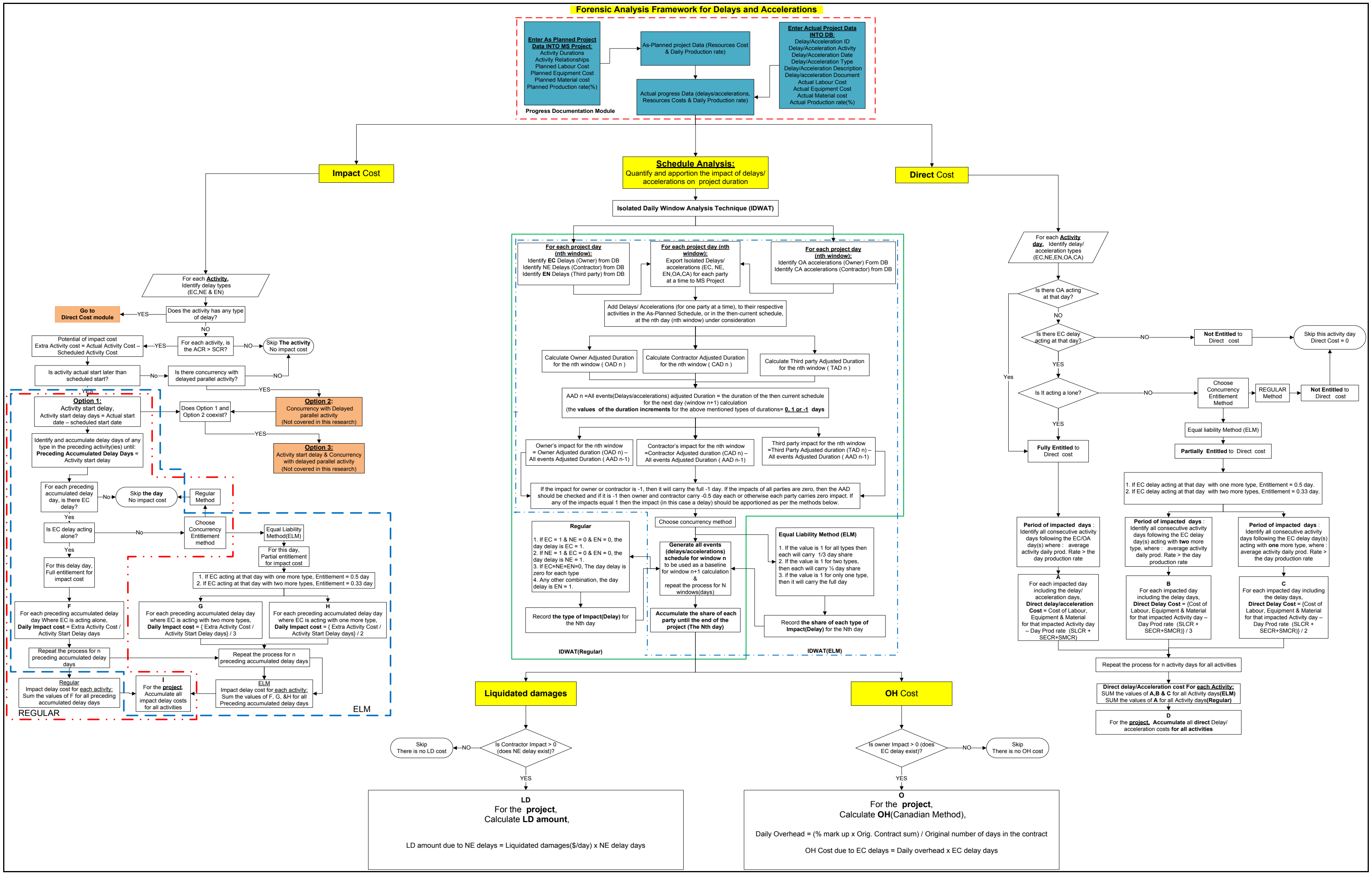


Figure 4-2 Integrated framework chart

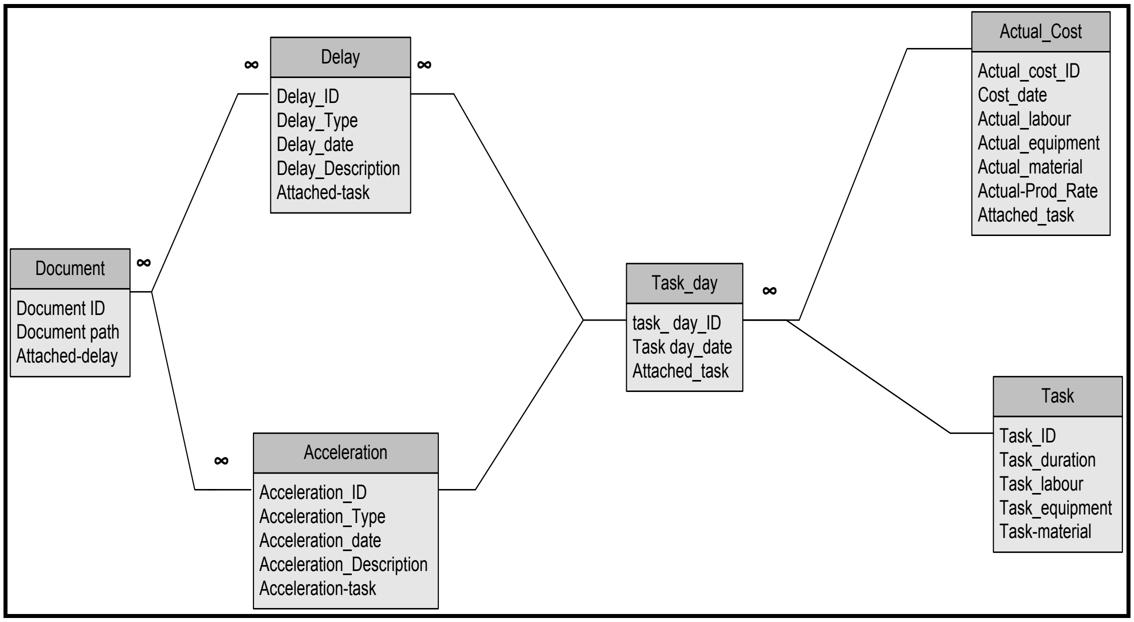


Figure 4-3 The ERD of the database

4.3.2 Progress Documentation Module

This component involves customizing MS Project (the scheduling software) to fit the requirements of the schedule analysis framework. MS Project is used as an interface wherein the user can perform all the framework functions from the MS project environment. This interface makes the schedule analysis and damage quantification functions smoother and easier to be integrated with the more routinely-conducted planning, scheduling, and control functions. The customizing is accomplished by creating a menu and submenus that cover the schedule analysis process. Through the use of some of these submenus, the delay/acceleration, the actual cost and the production data are entered into the database. Specially-designed forms for delay, acceleration, cost, and progress data entry are used for these tasks. The delay/acceleration data entry form allows the entry of delay/acceleration data for each activity at any given day of a project's duration. The same is true for the cost and progress data entry forms, where the data is entered for every activity on a daily basis. The data entry is performed for all activities regardless of their criticality status. Other submenus are devoted to the schedule analysis and damage calculation functions. As-planned, as-built, entitlement, and other adjusted schedules can also be created or restored by the scheduling software at any point of a project's life by using the submenu list.

4.3.3 Schedule Analysis Module

After acquiring the delay/acceleration data, the schedule analysis can be performed. This process involves measuring the impact of delays and accelerations on the duration of the project and allocating the responsibility to different parties, usually achieved by making use of schedule analysis techniques.

In this framework, the "but-for" technique and a technique introduced earlier called the "isolated daily window analysis technique (IDWAT)" were used.

4.3.3.1 "But-For" Technique

A schedule analysis module using the "But-For" technique was developed. Figure 4.4 shows a flow chart of the "But-For" module. In this technique, there are two points of view: that of the owner and that of the contractor.

Viewed from an owner's perspective, delays related to the owner and to any third party will be identified from the database and transferred to the scheduling software to be added to their respective activities in the as-planned schedule. A new schedule, "owner schedule", is then created and the owner's duration is calculated. The difference between the as-built duration and the owner's duration is the fault of the contractor's delays. The owner may claim liquidated damages based on this difference in duration.

On the other hand, from the contractor's point of view, delays related to the contractor will be identified from the database and added to their respective activities in the as-planned schedule. A new schedule, the "contractor schedule", is then created and the contractor's duration calculated. The difference between the as-built duration and the contractor's duration is the fault of the owner's delays, "including the third-party delays". The contractor may claim a time extension based on this duration difference.

If the contractor is seeking damage compensation, then the contractor and the third-party delays may be identified from the database and added to their respective activities in the as-planned schedule. A new schedule, "contractor and third-party schedule", is then calculated. The difference between the as-built duration and the "contractor and third-party" duration is the fault of the owner delays, "excluding third-party delays". The contractor may claim damages based on this duration difference.

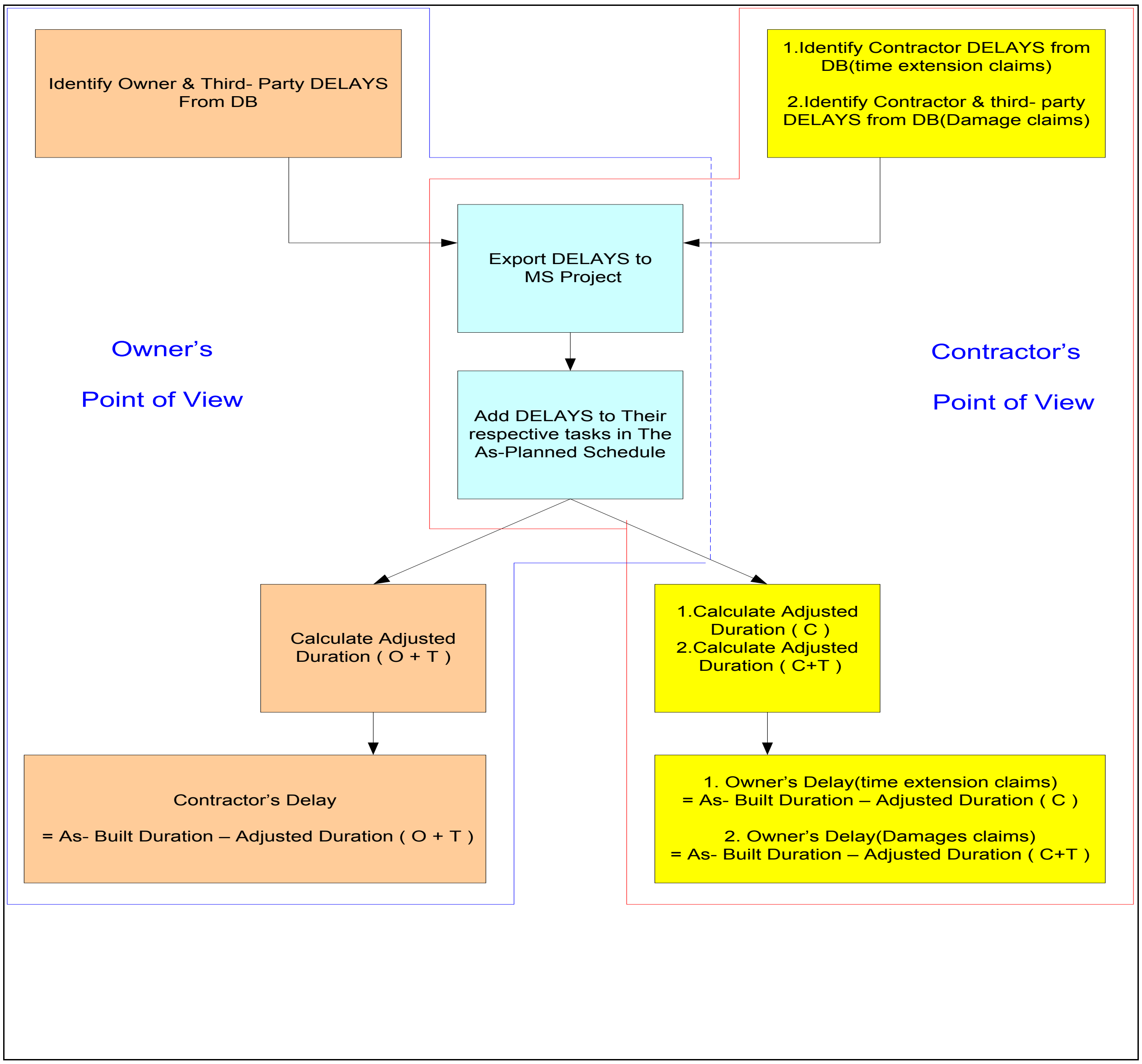


Figure 4-4 "But-for" Module

This module will be implemented in chapter five using Visual Basic for applications.

4.3.3.2 Isolated Daily Window Analysis Technique (IDWAT)

In this technique the project is divided into time frames (windows) of one-day duration for each window. This allows for all of the concurrent delays/accelerations and critical path dynamics issues to be covered. For delay concurrency, both the equal liability method (ELM), as explained in chapter 3, and the regular method will be adopted. Figure 4.5 depicts a flow chart of this technique.

The process starts by identifying the different types of delay/accelerations (EC, NE, EN, OA and CA) from the database on a daily basis. For each day, the events of the first party that has occurred on that day, for example, (EC) and (OA) owner events will be transferred to the scheduling software and added to their respective activities in the as-planned or in the "then-current" schedule at that day (window "n"). A new schedule with the owner-adjusted duration (OAD n) for window "n" will be calculated.

The same process is done for the other two parties for the same day (or window). In the case of NE and CA (contractor events), a second schedule with the contractor adjusted duration (CAD n) for window "n" will be calculated. In the case of EN (third party) delays, a third schedule with the third-party adjusted duration (TAD n) for window "n" will be calculated.

For each window, the increment (change in the duration) in each of the above-mentioned durations will be either 1 day , 0 days or -1 day depending on the type of events (delays or accelerations) and the criticality of their respective activities for that window (day). If the selected events include a delay or delays that affect a critical activity or activities, then the change in the duration will be 1 day. If the selected events include accelerations that affect all the critical activities, then the change in the duration will be -1 day. If there is no delay affecting a critical activity and there is no acceleration(s) affecting all of the critical activities, then the change in the duration will be 0 days.

The impact on the project duration caused by different parties for the window "n" will be calculated based on equations 3.1, 3.2, and 3.3 given in section 3.6. The same equations are also depicted in Figure 4.5.

The calculated impact on project duration for window “n” is then recorded based on the party that caused it. For window “n”, a value of 0 days, 1 day or -1 day of project delay/acceleration for each party will be recorded as follows:

EC = 0, 1 or -1

NE = 0, 1 or -1

EN = 0, 1 or -1

The all-events adjusted duration for window n (AAD n) is the duration of the adjusted schedule generated by inserting all types of events in window n. The all-events schedule for window n is considered a baseline or a current schedule for the next window, n+1 and it includes all critical and non-critical events of window n.

The impact on project duration for window “n”, which is equal to AAD n – AAD n-1, will be apportioned between the parties. If the impact on the project duration for window “n” is 0 days, which is to say, if there were no delays affecting critical activities and there were no accelerations affecting all critical activities, then obviously the share for each party is zero (EC = NE = EN = 0).

If the impact on project duration for window “n” is 1 day, in other words, if there was a delay or there were delays in that window affecting critical activity or activities, then the resulting one-day project delay will be apportioned between parties. The Equal Liability Method (ELM) and the regular method will be used to apportion the delay as follows:

According to the Equal Liability Method (ELM):

1. If the value of the project delay is one for all three types, then each type will carry one-third of the project delay day for window “n”.
2. If the value of the project delay is one for only two types of delay, then each of these two types will carry half of the project delay day for window “n”.
3. If the value of the project delay is one for only one type of delay, then this type will carry the full project delay day for window “n”.

The share of each party for the project delay at window "n" is recorded.

On the other hand, based on the regular method the project delay will be apportioned according to the following rules:

1. If EC = 1 and NE = 0 and EN = 0, then the EC type (Owner) will carry a project delay value of 1 day for window "n".
2. If NE = 1 and EC = 0 and EN = 0, then the NE type (Contractor) will carry a project delay value of 1 day for window "n".
3. If EC = 0 and NE = 0 and EN = 0, then each delay type will carry a project delay value of zero days for window "n".
4. If any other combination of EC, NE, and EN delay values occurs, then the EN type (third-party) will carry a project delay value of 1 day for window "n".

In the regular method the project delay day for window "n" is not fractioned but rather allocated to one party as a full day.

If the impact on project duration for window "n" is -1 day, in other words, if there was an acceleration affecting the critical activity or there were accelerations affecting all critical activities, then the resulting -1day impact will be apportioned between owner and contractor as follows:

1. If the accelerations affecting the critical activities are all OA, then the owner impact = -1day
2. If the accelerations affecting the critical activities are all CA, then the contractor impact = -1 day
3. If the accelerations affecting the critical activities are mixed (OA and CA) then the impact will be apportioned between owner and contractor, or -0.5 day for each.

The process of apportioning the impact on project duration is repeated until the end of the project for "n" windows (days). At the end of the repeated processes, the share of each type of impact (EC, NE, and EN), or in other words, the share of impact on project duration associated with each party (Owner, Contractor, and Third Party) is tallied. The end result will be impact amounts that are associated with each party. The sum of these amounts is the total impact on project duration, which is the difference between the as-built and the as-planned durations.

For the same project, the outcomes of using the Equal liability method and the regular method are equal as far as the total impact on project duration is concerned, but they may be different when it comes to individual party shares of the total impact. This is because in the ELM, the project delay day for any window "n" may be apportioned between the parties. This apportioning will affect the total share of each party and may cause the value for each party to contain fractions of a day. On the other hand, the regular method, as indicated above, calls for allocating the full project delay day for window "n" to only one party. As a result, the final value for each party will not contain any fractions.

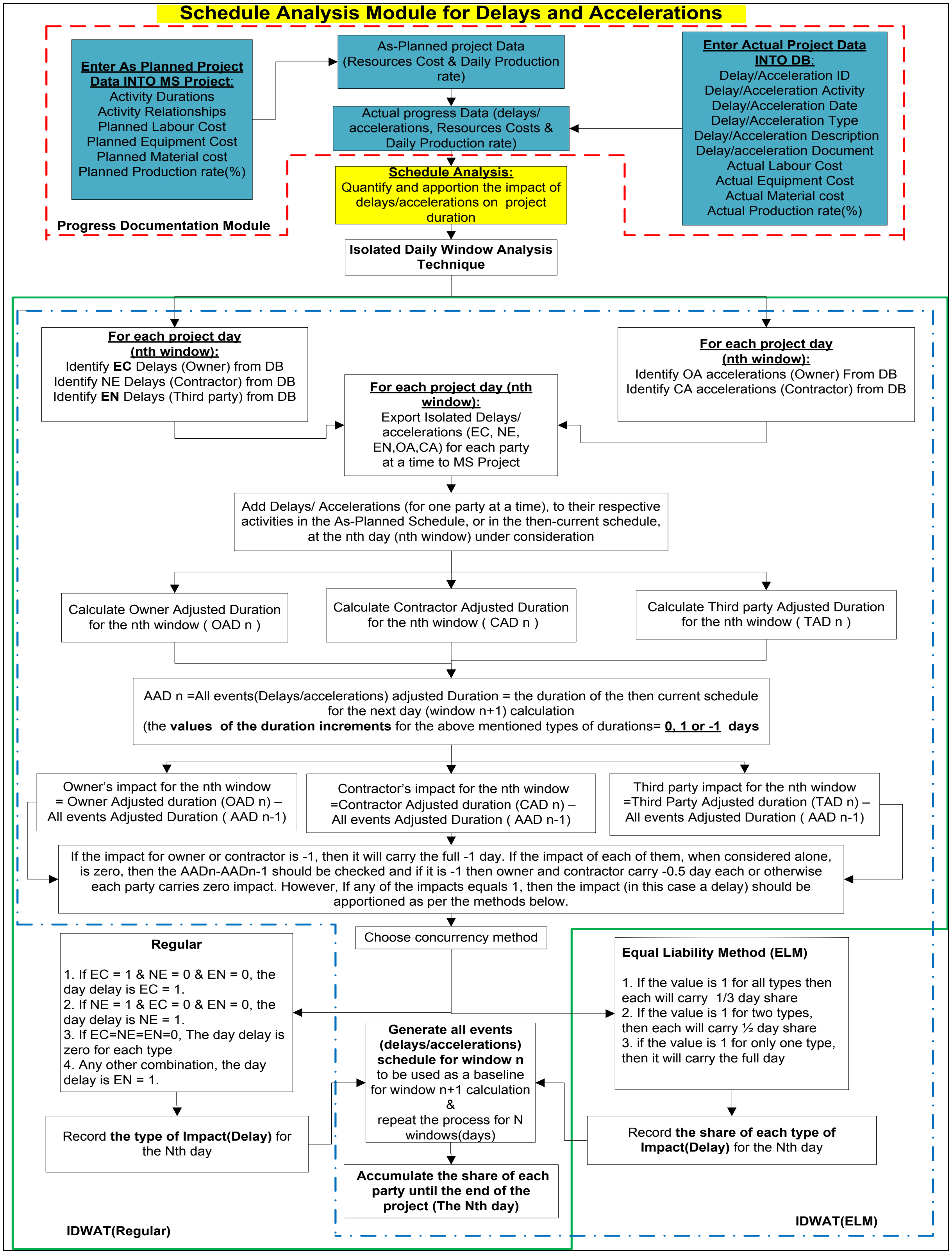


Figure 4-5 Schedule Analysis using Isolated Daily Window Analysis Technique (IDWAT)

4.3.4 Direct Cost Module

Direct cost refers to the cost of material, equipment, and labor associated with EC delays. For the purpose of this research, the direct cost is calculated on the activity day level. In each activity, days with recorded actual production less than the scheduled production are counted as the impacted days. These impacted days are affected by delays which are either total work stoppages or work slowdowns. When there is a total work stoppage, i.e., when production (percent complete) is equal to zero, the recorded cost of equipment, labor, and material for that activity day will be considered as the direct cost of delay. In the case of a slowdown, where production is higher than zero but lower than the scheduled production, the extra cost of equipment, labor, and material for that day is considered as a direct cost of delay. The extra cost is calculated by deducting the cost associated with the work performed (the earned value of the performed work) from the recorded actual cost of the impacted day. Generally, the direct delay cost or the extra cost for any given impacted activity day, whether it is due to a total work stoppage or due to a work slowdown, can be calculated using the following equation:

Direct daily delay cost = Actual daily cost (equip., Lab. & Mat.) – [(daily percent complete) x (SCR)] (4.1),

Where SCR: scheduled cost rate (cost per 1% of activity work) = Scheduled activity cost /100.

Since the direct costs that can be claimed by a contractor have to be caused by EC delays (owner delays), the direct cost model depicted in Figure 4.6 starts by identifying the delay type for each activity day from the DB. If there is no EC delay acting on the activity day under consideration, the day is skipped and deemed not entitled to direct cost calculation. If there is EC delay acting alone on the day under consideration, the day is considered to be fully entitled to direct cost calculations and the amount of direct cost is calculated using the aforementioned equation 4.1.

If the EC delay is acting on the day under consideration with one or two types of delays, then a concurrency method of entitlement should be applied. For the purpose of this research both the ELM and the regular method are applied, as discussed earlier in the schedule analysis module (section 4.3.3.2). If the regular method of entitlement is chosen, the day will not be entitled to direct cost calculation. If the ELM method is used, the day is considered to be partially entitled to direct cost calculation. The direct cost is first calculated using equation 4.1 and then divided by either two or three, depending on the total number of concurrently-acting delay types on that day. The result will be half of the direct cost of that day (as calculated by equation. 4.1) if there is an EC type acting with one other type of delay, and one-third if an EC type is acting with two other types of delay.

Direct cost calculations associated with owner-directed acceleration (OA) is also calculated using equation 4.1. If OA is acting on the activity day under consideration, it will be deemed fully entitled to direct cost calculation. As per the acceleration rules which were mentioned in section 3.5, there is no acceleration concurrency at the same activity. Hence there will be no need to apportion the acceleration-associated direct cost.

The process is repeated for every day in each activity, regardless of its criticality status. Next, the daily direct delay costs for all of the activity days are summed for each activity based on the selected concurrency entitlement method. The activity direct-delay costs are then accumulated to calculate the direct cost associated with EC delays on the project level. The same process is performed for the direct cost associated with OA accelerations.

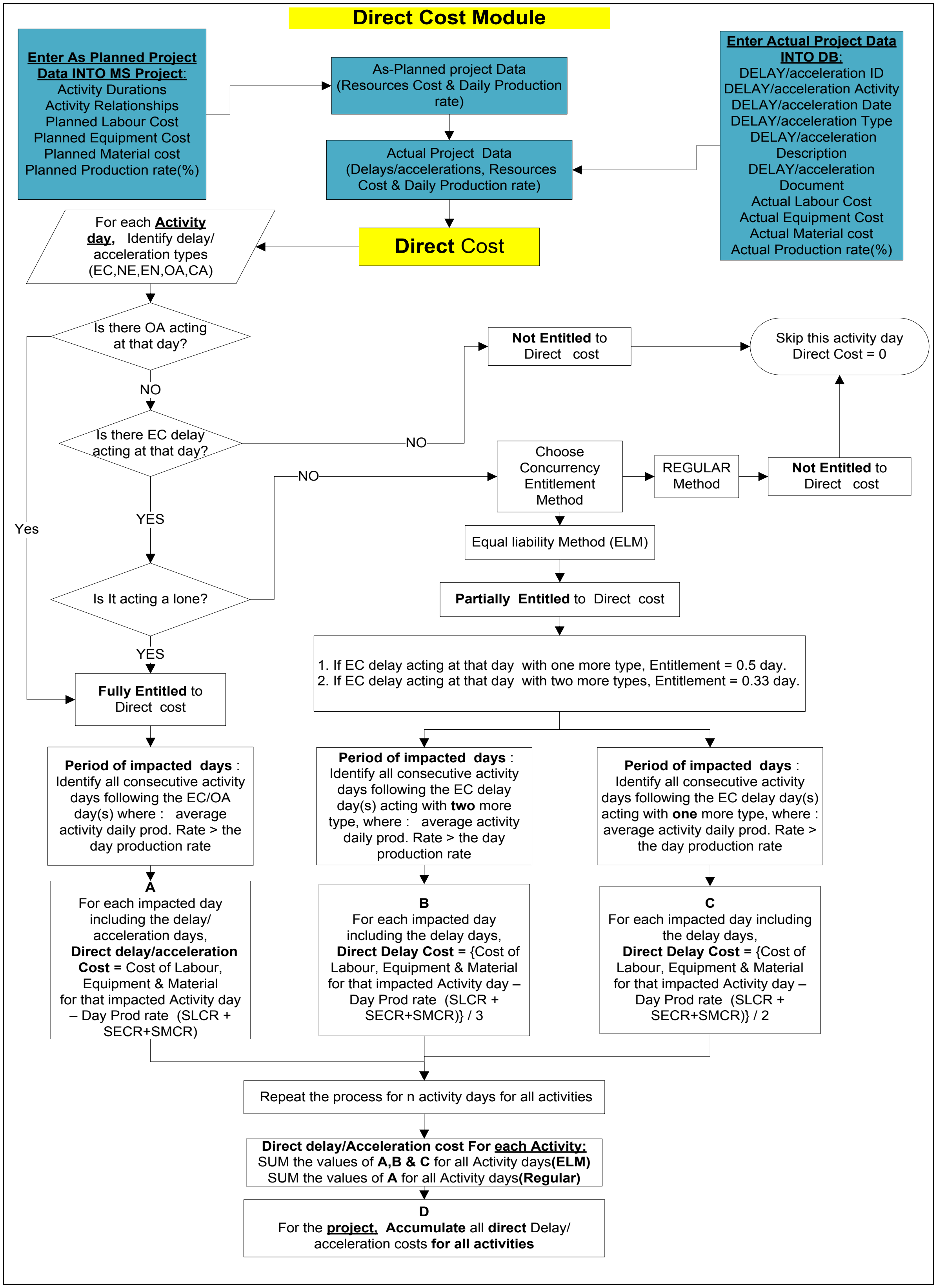


Figure 4-6 Direct Cost Module

4.3.5 Overhead Cost Module

The overhead cost refers to both the head office and the site overhead costs. The head office overhead can be determined based on the contractor's accounting records. The time-dependent items of the site overhead can be determined from the project bidding documents. For the purpose of this framework, a certain amount of daily overhead for both the head office and the site will be assigned as a value in the project database's constants table.

The overhead costs of delays are calculated on the project level and are directly related to the EC type (owner's) share of the project delay. The Canadian method is used in this framework to calculate the overhead cost of delays. Figure 4.7 depicts a flow chart of the overhead cost module.

The module uses the isolated daily window analysis technique (IDWAT) to calculate the EC (owner's) share of the project delay. It starts by identifying each party's delays/accelerations for every project day from the DB. These delays/accelerations are sent to the scheduling software to calculate their impact on the project's delay. The impact will be apportioned based on either the ELM or the regular method, as explained in section 4.3.3.2.

When the EC (owner's) share of the impact on the project duration (EC delay) is determined, the Canadian formula is then used to calculate the effect of the EC delays on the overhead cost. According to the Canadian formula, a daily overhead amount is calculated and multiplied by the EC delay to get the overhead cost of delays due to Owner delays as per the following equations (Trauner,T. J. et al, 2009):

Daily Overhead = (% markup x Orig. Contract sum) / Original number of days in the contract (4.2)

OH Cost due to EC delays = Daily overhead x EC delay days (4.3)

Similar equations can be used to calculate the site overhead costs by replacing the (% markup x Orig. Contract sum) in equation 4.3 by (Bid cost of time-dependent site overhead items).

4.3.6 Liquidated Damages Module

Liquidated damages refer to the damages incurred by the owner due to the contractor delay. Many contracts specify a liquidated damages rate ($/day). Similar to the overhead cost, liquidated damages are calculated on the project level by performing schedule analysis using the IDWAT. The NE delays are determined based on the schedule analysis results, and then multiplied by the liquidated damages rate as depicted in Figure 4.8

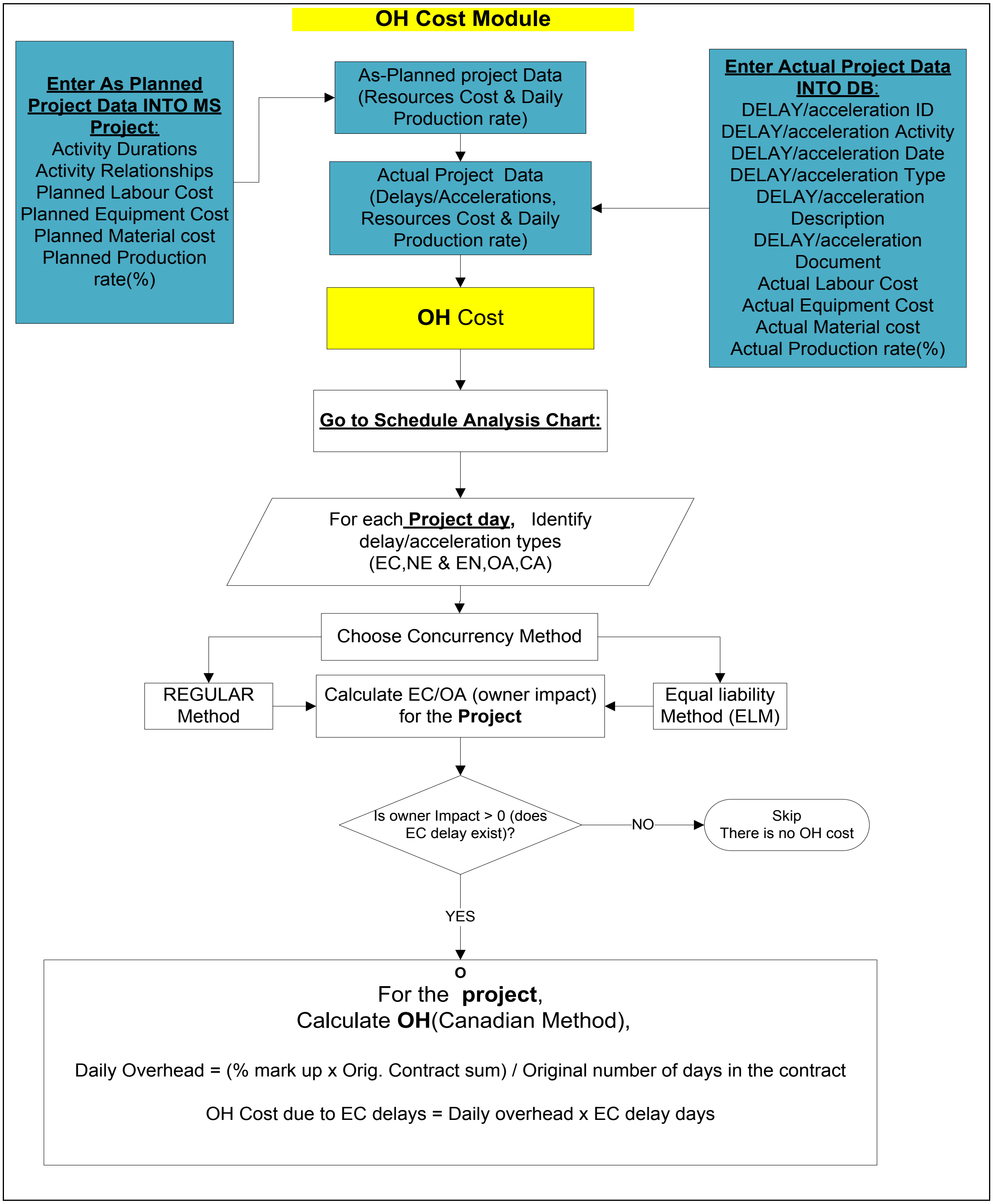


Figure 4-7 Overhead Cost Module

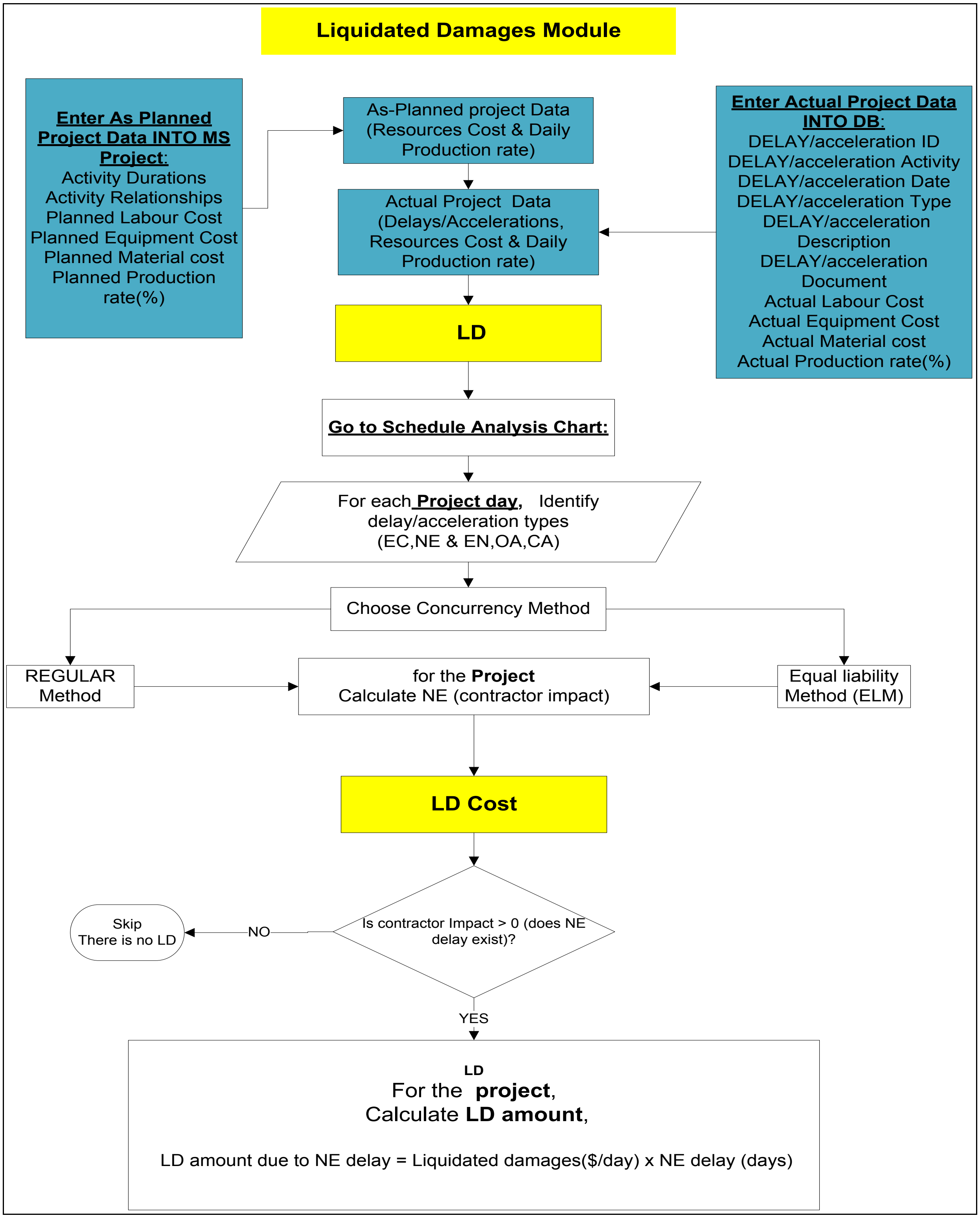


Figure 4-8 Liquidated Damages Module

4.3.7 Impact Cost Module

The impact cost refers to the cost incurred by the contractor as a result of owner delays in the form of lost productivity. The loss of productivity in a specific activity may occur as a result of delays in its preceding activities that may in turn cause the sequence or method of work to be disrupted. This is sometimes referred to as the ripple effect. The loss of productivity and the resulting impact cost are usually the most difficult components of delay damage quantification.

An extreme-case scenario of an impact cost situation for a specific activity (Activity A) would be a combination of the following circumstances:

1. The activity (Activity A) is directly affected by some or all of the three types of delays (EC, NE, EN).
2. The start of Activity A is delayed due to a delay or delays to one or more of its predecessors.
3. A concurrency with another activity (Activity B) on a parallel path, which would otherwise not exist, is caused by a delay to its start or duration or both, due to the fact that (Activity B) is directly affected by some or all of the three types of delays (EC, NE, and EN).
4. A concurrency with another activity (Activity B) on a parallel path, that would otherwise not exist, is caused by a delay to its start due to a delay or delays to one or more of its predecessors.

As can be seen from the circumstances listed above, more scenarios can be generated depending on the combination of circumstances, delay types, and number of activities involved. This makes modeling the impact cost calculation for an activity an extremely difficult and time-consuming task.

For the purpose of this research, only activities that are not directly affected by delays/accelerations will be considered for impact cost calculation. These activities will be further scrutinized for an-over budget situation in order to be eligible for further consideration. For this category of activities, the following options may exist:

Option 1: If Activity A is eligible for impact cost calculation according to the conditions listed above, and if its actual start is later than the scheduled start, then a delay due to predecessor activity/ies must be investigated further. This is the option adopted in this research, as the impact cost module investigates this option and takes no further action towards the remaining two options.

Option 2: If Activity A is eligible for impact cost calculation and its actual start is not later than the scheduled start (Option 1 does not exist), then the situation of an impact cost due to a concurrency with a delayed parallel activity (Activity B) must be investigated further. Activity B may be delayed directly or due to delay(s) at one or more of its predecessors. This option is not included in this research, but could be pursued as an extension of the module in future studies.

Option 3: This option occurs when option 1 and option 2 are both applicable and a concurrency of the impact costs exists. This option further complicates the calculation of the impact cost and is also disregarded in this research.

For the purpose of this research, the impact cost is manifested as the extra direct cost of activities that are not directly delayed (they do not have delays of their own). In other words, activities whose durations are not extended but that still suffer a budget overrun. This budget overrun is presumably due to a delay in the activity's start as a result of a delayed predecessor that may have caused a disruption and loss of productivity.

The impact cost module depicted in Figure 4.8 starts by identifying the types of delays/accelerations for each activity. If the activity has any kind of delay/acceleration, it will be skipped, since it will be deemed not eligible for impact cost calculation within the context of this research, as discussed earlier. This activity is still eligible for direct cost and must be considered for direct cost calculation.

If the activity has no delays/accelerations of its own, then its actual cost must be compared with its planned cost. If the planned cost is equal to or higher than the actual cost, then the activity is skipped, as it is not eligible for impact cost calculation. , However, the activity is considered eligible for impact cost calculation if the actual cost is higher than the planned cost. The value of the potential impact cost for that activity is deemed to be the extra activity cost, which can be further divided by the activity start delay days to get the value of the potential impact cost for every day of activity delay. These values may be calculated using the following equations:

Extra activity cost = Actual activity cost – Planned activity cost (4.4)

The daily impact cost = extra activity cost / Activity start delay days (4.5)

After determining an activity's eligibility for impact cost calculation, the activity start is scrutinized to see if it started later than its planned starting date. If it started later than its planned starting date, Option 1, which is the only scenario adopted for impact cost calculation in this research, will be applied as depicted in Figure 4.9.

If the activity start is not delayed, a concurrency with a delayed parallel activity should be investigated. If such concurrency exists, then an option 2 situation, as depicted in figure 4.8, would be applicable. For the purpose of this research option 2 was not included as an impact cost calculation scenario. On the other hand, if there is no concurrency with a delayed activity, the activity will be skipped and no impact cost will be calculated.

A third option will evolve as a result of the coexistence of option 1 and option 2. In other words, if a delay in the start of an activity eligible for impact cost is combined with a concurrency of that activity with another delayed parallel activity, then a third scenario (Option 3) will be applicable. Option 3 is also excluded from the impact cost calculation scenarios in this research. This will leave us with option 1, which involves an over-budget activity that is not directly affected by delays but that has a start delayed as a result of delayed predecessors.

The module proceeds by identifying and accumulating the delay days of any type in the preceding activities, until the following equation is satisfied:

Preceding accumulated delay days = Activity start delay days (4.6)

Each preceding accumulated delay day will be scrutinized for types of delays. As the impact cost is directly related to the existence of EC delays, if there is no EC delay type in that specific preceding accumulated day, then the accumulated day will be skipped, as will one of the activity start delay days, and no impact cost will be calculated for that day. This part of the module propagates backwards and attempts to accumulate delays that are equal to the activity start delay.

If there is an EC delay in the preceding accumulated day and it acts alone, then an equivalent activity start delay day will be fully entitled to a daily impact cost calculation, as per the aforementioned equation. 4.5

If the preceding accumulated day has an EC delay acting with one or more types of delay, then a concurrency situation exists and must be resolved. The entitlement and outcome of the impact cost calculation depends on the concurrency entitlement method chosen. If the regular method is used, then the accumulated day will be skipped, as will one of the activity-start delay days, and no impact cost will be calculated for that day. On the other hand, if the equal liability method is used, an equivalent activity start delay day will be deemed as partially entitled to impact cost. This partial impact cost will be calculated as follows:

1. If the EC is acting with only one additional type of delay, the daily impact cost will be calculated by:

   The daily impact cost = {extra activity cost / Activity start delay days}/ 2 (4.7)

2. If the EC is acting with two other types of delay, the daily impact cost will be calculated by:

   The daily impact cost = {extra activity cost / Activity start delay days}/ 3 (4.8)

Any delay that is preceded by acceleration in the backward delay accumulation process will not be considered, as it will be deemed as a consumer of the float that was created by the acceleration. Hence, the effect of a successive acceleration and delay of an activity (or a group of activities) on the start of the successor activity is zero.

In order to find the impact cost on the activity level, the process of scrutinizing types of delays and calculating impact costs for the activity under consideration is repeated for N preceding accumulated delay days, which are equivalent to the activity start delay days. Depending on the type of concurrency method and the types of delays encountered in the preceding accumulated delay days, the impact cost of each eligible activity is calculated by adding the daily impact costs for all the activity start delay days. The project level impact cost is obtained by repeating the process and adding up the impact cost for all of the eligible activities.

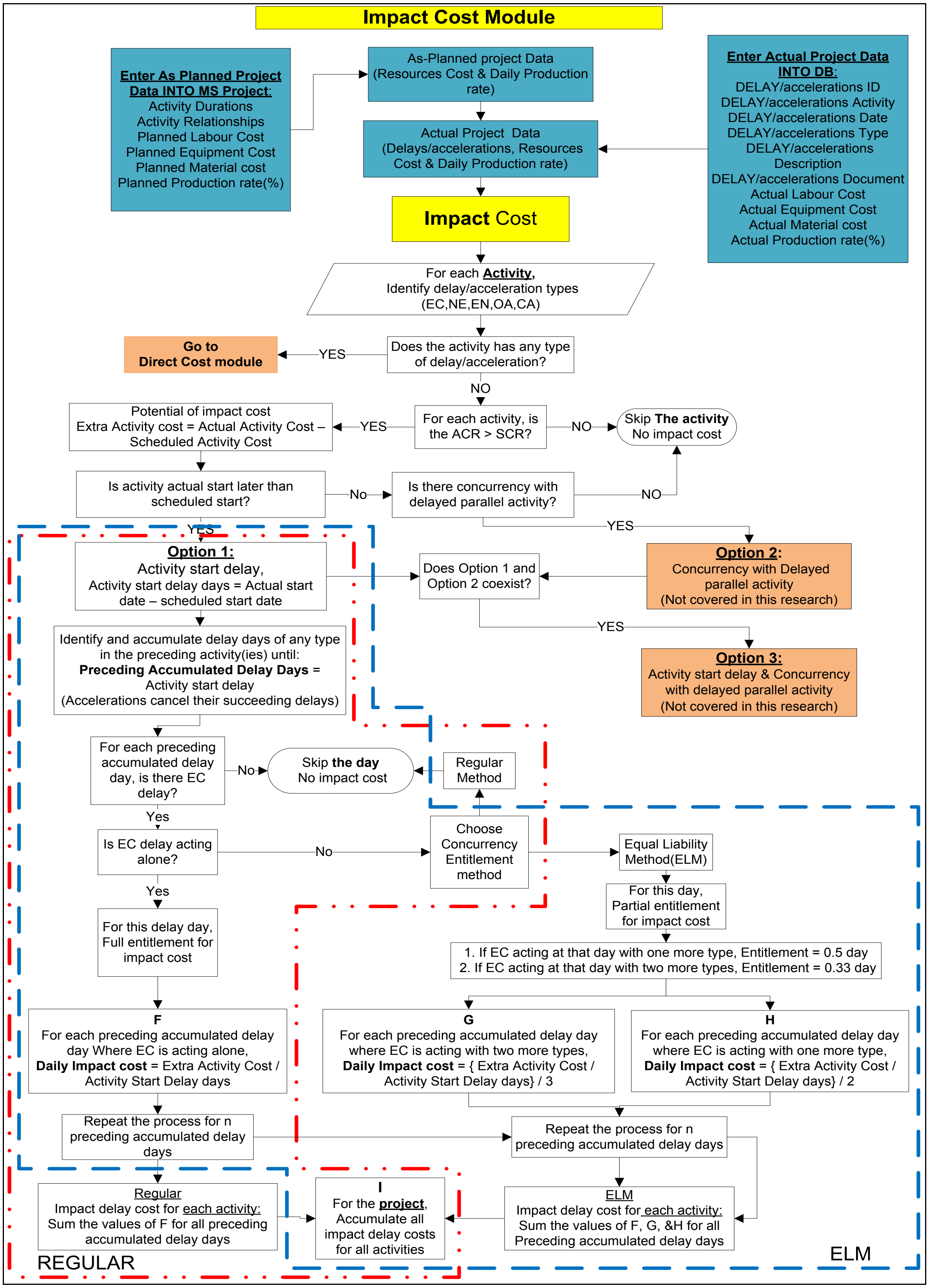


Figure 4-9 Impact Cost Module

4.3.8 Acceleration-delay Scenarios Modules

The direct cost module is modified to account for the cost with contractor acceleration (CA) and the cost without CA acceleration. The liquidated damages module is also modified to account for the damages associated with contractor acceleration (CA) and those without CA acceleration. Figures 4.10, 4.11 and 4.12 depict the modules for direct cost -- acceleration, direct cost --non-acceleration and liquidated damages -- acceleration/non-acceleration respectively.

Based on these modules, contractor acceleration (CA) cost and the liquidated damages for each scenario can be estimated. The net saving impact (NSI) for each scenario will also be calculated according to the following equation:

NSI = the maximum liquidated damages (LD max) – Liquidated damages of the scenario x (LD x) – Acceleration cost of the scenario x (AC x) (4.9)

Where:

LD max = maximum liquidated damages due to contractor delays (NE) before applying accelerations;

LD x = Liquidated damages of scenario x = NE delay days of scenario x (daily LD rate); and

AC x = Acceleration cost of scenario x = cost of contractor accelerations (CA) of scenario x (AC x includes the cost of all accelerated days in the scenario, and not only that of the last day)

The net saving impact (NSI) calculation for an acceleration scenario takes into consideration the liquidated damages and the acceleration cost of that scenario. The value of the (NSI) for each acceleration scenario will determine if the scenario is justified or not. If the NSI value is greater than zero, then the scenario is justified. If the NSI value is equal to or less than Zero, then the scenario is not justified. The highest NSI value indicates the best-justified scenario.

4.3.9 Visual basic for Applications Module

The framework implementation process will be explained in detail in chapter five. Visual Basic for applications was used to integrate the scheduling software (MS Project) with the database management system (Access). This integration is an essential step towards smoothing the data flow between the applications and automating the framework procedures. A progress data documentation module, delay analysis modules and delay damage calculation modules were all implemented using Visual Basic for applications. MS Project, with a customized menu list designed for schedule analysis, was used as an interface. This eased the schedule analysis and damage quantification procedures and made them an integral part of the daily scheduling and monitoring functions.

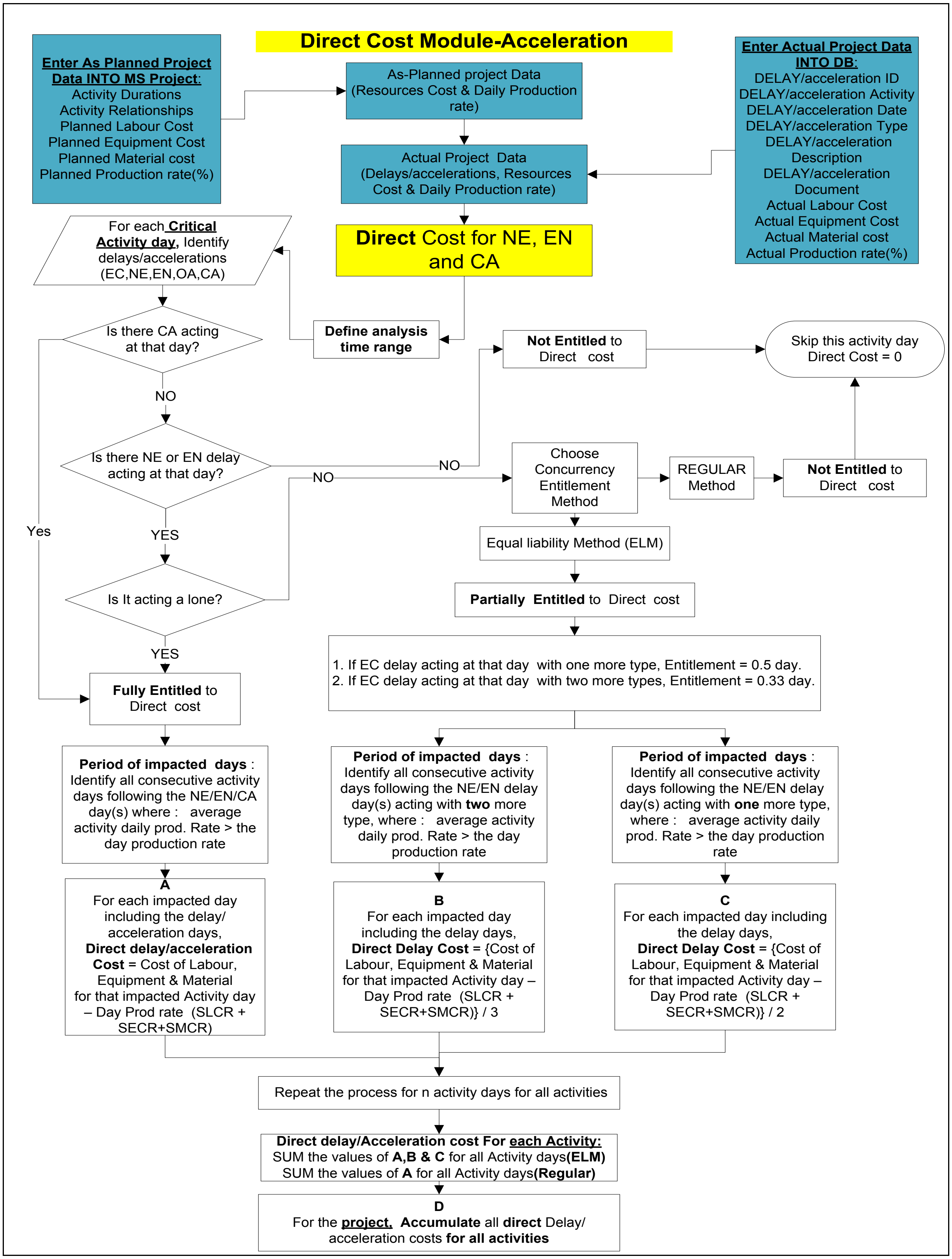


Figure 4-10 Direct Cost - Acceleration Module

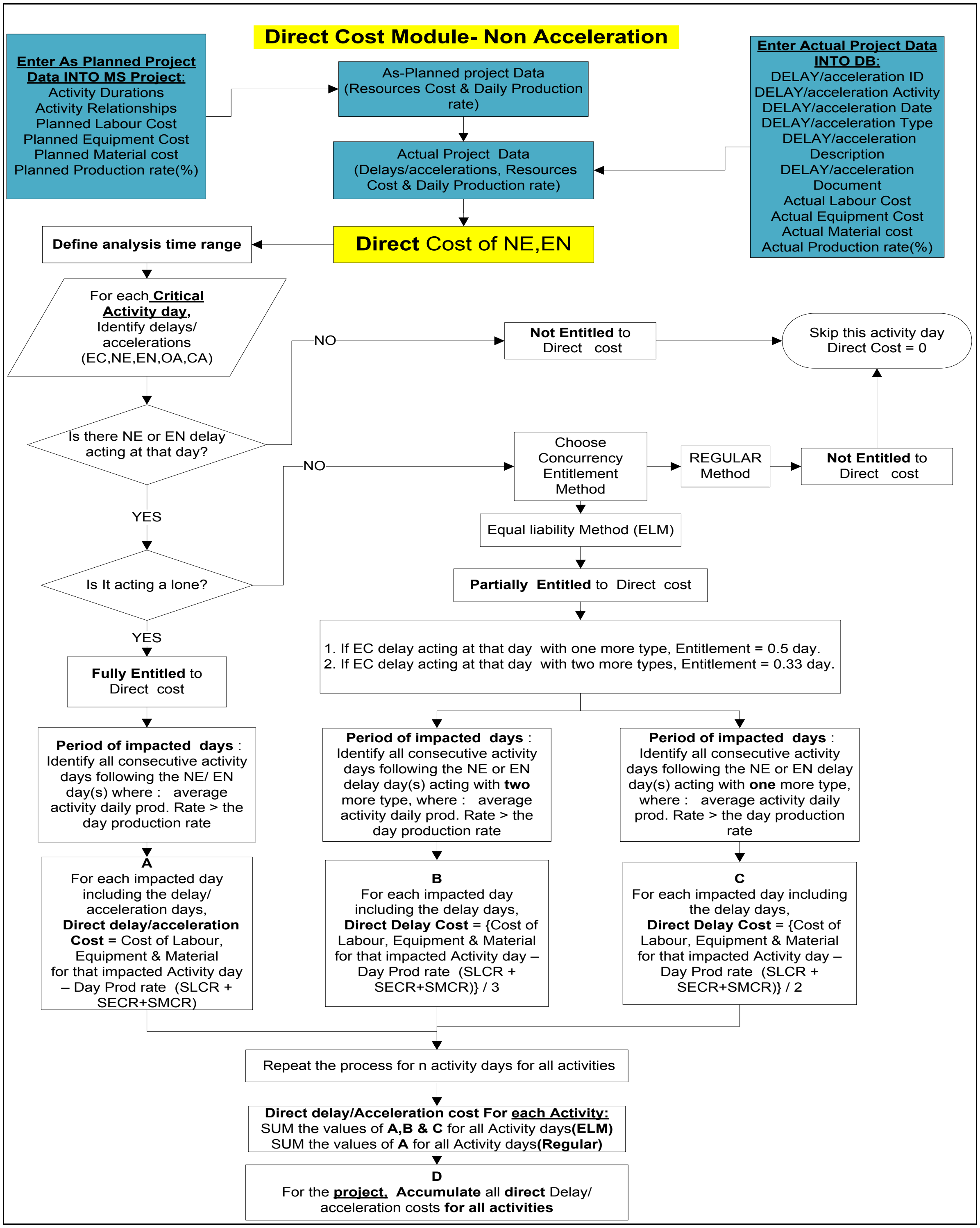


Figure 4-11 Direct Cost - Non Acceleration Module

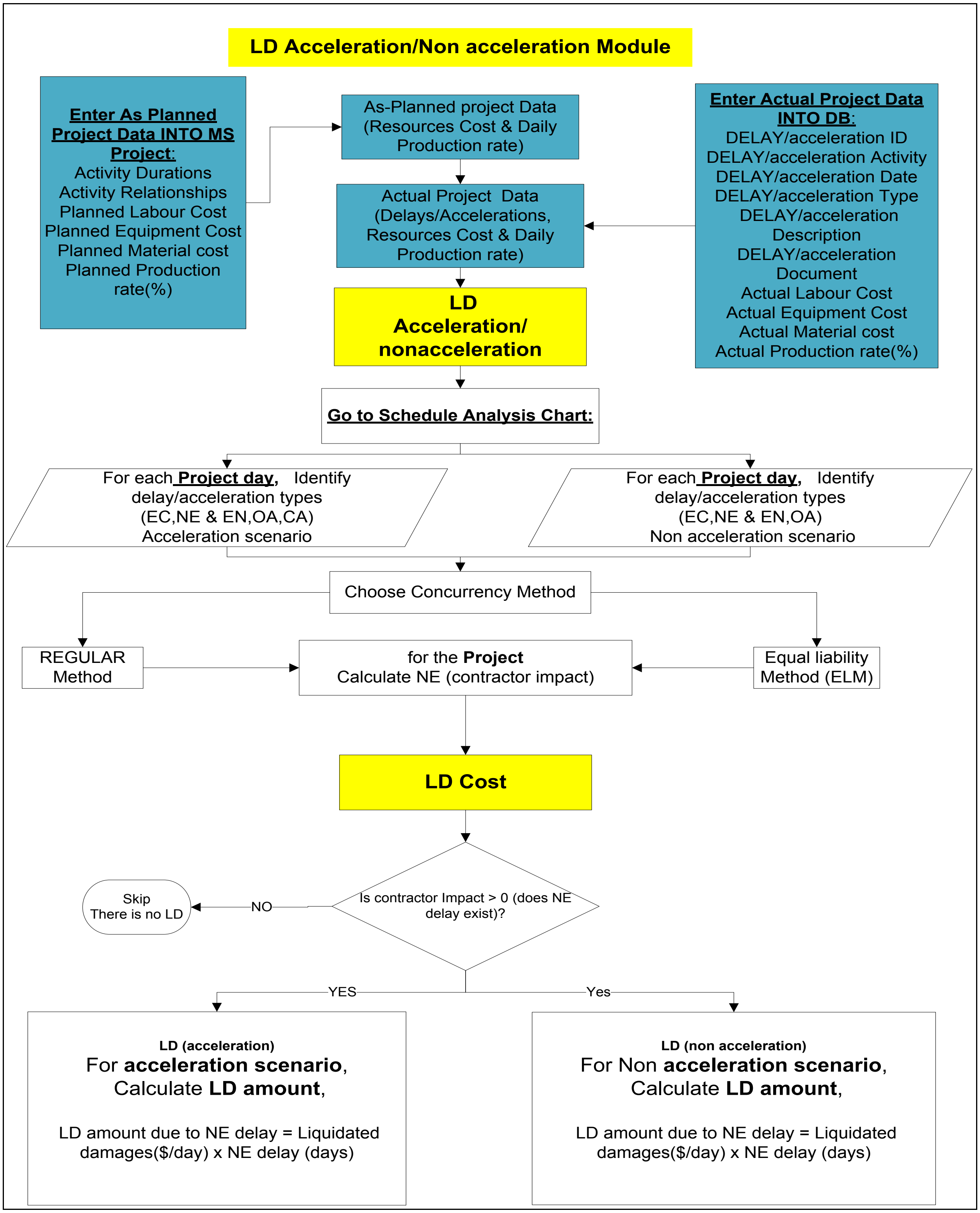


Figure 4-12 Liquidated Damages - acceleration/non acceleration Module

4.4 Framework Outcome

The final product of the framework will be in the form of:

- Tables that show the impact of all events (accelerations/delays), the impact of the actions (delays/accelerations) of the owner, of the contractor and of the third party.
- Tables that show the damages incurred by the owner and by the contractor as a result of the actions (delays/accelerations) of each other.
- Graphical representation of impacts (Bar charts) depicting total delay/acceleration, contractor delay/acceleration, owner delay/acceleration and third-party delay/acceleration.
- Graphical representation of the effect of different types of events on a specific activity, or on a group of activities within a specific timeframe. This representation is important in cases of concurrent delays and in cases that involve a dynamic critical path.
- Reports listing documents related to each delay or group of delays to help in proving the causation of delays.
- Schedules depicting the course of events throughout the life of the project. A schedule can be produced for each single day of the project.

By using this model, a user should be able to answer the basic questions: Who delayed what and when? What is each party's share of the total project delay? What are the costs incurred by each party as a result of delays?

4.5 How does the framework work?

The framework accounts for delays and accelerations from day one. The data documentation (during construction) phase starts when the as-planned schedule is put in place, with the approval of all concerned parties. The as-planned schedule is then saved in the database for further use in the tracking and analysis phases. As soon as the project starts, the project progress and delay/acceleration data is entered in the database. A regular update of the schedule is usually due at equal time intervals or at the request of the project manager. The update can be prompted by an occurrence of a major delay, or by a disruption or an event that may cause such a delay.

Progress and delay data can be entered on a daily basis as well. The more often updates are performed the more accurate and timely is the information. For the purpose of this framework, the progress data must be entered on a daily basis.

In the updating process, whenever there is a change in activity duration (a delay or acceleration is encountered), a series of actions will be required by the framework to identify the delay/acceleration data and save it to the database. One of these actions is delay classifications where the user has to enter the type of delay/acceleration. The process of entering progress and delay/acceleration data will continue until the end of the project, when an as-built schedule is produced and saved in the database for further use.

By the end of the project, well-documented progress data will be available to be used in schedule analysis and damage calculation. The progress data that was collected and documented in the database will be used to perform schedule analysis using the IDWAT. As a result of the analysis process, the delays/accelerations' impact on the project duration can be assessed and the responsibility of the owner and the contractor can be identified. Furthermore, the cost incurred by each party can be calculated.

In performing schedule analysis, delay/acceleration and activity data has to be transferred between the database and MS Project and vice versa. This may need to be done many times, based on the method used and the number of timeframes (windows) selected. As per the IDWAT, each window should have 4 cycles of schedule calculation; one for each party and one for all parties combined. A comparison of schedules before and after each cycle of schedule calculation is performed to assess the impact of the events (delays/accelerations) of that cycle on the project duration. The entire schedule analysis process is automated to minimize user interaction, reduce errors and save time.

Finally, reports are produced to demonstrate the responsibility of each party on the project delay. Other reports are also generated to represent the costs incurred by each party as a result of the actions (delays/acceleration) of the other party.

Schedule delay/acceleration analysis is mainly conducted after the project is complete. However, it is worth mentioning that one of the advantages of this framework is the possibility of performing delay/acceleration analysis during the construction phase.

Chapter 5

FRAMEWORK IMPLEMENTATION PROCESS

5.1 Introduction

As explained in chapter 4, the delay analysis framework makes use of MS Project as a scheduling tool to generate the various schedules and perform the CPM calculations needed in schedule analysis. The schedule analysis framework is located in a global file so that it can be used with any newly created project file. When a new project file is created, the schedule analysis framework is automatically activated and a window introducing the framework appears, as shown in Figure 5.1. MS Project was also used as the interface for users to enter the as-planned, progress and delay/acceleration project data. A new menu, called the Schedule Analysis menu, was created to contain all of the submenus required to cover the schedule analysis process (Figure 5.2).

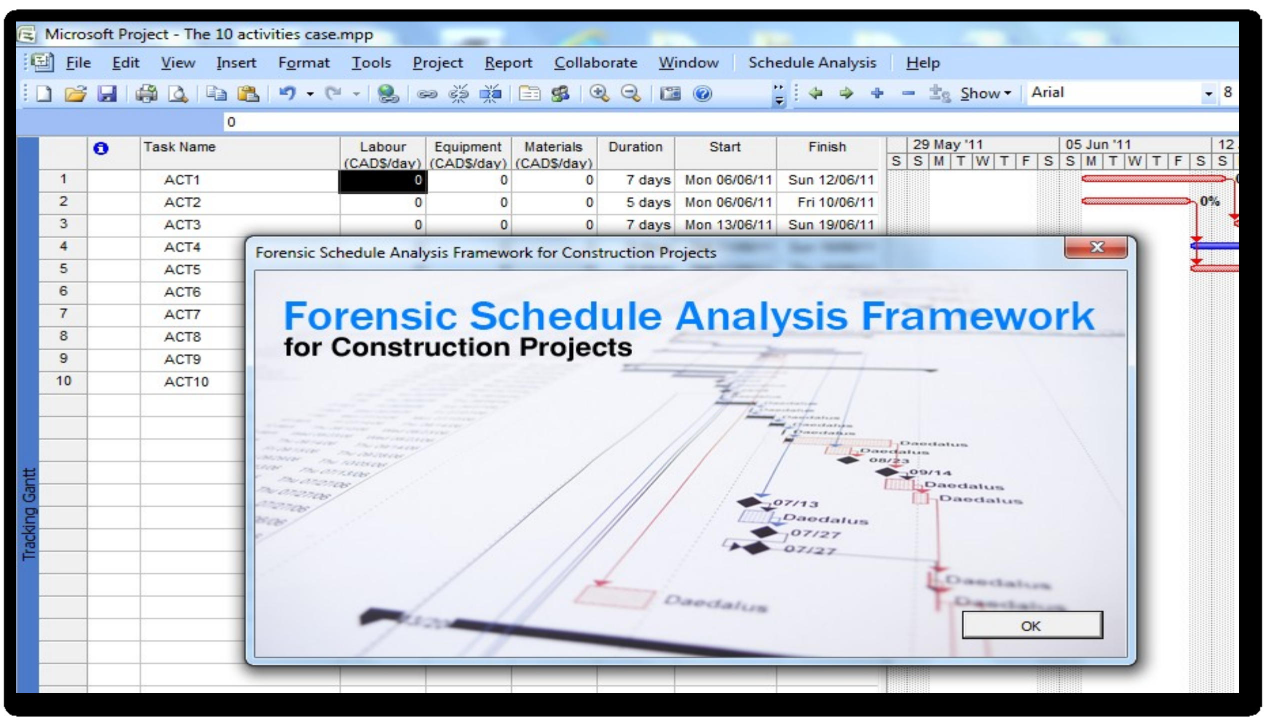


Figure 5-1 Schedule Analysis Framework Activation

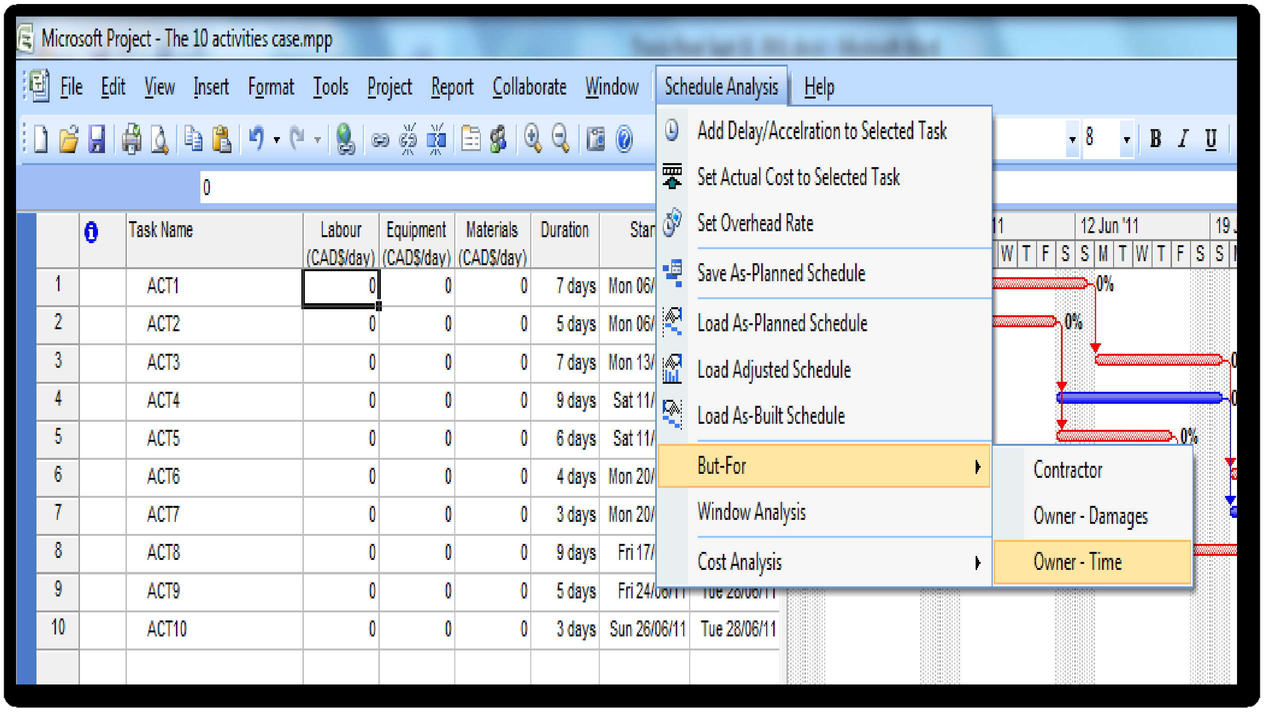
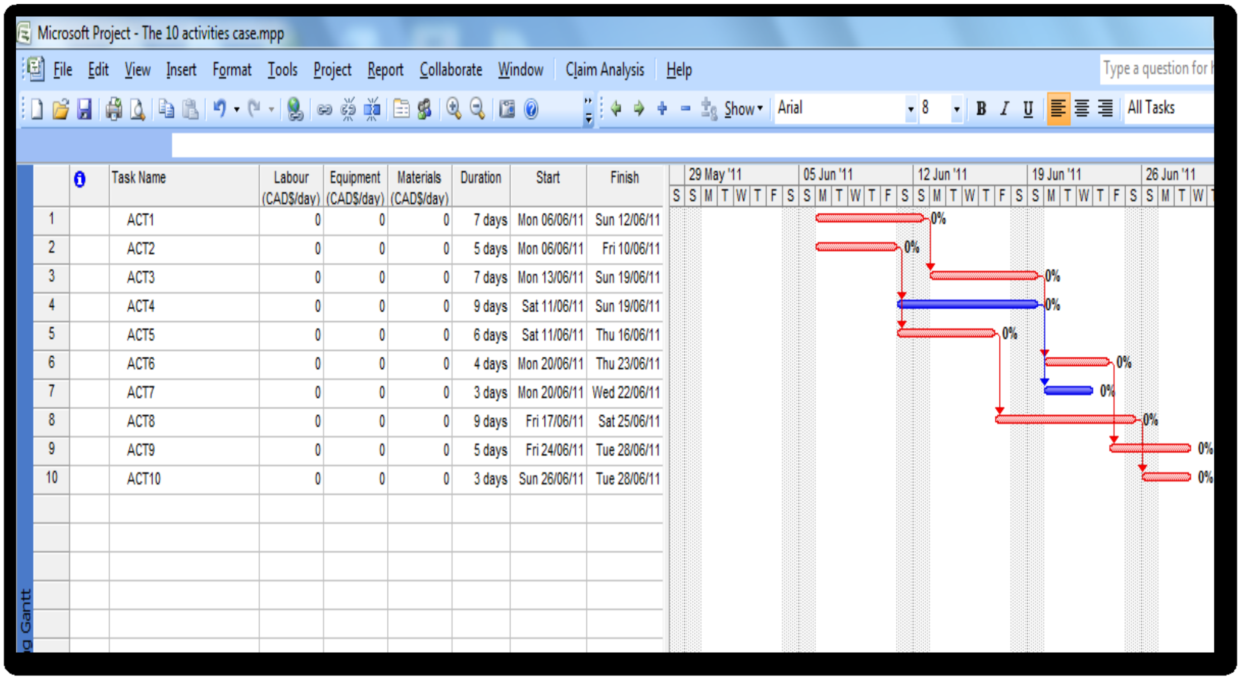


Figure 5-2 Schedule Analysis Menu & submenus

5.2 Progress Documentation Module

The user starts entering the project information related to the as-planned schedule into an MS Project file. This information includes activity names, relationships, durations, costs, and production rates (the percent of the as-planned tasks to be completed per day). When finished entering the as-planned information, the user must save the as-planned data for further reference by selecting the Save As-Planned schedule submenu. Figures 5.3 and 5.4 show respectively the tracking Gantt chart and the precedence network views of the as-planned schedule of a 10-activity project case adopted from Kraiem (1987).This project case contains many types of delays and will be used here to present the framework. It will also be used later to validate and verify the results of the delay analysis technique. As can be observed in Figure 5.3, the as-planned duration of this project is 23 days.



	Task Name	Labour (CAD$/day)	Equipment (CAD$/day)	Materials (CAD$/day)	Duration	Start	Finish
1	ACT1	0	0	0	7 days	Mon 06/06/11	Sun 12/06/11
2	ACT2	0	0	0	5 days	Mon 06/06/11	Fri 10/06/11
3	ACT3	0	0	0	7 days	Mon 13/06/11	Sun 19/06/11
4	ACT4	0	0	0	9 days	Sat 11/06/11	Sun 19/06/11
5	ACT5	0	0	0	6 days	Sat 11/06/11	Thu 16/06/11
6	ACT6	0	0	0	4 days	Mon 20/06/11	Thu 23/06/11
7	ACT7	0	0	0	3 days	Mon 20/06/11	Wed 22/06/11
8	ACT8	0	0	0	9 days	Fri 17/06/11	Sat 25/06/11
9	ACT9	0	0	0	5 days	Fri 24/06/11	Tue 28/06/11
10	ACT10	0	0	0	3 days	Sun 26/06/11	Tue 28/06/11

Figure 5-3 Planned Gantt view for the 10-activity case project (Kraiem, 1987)

From the project's first day, the user will enter the project's progress data including delay, acceleration, cost and production data. Whenever a delay/acceleration in an activity's duration occurs, the user can document that delay/acceleration by entering the delay/acceleration-related data using the "Add delay/acceleration to selected task" submenu, which brings up, a "Delay/acceleration Definition" form, as shown in Figure 5.5.

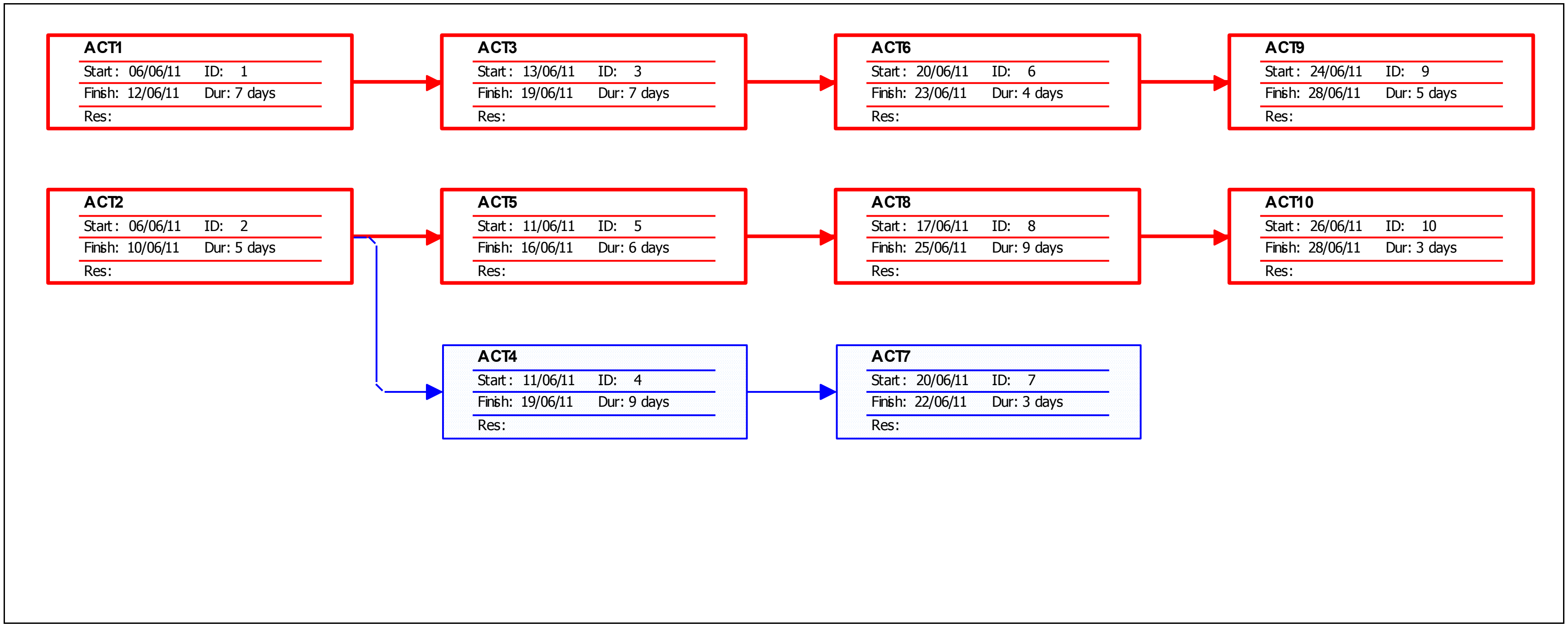


Figure 5-4 As-planned precedence network view for the 10-activity case project (Kraiem, 1987)

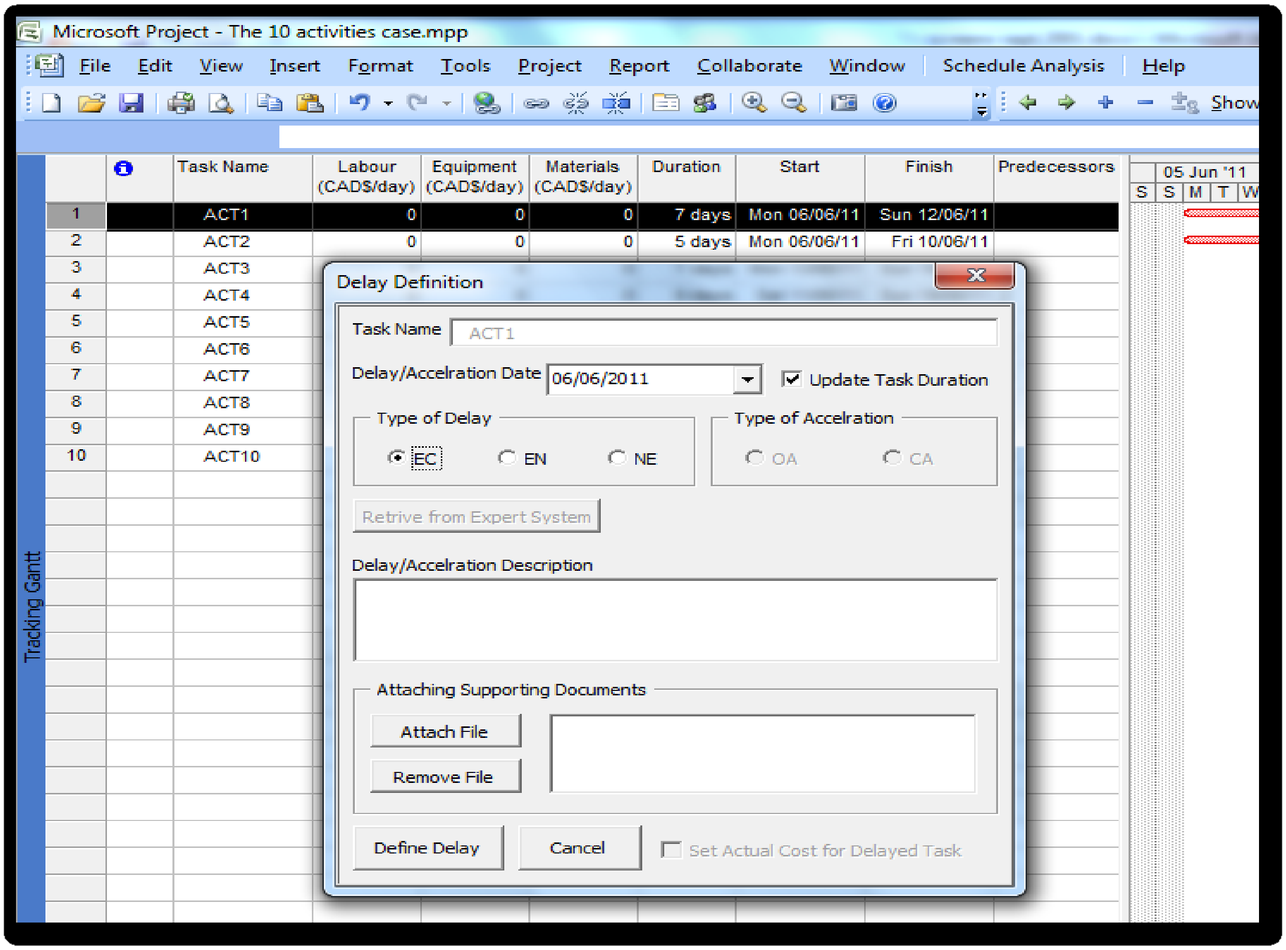


Figure 5-5 Delay/Acceleration Definition Form

In this form, the user will be asked to record the delay/acceleration type (EC, NE, EN, OA, CA), delay/acceleration date and a delay/acceleration description on a daily basis. While the selected activity name (task name) will be filled in automatically, the user will have the choice of attaching the files of supporting documents related to that delay/acceleration. An expert system or a DSS can be attached to the framework at this point to help the user to classify delays/accelerations. The expert system could be accessed from the same form by pressing the "Retrieve from Expert system" button. Such a system is usually tailored to a specific type of contract and is not within the scope of this research. After filling in the delay/acceleration definition form, the user should save the delay/acceleration data to the database by pressing the "Define Delay/acceleration" button.

Another submenu, called "Set actual cost to selected task", is used to access a form called "Set Actual Cost", shown in Figure 5.6. This form is used to enter the actual values of labor, equipment, and material cost, as well as the production rate (percent completed per day) for each activity day. After filling in the "Set Actual Cost" form, the user should save the cost and production data to the database by pressing the "Set Actual Costs" button. There is also a submenu for establishing an overhead cost value for a project. Based on the project and the contractor's company records, certain daily office and site overhead values can be assigned to the project and saved for subsequent overhead cost calculations. Figure 5.7 shows the form used to enter the overhead cost.

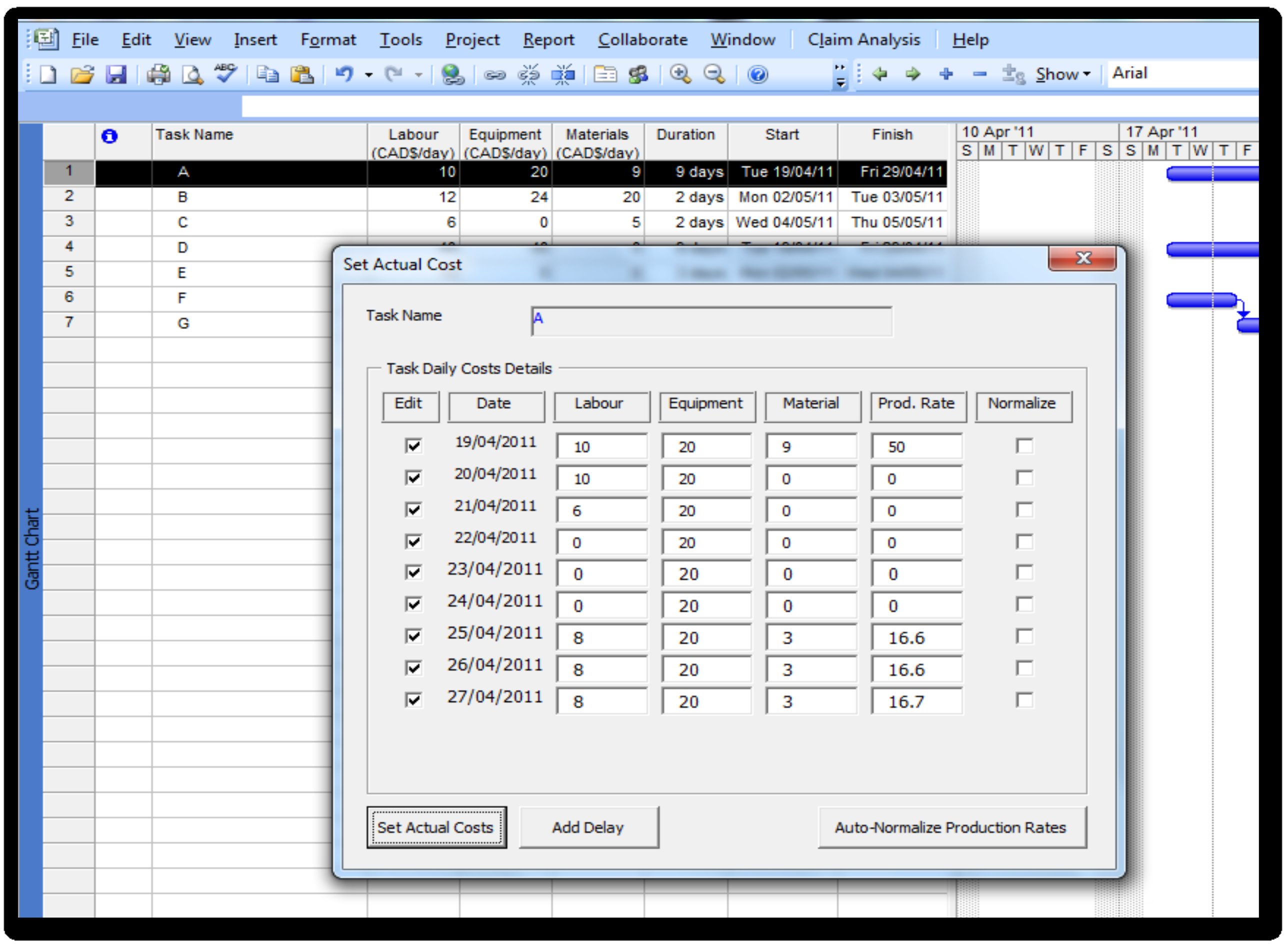


Figure 5-6 Set Actual Costs Form

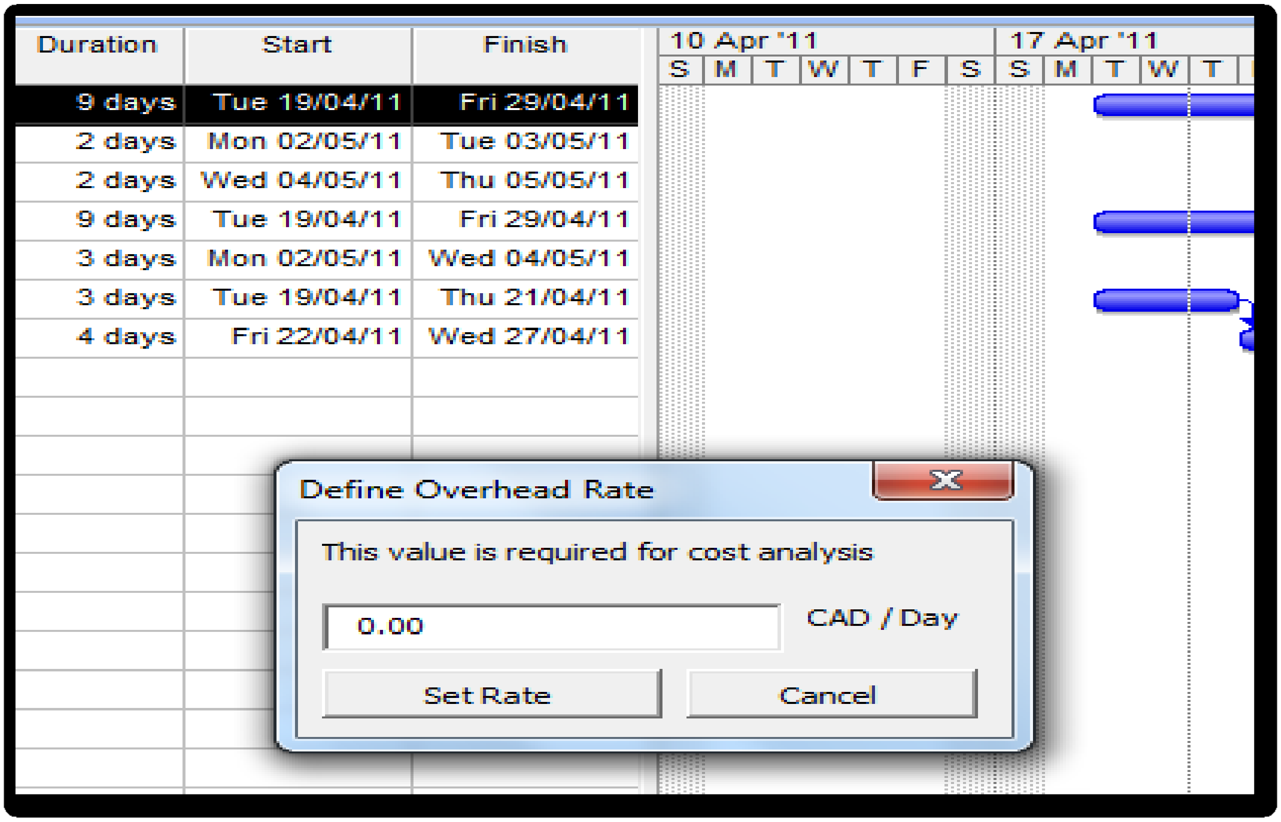


Figure 5-7 Define Overhead Rate Form

Each time the project encounters a delay/acceleration, the delay/acceleration and progress data will be transferred to the database, as mentioned above. The delay/acceleration data will go to the database's Delay/acceleration tables, while the cost and production data will go to the Actual costs table. There are three more tables in the database, one for documents, another for project constants such as the overhead values, and a third table for the project tasks. Figure 5.8 shows the database's Delay table.

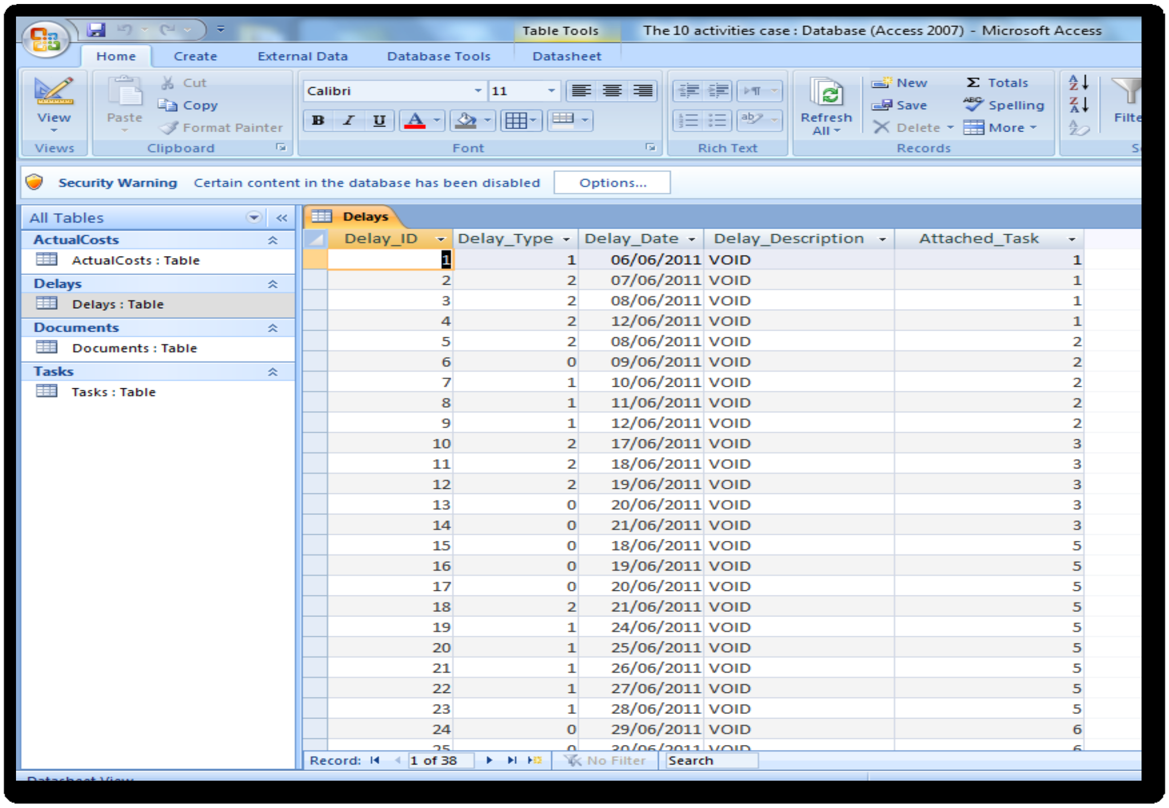


Figure 5-8 Database Delay Table

As the delay/acceleration data is entered into the database, activity durations and project schedules are automatically updated. The as-built schedule is produced by entering the progress and delay/acceleration data of the last day of the project. The as-built schedule can be reproduced later by means of the "Load As-built Schedule" submenu, which retrieves the actual project data from the database. The project schedule can be produced at any point during the life of the project through the "Load Adjusted schedule" submenu. By pressing the "Load Adjusted schedule" submenu, a form in which to choose the adjusted date will appear. The progress and delay/acceleration data of all of the project days up to the selected adjusted date will be retrieved from the database and added to its respective activities at their respective dates, producing the adjusted schedule at that specific date. The as-planned schedule can be reproduced at any time by using the "Load As-planned Schedule" submenu.

If the project undergoes major changes during construction, the as-planned schedule (the baseline) can be redefined via the "Save As-planned Schedule" submenu. When this submenu is used, the framework will ignore the original as-planned schedule and adopt the newly saved as-planned schedule in any future calculations.

Figures 5.9 and 5.10 show the tracking Gantt view of the as-built schedule and the July 1st, 2011 adjusted schedule for the 10-activity case project, respectively.

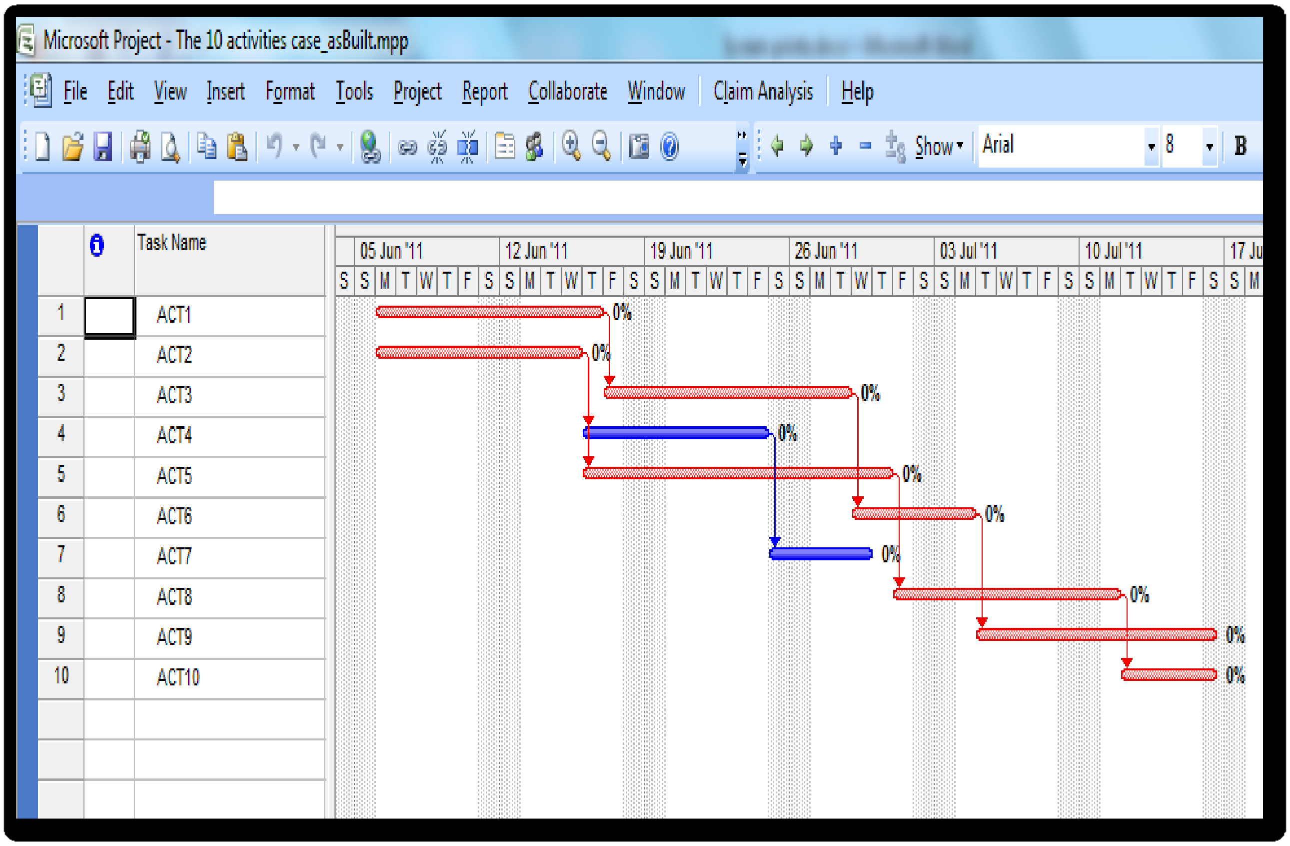


Figure 5-9 The 10-activity as-built schedule, tracking Gantt view (Kraiem, 1987)

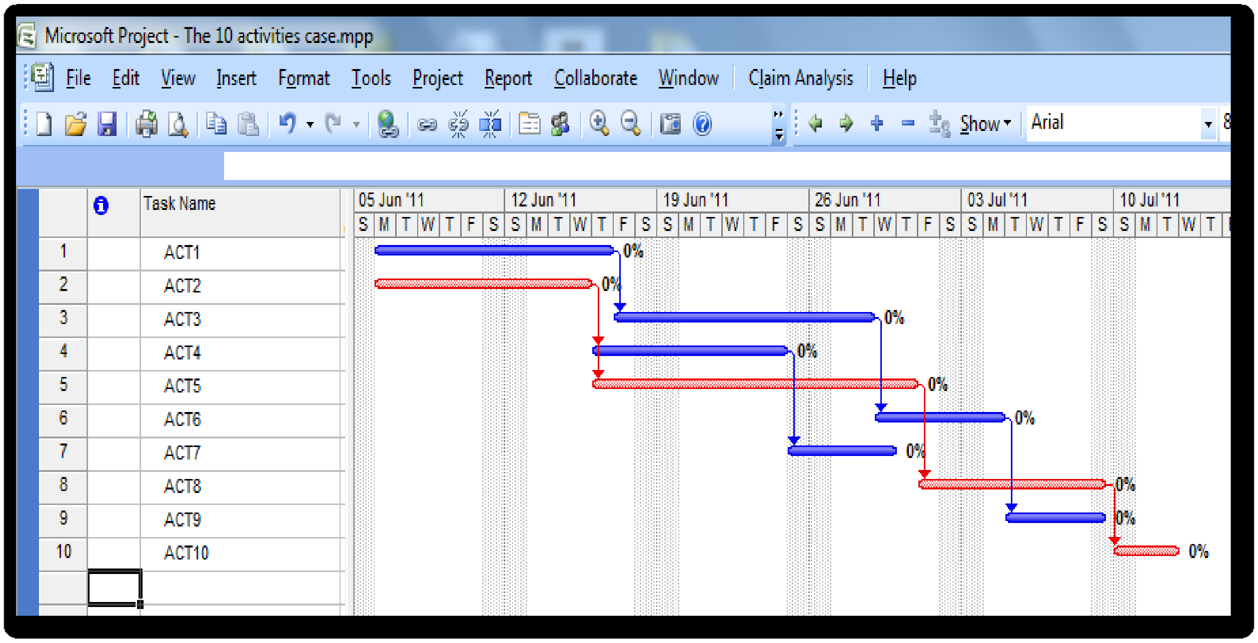


Figure 5-10 The 10-activity July 1st, 2011 adjusted schedule

5.3 Schedule Analysis Modules

By the end of a project, the user will have the as-planned schedule and the as-built schedule, and all of the project's delay/acceleration and progress data will be documented. Analysis of the schedule and quantification of the delay/acceleration costs can be performed using the as-planned, as-built and progress data (data related to delays, accelerations, costs and production) that are saved in the database.

To perform a schedule analysis, one or more of the schedule analysis techniques must be used. The delay/acceleration data was saved in the database based on the event identity concept presented in section 3.3. This form of delay/acceleration identification allows for the use of most schedule analysis techniques.

For the purpose of this research, the 'But-for' technique and the newly-introduced Isolated daily window analysis technique (IDWAT) are utilized.

5.3.1 'But-for' Analysis Module

The 'But-for' delay analysis is implemented through the 'But-for' submenu. By clicking the 'But-for' submenu as shown in Figure 5.2, the user has to choose between the contractor's and the owner's perspective. The "but-for" owner's point of view (the contractor is the claiming party) is further divided into time extension and damage claims, as was explained in section 4.3.3.1.

If the "But-for" contractor's perspective is chosen (the owner is the claiming party), the owner (EC) and the third-party (EN) delays are added to their respective activities in the as-planned schedule. In the case of the "But-For" owner -- *time extension option* (contractor is the claiming party), the contractor (NE) delays are added to their respective activities in the as-planned schedule. For the "But-For" owner -- *damages option* (contractor is the claiming party), the contractor (NE) and third-party (EN) delays are added to their respective activities in the as-planned schedule. In all the above-mentioned "but-for" cases, the delays are added to their respective tasks at their respective dates (although for the "but-for", they are not necessary to be at their respective dates) in a one-shot action. A "But-for" analysis results summary is generated upon the selection of one of these options, as shown in Figure 5.11 for the case of the 'but-for' contractor analysis results summary (owner is the claiming party). In addition to the claiming party's name and both the as-planned and the as-built project durations, the results summary includes the project duration experienced by the claiming party (the owner) and the delay caused by the opposite party (the contractor).

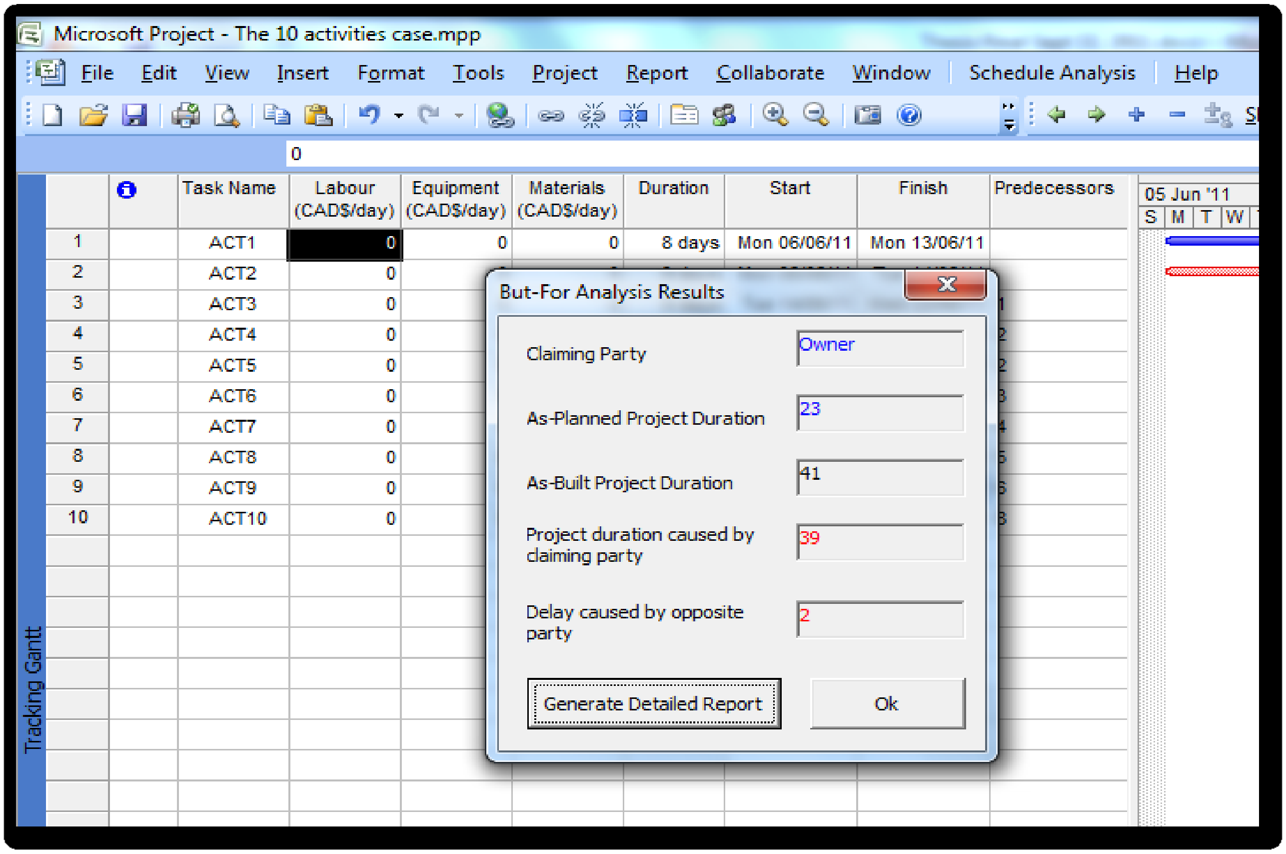


Figure 5-11 "But-for" contractor analysis results summary (owner is the claiming party)

The results summary contains a button to generate a detailed report. By clicking the detailed report button, tracking Gantt views of the as-planned, as-built and the “But-for” owner (Time extension or damages) or the “But-for” contractor schedules are produced and presented together. Figure 5.12 shows part of a detailed report and Figure 5.13 shows the three generated schedules for the “But-for” contractor (owner is the claiming party) for the 10-activity case project.

Integrated Schedule Analysis Framework

Information:

Project Name	Report Created On	Analysis Technique	Claiming Party
The 10 activities case.mpp	20/07/2011 8:09:41 PM	But-For Contractor	Owner

Summary Report:

	As-Planned	As-Built	But-For Contractor Schedule
Start Date	06/06/2011	06/06/2011	06/06/2011
Finish Date	28/06/2011	16/07/2011	14/07/2011
Duration	23 day(s)	41 day(s)	39 day(s)
Delay	18 day(s)		
Owner Delay	16 day(s)		
Contractor Delay	2 day(s)		

Detailed Report:

Task	Delay Information				
	Type	Duration	Date	Description	Documents
ACT1	EN	1 day	06/06/2011	Bad weather	Weather report
	NE	1 day	07/06/2011	Labor shortage	Site report
	NE	1 day	08/06/2011	Labor shortage	Site report
	NE	1 day	12/06/2011	Material shortage	Site report
ACT2	NE	1 day	08/06/2011	VOID	
	EC	1 day	09/06/2011	VOID	
	EN	1 day	10/06/2011	VOID	
	EN	1 day	11/06/2011	VOID	
	EN	1 day	12/06/2011	VOID	

Figure 5-12 Detailed report from the 'but-for" contractor perspective (owner is the claiming party)

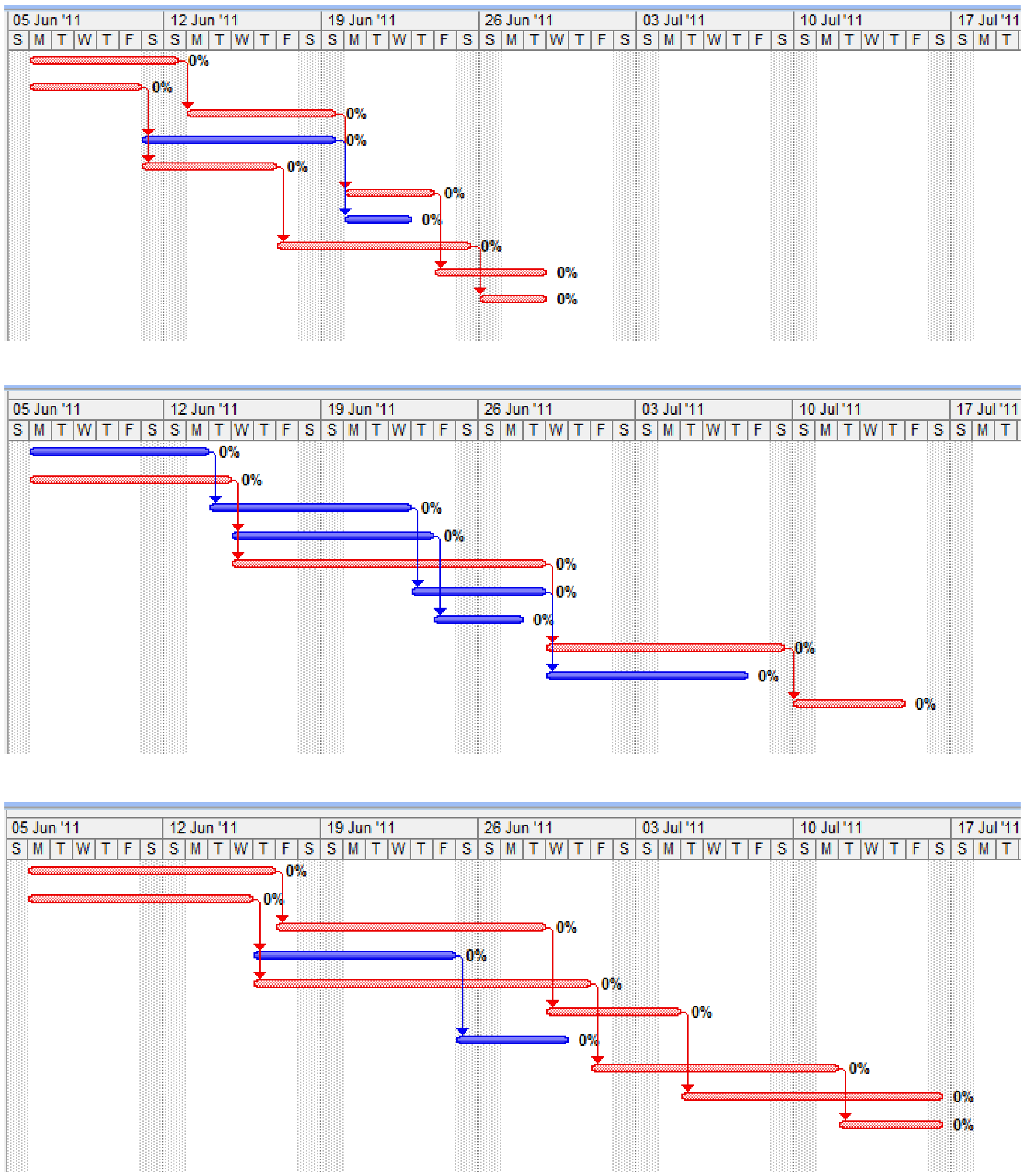


Figure 5-13 Schedules generated for the "but-for" contractor perspective (owner is the claiming party)

The same process can be done with the two “but-for” owner (contractor is the claiming party) options of time and damages. Each of these options will have its results summary, schedules and detailed report.

5.3.2 Isolated Daily Window Analysis Technique (IDWAT)

The Isolated daily window analysis technique is implemented through the use of the window analysis submenu. Based on the concurrent delays liability method selected, the window analysis will be further divided into Regular and ELM (Equal Liability Method) categories. By clicking the ELM submenu, for example, a window appears with a form to define the window range (Figure 5.14). After selecting the start and finish date of the analysis range, the user is requested to click the "Analyze range" button. By clicking the "Analyze range" button, a series of actions within the framework will be triggered, along with cycles of schedule calculations.

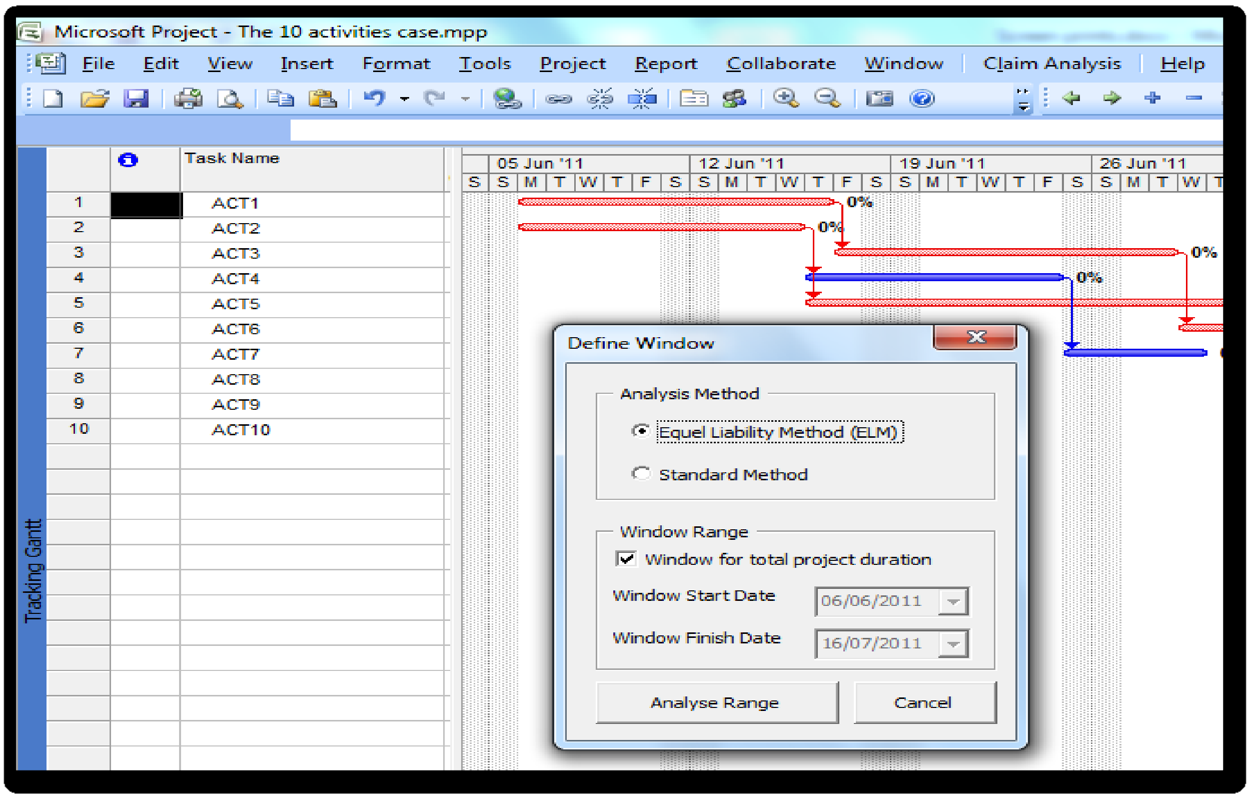


Figure 5-14 Define window range form

The daily window analysis requires daily schedule calculations to quantify the impact on project durations due to different types of delays/accelerations. Since there are three parties, the schedule calculation is run four times for every project day: one time for each of the three parties' events and a fourth time with all the delays/accelerations combined. To run a first cycle of schedule calculations for any project day, the framework picks up the events of the first party (the EC and OA, for example) for that day from the database (Access) and sends them to the scheduling software (MS Project) to be added to their respective activities in the as-planned or the current schedule of that day (date). The schedule calculation is then performed to quantify the impact of the first party's events (here the owner's events) on the project schedule duration for that day and an adjusted schedule is produced. The impact on the project duration due to EC delays and OA accelerations for that day is the difference between the newly-produced adjusted schedule duration and the as-planned or the then-current schedule duration. The impact on the project duration should be 1 day, -1 day or zero days, depending on the combination of events and the criticality of the respective activities on that specific date. The same process is repeated for the same day; a second and a third cycle of project schedule calculations are run with the second and the third parties' events (NE, CA and EN). For each of these schedule cycle calculations, an impact on the project duration of 1 day, -1 day or zero days will be generated depending on the combination of events and the criticality of the respective activities on that specific date. A fourth cycle of project schedule calculation is performed with the three types of delays combined. The schedule produced in the fourth cycle with all delays included will also have a duration equivalent to 1 day, -1 day or zero days. If the multiple critical paths were accelerated by different parties, the fourth cycle will produce an impact of -1 day, while each of the owner and the contractor cycles, when calculated alone, will produce an impact of zero days. The all-events schedule produced in the fourth calculation cycle is considered as the current schedule (or baseline) for the next day's schedule calculation cycles.

After running the first three calculation cycles for any day, the three parties are deemed to have impacted the project duration by 1 day, -1 day or zero days. If at least one of the schedule calculation cycles produced an impact of one day, then the project will be delayed by one day. If more than one of the schedule calculation cycles produced an impact of 1 day, the schedule will still be delayed by one day for that date. However, this one day delay of the project duration must be apportioned between the parties. If one of the owner or the contractor cycles produced an impact of -1 day, the schedule is accelerated by one day and this -1 day of acceleration will be recorded for the party that caused it. However, if the acceleration was produced as a result of all-events combined (i.e., , as a result of combining owner and contractor accelerations), then the -1 day acceleration will be apportioned between owner and contractor: -0.5 day for each.

5.3.2.1 Equal Liability Method (ELM)

According to the Equal liability method (ELM) for concurrent delays, if only one type of delay (one schedule calculation cycle) results in one day of project delay, then the one day of project delay due to delays occurring on that day (date) will be fully allocated to that type of delay (the one day of project delay will be allocated to the party that caused that type of delay). If two types of delay (two schedule calculation cycles) result in one day of project delay for each, then the one day of project delay due to delays that occurred on that day (date) will be equally apportioned between the two types, and half a day of project delay will be allocated to each of them. Finally, if all three types of delays (three schedule calculation cycles) result in one day of project delay for each, then the one day of project delay due to delays on that day (date) will be equally apportioned between the three types and so one-third of a day of project delay will be allocated to each party.

This process of calculating project duration delay as a result of the three types of delay (three schedule calculation cycles) and the resulting apportionment of that delay are then repeated for every day of the project -- four scheduled calculation cycles per day. Figure 5.15 depicts the process of the isolated daily window analysis calculation as it appears on the MS Project tracking Gantt view. The share of each type of delay (the share of each party) from the overall project delay is then accumulated day by day until the end of the project.

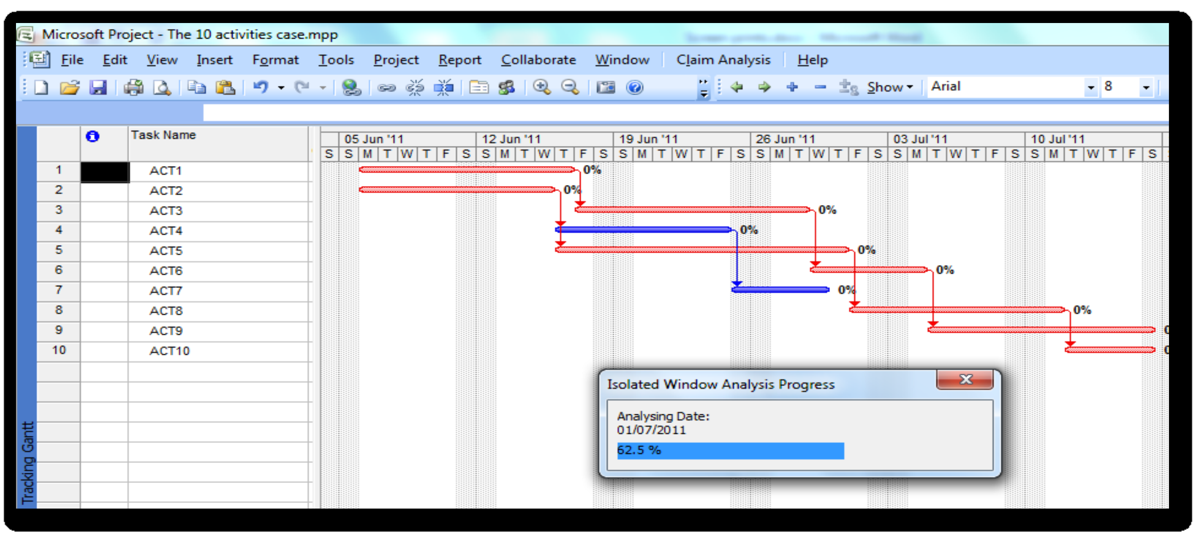


Figure 5-15 The process of IDWAT calculations

The values of all of the accumulated shares of delay/acceleration for each of the three parties are then shown in an isolated daily window analysis summary report, as shown in Figure 5.16. Finally, the sum of these share values is equal to the total impact on project duration. A detailed report for the isolated daily window analysis can be generated by clicking the "Generate detailed report" button located at the end of the summary results report. Figure 5.17 shows a sample detailed report of the isolated daily window analysis for the 10-activity project case.

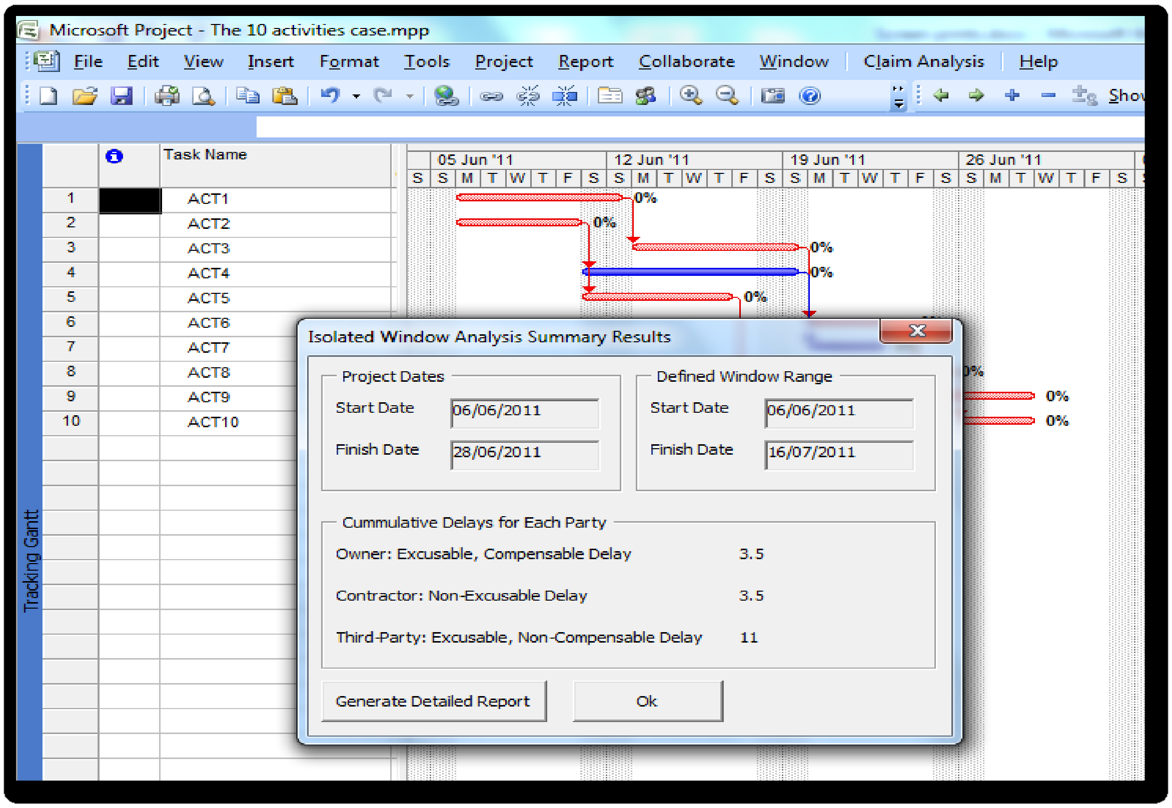


Figure 5-16 IDWAT - ELM summary report

Integrated Schedule Analysis Framework

Information:

Project Name	Report Created On	Analysis Technique	Claiming Party
The 10 activities case.mpp	20/07/2011 8:56:39 PM	IDWAT-ELM	ALL

Summary Report:

	Project	Window Range
Start Date	06/06/2011	06/06/2011
Finish Date	28/06/2011	16/07/2011
Duration	23 day(s)	41 day(s)
Total Delay	18 day(s)	
Owner Delay	3.5 day(s)	
Third Party Delay	11 day(s)	
Contractor Delay	3.5 day(s)	

Detailed Report:

Task	Delay Information				
	Type	Duration	Date	Description	Documents
ACT1	EN	1 day	06/06/2011	Bad weather	
	NE	1 day	07/06/2011	Labor shortage	
	NE	1 day	08/06/2011	Labor shortage	
	NE	1 day	12/06/2011	Material shortage	
ACT2	NE	1 day	08/06/2011	VOID	
	EC	1 day	09/06/2011	VOID	
	EN	1 day	10/06/2011	VOID	
	EN	1 day	11/06/2011	VOID	

Figure 5-17 Detailed report of the IDWAT-ELM for the 10-activity project case

5.3.2.2 Regular Method

Again, according to the regular method for concurrent delays, if only one type of delay (one scheduled calculation cycle) results in one day of project delay, then the one day of project delay due to delays occurring on that day (date) will be fully allocated to that type of delay (in other words, the one day of project delay will be allocated to the party that caused that type of delay). If two or three types of delay (two or three schedule calculation cycles) each result in one day of project delay, then the one day of project delay due to delays occurring on that day (date) will be allocated as a full day based on the following rules:

1. If (EC & NE) are the only types causing the project delay on that day, the one-day delay of the project duration will be considered as a third-party EN delay, where the contractor is only entitled to a time extension.
2. If other combinations of delays involving EN types cause the project delay on that day, the one-day delay of the project duration will also be considered as a third-party EN delay, where the contractor is only entitled to time extension.

According to these rules, the one-day project delay resulting from any project day's schedule calculation cycles will be allocated as a full day to one of the parties (designated as one of the types of delay). This process of calculating project duration delay as a result of the three types of delay (three schedule calculation cycles) and the resulting allocation of that full day of delay (if any) to one party (one type of delay) is then repeated for every day of the project; three schedule calculation cycles per day. Similar to the ELM, an isolated window analysis summary results report (Regular method) will be produced and a detailed report will be generated. The results of this liability method will differ from that of the ELM because the ELM apportions the project delay day between the parties, causing them to carry fractions of delay days, while, the regular method only allows the full project delay day to be allocated to a single party.

5.4 Delay Cost Modules

The delay cost modules; namely the direct cost, the overhead cost, the impact cost, and the liquidated damages modules, are all implemented through the cost analysis submenu. By clicking the cost analysis submenu, the framework will trigger a series of cost calculations based on the formulas and process presented in chapter four.

The first cost to be calculated is the direct cost. It is calculated on the activity-day level, since delays/accelerations as well as cost and production data are recorded on the activity-day level. The impact cost, however, is calculated on the activity level.

Finally, the overhead cost of delays and the liquidated damages are time-dependent costs that are related to the schedule analysis results, and as such are integrated with the schedule analysis module.

A cost analysis summary result for the 7 activities case, containing the direct, the overhead, and the impact cost as well as the total delay cost value is produced using the ELM method of concurrency (Figure 5.18). Another report to calculate the liquidated damages, from an owner perspective is also produced as presented in Figure 5.19. Detailed reports for cost analysis can also be generated by clicking the "Detailed Report" button. Similar reports can be produced using the Regular method of concurrency as shown in Appendix B.

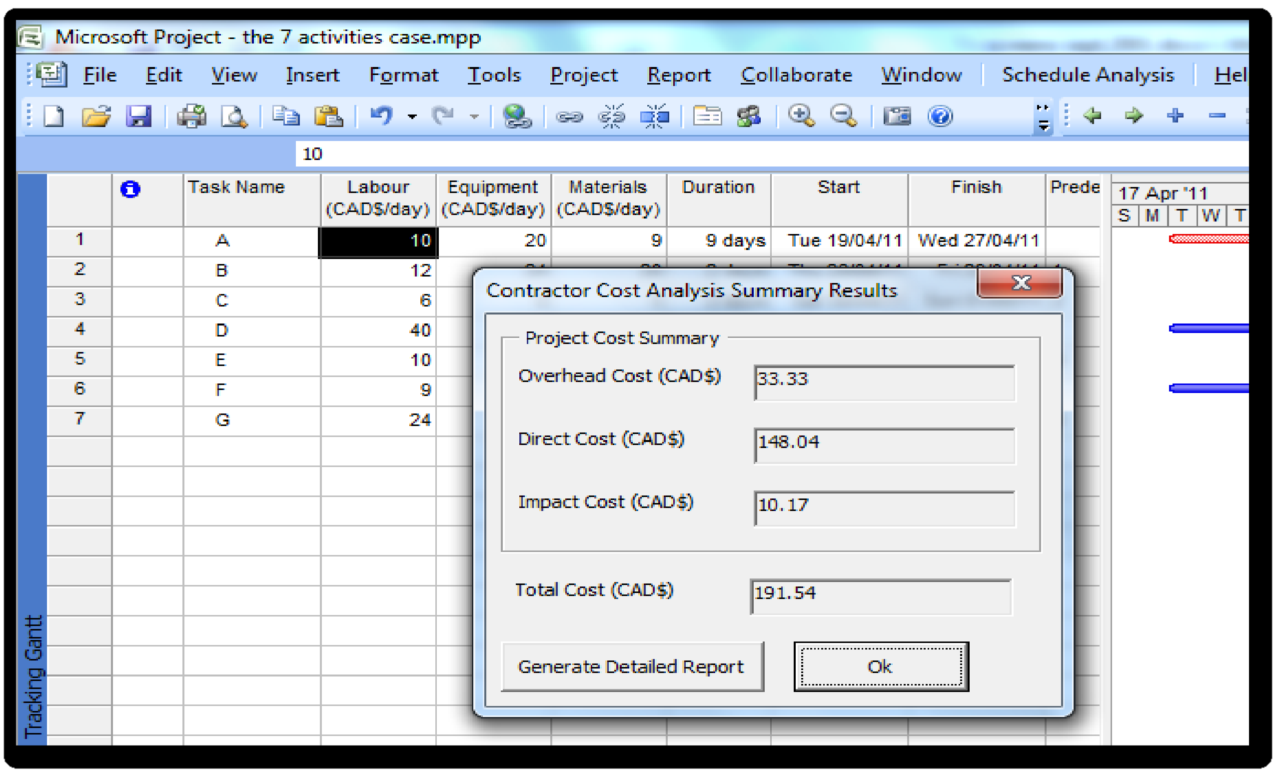


Figure 5-18 Contractor cost analysis summary report

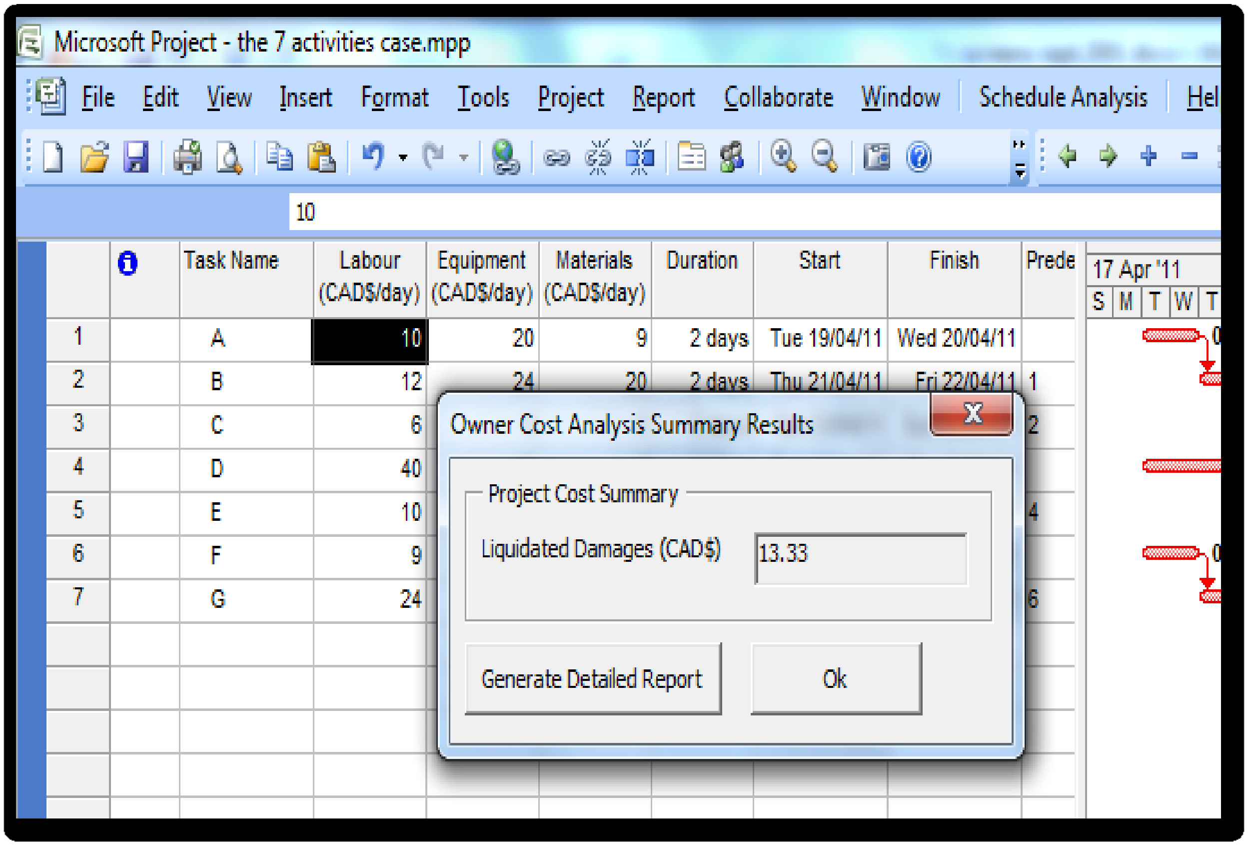


Figure 5-19 Owner cost analysis summary report

Chapter 6

FRAMEWORK PERFOMANCE

6.1 Introduction

A hypothetical 10-activity project case, previously published and applied in other studies (Kraiem, 1987; Alkass, 1996), is used to test the performance of the framework from a time perspective. This case is manually calculated on a daily basis and the outcome compared with that of the developed framework. The results are further compared with those of previous studies. In this 10-activity case project, there are concurrent delays on parallel activity levels but there is no concurrency on the same activity-day level.

Another case project, with 7 activities, will be used to test the framework from both the time and cost perspectives. In this case, there are concurrencies on both the activity-day and the parallel-paths levels. This case is also loaded with resource costs and daily production levels to help test the cost modules. This cost and production-loaded case is also manually calculated on a daily basis and the outcomes are compared with those of the developed framework.

A third case project, with 7 activities, will be used to test the framework from both the time and cost perspectives. The activities in this project have experienced delays and accelerations. This case is also loaded with resource costs and daily production levels to help test the delay/acceleration cost modules. This cost and production-loaded case is also manually calculated on a daily basis and the outcomes are compared with those of the developed framework.

6.2 Test case – assumptions and conditions

A project test case should satisfy the following conditions and assumptions in order to be an appropriate model for testing the developed framework. Some of these conditions are imposed to allow the different advantages of the framework to be tested, while other conditions are to avoid some of its limitations:

1. The case should include either the three types of delays (EN, NE, and EC) or all types of delays and accelerations (EN, NE, EC, OA, and CA).
2. The case should include parallel paths and different combinations of concurrent delays on the activity day level and/or on the parallel activity level. In the case where accelerations and delays are experienced, different concurrency combinations (on parallel activities) should exist.
3. At least one test case should be loaded with resource costs (Labour, Equipment, and Material) and production level (percentage of the work activity accomplished) data on a daily basis. The total production at the end of the activity should be 100%.
4. The as-planned daily production level for each activity is assumed to be uniformly distributed over the activity period. For example, the as-planned daily production for activity A which has a 5-day as-planned duration = 100% ÷ 5 = 20%.
5. The as-planned resource costs for each activity are assumed to be uniformly distributed over the activity period. Therefore, the as-planned daily labor costs are the same for each activity day. The same holds true for the equipment and material costs.
6. The actual daily cost for each activity is not likely to be either uniformly distributed or equal to the as-planned cost values.
7. The actual daily production level for each activity is not likely to be either uniformly distributed or equal to the as-planned production values. However, it must add up to 100% at the end of each activity.
8. The logic used for each case is basic FS (finish to start logic) with no lags. It is assumed that the logic will remain unchanged during the project. However, the float and the criticality of activities will change on a daily basis, depending on the delays/accelerations encountered.

6.3 Schedule Delay Analysis

Schedule analysis involves determining each party's share of the project delay/acceleration. Based on the outcome of this analysis, the contractor’s entitlement for both time extension and damages and the owner’s entitlement for damages are determined. The main schedule analysis technique employed in the framework is the Isolated daily window analysis technique (IDWAT), introduced in chapter three. The "but-for" technique is also used to show that the data documentation model, based on the event identity concept (EIC), allows for the use of other techniques.

In the IDWAT, there are two methods of addressing concurrent delays: the regular method and the Equal Liability Method (ELM), which were introduced in chapter 3. On the other hand, the "but-for" technique has two points of view: the owner and the contractor perspectives. The contractor's point of view is further divided into two views: the time extension view (EOT), which is the traditional contractor point of view, and the damages point of view, which is newly-introduced version of the contractor's point of view concerning entitlement for damages.

The daily documentation of delay/acceleration data based on the event identity concept makes it possible to produce any type of schedule for the project at any time. This facilitates the use of either the as-planned or the as-built schedules as the starting point of delay/schedule analysis, and is actually what makes it possible to use almost any delay/schedule analysis technique.

6.3.1 The 10-activity case

The as-planned duration of this case is 23 days and the as-built duration is 41 days. Figures 6.1and 6.2 show the as-planned and the as-built schedules, respectively.

Both the "but-for" and the IDWAT techniques were used to analyze delays in this case, as demonstrated below:

A) "But-for" technique:

The adjusted schedules for the three points of view (Owner, contractor-EOT, and contractor-damages) used in the "but-for" technique are manually calculated. Each schedule is calculated by inserting the specific points of view delays into their respective activities at one time, regardless of the date of their occurrence. This will result in an adjusted schedule with the delays that each party is willing to accept responsibility for. The difference between the as-built schedule and the adjusted schedule will be the responsibility of the other party. The three points of view and their adjusted schedules are manually calculated, as follows:

1. The owner's point of view:

This is also called the "but-for" contractor delay. The adjusted schedule of the owner's point of view is produced by inserting the delays that the owner is accepting responsibility for (the EC delays) and the delays caused by the third party (the EN delays). The duration of the resulting adjusted schedule of the owner's point of view for the 10-activity case is 39 days, as indicated in Figure 6.3. The delay caused by the contractor will thus be the difference between the as-built duration, which is 41 days, and the owner's point of view adjusted duration, which is 39 days.

Contractor delay = 41 – 39 = 2 days

According to this result, the owner is entitled to either liquidated damages or real damages for two days of delay. This result is identical to earlier results (Alkass, 1996).

Act - Days	1	2	3	4	5	6	7	8	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
ACT1	1	1	1	1	1	1	1																																	
ACT2	2	2	2	2	2																																			
ACT3								3	3	3	3	3	3																											
ACT4						4	4	4	4	4	4	4	4						`																					
ACT5						5	5	5	5	5																														
ACT6														6	6	6	6																							
ACT7														7	7	7																								
ACT8											8	8	8	8	8	8	8	8	8																					
ACT9																		9	9	9	9	9																		
ACT10																				10	10	10																		

Figure 6-1 The 10-activity case - As-planned Schedule

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																														
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																															
ACT3												NE	NE	NE	EC	EC	3	3	3	3	3	3	3																		
ACT4											4	4	4	4	4	4	4	4	4	`																					
ACT5											5	5	EC	EC	EC	NE	5	5	EN	EN	EN	EN	EN	5	5																
ACT6																								EC	EC	6	6	6	6												
ACT7																				7	7	EC	NE	7																	
ACT8																										8	8	8	8	EN	8	8	EC	8	8	8					
ACT9																														9	9	EC	EN	EN	NE	NE	9	9	NE	EC	9
ACT10																																					EN	EN	10	10	10

Figure 6-2 The 10-activity case - As-Built Schedule

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
ACT1	EN	1	1	1	1	1	1	1																																	
ACT2	2	2	2	EC	EN	EN	EN	2	2																																
ACT3									3	3	3	3	3	3	EC	EC	3																								
ACT4										4	4	4	4	4	4	4	4	4		`																					
ACT5										5	5	5	EC	EC	EC	5	5	5	EN	EN	EN	EN	EN																		
ACT6																		6	6	6	6	EC	EC																		
ACT7																			7	7	7	EC																			
ACT8																								8	8	8	8	8	8	EN	8	8	EC	8							
ACT9																								9	9	9	9	9	EC	EC	EN	EN									
ACT10																																			10	10	EN	EN	10		

Figure 6-3 The 10-activity case - "But-for" Adjusted Schedule, Owner's view (contractor delays)

2. *The contractor's point of view - EOT:*

This is also called the "but-for" owner point of view-EOT. The adjusted schedule of the contractor point of view-EOT is produced by injecting the delays that the contractor accepts responsibility for (NE delays). The duration of the resulting adjusted schedule for the contractor's point of view-EOT for the 10-activity case is 32 days, as shown in Figure 6.4. Therefore, the delay caused by the owner and by the third party will be the difference between the as-built duration, which is 41 days, and the duration of the contractor's point of view-EOT adjusted schedule, which is 32 days.

Owner delay (EOT) = 41 – 32 = 9 days

According to this result, the contractor is entitled to an extension of time (EOT) equivalent to the 9 days of delay caused by both the owner and the third party. This result is similar to results published earlier (Alkass, 1996).

3. *The contractor's point of view -- Damages:*

This is also called the "but-for" owner point of view-damages. The adjusted schedule of the contractor point of view-damages is produced by inserting the delays that the contractor is accepting responsibility for (the NE delays) and the third-party's (or EN) delays. The duration of the resulting adjusted schedule of the contractor's point of view-damages for the 10-activity case is 36 days, as indicated in Figure 6.5. The delay caused by the owner is thus the difference between the as-built schedule duration, which is 41 days, and the duration of the contractor's point of view-damages adjusted schedule, which is 36 days.

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
ACT1	1	NE	NE	1	1	1	NE	1	1	1																															
ACT2	2	2	NE	2	2	2																																			
ACT3											3	NE	NE	NE	3	3	3	3	3	3																					
ACT4							4	4	4	4	4	4	4	4	4					`																					
ACT5							5	5	5	5	5	NE	5																												
ACT6																					6	6	6	6																	
ACT7																7	7	7	NE																						
ACT8														8	8	8	8	8	8	8	8	8																			
ACT9																									9	9	9	9	9	NE	NE	NE									
ACT10																							10	10	10																

Figure 6-4 The 10-activity case adjusted schedule, "but-for" owner's view/contractor's view- adjusted EOT schedule

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
ACT1	1	NE	NE	1	1	1	NE	1	1	1	EN																														
ACT2	2	2	NE	2	2	2	EN	EN	EN																																
ACT3												NE	NE	NE	3	3	3	3	3	3	3																				
ACT4										4	4	4	4	4	4	4	4	4		`																					
ACT5										5	5	NE	5	EN	EN	EN	EN	EN	5	5	5																				
ACT6																						6	6	6	6																
ACT7																			NE	7	7	7																			
ACT8																						8	EN	8	8	8	8	8	8	8	8										
ACT9																										9	9	9	9	NE	NE	NE	EN	EN	9						
ACT10																																10	10	10	EN	EN					

Figure 6-5 The 10-activity case "But-for" owner's perspective/contractor's view - adjusted damages schedule

Owner delay (damages) = 41 – 36 = 5 days

According to this result, the contractor is entitled to damages for the five days of delay caused by the owner. There are no previously published results for this point of view.

By running the delay analysis using the framework's submenu for the "but-for" technique, the same results were attained for the three aforementioned points of view, as was shown in Figure 5.10 and can be seen in Figures 6.6-6.7.

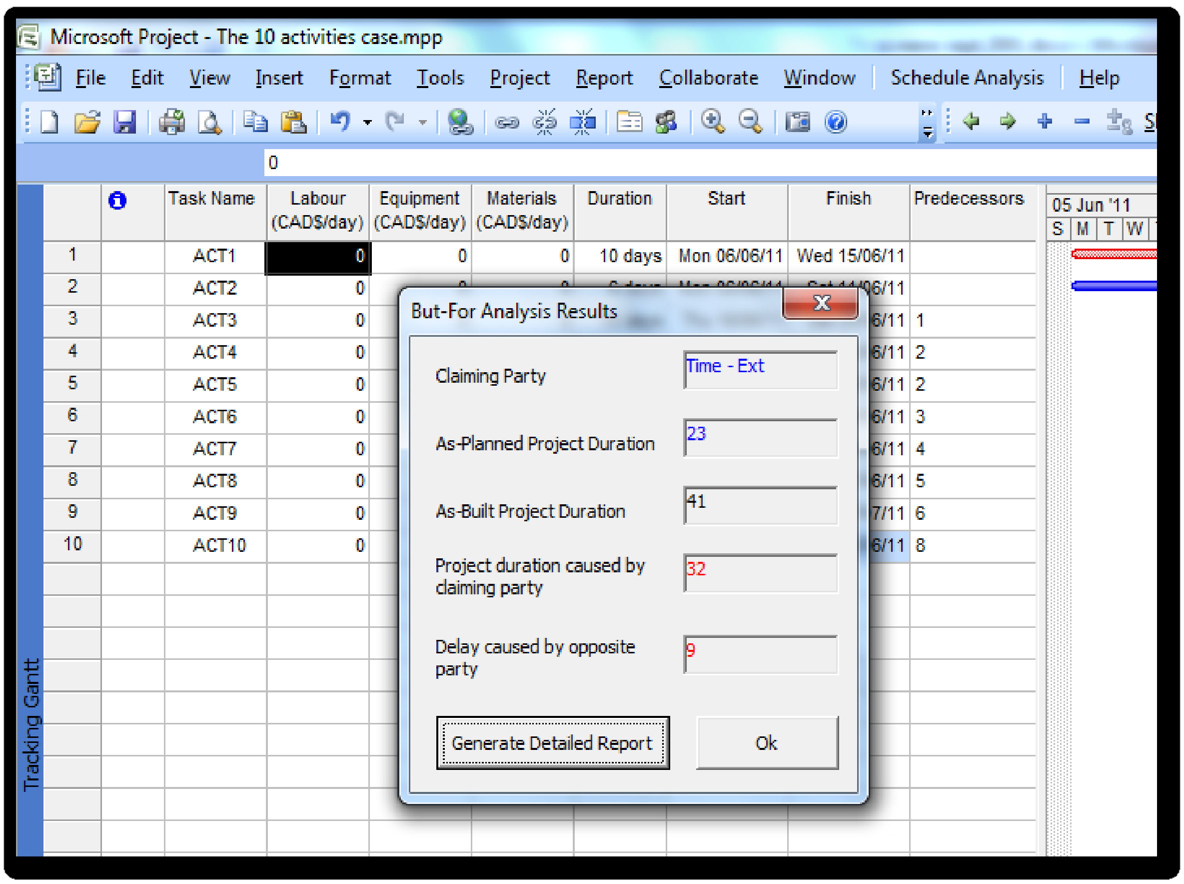


Figure 6-6 The 10-activity case - "But-for" results, contractor's view-EOT

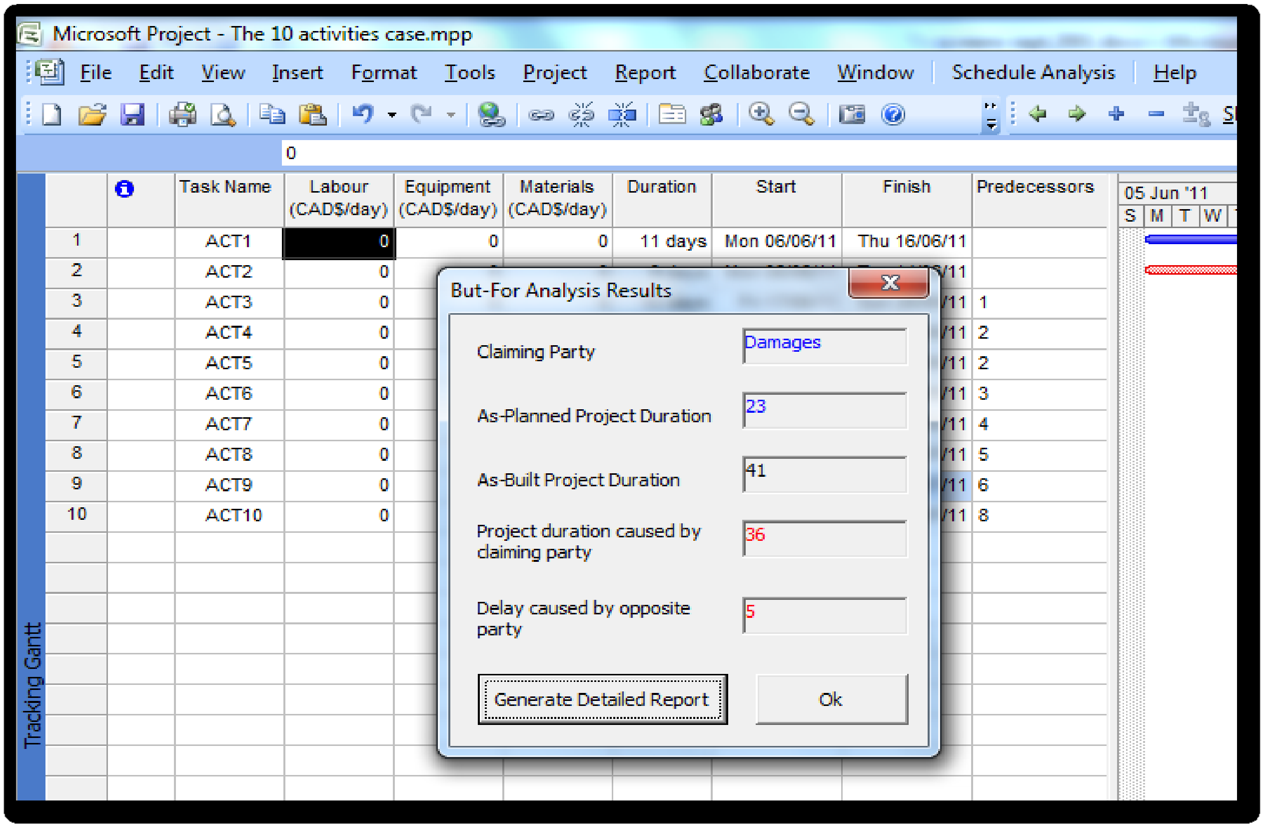


Figure 6-7 The 10-activity case- "But-for" results, contractor's view - Damages

B) Isolated Daily window Analysis technique (IDWAT)

The schedules of the Isolated daily window analysis technique (IDWAT) are calculated manually, using two methods of addressing concurrent delays: the Equal Liability Method (ELM) and the regular method.

1. IDWAT (ELM):

In this approach, the project is divided into daily windows and delays/accelerations (events) are inserted on a daily basis into the as-planned or the then-current schedule (baseline schedule). For each day, the events of each party are inserted on their own to observe their effect on the overall project duration. For any single day, the effect of each party's events will be 1 day, -1day or zero days. For any specific daily window, if only one party's events, when applied alone, affects the project duration by one day, it will carry the whole delay day of that window. In any window, if two parties' events affect the project duration by 1 day, and if each of them, when applied separately, has the same effect, then the delay day is divided between the two parties -- half a day for each. If three parties' events affect the project duration by 1 day in any window and each of them has the same effect when applied separately, the delay day is divided between the three parties -- one-third of a day for each. If the owner events' effect on the project duration is -1 day, the owner is deemed to have accelerated the project by -1 day. The same is also true for the contractor. However, if the effects of each of their events, when inserted alone, are 0 days and the effect of their events, when inserted together, is -1 day, the -1 day (one day acceleration) will be apportioned between them; -0.5 day for each. For any window, the adjusted schedule produced by inserting all parties' events simultaneously will be used as a baseline for the next daily window schedule calculation. The shares of the daily delays/accelerations for each party are summed up at the end of the project to get their total contribution to the overall impact on project duration. The sum of the contributions of the three parties should be equal to the total project delay or acceleration, which is calculated by subtracting the as-planned duration from the as built-duration.

As mentioned above, the as-planned duration of the 10-activity case is 23 days and the as-built duration is 41 days. This makes the total project delay = 41 – 23 = 18 days.

According to the manual calculation of the IDWAT (ELM) for the 10-activity case, the total of the party delays is 18 days, which is equal to the total project delay. The owner's share of the total delay is 3 ½ days, the contractor's share of the total delay is 3 ½ days, and the third-party share of the total delay is 11 days.

By running the delay analysis using the framework's submenu for the IDWAT (ELM), the same results are attained for the three aforementioned shares of delay and the total delay, as indicated in Figure 6.8.

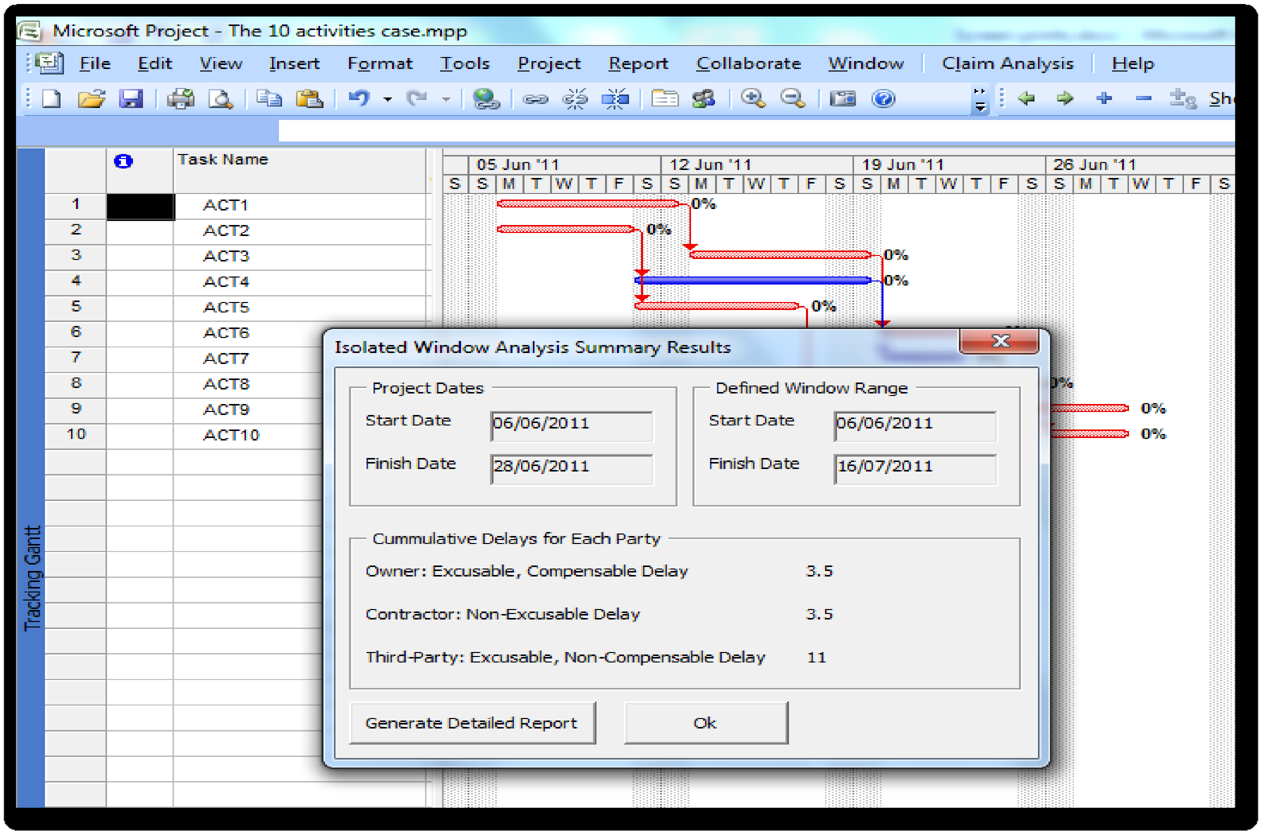


Figure 6-8 The 10-activity case - IDWAT (ELM) summary of the results

As an example, Figures 6.9 - 6.11 show the adjusted schedules produced for the end of day 13 from the 10-activity case using the IDWAT-ELM. More details regarding the manual calculation of the IDWAT (ELM) for the 10-activity case can be found in appendix A-1.

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												NE	NE	3	3	3	3	3	3	3												
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	5	5	5	5																
ACT6																					6	6	6	6								
ACT7																				7	7	7										
ACT8																	8	8	8	8	8	8	8	8	8							
ACT9																									9	9	9	9	9			
ACT10																										10	10	10				
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1																			
O Delay																																
C Delay		1	1										1/2																			
T Delay	1					1	1																									
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6																			

Figure 6-9 The 10-activity case - IDWAT (ELM), end of day 13 schedule (NE inserted alone).

Note: When the NE delays are inserted alone, the project duration is affected. This is because the NE delay acted on activity 3 on day 13, and the path (1, 3, 6, and 9) was critical at the beginning of day 13. As a result, this delay is recorded in the summary as a C Delay. The value of the C delay is ½ day because there is a concurrency with an EC delay in a parallel critical activity (activity 5).

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												NE	3	3	3	3	3	3	3													
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	EC	5	5	5	5															
ACT6																				6	6	6	6									
ACT7																				7	7	7										
ACT8																		8	8	8	8	8	8	8	8	8						
ACT9																								9	9	9	9	9				
ACT10																											10	10	10			
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1																			
O Delay													1/2																			
C Delay		1	1																													
T Delay	1					1	1																									
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6																			

Figure 6-10 The 10-activity case - IDWAT (ELM), end of day 13 schedule (EC inserted alone).

Note: When the EC delay is inserted alone, the project duration is affected. This is because the EC delay acts on activity 5 on day 13, while the path (2, 5, 8, and 10) was critical at the beginning of day 13. As a result, this delay is recorded in the summary as the O Delay. The value of the O delay is ½ day because there is a concurrency with an NE delay in a parallel critical activity (activity 3).

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												NE	NE	3	3	3	3	3	3	3												
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	EC	5	5	5	5															
ACT6																					6	6	6	6								
ACT7																				7	7	7										
ACT8																		8	8	8	8	8	8	8	8	8						
ACT9																									9	9	9	9	9			
ACT10																											10	10	10			
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1																			
O Delay													1/2																			
C Delay		1	1										1/2																			
T Delay	1					1	1																									
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6																			

Figure 6-11 The 10-activity case - IDWAT (ELM), end of day 13 schedule (both NE & EC inserted)

Note: In this figure, a contractor delay (NE) acts on activity 3 on day 13, which affects (when applied alone) the overall project duration by one day. At the same time (on day 13), an owner delay (EC) is acting on activity 5, which also affects (when applied alone) the overall project duration by one day. Therefore, the one-day project delay that occurs at the end of day 13 will be apportioned between the contractor and the owner, half a day for each. **This end of day 13 schedule with all the delays inserted (NE &EC) will be the baseline for the end of day 14 window calculations.**

2. IDWAT – (Regular Method):

In this approach, the project is divided into daily windows and the delays/accelerations are inserted on a daily basis into the as-planned or the then-current schedule (baseline schedule). For each daily window, each party's events are inserted alone to see their effect on the overall project duration. For any single day, the effect of the delays/accelerations will be 1 day, -1 day or zero days.

For any window, if only one party's events affect the project duration by -1 day, and the other two parties have no effect, the party that affects the project duration will carry the whole delay day of that window. If none of the parties' events, when applied separately, affect the project duration, then the project will have zero impact and each party will carry a zero share of the impact on the project duration for that window. Any other combination of delays affecting the project duration when applied separately are considered to be third-party delays. This third-party delay consideration includes the scenario of concurrency between owner and contractor delays, where both affect the project duration when applied separately. In this scenario, the project delay will be treated as a third-party delay where the contractor is only entitled to an extension of time and not to damages. According to the regular method of concurrency and as per the aforementioned rules, the daily project delay will not be apportioned between parties but will be allocated as a one-day delay to one of them. However, in the case of accelerations, the rules previously mentioned for the ELM will also be applied. Either the owner or the contractor will carry the full day of acceleration if their events accelerate the project separately. However, if they accelerate the project jointly, the acceleration will be apportioned between them: -0.5 day for each

The adjusted schedule produced by inserting all parties' events will be used as a baseline for the next daily window schedule calculation. Each party's share of the impact on project duration is summed at the end of the project to determine its total contribution to the overall project delay or acceleration. In contrast with the ELM method, the parties' shares of the project delay will be whole delay days with no fractions. Similar to the ELM, the sum of the contributions of the three parties should be equal the total impact on project duration, calculated by subtracting the as-planned duration from the as-built duration.

As mentioned above, the as-planned duration of the 10-activity case is 23 days and the as-built duration is 41 days. This makes the total project delay = 41 – 23 = 18 days.

As per the manual calculation of the Regular Method for the 10-activity case, the combined party delay comes to 18 days. The owner's share of the total party delay is 2 days, the contractor's share is 2 days, and the third-party share is 14 days.

By running the schedule analysis using the framework's submenu for the Regular Method, the same results are attained for the three aforementioned shares of delay and the total delay, as indicated in Figure 6.12.

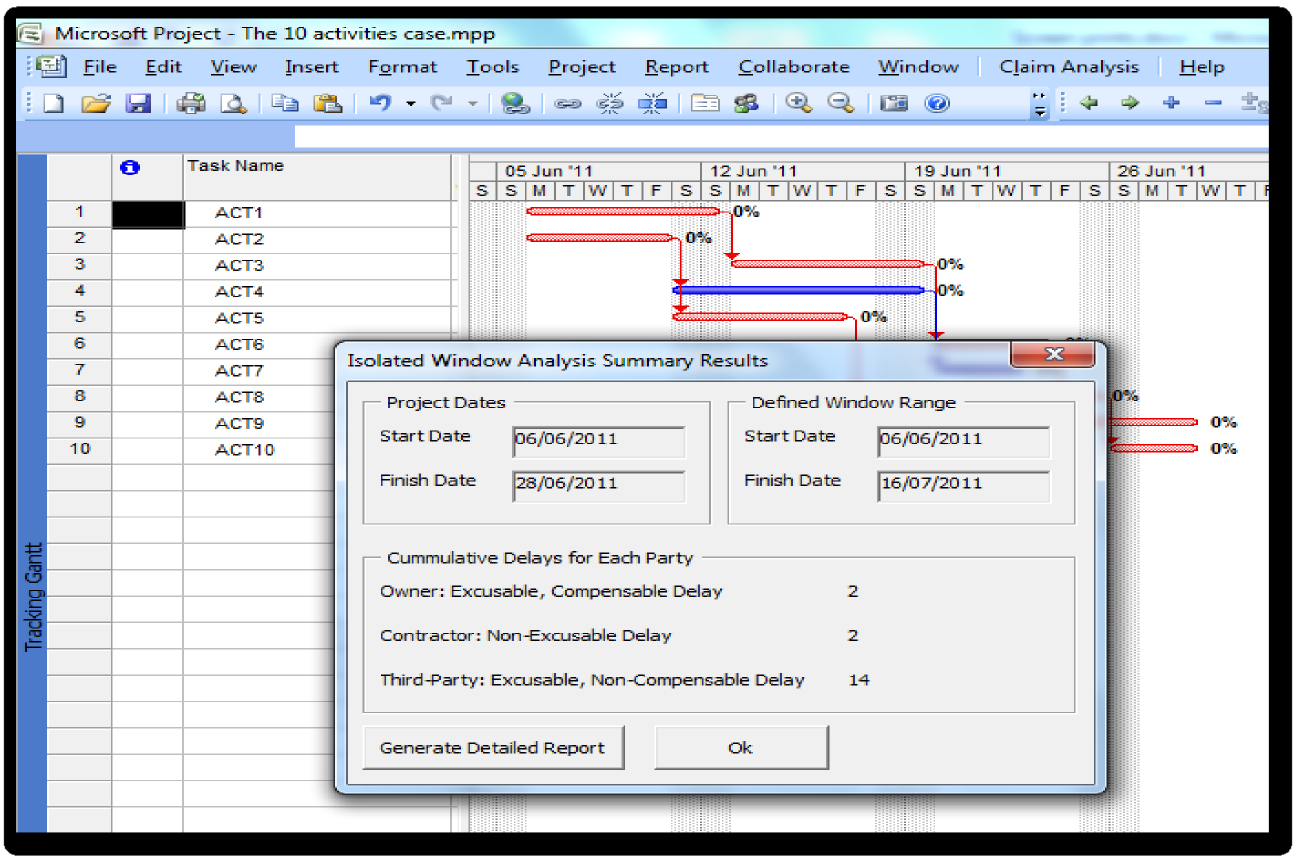


Figure 6-12 The 10-activity case - IDWAT (Regular Method), summary results

As an example, Figures 6.13-6.15 show the adjusted schedules produced at the end of day 13. More details regarding the manual calculation of the IDWAT (Regular Method) for the 10-activity case can be found in appendix A-2.

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												NE	NE	3	3	3	3	3	3	3												
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	5	5	5	5																
ACT6																					6	6	6	6								
ACT7																				7	7	7										
ACT8																	8	8	8	8	8	8	8	8	8							
ACT9																									9	9	9	9	9			
ACT10																										10	10	10				
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1																			
O Delay																																
C Delay		1	1										1																			
T Delay	1					1	1																									
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6																			

Figure 6-13 The 10-activity case - IDWAT (Regular Method), end of day 13 schedule, (NE inserted alone)

Note: When inserting the NE delays alone, the project duration is affected. This is because the NE delay is acting on activity 3 on day 13 and the path (1, 3, 6, 9) was critical at the beginning of day 13. As a result, this delay is temporarily recorded in the summary as a C delay. Since there is a concurrency with an EC delay at a parallel critical activity (activity 5), the C delay of 1 day will eventually be recorded as a third-party delay.

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												NE	3	3	3	3	3	3	3													
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	EC	5	5	5	5															
ACT6																				6	6	6	6									
ACT7																				7	7	7										
ACT8																		8	8	8	8	8	8	8	8	8						
ACT9																								9	9	9	9	9				
ACT10																											10	10	10			
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1																			
O Delay													1																			
C Delay		1	1																													
T Delay	1					1	1																									
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6																			

Figure 6-14 the 10-activity case - IDWAT (Regular Method), end of day 13 schedule (EC inserted alone)

Note: When inserting the EC delay alone, the project duration is affected. This is because the EC delay acted on activity 5 on day 13 and the path (2, 5, 8, and 10) was critical at the beginning of day 13. As a result, this delay is recorded in the summary as O delay. Because there is a concurrency with an NE delay at a parallel critical activity (activity 3), the O delay of 1 day will eventually be recorded as a third-party delay.

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												NE	NE	3	3	3	3	3	3	3												
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	EC	5	5	5	5															
ACT6																					6	6	6	6								
ACT7																				7	7	7										
ACT8																		8	8	8	8	8	8	8	8	8						
ACT9																									9	9	9	9	9			
ACT10																											10	10	10			
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1																			
O Delay																																
C Delay		1	1																													
T Delay	1					1	1						1																			
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6																			

Figure 6-15 The 10 activity case - IDWAT (Regular Method), end of day 13 schedule (both NE and EC inserted)

Note: Here, there is a contractor delay (NE) acting on activity 3 on day 13, which affects (when applied alone) the overall project duration by one day. At the same time (on day 13), there is an owner delay (EC) acting on activity 5 which also affects (when applied alone) the overall project duration by one day. As per the regular method, the one-day project delay at the end of day 13 will be considered as a third-party delay. **This end of day 13 schedule with all the delays inserted (NE and EC) will be the baseline for the End of day 14 window calculations.**

3. IDWAT - (ELM) and (Regular) Results Comparisons:

As mentioned earlier, the results of the IDWAT (ELM) and IDWAT (Regular Method) for the 10-activity case differ as to each party's share of the total project delay, mainly due to how concurrent delays are addressed. According to the ELM, the concurrent delays that belong to different parties are equally liable and the delay caused by these concurrent delays must be apportioned equally among them, making the shares contain fractions of delay days. On the other hand, the more traditional Regular method dictates that whenever there is a concurrency involving a third-party delay, the full delay day resulting from that concurrency is considered a third-party delay in which the contractor is only entitled to a time extension. The same is true when there is a concurrency involving contractor and owner delays, where the contractor is considered to be entitled to only a time extension and each party is supposed to absorb its own expenses. Hence, the full delay day resulting from this concurrency is also considered a third-party delay. Table 6.1 summarizes the results of both methods for the 10-activity case.

Technique / **Delay**	IDWAT- ELM (days)	IDWAT- Regular (days)
Owner Delay (EC)	3 ½	2
Contractor Delay (NE)	3 ½	2
Third-party Delay (EN)	11	14
Total Delay	18	18

Table 6-1 Results of the IDWAT-ELM and the IDWAT-Regular methods

As per the above-mentioned results and according to the ELM, the contractor will be entitled to a time extension equivalent to the delay caused by both the owner and the third party (3 ½ + 11 = 14 ½ days). According to the same method, the contractor is entitled to damages for the delay caused by the owner (3 ½ days). The owner is also entitled to liquidated damages for the delay caused by the contractor (3 ½ days). The main rationale behind the ELM is to be fair with all parties, treating them by the same standards by recognizing that their costs (which would otherwise be absorbed by each party according to the regular method) are not equal. Therefore, they should be equally liable for each day of delay caused by their concurrent delays instead of simply adopting the easy method of considering concurrent delays to be third-party delays.

A concurrent delay situation involving owner and contractor delays resulting in a one-day delay to the project duration will be equally apportioned between the owner and the contractor. This will result in a ½ day time extension and damage compensation for the contractor and a ½ day of liquidated or real damages for the owner.

On the other hand, according to the Regular method, the contractor will be entitled to a time extension equivalent to the delay caused by both the owner and the third party (2 + 14 = 16 days). According to this method, the contractor is entitled to damages for the delay caused by the owner (2 days). The owner is also entitled to liquidated or real damages for the delay caused by the contractor (2 days).

4. IDWAT Results - Comparisons with previous studies:

The 10-activity case was initially used by Kraiem (1987) to assess concurrent delays in construction projects. Kraiem's approach involved generating three adjusted schedules by removing different types of delays (as groups of delays) from the as-built schedule. These groups of delays include non-excusable, excusable, and concurrent excusable and non-excusable delays. The durations of these adjusted schedules were then subtracted from the as-built duration to assess the delay caused by the removed delay groups.

The same case was also used by Alkass (1996) to evaluate and compare different delay analysis techniques, including the isolated delay technique (IDT). The IDT technique involves dividing the project into windows and inserting different types of delays in each window according to the point of view under consideration. The owner's point of view involves inserting the NE delays and calculating the adjusted project duration for each window. The difference between the as-planned duration and the first window's adjusted duration is the delay due to NE delays for the first window. The first window's adjusted duration is updated by adding the EN delays to get an updated duration before running the analysis for the second window. The process is repeated for each window and the summation of the delays of all of the windows is the total delay caused by NE delays.

A similar process is conducted for the contractor's point of view, by adding both the EN and the EC delays to the first window. The difference between the as-planned duration and the adjusted duration for the first window is the delay due to both the EC and EN delays from the first window. The process is repeated for each window in turn, and the summation of all of the window delays is the total delay caused by both EC and EN delays.

Table 6.2 shows a comparison between the results of the IDWAT-regular, IDWAT-ELM, Kraiem's approach (Kraiem, 1987), and of the IDT technique (Alkass, 1996).

Technique / **Delay**	IDWAT-ELM (days)	IDWAT-Regular (days)	Kraiem's approach (Kraiem,1987) (days)	IDT (Alkass,1996) (days)
Owner Delay (EC)	3 ½	2	2	16 *
Contractor Delay (NE)	3 ½	2	1	6
Third party Delay (EN)	11	14	15	-
Total delays	18	18	18	22

Table 6-2 Results of IDWAT-ELM, IDWAT-Regular, Kraiem's approach, and the IDT

*: This delay includes both EC and EN (in other words, the owner and the third-party delays combined).

The results in table 6.2 reveal discrepancies between different techniques. The results of the IDWAT-ELM and the IDWAT-Regular methods were discussed earlier. In this section, the results of IDWAT-Regular will be compared to previous studies because they all use the regular concurrency method.

Although the total project delay and the owner's share of Kraiem's approach are similar to those of the IDWAT-Regular, the contractor's share is only 1 day and the third-party share is 15 days. The overestimation of the third-party delay and the underestimation of the contractor delay occur because the project is treated as one window. This approach overlooks the dynamic nature of the critical path and undermines the concurrency effect.

The IDT results, on the other hand, show a total delay of 22 days. The owner's delay, which includes the third-party delay, is 16 days, which is similar to the combined EC and EN delays of the IDWAT-Regular approach. The contractor delay is 6 days, which is three times that of the IDWAT-Regular results. These exaggerated results for the contractor delay are because the contractor delays were inserted into each window's as-planned or adjusted schedule without accounting for the fluctuation of the critical path within the window and without taking the concurrency with other types of delay into consideration. In other words, some of the NE delays were inserted into activities that were deemed critical as per the criticality status at the beginning of the window, and which would have been deemed non-critical had other types of delays been considered within that window. The following is a step by step explanation of the source of discrepancy between the IDT and the IDWAT-Regular results for the contractor share of the project delay -- the NE delay:

The 10-activity case was divided into three windows as follows (Alkass, 1996):

Window 1

From day 1 to day 11

Completion duration 26 days (excluding both EN and EC delays)

As-planned duration 23 days

Delay due to NE delays: 3 days

Window 2

From day 12 to day 25

Completion duration 30 days

Adjusted Window 1 duration (Baseline for window 2) 27 days (Including EN delays and excluding EC delays)

Delay due to NE delays: 3 days

Window 3

From day 26 to day 41

Completion duration 33 days

Adjusted Window 2 duration 33 days (Including EN delays and excluding EC delays)
(Baseline for window 3)

Delay due to NE delays: 0 days

Total EN delay = 3 +3 + 0 = 6 days

As demonstrated in the detailed calculations in Appendix A-2, for window 1, the NE delays occurred on days 2, 3, and 7. For day 2, the NE delay acted on act.1 while it was a critical activity, which resulted in 1 day of project delay. The same thing occurred on day 3, when the NE delay acted on act.1 while it also was a critical activity, which resulted in another 1 day of project delay. There was another NE delay on day 3, acting on act. 2, but it was not critical and hence did not affect the project duration. In addition, on day 7, the NE delay acted on act.1 when it was not critical and so caused no delay to the project. Therefore, the window 1 calculations resulted in 2 days of project delay. According to the IDT window 1 calculations, the NE delays inserted in the aforementioned activities caused a delay of 3 days.

Using the IDT technique, the EN delays should be inserted in the window 1 completion schedule before starting the window 2 calculations. This is not adequate, since the window 1 EC delays should also be inserted. This is a crucial step to determine the criticality of the activities and because of concurrency issues.

By injecting both the NE and EC delays in the window 1 completion schedule, the window 1 adjusted schedule duration will become 28 days instead of 27 days, as stated in the IDT example.

For window 2, the NE delays occurred on days 12, 13, 14, 16, and 23. On day 12, the NE delay acted on act.3, but it was not critical and so had no effect on the project delay. On day 13, the NE delay acted on act.3 and affected the project duration when applied on its own, but there was a concurrency with an EC delay that acted on Act.5 while it was critical. According to the regular concurrency method, the combined effect of the NE and the EC delays acting on day 13 will be considered as a third-party delay. Therefore, the NE delay for day 13 will not be deemed as affecting the project delay on its own. The same is true for days 14 and 16 because there is a concurrency between the NE and the EC delays. On day 23, the NE delay acted on Act.7 which was not critical, and as a result, the NE delay had no effect on the project duration. Hence, in window 2 (from day 12 to day 25) there is no effect on project delay that can be solely associated with NE delays. This is different from the IDT results, which indicated a 3-day project delay as a result of injecting NE delays within window 2.

For window 3, NE delays occurred on days 35, 36, and 39 where they acted on Act.9 when it was not critical and so had no effect on the project delay. The difference between the results of the IDT and the IDWAT-Regular methods in terms of the NE share of the project delay (6-2=4 days) is due to the fact that the IDT ignores the concurrency and the real time critical path within windows. This is because the IDT did not include the EC or EN delays within window 1 and excluded the EC delays in windows 2 and 3. Therefore, the effect of the NE delays was exaggerated.

6.3.2 The 7-activity case

The as-planned duration of this case is 6 days and the as-built duration is 13 days. Figures 6.16 and 6.17 show the as-planned and the as-built schedules, respectively. Both the but-for and the IDWAT techniques were used to analyze delays in this case, as demonstrated below:

A) But-for technique:

The but-for technique is used with the adjusted schedules for the three points of view (Owner, contractor-EOT, Contractor-damages) calculated manually. Each schedule is calculated by injecting specific point of view delays into their respective activities in one turn regardless of the date of their occurrence. This will result in an adjusted schedule with delays that the party is willing to accept responsibility for. The difference between the as-built schedule and the adjusted schedule will be the responsibility of the other party. The three points of view and their adjusted schedules are manually calculated as follows:

1. The owner point of view:

This is also called the “but-for” contractor point of view. The adjusted schedule of the owner point of view is produced by injecting the delays that the owner is accepting responsibility for (EC delays) and the delays caused by the third party (EN delays). The duration of the resulting adjusted schedule of the owner’s point of view for the 7 activities case is 12 days as shown in Figure 6.18. Therefore, the delay caused by the contractor will be the difference between the as-built duration, which is 13 days, and the owner’s point of view adjusted duration, which is 12 days.

Contractor delay = 13 – 12 = 1 day

The 7 activities as-planned schedule

Act (Dura.)	Date (Day)								
	1	2	3	4	5	6	7	8	9
1 (2)									
2 (2)									
3 (2)									
4 (3)									
5 (3)									
6 (2)									
7(4)									

Figure 6-16 The 7-activity case - As-planned schedule

As-planned duration = 6 days

The 7 activities as-built schedule

Act (Dura)	Date(Day)													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
1 (9)		O(EC) C(NE) T(EN)	O(EC) C(NE)	O(EC)	C(NE)	O(EC)	O(EC) C(NE)	O(EC) C(NE)							
2 (2)															
3 (2)															
4 (9)		C(NE) T(EN)	C(NE)	T(EN)	T(EN)		O(EC)	C(NE)							
5 (3)															
6 (3)		T(EN)													
7 (4)															

Figure 6-17 The 7-activity case - As-built schedule

As-built duration = 13 days

The7 activities - But for contractor (Owner's point of view) – Adjusted schedule

	Date														
Act (Dura)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
1 (7)			O(EC) T(EN)	O(EC)	O(EC)	O(EC)	O(CE)	O(EC)							
2 (2)															
3 (2)															
4 (6)				T(EN)	T(EN)	T(EN)	O(EC)								
5 (3)															
6 (3)			T(EN)												
7 (4)															

Figure 6-18 The 7-activity case - Adjusted schedule - owner's view

Adjusted duration due to the addition of EC & EN delays = 12 days

Note: The duration caused by the claiming party, which is the owner in this case, is a result of adding his/her delays along with the third-party delays to the as-planned schedule in one shot. Since the framework accounts for concurrency on the activity day level, if EC and EN delays occur on the same day, they should be added to one day in the as-planned schedule to avoid exaggeration of the delay impact.

According to this result, the owner is entitled to liquidated damages or real damages for 1 day of delay.

2. The contractor point of view- EOT:

This is also called the "but-for" owner point of view-EOT. The adjusted schedule of the contractor point of view-EOT is produced by injecting the delays that the contractor is accepting responsibility for (NE delays). The duration of the resulting adjusted schedule of the contractor's point of view-EOT for the 7 activities case is 11 days as shown in Figure 6.19. The delay caused by the owner and the third party will thus be the difference between the as-built duration, which is 13 days, and the duration of the contractor's point of view-EOT adjusted schedule ,which is 11 days.
Owner delay (EOT) = 13 – 11 = 2 days
According to this result, the contractor is entitled to extension of time (EOT) equivalent to the 2 days of delay caused by both the owner and the third party.

3. The contractor point of view- Damages:

This is also called the "but-for" owner point of view-Damages. The adjusted schedule of the contractor point of view-damages is produced by injecting the delays that the contractor is accepting responsibility for (NE delays) and the third-party's (EN) delays. The duration of the resulting adjusted schedule of the contractor's point of view-damages for the 7 activities case is also 11 days, as shown in Figure 6.20. So, the delay caused by the owner will be the difference between the as-built duration (13 days) and the duration of adjusted schedule duration of the contractor's point of view-damages, or 11 days.

The 7 activities - But for owner (Contractor's point of view – Extension of time) - Adjusted schedule

Act (Dura)	Date(Day)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
1 (7)			C(NE)	C(NE)	C(NE)	C(NE)	C(NE								
2 (2)															
3 (2)															
4 (6)				C(NE)	C(NE)	C(NE)									
5 (3)															
6 (2)															
7 (4)															

Figure 6-19 The 7-activity case - adjusted schedule - contractor's view - EOT

Adjusted duration due to addition of NE Delays = 11 days

Note: In the time extension option of the contractor point of view, the duration caused by the claiming party, in this case the contractor, is a result of adding the contractor's delays only to the as-planned schedule in one shot.

The 7 activities – But-for owner (Contractor's point of view – Damages) – Adjusted schedule

Act (Dura)	Date(Day)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
1 (7)			C(NE) T(EN)	C(NE)	C(NE)	C(NE)	C(NE								
2 (2)															
3 (2)															
4 (6)				C(NE) T(EN)	C(NE)	T(EN)	T(EN)	C(NE)							
5 (3)															
6 (2)		T(EN)													
7 (4)															

Figure 6-20 The 7 activity case - adjusted schedule - contractor's view - damages

Adjusted duration due to the addition of NE & EN delays = 11 days

Note: In the damages option of the contractor point of view, the duration is a result of adding contractor's delays and third-party delays to the as-planned schedule in one shot. In the 7-activity case project, it is a coincidence that the extension of time option and the damages option resulted in the same number of delay days. They are not necessarily equal.

Owner's delay (contractor's view-damages) = 13 – 11 = 2 days

According to this result, the contractor is entitled to damages for the 2 days of delay caused by the owner.

By running the delay analysis using the framework's submenu for the but-for technique, the same results were attained for the three aforementioned points of view, as can be observed in Figures 6.21-6.23.

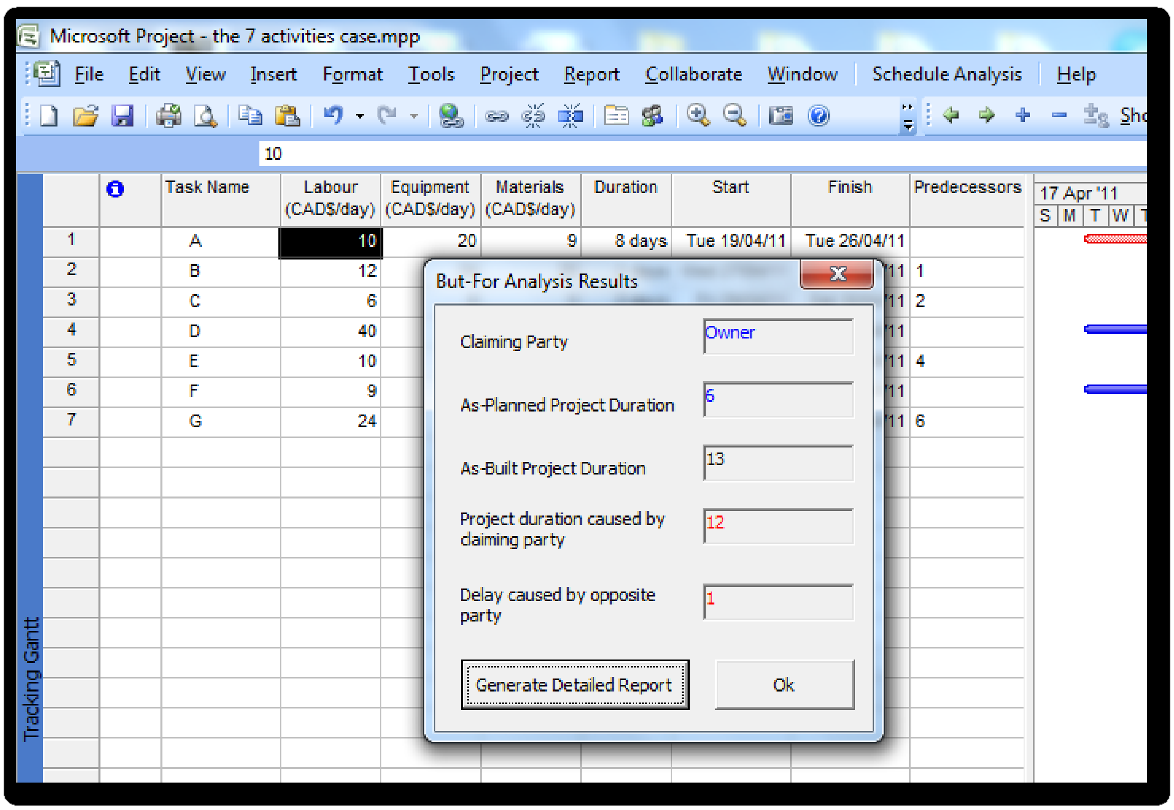


Figure 6-21 The 7 activity case - But-for results - owner's view

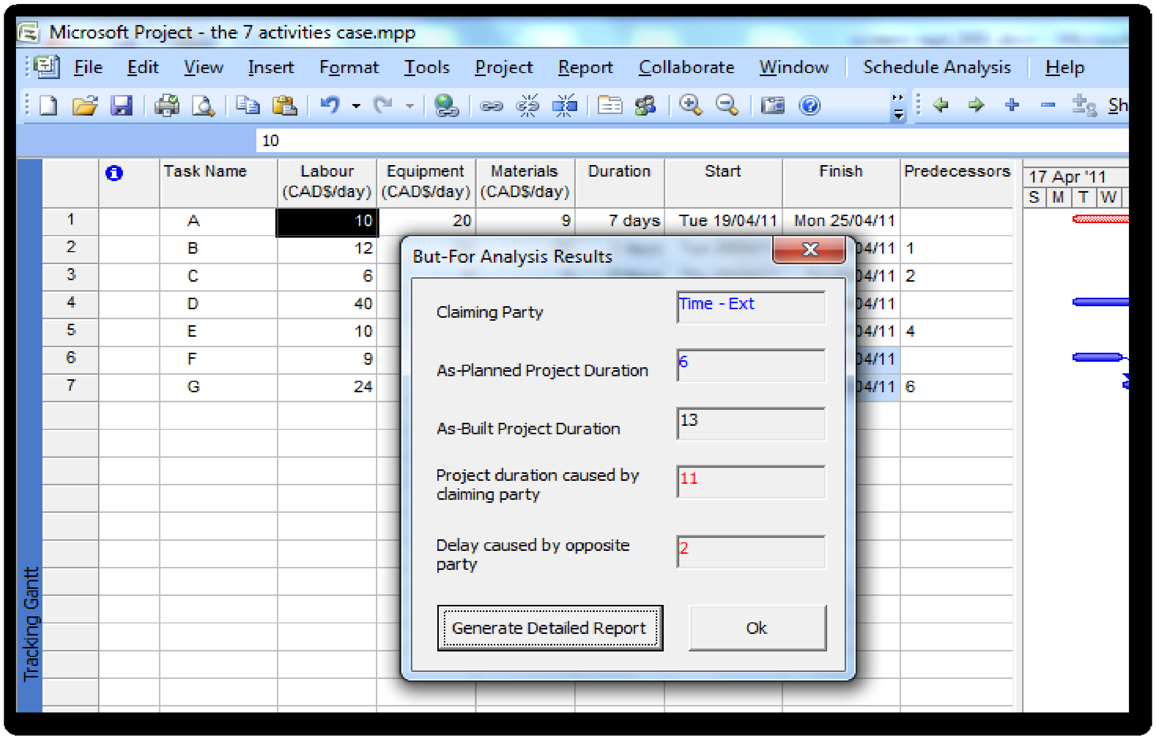


Figure 6-22 The 7 activity case - But-for results - contractor's view-EOT

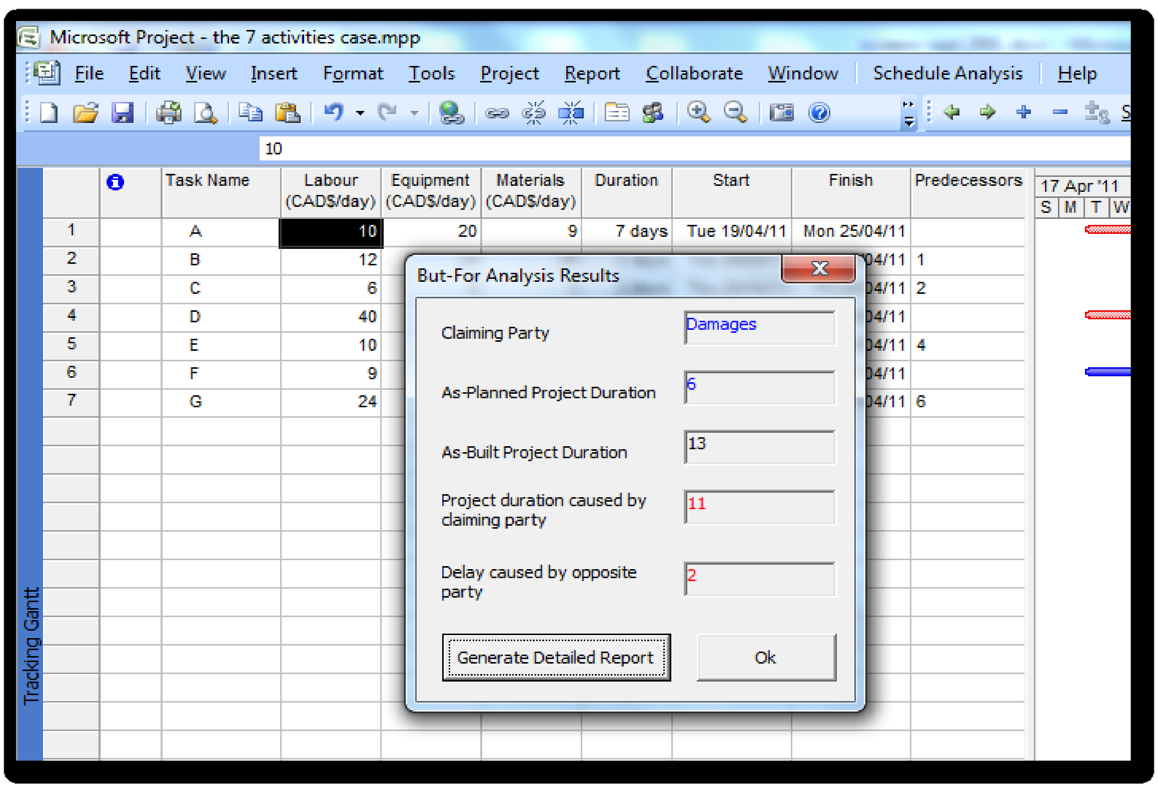


Figure 6-23 The 7 activity case - But-for results - contractor's view - Damages

B) Isolated Daily window Analysis technique (IDWAT)

The schedules of the isolated daily window analysis technique (IDWAT) are manually calculated using the two methods of tackling concurrent delays: the Equal Liability Method (ELM) and the regular method.

1. IDWAT (ELM):

   Similar to the 10 activities case discussed earlier, the delay analysis for the 7 activities case using the IDWAT (ELM) was performed manually. The results are shown in Figure 6.24. For more details of the day-by-day delay analysis calculation, please see appendix A-3. By running the delay analysis using the framework's submenu for the IDWAT (ELM) technique, the same results were attained, as shown in Figure 6.25.

2. IDWAT (Regular):

   Using the IDWAT (Regular), the manually calculated delay analysis results are as shown in Figure 6.26. For more details of the day-by-day delay analysis calculation, please see appendix A-4. By running the delay analysis using the framework's submenu for the IDWAT (Regular) technique, the same results were attained, as indicated in Figure 6.27.

The 7 activities as-built - end of day 8 bar chart- **IDWAT (ELM)**

	Date														
Act (Dur)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
A (9)		O(EC) C(NE) T(EN)	O(EC) C(NE)	O(EC)	C(NE)	O(EC)	**O(EC)** **C(NE)**	O(EC) C(NE)							
B (2)															
C (2)															
D (9)		C(NE) T(EN)	C(NE)	T(EN)	T(EN)		O(EC)	C(NE)							
E (3)															
F (3)		T(EN)													
G (4)															
Daily Delay	0	1	1	1	1	1	1	1							
Owner		1/3	1/2	1/2	0	1	1/2	1/2							
Contractor		1/3	1/2	0	1/2	0	1/2	1/2							
Third-party		1/3	0	1/2	1/2	0	0	**0**							
Cum. delay	0	1	2	3	4	5	6	7	7	7	7	7	7		

Figure 6-24 The 7-activity case - IDWAT (ELM)

Results of delay analysis using isolated daily window analysis technique (with equal liability method for concurrency).

Owner (EC) total delay = 1/3 + 1/2+ 1/2 + 1+1/2+1/2 = 3 1/3 days

Contractor (NE) total delay = 1/3 + 1/2 + 1/2 +1/2+1/2 = 2 1/3 days

Third-party (EN) total delay = 1/3 + 1/2 + 1/2 = 1 1/3 days

Project total delay = 3 1/3 + 2 1/3 + 1 1/3 = 7 days

Note: At day 1 of the project there were no delays. After day 8 there were no more delays.

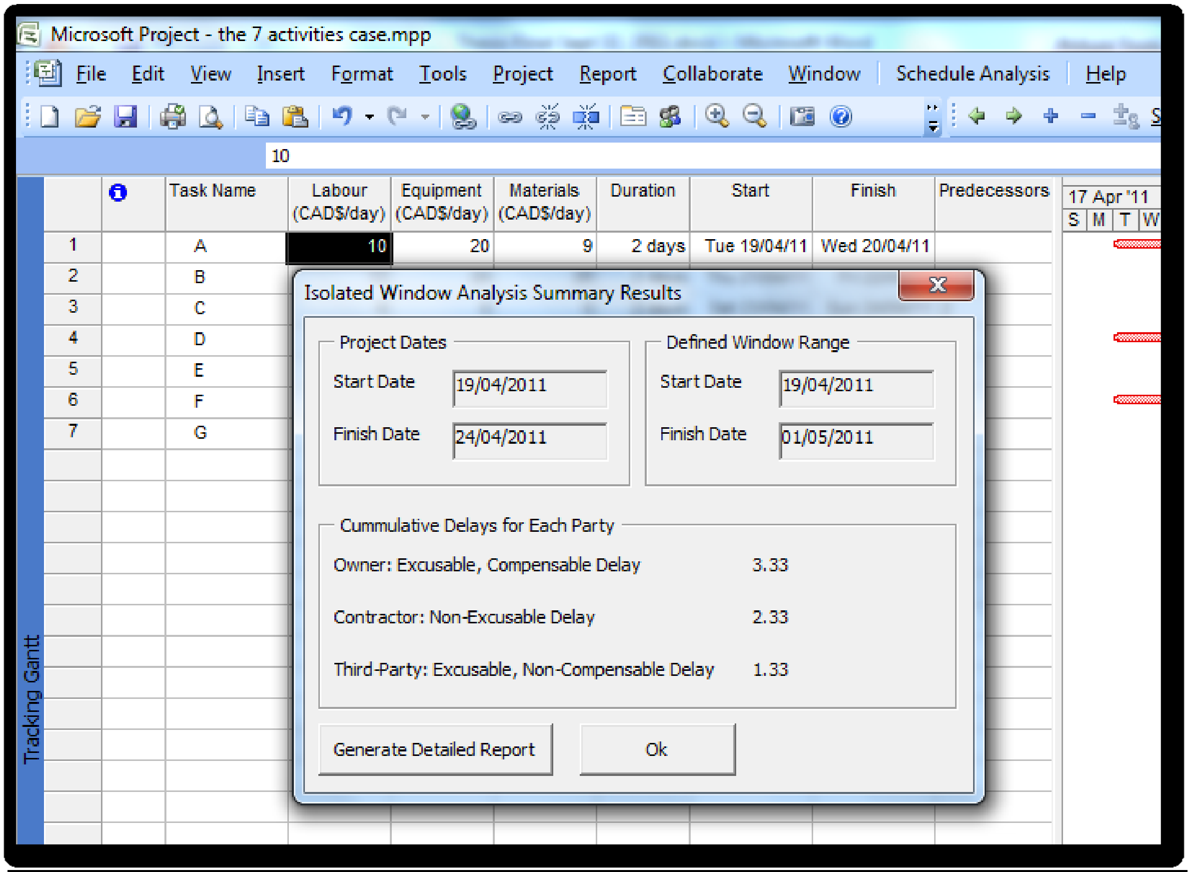


Figure 6-25 The 7-activity case - IDWAT (ELM) - Summary results

The 7 activities as-built - end of day 8 bar chart- **IDWAT (Regular)**

	Date														
Act (Dur)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
A (9)		O(EC) C(NE) T(EN)	O(EC) C(NE)	O(EC)	C(NE)	O(EC)	**O(EC)** **C(NE)**	O(EC) C(NE)							
B (2)															
C (2)															
D (9)		C(NE) T(EN)	C(NE)	T(EN)	T(EN)		O(EC)	C(NE)							
E (3)															
F (3)		T(EN)													
G (4)															
Daily Delay	0	1	1	1	1	1	1	1							
Owner						1									
Contractor															
Third-party		1	1	1	1		1	1							
Cum. delay	0	1	2	3	4	5	6	7	7	7	7	7	7		

Figure 6-26 The 7- activity case - IDWAT (Regular)

Note: At the beginning of day 8 there was one critical path (A, B, C). Also on this path, contractor and owner delays act concurrently on day 7. According to the regular method, the two concurrent delays are recorded in the summary as a one day of third-party delay. The contractor delay acting on activity D was not considered because the path (D, E) was not critical at the beginning of day 8.

Results of delay analysis using the isolated daily window analysis technique (with the Regular method for concurrency)

Owner (EC) total delay = 1 = 1 day

Contractor (NE) total delay = 0 = 0 day

Third-party (EN) total delay = 1+1+1+1+1+1 = 6 days

Project total delay = 1 + 0 + 6 = 7 days

Note: On day 1 of the project there were no delays. Also, there were no more delays after day 8.

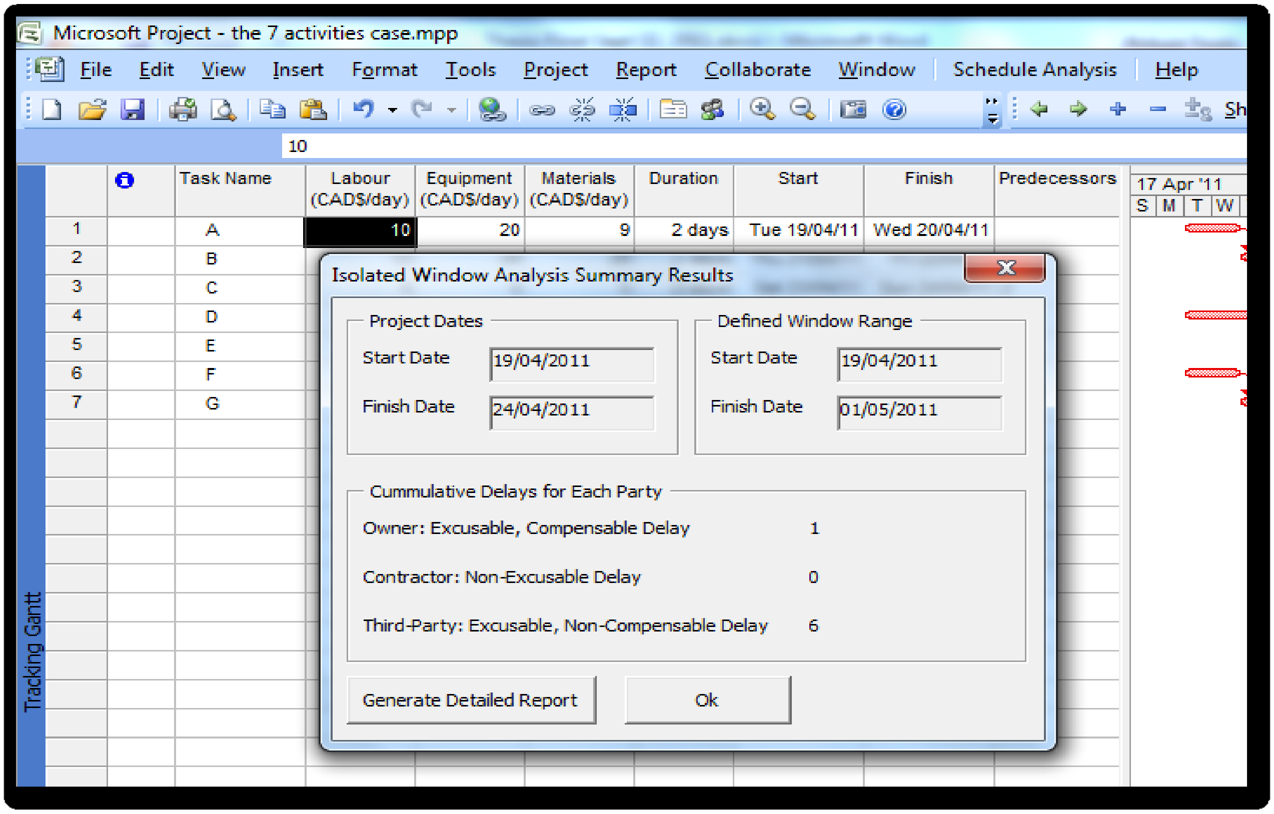


Figure 6-27 the 7-activity case - IDWAT (Regular) - Summary results

6.4 Schedule Delay/Acceleration Analysis

When accelerations are included in the schedule analysis, the acceleration rules are applied, as explained in section 5.3. The 7 activities case is modified to contain both delays and accelerations. It is called hereafter the 7 activities case-accelerations/delays and is used to test the performance of the schedule analysis module, considering both delays and accelerations.

The as-planned schedule of the 7 activity case-accelerations/delays is the same as that of Figure 6.16. The as-built and the schedule analysis results of the IDWAT (ELM) and IDWAT (Regular) methods for both accelerations and delays are shown in Figures 6.28 and 6.29, respectively.
As can be seen from Figures 6.28 and 6.29, the net impact on the project duration was 1 day of delay in both cases, while the shares of impacts for individual parties vary according to each method. In the case of the ELM method, the parties are deemed to have contributed to the net impact by 1/3 day of delay. With the Regular method, both the owner and the contractor are

deemed to have accelerated the project by ½ day of acceleration; which is represented in the figure as -1/2 day of delay. As for the third party, it is deemed to have delayed the project by 2 days.

It is worth noting that for both methods, day 1 of the project was accelerated by both the owner and the contractor. As per the IDAWT, OA and CA have to be inserted separately. When the OA acceleration is inserted alone, the project will not be accelerated (impact = 0). The same occurs when CA accelerations are inserted alone. However, when the accelerations of both the owner and the contractor are inserted, the project will be accelerated by one day (impact = -1). This impact is then apportioned between the owner and the contractor, so there is - 0.5 day of impact for each party.

On the other hand, day 7 of the project witnessed two owner accelerations on the only two parallel paths that day. These two owner accelerations, when inserted alone, resulted in one day of acceleration to the project duration (impact = -1). Also, on day 3, there was OA acceleration on one critical path and an EC delay on a parallel critical path. As per the acceleration rules, the delay will prevail and the impact on the project duration will be one day of delay due to the EC delay (impact = 1). It is interesting to observe that at the end of day 1, one day of float was created as a result of accelerating the project due to the OA and CA accelerations. This one day of float was consumed on day two by the delay caused by the three parties (EC, NE, EN). For the purpose of this research, the float is considered to be the project's property and is consumed on a first-come, first-served basis. Appendices A-7 and A-8 present more details of the day-by-day calculation and schedules of the IDWAT (ELM) and the IDWAT (Regular) methods, respectively.

End of day 7 bar chart –As-built- **IDWAT (ELM)**

Act(Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	OA								
B (2)		O(EC)	OA						
C (2)				O(EC)	O(EC)	O(EC)	OA		
D (3)	CA	C(NE)	O(EC)						
E (3)									
F(2)	CA								
G(4)		T(EN)		C(NE)		C(NE)	OA		
Daily Impact	-1	1	1	0	0	1	-1		
Owner	- 0.5	1/3	1	0	0	0.5	-1		
Contractor	- 0.5	1/3	0	0	0	0.5	0		
Third party	0	1/3	0	0	0	0	0		
Cum. delay	-1	0	1	1	1	2	1		

Figure 6-28 The 7-activity case - accelerations/delays - IDWAT (ELM)

Results of schedule analysis using the isolated daily window analysis technique (with the equal liability method for concurrency).

Owner (EC & OA) total impact = -1/2 + 1/3 + 1 + 1/2 - 1 = 1/3 days

Contractor (NE & CA) total impact = -1/2 + 1/3 + 1/2 = 1/3 days

Third party (EN) total impact = 1/3 = 1/3 days

Project total delay = 1/3 + 1/3 + 1/3 = 1 day

End of day 7 bar chart –As-built- **IDWAT (Regular)**

Act(Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	OA								
B (2)		O(EC)	OA						
C (2)				O(EC)	O(EC)	O(EC)	OA		
D (3)	CA	C(NE)	O(EC)						
E (3)									
F(2)	CA								
G(4)		T(EN)		C(NE)		C(NE)	OA		
Daily Impact	-1	1	1	0	0	1	-1		
Owner	- 0.5	0	1	0	0	0	-1		
Contractor	-0.5	0	0	0	0	0	0		
Third party	0	1	0	0	0	1	0		
Cum. delay	-1	0	1	1	1	2	1		

Figure 6-29 The 7-activity case - accelerations - IDWAT (Regular)

Results of schedule analysis using the isolated daily window analysis technique (with the Regular method for concurrency).

Owner (EC & OA) total impact = -1/2 + 1 - 1 = - 1/2 days

Contractor (NE & CA) total impact = -1/2 = - 1/2 days

Third party (EN) total impact = 1 + 1 = 2 days

Project total delay = - 1/2 - 1/2 + 2 = 1 day

6.5 Delay Cost Analysis

Delay cost analysis involves determining the cost incurred by both the contractor and the owner as a result of the delays caused by the opposite party. Quantifying the contractor cost includes the calculation of the direct cost, the impact cost and the overhead cost. The overhead cost includes both home office and site overhead costs. On the other hand, the owner cost is usually calculated by using the liquidated damages clause that is embedded in many types of contracts. In the absence of a liquidated damages clause, actual damages estimation may be necessary.

The 7-activity case is used to calculate different delay-associated costs. The as-planned schedule of the 7-activity case is loaded by resource cost data; labor cost, equipment cost, and material cost. It is also loaded by production data as a percentage per day. The resource cost and production data for the as-planned schedule were assumed to be uniformly distributed over each activity, as shown in Figure 6.30.

The actual resource costs and production rates are also recorded for each activity day as part of the progress data entry during the tracking phase of the project, resulting in an as-built schedule loaded by resource costs and production data. The delay costs for both the contractor and the owner can be calculated based on planned cost, actual cost, planned production, actual production, and delay analysis results. The following cost calculations are based on the delay cost modules discussed in chapter four.

6.5.1 Contractor's Direct Cost

Based on the direct cost module of Figure 4.6, the direct cost of the 7-activity case is calculated manually using both the ELM and the Regular methods.

The direct cost is calculated at the activity day level by targeting eligible activity days, defined as those affected by EC delays. Equation 4.1 is used to calculate the direct cost for each eligible day. If there is a concurrency between EC delay and other delays on any day, the direct cost for that day is allocated based on the concurrency method. If the ELM is applied, the direct cost will be apportioned between the concurrent types of delays. If the Regular method is applied, the direct cost for the activity day under consideration will be allocated completely (without apportionment) to the third party, leaving the direct cost associated with EC delay equal to zero.

Based on the ELM method, the direct cost associated with EC delay for activity A is shown in Figure 6.31. As an example, for day 2 of activity A, the production is zero which means a total stop of work. By applying equation 4.1, the daily direct cost (DDC) for this day is equal to the summation of the resource costs (LC+EC+MC). The amount of the DDC for this day is \$30, and since there is a concurrency between the EC and both EN and NE delays, the DDC will be apportioned between the three delays, leaving the EC-associated DDC (EC) equal to \$10.

Another example is day 7 of activity A where there are EC and NE concurrent delays and the actual production is 16.6%. This actual production is greater than zero and less than the planned production which is 50%, which implies a slowdown. Applying equation 4.1 will result in the following:

DDC = ACD – AP (SCR) = (LC+EC+MC) – AP (SCR)

= (8+20+3) - 0.166(0.78) = <u>\$18.052</u>

where:

DDC: Direct daily cost

ACD: Actual cost of activity day = Labour cost (LC) + Equipment Cost (EC) +Material cost (MC);

AP: actual production = 16.6%; and

SCR: scheduled cost rate = scheduled activity cost/100 = \$78/100 = \$0.78

Since there is a concurrency between EC and NE delay at day 7 of activity A, the DDC amount will be apportioned between the two, resulting in a DDC (EC) of <u>\$ 9.026</u>

These calculations are repeated for all days in activity A and the amounts of DDC (EC) are summed up to get the EC-associated activity direct cost; ADC (EC). The ADC (EC) amounts of all activities are then summed up to get the EC-associated project direct cost. As per the ELM manual calculation of the 7 activities case, the EC associated project direct cost D = $148.04. For more details please see appendix A-5.

For the Regular method, the direct cost associated with EC delay for activity A is shown in Figure 6.32. Both days 2 and 7 of activity A had concurrency, hence the DDC (EC) for each of those two days is zero because the concurrency resulted in a third party delay. However, days 4 and 6 have EC delays acting alone for each of them and their actual production is zero. By applying equation 4.1, the resulting DDC (EC) for each day equals the actual resource cost of the day, or $20. This calculation is repeated for all of the activity days to get the activity direct cost for activity A, which is $40. As per the Regular method, the project direct cost D = $98. Appendix A-6 covers the 7-activity manual calculation of direct costs in greater detail.

Act(Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2) SC= $ 78	LH(Hour)= 5 LC(Cost)$=10 EH(Hour)=2 EC(Cost)$=20 MU(Unit)=1 MC(Cost)$=9 SP(%)=50	LH=5 LC=10 EH=2 EC=20 MU=1 MC=9 SP(%)=50							
B (2) SC= $ 112			LH=4 LC=12 EH=2 EC=24 MU=2 MC=20 SP(%)=50	LH=4 LC=12 EH=2 EC=24 MU=2 MC=20 SP=50					
C (2) SC= $ 22					L=3 LC=6 E=0 EC=0 M=1 MC=5 SP(%)=50	L=3 LC=6 E=0 EC=0 M=1 MC=5 SP(%)=50			
D (3) SC= $ 240	LH=10 LC=40 EH=4 EC=40 MU=0 MC=0 SP(%)=33.33	LH=10 LC=40 EH=4 EC=40 MU=0 MC=0 SP(%)=33.33	LH=10 LC=40 EH=4 EC=40 MU=0 MC=0 SP(%)=33.34						
E (3) SC= $ 30				LH=5 LC=10 EH=0 EC=0 MH=0 MC=0 SP(%)=33.33	LH=5 LC=10 EH=0 EC=0 MH=0 MC=0 SP(%)=33.33	LH=5 LC=10 EH=0 EC=0 MH=0 MC=0 SP(%)=33.34			
F (2) SC= $ 30	LH=3 LC=9 EH=0 EC=0 MU=2 MC=6 SP(%)=50	LH=3 LC=9 EH=0 EC=0 MU=2 MC=6 SP(%)=50							
G(4) SC= $ 392			LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 SP(%)=25	LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 SP(%)=25	LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 SP(%)=25	LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 SP(%)=25			

Figure 6-30 The 7-activity as-planned loaded schedule(loaded with scheduled resource costs and production rates data)

Act (Dur)	Date														
	1	2	3	4	5	6	7	8	9	10	11	12	13		
A (9) AC= $ 248 ADC(EC)= **$ 90.039**	LH(Hour)= 5 LC(Cost)$=10 EH(Hour)=2 EC(Cost)$=20 MU(Unit)=1 MC(Cost)$=9 AP(%)=50	**O(EC)** C(NE) T(EN) **LH=5** **LC=10** EH=2 EC=20 MU=0 MC=0 AP(%)=0 **DDC(EC)=10** DC(NE)= 10 DC(EN)= 10 DDC = 30	**O(EC)** C(NE) **LH=3** **LC=6** EH=2 EC=20 MU=0 MC=0 AP(%)=0 **DDC(EC)=13** DC(NE)= 13 DDC= 26	**O(EC)** **LH=0** **LC=0** EH=2 EC=20 MU=0 MC=0 AP(%)=0 **DDC(EC)=20** DDC= 20	**C(NE)** LH=0 LC=0 EH=2 EC=20 MU=0 MC=0 AP(%)=0 DDC(NE)=20 DDC= 20	**O(EC)** LH=0 LC=0 EH=2 EC=20 MU=0 MC=0 AP(%)=0 **DDC(EC)=20** DDC= 20	**O(EC)** C(NE) **LH=4** **LC=8** EH=2 EC=20 MU=0.330 MC=3 AP(%)=16.6 **DDC(EC)=9.026** DC(NE)= 9.026 **DDC= 18.052**	**O(EC)** C(NE) **LH=4** **LC=8** EH=2 EC=20 MU=0.330 MC=3 AP(%)=16.6 **DDC(EC)=9.026** DC(NE)= 9.026 **DDC= 18.052**	**LH=4** **LC=8** EH=2 EC=20 MU=0.334 MC=3 AP(%)=16.7 **DDC(EC)=8.987** DC(NE)= 8.987 **DDC= 17.974**						
B (2) AC= $ 120 SC= $ 112 **EXC = $ 8** **ASD=7days** **DIC= $ 8/7** ADC(EC)= **$0** **AIC(EC)= $ 4.38**		**DIC(EC) = 0.381** DIC(NE) = 0.381 DIC (EN)= 0.381	**DIC(EC) = 0.571** DIC(NE) = 0.571	**DIC (EC)= 1.143**		**DIC (EC)= 1.143**	**DIC(EC) = 0.571** DIC(NE) = 0.571	**DIC(EC) = 0.571** DIC (NE)= 0.571		LH=4 **LC=16** EH=2 EC=24 MU=2 MC=20 AP(%)=50	LH=4 **LC=16** EH=2 EC=24 MU=2 MC=20 AP(%)=50				
C (2) AC= $ 28 SC= $ 22 EXC= $6 ASD= 7 days DIC= $ 6/7 ADC(EC)= **$ 0** **AIC(EC)= $ 3.29**		**DIC(EC) = 0.286** DIC(NE) = 0.286 DIC (EN)= 0.286	**DIC (EC)= 0.429** DIC(NE) = 0.429	**DIC (EC)= 0.858**		**DIC (EC)= 0.858**	**DIC(EC) = 0.429** DIC(NE) = 0.429	**DIC(EC) = 0.429** DIC(NE) = 0.429				L=3 **LC=9** E=0 EC=0 M=1 MC=5 AP(%)=50	L=3 **LC=9** E=0 EC=0 M=1 MC=5 AP(%)=50		

Figure 6-31 Activities A, B and C -- direct and impact costs (ELM)

	Date														
Act (Dur)	1	2	3	4	5	6	7	8	9	10	11	12	13		
A (9) AC= $ 248 ADC(EC)= **$ 40**	LH(Hour)= 5 LC(Cost)$=10 EH(Hour)=2 EC(Cost)$=20 MU(Unit)=1 MC(Cost)$=9 AP(%)=50	**O(EC)** C(NE) T(EN) **LH=5** **LC=10** EH=2 EC=20 MU=0 MC=0 AP(%)=0 **DDC(EC)= 0** DC(NE)= 0 DC(EN)= 30 DDC = 30	**O(EC)** C(NE) **LH=3** **LC=6** EH=2 EC=20 MU=0 MC=0 **AP(%)=0** **DDC(EC)= 0** DC(NE)= 0 DC(EN)=26 DDC= 26	**O(EC)** **LH=0** **LC=0** EH=2 EC=20 MU=0 MC=0 AP(%)=0 **DDC(EC)= 20** DDC= 20	**C(NE)** LH=0 LC=0 EH=2 EC=20 MU=0 MC=0 AP(%)=0 DDC(NE)= 20 DDC= 20	**O(EC)** LH=0 LC=0 EH=2 EC=20 MU=0 MC=0 AP(%)=0 **DDC(EC)= 20** DDC= 20	**O(EC)** C(NE) **LH=4** **LC=8** EH=2 EC=20 MU=0.330 MC=3 **AP(%)=16.6** **DDC(EC)=0** DC(NE)= 0 DC(EN)= 18.052 **DDC= 18.052**	**O(EC)** C(NE) **LH=4** **LC=8** EH=2 EC=20 MU=0.330 MC=3 **AP(%)=16.6** **DDC(EC)= 0** DC(NE)= 0 DC(EN)= 18.052 **DDC= 18.052**	**LH=4** **LC=8** EH=2 EC=20 MU=0.334 MC=3 **AP(%)=16.7** **DDC(EC)= 0** DC(NE)= 0 DC(EN)= 18.052 **DDC= 17.974**						
B (2) AC= $ 120 SC= $ 112 **EXC = $ 8** **ASD= 7 days** **DIC= $ 8/7** ADC(EC)= **$ 0** **AIC(EC)= $ 2.286**		**DIC(EC) = 0** DIC(NE) = 0 DIC (EN)= 1.143	**DIC(EC) = 0** DIC(NE) = 0. DIC (EN)= 1.143	**DIC (EC)= 1.143**	DIC(NE) = 1.143	**DIC (EC)= 1.143**	**DIC(EC) = 0** DIC(NE) = 0 DIC (EN)= 1.143	**DIC(EC) = 0** DIC (NE)= 0 DIC (EN)= 1.143		LH=4 **LC=16** EH=2 EC=24 MU=2 MC=20 AP(%)=50	LH=4 **LC=16** EH=2 EC=24 MU=2 MC=20 AP(%)=50				
C (2) AC= $ 28 SC= $ 22 EXC= $6 ASD= 7 days DIC= $ 6/7 ADC(EC)= **$ 0** **AIC(EC)= $ 1.716**		**DIC(EC) = 0** DIC(NE) = 0 DIC (EN)= 0.858	**DIC (EC)= 0** DIC(NE) = 0 DIC (EN)= 0.858	**DIC (EC)= 0.858**	DIC(NE) = 0.858	**DIC (EC)= 0.858**	**DIC(EC) = 0** DIC(NE) = 0 DIC (EN)= 0.858	**DIC(EC) = 0** DIC(NE) = 0 DIC (EN)= 0.858				L=3 **LC=9** E=0 EC=0 M=1 MC=5 AP(%)=50	L=3 **LC=9** E=0 EC=0 M=1 MC=5 AP(%)=50		

Figure 6-32 Activities A, B, and C -- direct and impact costs (Regular)

6.5.2 Contractor's Impact Cost

Based on the impact cost module of Figure 4.9, the impact cost of the 7 activities case is calculated manually using both the ELM and the Regular methods. As described in section 4.3.6, the impact cost is calculated on the activity level. For the purpose of this research, the impact cost is deemed to be caused by a delay in the start of the activity due to delays occurring in preceding activities.

If the activity has no delays of its own and its actual cost is greater than its scheduled cost, then it is considered for impact cost calculation. The second step is to check if the activity start is delayed and if it has no concurrency with a delayed parallel activity. If this is the case, then Option 1 of the impact cost module will apply. According to this option, the magnitude of the delay of the activity start is determined (number of days the activity start is delayed). A daily impact cost of delay is computed by dividing the extra cost of the activity by the number of days of delay in the activity's start.

The third step would be to check delays in the preceding activities and accumulate the delay days in these activities, which are equivalent to the delay in the start of the activity under consideration. Each accumulated delay day in the preceding activities will be checked for the existence of EC delay and concurrency with other types of delays. If there is no EC delay in the accumulated day, then the impact cost for that day is skipped. If EC delay exists on its own in the accumulated delay day, it will carry a full impact cost equal to the daily impact cost of the activity under consideration. If it exists and it is concurrent with other types, then one of the concurrency methods will be applied.

If the Regular method is applied, the impact cost for the accumulated day will be skipped. However, if the ELM method is applied, the impact cost for the accumulated delay day will be apportioned.

As an example, activity B of the 7 activities case has no delays of its own and it has an actual cost greater than its scheduled cost, which makes it a candidate for impact cost calculation. Its start is delayed by 7 days because of its preceding activity. Having completed the backward calculation of the accumulated delay days in the preceding activity, the impact costs were found to be $ 4.38 and $ 2.286, per the ELM and the Regular methods, respectively. Figures 6.31 and

6.32 show the impact costs of activities B and C of the 7 activities case. Appendices A-5 and A-6 show detailed calculations of the impact costs of the 7 activities case according to the ELM and the Regular methods, respectively.

6.5.3 Contractor's Overhead Cost

The contractor's overhead cost is calculated based on the overhead cost module of Figure 4.7. It is calculated on the project level and is directly related to the EC delays, as explained in section 4.3.5. The first step towards calculating the overhead cost is analyzing the delays to quantify the owner's share of the project delay (EC delays), using both the ELM and the regular method. The second step involves multiplying the EC delay in days by the daily overhead cost to get the total overhead cost that the contractor incurred as a result of the owner's delays.

As for the 7 activities case, the combined office and daily site overhead cost was assumed to be \$10. The contractor's overhead costs were as follows:

Overhead cost (ELM) = EC delay (days) × daily overhead cost (\$)

= 3 1/3 × 10 = <u>\$ 33.33</u>

Overhead cost (Regular) = EC delay (days) × daily overhead cost (\$)

= 1 × 10 = <u>\$ 10</u>

6.5.4 Owner's Liquidated Damages

The owner's liquidated damages are calculated as indicated on the module of Figure 4.8 and as explained in section 4.3.7. The daily liquidated damages for the 7 activities project is assumed to be \$6/day. The liquidated damages of the 7 activities case were calculated as follows:

Liquidated damages (ELM) = NE delay (days) × daily liquidated damages

= 2 1/3 × 6 = <u>\$ 14</u>

Liquidated damages (Regular) = NE delay (days) × daily liquidated damages

= 0 × 6 = <u>\$ 0</u>

Figures 6.33 & 6.34 show results produced for the 7 activities case using the framework's cost analysis submenu. These are identical to the aforementioned results of the manually-calculated delay cost analysis. Appendices A-5 and A-6 include more details on the process of manually calculating liquidated damages.

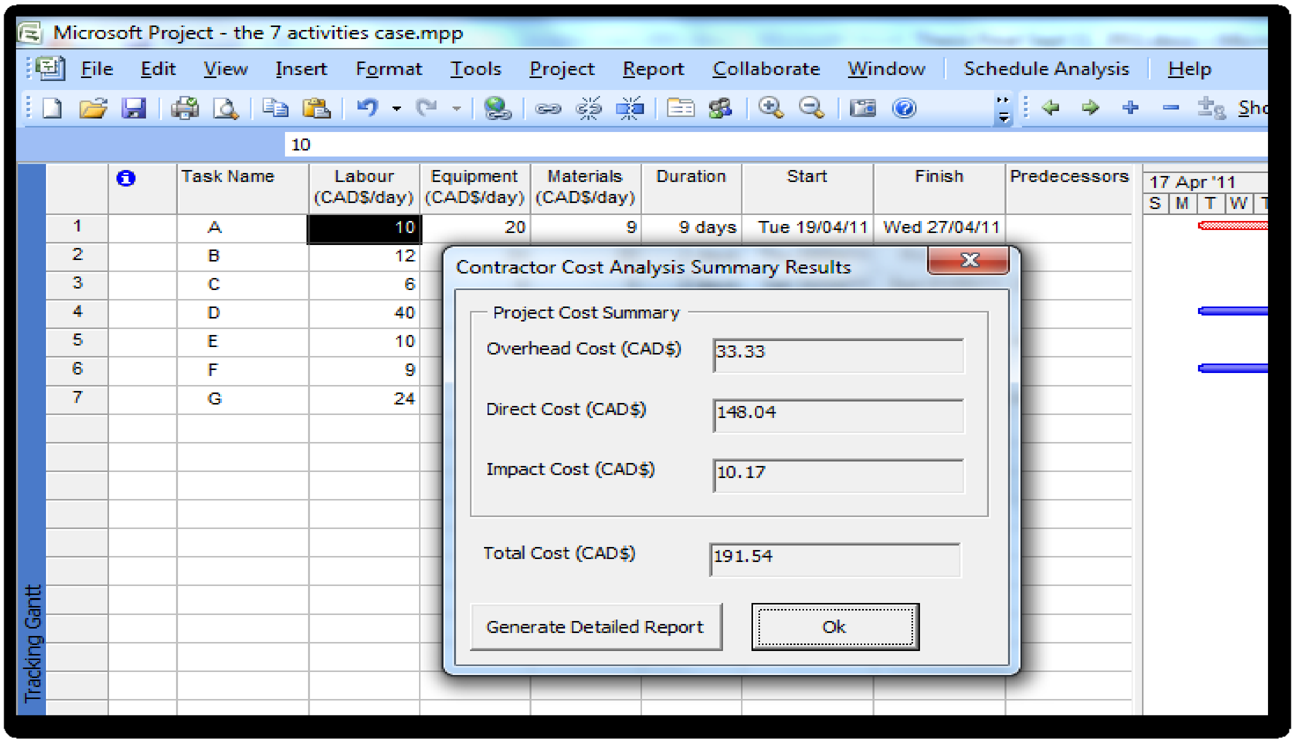


Figure 6-33 Contractor cost analysis results (ELM)

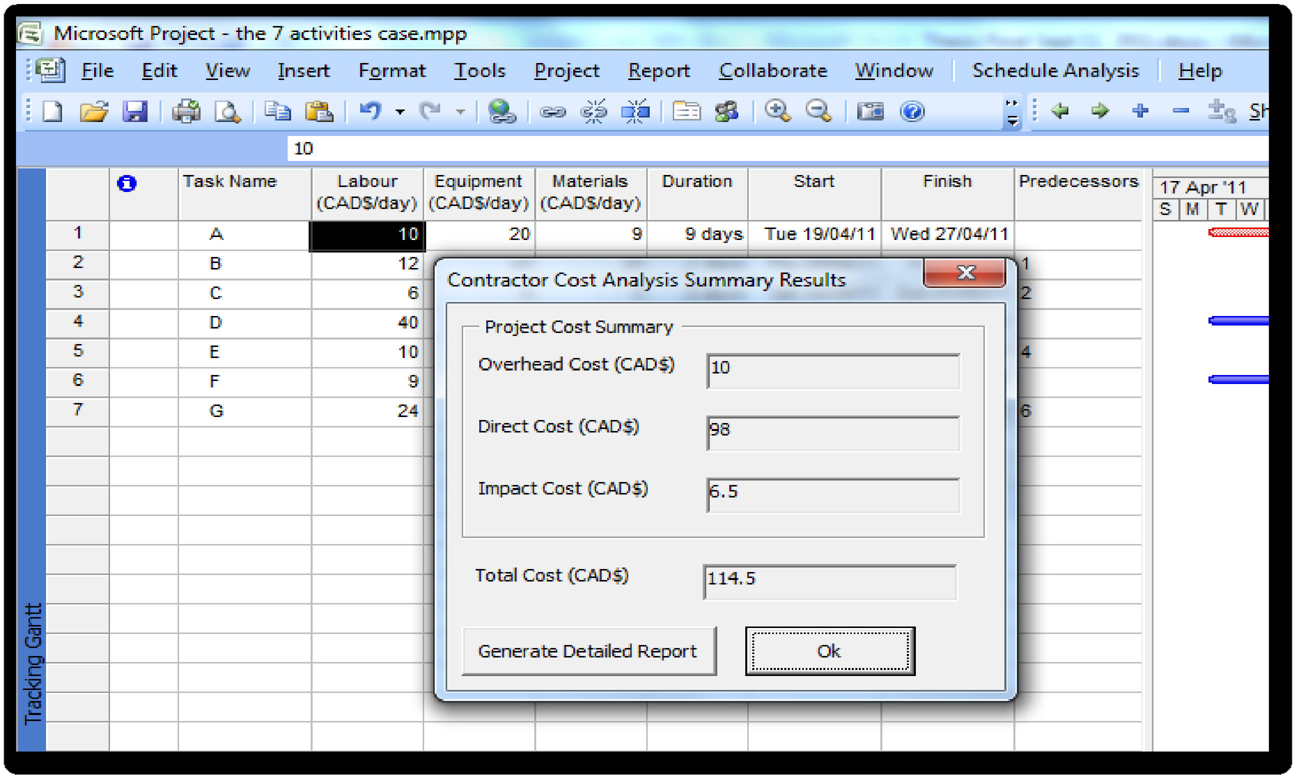


Figure 6-34 Contractor cost analysis results (Regular)

6.6 Delay/Acceleration Cost Analysis

When accelerations are included in the schedule analysis, acceleration rules (as explained in section 5.3) are applied; the impact of each party on the project duration will be affected and may contain minus net values or accelerations. These differences in the outcomes of the schedule delay/acceleration analysis versus the outcome of the purely delay analysis will also impact the damage calculations. The as-planned and the as-built schedules of the 7 activities case-accelerations/delays are loaded with the planned and actual resource costs and production data. These loaded schedules will be used to calculate damages incurred by the owner and the contractor as a result of the actions of each party's counterpart. Figure 6.30 shows the as-planned cost and the production-loaded schedule of the 7-activity case-accelerations/delays.

6.6.1 Acceleration Cost

Acceleration cost refers to the cost incurred by the contractor as a result of owner-directed acceleration (OA). As with delay direct cost, the acceleration cost will be calculated on the activity-day level using equation 4.1 as depicted in Figure 4.5.

Only owner-directed (OA) acceleration days are deemed eligible for the acceleration cost calculation. As per rules for calculating acceleration, there is no concurrency of accelerations or accelerations and delays at the activity day level. Therefore, the ELM and the Regular method have no role to play in the acceleration cost calculation, and so the acceleration cost for any eligible day will be fully allocated as OA acceleration cost. The acceleration costs for activities A, B and C are shown in Figure 6.35.

As an example, the as-planned duration of activity A is 2 days and it was accelerated to 1 day, which makes the production rate for that day 100%. By applying equation 4.3, the acceleration cost (AXC) for day 1 of activity A is equal to:

AXC = ACD – AP (SCR) = (LC+EC+MC) – AP (SCR)

= (24+40+18) – 100.0(0.78) = $4

Where:

AXC: Acceleration daily cost;

ACD: Actual cost of activity day = Labor cost (LC) + Equipment Cost (EC) +Material cost (MC);

AP: actual production = 100%; and

SCR: scheduled cost rate = scheduled activity cost/100 = $78/100 = $0.78

These calculations are repeated for all days in each activity and the amounts of AXC (OA) are summed to get the AAC -- the activity acceleration cost associated with (OA) accelerations. The AAC amounts of all activities are then summed to get A: the OA-associated project acceleration cost. As per the manual calculation of the 7-activity case delays/accelerations, the OA-associated project acceleration cost A = $20. For more details please see appendix A-9.

Act (Dur.)	Date								
	1	2	3	4	5	6	7	8	9
A (2) AAC = $4	OA **LH=12** **LC=24** EH=4 EC=40 MU=2 MC=18 AP(%)=100 AXC= 4								
B (2) ADC=$12 AAC=$6		O(EC) LH=4 LC=12 EH=0 EC=0 MU=0 MC=0 AP(%)=0 DDC=12	OA LH=10 LC=30 EH=4 EC=48 MU=4 MC=40 AP(%)=100 AXC=6						
C (2) ADC=$6 AAC=$4				O(EC) L=3 LC=6 E=0 EC=0 M=0 MC=0 AP(%)=0 DDC=6	O(EC) L=0 LC=0 E=0 EC=0 M=0 MC=0 AP(%)=0 DDC=0	O(EC) L=0 LC=0 E=0 EC=0 M=0 MC=0 AP(%)=0 DDC=0	OA L=8 LC=16 E=0 EC=0 M=2 MC=10 AP(%)=100 AXC=4		
D (3) ADC=$0	CA LH=22 LC=48 EH=8 EC=80 MU=0 MC=0 AP(%)=66.66	C(NE) LH=5 LC=20 EH=0 EC=00 MU=0 MC=0 AP(%)=0	O(EC) LH=0 LC=0 EH=0 EC=0 MU=0 MC=0 AP(%)=0 DDC=0	LH=10 LC=40 EH=4 EC=40 MU=0 MC=0 AP(%)=33.33					
E (3) **EXC = $ 6** **ASD= 1 days** **DIC= $ 6/1=$6** ADC(EC)= **$ 0** **AIC(EC)= $ 6**			**DIC(EC) = $6**		LH=6 LC=12 EH=0 EC=0 MH=0 MC=0 AP(%)=33.33	LH=6 LC=12 EH=0 EC=0 MH=0 MC=0 AP(%)=33.33	LH=6 LC=12 EH=0 EC=0 MH=0 MC=0 AP(%)=33.33		

Figure 6-35 Activity A, B, C, D and E Acceleration, direct and impact costs

6.6.2 Contractor's Direct Cost

The contractor's direct costs refer to the cost incurred by a contractor as a result of owner (EC) delays. For this case, direct costs are calculated in the same way as the delays-only case that was discussed in section 6.5.1. Since the 7-activity delays/accelerations case does not have concurrent delays at the delay-activity level, the ELM and the Regular method evaluations are not required.

Based on the direct cost module of Figure 4.6 and equation 4.1, the direct cost of the 7-activity delays/accelerations case is calculated manually. Evaluating one example, the 1st day of activity C, as shown in Figure 6.35, has a production of zero, which means a total work stoppage. By applying equation 4.1, the daily direct cost (DDC) for this day is equal to:

DDC = ACD – AP (SCR) = (LC+EC+MC) – AP (SCR)

= (6+0+0) - 0.0(0.78) = $6

Where:

DDC: Direct daily cost

ACD: Actual cost of activity day = Labor cost (LC) + Equipment Cost (EC) + Material cost (MC);

AP: Actual production = 0.0%; and

SCR: scheduled cost rate = scheduled activity cost/100 = $78/100 = $0.78

These calculations are repeated for every day in each activity and the amounts of DDC (EC) are summed up to get the EC-associated activity direct costs, or the ADC (EC). The ADC (EC) amounts of all the activities are then summed up to get D --the EC-associated project direct cost. Manual calculation of the 7-activity delays/accelerations case results in an EC-associated project direct cost of D = $18. For more details please see appendix A-9.

6.6.3 Contractor's Impact Cost

The contractor's impact cost refers to the cost incurred by the contractor due to a disruption of the activity's work caused by owner (EC) delays. One of the scenarios that may lead to a disruption of an activity's work is when the start of an activity is delayed; referred to in this thesis as option 1. This delay in the start of an activity may increase the cost of performing the work due to weather changes, manpower shortage, and trade stacking. For this case, the impact cost is calculated in the same way as in the delays-only case presented in section 6.5.2. The 7-activity delay/acceleration case does not have concurrent delays at the delay-activity level, which means that the ELM and the Regular method evaluations will not be needed.

Based on the impact cost module in Figure 4.9, the impact cost of the 7-activity delays/accelerations case is calculated manually. As described in section 4.3.6, the impact cost is calculated on the activity level. For the purpose of this research, the impact cost is deemed to be caused by a delay in the start of the activity due to delays occurring in preceding activities. As per Figure 4.9, the accelerations cancel the impact of their succeeding delays.

To take one example, activity E of the 7 activities delays/accelerations case has no delays of its own and it has an actual cost greater than its scheduled cost, which makes it a candidate for impact cost calculation. Its start is delayed by 1 day because of its preceding activity. After the backward calculation of the accumulated delay days in the preceding activity was completed, the impact costs were found to be $ 6. Figure 6.35 shows the impact cost of activity E. Appendix A-9 shows the calculations of the impact costs of the 7-activity delays/accelerations case in full detail.

6.6.4 Contractor's Overhead Cost

The contractor's overhead cost is calculated based on the overhead cost module indicated in Figure 4.7. It is calculated on the project level and is directly related to the EC delays as explained in section 4.3.5. It is also affected by accelerations since they directly affect the outcomes of the delay/acceleration schedule analysis. The share of the impact on project duration for each party is also affected by accelerations. In some cases, the total impact on the project duration or the share of the contractor and/or the owner may have a minus value, indicating a net acceleration.

The first step towards calculating the overhead cost is analyzing delays and accelerations to quantify the owner's share of the impact on the project duration. Using both the ELM and the Regular method, the owner's impact may be a net delay (EC) or zero or a net acceleration (-EC or OA). Figures 6.28 and 6.29 show the delay/acceleration analysis of the 7-activity delays/accelerations case for the ELM and the Regular method, respectively. The second step involves multiplying the EC delay in days by the daily overhead cost to get the total overhead cost that was incurred by the contractor as a result of the owner's delays.

The combined office and site daily overhead costs for the 7-activity delays/accelerations case were assumed to be \$10/day. Based on this value, the contractor's overhead costs were as follows:

Overhead cost (ELM) = EC delay (days) × daily overhead cost (\$)

= 1/3 × 10 = <u>\$ 3.33</u>

Overhead cost (Regular) = EC delay (days) × daily overhead cost (\$)

= -1/2 × 10 = <u>\$ -5</u>

What do a minus EC and overhead cost values mean? They indicate that the owner's actions have contributed to the acceleration of the project or at least to a mitigation of the project delay effect. By shortening the project's anticipated duration or mitigating the effect of other party's delays, the owner would theoretically contribute to reducing the office and site overhead. If this contribution accounted for, the value of the savings in the overhead cost will affect the total amount of damages incurred by the contractor. Another way of looking at the minus value is to consider that there was simply no increase of the OH cost as a result of the owner's actions: OH = <u>\$ 0.</u>

When calculating the contractor's total delay cost or the contractor's total cost due to the owner's impacts (delays/accelerations), the final outcome will differ depending on if the minus value of the overhead cost is considered, and how. As an example, the total damages incurred by the contractor based on the Regular method are calculated as follows:

O: OH amount ($ 60)/(6 days of original duration) x No of EC delay days for the whole project (-1/2 days) = $ -5; in other words 0 increase in OH cost.

Contractor's Total Project Delay Cost = D + I + O = 18 + 6 - 5 = $ 19 (1^{st} option, assuming savings in OH cost)

Contractor's Total Project Delay Cost = D + I + O = 18 + 6 + 0 = $ 24 (2^{nd} option, assuming 0 increase in OH cost)

Contractor's Total Cost due to owner's impacts (delays/accelerations) = 19 + 6 = $ 25 (based on option 1)

Contractor's Total Cost due to owner's impacts (delays/accelerations) = 24 + 6 = $ 30 (based on option 2)

Appendices A-9 and A-10 include more details of manually calculated overhead costs.

6.6.5 Owner's Liquidated Damages

The owner's liquidated damages are calculated as indicated on the module of Figure 4.8 and as explained in section 4.3.7. The daily liquidated damages for the 7 activities delays/accelerations project is assumed to be $6/day. Based on the results presented in Figures 6.28 and 6.29, the liquidated damages of the 7 activities delays/accelerations case were calculated as follows:

Liquidated damages (ELM) = NE delay (days) × daily liquidated damages

= 1/3 × 6 = $ 2

Liquidated damages (Regular) = NE delay (days) × daily liquidated damages

= -1/2 × 6 = $ -3

Again, the minus sign in the Regular method simply means that there are no liquidated damages that can be claimed by the owner. The contractor has actually contributed to the acceleration of the project duration or at least to the mitigation of the effect of other party's delays. Appendices A-9 and A-10 include more details of manually calculated liquidated damages.

6.6.6 Delay-Acceleration Scenarios

The 7-activity case was modified to account for contractor delays (NE) in the first 3 days which resulted in a delay of 3 days to the project duration. After day 3 of the project, the contractor will have to decide whether to accelerate the project to avoid paying $10/day for liquidated damages. The decision to accelerate or not is very much dependent on the net savings that will be attained by such acceleration. Also, the net saving impact (NSI) helps to determine the duration and the timing of acceleration. As was explained in sections 3.6 and 4.3.8 and based on equation 4.9, the net saving impact (NSI) is calculated for each scenario. Scenarios 2.1 and 4.1 were found to be the most favorable because they produce the highest net savings impact of $6 for each. Scenario 2.1 calls for accelerating the project on day 4 for only 1 day while scenario 4.1 calls for accelerating the project by 1 day at day 8. Other scenarios call for accelerating the project for 2 or three days but they result in fewer saving. In fact, scenario 2.3 which calls for accelerating the project for 3 days on days 4, 5, and 6, which results in a net loss of $1. Figures 6.36 and 6.37 show time and cost views, respectively, as bar charts of scenario 2.1. Appendices A-11 and A-12 include more details for manually calculated scenarios.

Scenario # 2.1: Acceleration on day 4(end of day 4 bar chart) - time

Act(Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	NE	NE	NE	CA					
B (2)									
C (2)									
D (3)	EN								
E (3)									
F(2)	NE	NE							
G(4)									
Daily impact	1	1	1	-1					
Owner	0	0	0	0					
Contractor	0.5	1	1	-1					
Third party	0.5	0	0	0					
Cum. delay	1	2	3	2					

Figure 6-36 Scenario # 2.1(Acceleration on day 4) - End of day 4 bar chart- time

Results of schedule analysis using isolated daily window analysis technique (with equal liability method for concurrency)

Owner (EC & OA) total Impact = 0 days

Contractor (NE & CA) total Impact = 1/2 + 1 + 1-1 = 1 ½ days

Third party (EN) total Impact = 1/2 = 1/2 days

Project total delay = 0 + 1 ½ + 1/2 = 2 days

Scenario # 2.1: Acceleration on day 4(end of day 4 bar chart) - cost

Act(Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0	CA **LH=12** **LC=24** EH=4 EC=40 MU=2 MC=18 AP(%)=100 AXC= 4					
B (2)									
C (2)									
D (3)	EN LH=5 LC=20 EH=0 EC=00 MU=0 MC=0 AP(%)=0								
E (3)									
F(2)	NE LH=3 LC=9 EH=0 EC=0 MU=0 MC=0 AP(%)=0	NE LH=3 LC=9 EH=0 EC=0 MU=0 MC=0 AP(%)=0							
G(4)									

Figure 6-37 Scenario # 2.1(Acceleration on day 4) - End of day 4 bar chart - cost

Contractor impact = 1 ½ days, Project total delay = 2 days, Acceleration cost (Scenario2.1) = $ 4

Liquidated damages (Scenario 2.1, assuming the daily LD = $ 10) = 1 ½ (days) × $ 10 = $15

NSI 2.1 = LD max - LD2.1 – AC2.1 = 25 – 15 – 4 = $ 6 (this indicates that spending $ 4 to accelerate the project on Day 4 reduced the Liquidated damages by $ 10 producing a net savings of $ 6 on day 4)

Chapter 7

CONCLUSION: CONTRIBUTIONS, LIMITATIONS and FUTURE WORK

7.1 Summary

Delay analysis, as a part of the claim preparation process, is a relatively complex and demanding process. It involves digging into a number of documents to extract a variety of delay information and reconstructing the course of events in construction projects. The extracted delay information usually includes the duration and the causation of delays (a delay's type), the date of a delay, the affected activities, and other supporting information. Clearly, this is a time-consuming and thus costly process. The information may be misplaced or distorted as a result of a lack of timely documentation. The use of information technology in this process will bring multiple benefits to all the parties involved in claim preparation.

This research presents a methodology for timely capturing and documenting delay data in a standardized, useful form. This data is then made easily accessible to delay and cost analysis modules through the integration of the scheduling program (MS Project) with the relational database (MS Access). In addition to the database and the scheduling software, the methodology includes modules for delay/acceleration analysis (apportioning project delay/acceleration between parties), cost analysis (delay/acceleration damage quantification), and a Visual Basic for applications (VBA) module. The VBA module is mainly used to automate procedures and integrate different parts of the framework. The research successfully addressed the following:

1. Documenting delay/acceleration-related information as it happens, minimizing the loss of information and facilitating the retrieval of such information when needed for analysis.
2. Documenting delay/acceleration data in a basic format using the Event identity concept (EIC).
3. Introducing the equal liability method (ELM) of concurrency entitlements for different parties. The ELM gives all parties the same rights to both time and costs based on their share of delay.

4. Introducing the Isolated daily window analysis technique (IDWAT), which uses delay data documented based on the DIC. The IDWAT also uses the ELM and the Regular method of concurrency entitlement.
5. Providing an instant delay/acceleration analysis facility during and after construction by modeling two delay analysis techniques (IDWAT & "But-for").
6. Extracting the required delay data instantaneously, based on the technique used, and writing it directly to MS Project so that it can perform schedule calculations.
7. Apportioning project delay responsibility between the owner and the contractor in a much more reasonable and fair manner.
8. Providing output reports for delay/acceleration analysis and delay/acceleration damages for all parties.

As presented in chapter four, it is clear that the developed model has advantages that are made possible by the integration of many procedures and components. The comparison with previous studies and the outcome of the manually calculated test cases demonstrated the accuracy of the results obtained by this framework.

This framework and its methodology are intended to be used by owners and contractors to document delay/acceleration incidents as they happen, analyze delays/accelerations, and to calculate delay/acceleration damages for all parties. It provides an accurate, rapid, and economic apportioning of responsibility for project delay and calculates the cost of delays/accelerations for each party with minimum errors.

7.2 Contribution

The contributions of this research include the following:

1. The development of a forensic delay analysis framework for construction projects. The framework integrates a relational database (MS Access), a scheduling program (MS Project), delay/acceleration analysis modules, and delay/acceleration cost quantification modules. The developed framework can be used as a negotiating tool to help settle

delay/acceleration – related disputes. Contractors, owners, consultants and lawyers can make use of it both during construction and after the project is completed.

2. The introduction of an event identity concept (EIC) to help document delays/acceleration in their basic format. This format helps to prevent delays from going unaccounted for (and causing concurrency situations to be overlooked) and helps prevent them from being counted more than once (which could cause an exaggeration of the delay/acceleration analysis results). This format helps to document delays/accelerations regardless of the criticality of the related activity on the date of the delay/acceleration occurrence, thereby helping to keep track of the real critical path at every day of the project. Because of the cumulative effect of delays/accelerations and float consumption/generation, a delay/acceleration acting on a non-critical activity may very well have an impact on the outcome of delay/acceleration analysis 'down the road'.
3. It introduces an equal liability method (ELM) to determine liabilities for different parties in delay concurrency situations. The ELM is based on the assumption that all parties are equally liable for the delays they cause, and on the fact that their incurred costs in delay situations are not necessarily equal.
4. The introduction of an isolated daily window analysis technique (IDWAT) using delay data documented based on the EIC concept, and which employs both the ELM and the regular method of concurrency entitlements. The IDWAT was evaluated by comparing its outcome with those of other techniques from earlier studies.
5. The development of a computer program using the Visual Basic for application language (VBA). VBA was used to develop and implement data entry modules, delay/acceleration analysis modules, and cost analysis modules. It was also used here to create the forms and reports and to integrate MS Project and Access with each other and with the data entry, delay/acceleration analysis, and cost analysis modules. The developed program uses MS Project as an interface, thereby making the delay documentation and analysis functions integral parts of the routinely-performed scheduling and monitoring functions. The framework performance was validated by comparing its results with those of an earlier case study and with manually-calculated results.

7.3 Limitations

Some of the limitations in the scope of the framework are that:

1. The CPM logic is restricted to the basic FS relationship, and it is assumed to be maintained throughout the project.
2. A calendar of seven working days per week is used.
3. The impact cost calculation was performed using only one scenario (Option 1).

7.4 Suggestions for future work

This research has added to the domain of delay analysis by developing and implementing an integrated delay/acceleration analysis and cost quantification framework. However, the following points are suggested for future work and enhancement:

1. Covering other kinds of schedule logic and calendars. This includes covering FF, SS and SF relationships. It also entails considering relationship lags and applying different kinds of calendars.
2. Integrating an expert system especially tailored for specific types of contracts to help in better classifying delays. FIDIC contracts can be used as a knowledge base to develop an expert system that can help in classifying delays and determining entitlements in the case of concurrency.
3. Considering other scenarios and methods of calculating delay damages. In the case of impact cost for example, more options (more activities) can be included in the calculation.
4. Considering other methods of float ownership. Apportionment of float can be performed based on predefined rules that can be embedded in contracts. Such rules can be as simple as allocating the float to one party or dividing it between parties based on a certain percentage for each. It can be more complicated and requires that each party gets a float based on his share of the project risk.

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APPENDIX A-1:

THE 10-ACTIVITIES CASE – IDWAT (ELM)

The 10 activities, as-planned

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
ACT1	1	1	1	1	1	1	1																																	
ACT2	2	2	2	2	2																																			
ACT3								3	3	3	3	3	3	3																										
ACT4						4	4	4	4	4	4	4	4	4						`																				
ACT5						5	5	5	5	5	5																													
ACT6															6	6	6	6																						
ACT7															7	7	7																							
ACT8												8	8	8	8	8	8	8	8	8																				
ACT9																			9	9	9	9	9																	
ACT10																					10	10	10																	

End of day 4

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	1	1	1	1																						
ACT2	2	2	NE	EC	2	2	2																									
ACT3											3	3	3	3	3	3	3															
ACT4								4	4	4	4	4	4	4	4	4				`												
ACT5								5	5	5	5	5	5																			
ACT6																		6	6	6	6											
ACT7																	7	7	7													
ACT8														8	8	8	8	8	8	8	8	8										
ACT9																						9	9	9	9	9						
ACT10																							10	10	10							
Daily delay	1	1	1	0																												
O Delay																																
C Delay		1	1																													
T Delay	1																															
Cum. Delay	1	2	3	3																												

Note: Although there was an owner (EC) delay acting on day 4 in activity 2, this delay was not recorded under O delay in the summary because it did not affect the overall duration of the project. (Path 2, 5, 8, 10 was not critical at the beginning of day 4.)

End of day 5

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	1	1	1	1																						
ACT2	2	2	NE	EC	EN	2	2	2																								
ACT3											3	3	3	3	3	3	3															
ACT4									4	4	4	4	4	4	4	4	4			`												
ACT5									5	5	5	5	5	5																		
ACT6																		6	6	6	6											
ACT7																		7	7	7												
ACT8															8	8	8	8	8	8	8	8	8									
ACT9																						9	9	9	9	9						
ACT10																								10	10	10						
Daily delay	1	1	1	0	0																											
O Delay																																
C Delay		1	1																													
T Delay	1																															
Cum. Delay	1	2	3	3	3																											

Note: Although there was a third-party (EN) delay acting on day 5 in activity 2, this delay was not recorded under T delay in the summary because it did not affect the overall duration of the project. (Path 2, 5, 8, 10 was not critical at the beginning of day 5). However, it became critical at the end of day 5.

End of day 7 – (NE injected alone)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	2	2	2																							
ACT3												3	3	3	3	3	3	3														
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5										5	5	5	5	5	5																	
ACT6																			6	6	6	6										
ACT7																				7	7	7										
ACT8																8	8	8	8	8	8	8	8	8								
ACT9																							9	9	9	9	9					
ACT10																									10	10	10					
Daily delay	1	1	1	0	0	1																										
O Delay																																
C Delay		1	1																													
T Delay	1					1																										
Cum. Delay	1	2	3	3	3	4	5																									

Note: When injecting the NE delays alone, the project duration will not be affected. This is because the NE delay acting on activity 1 on day 7 while the path (1, 3, 6, 9) was not critical at the beginning of day 7. Therefore, this delay was not recorded in the summary.

End of day 7- (EN injected alone)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	1	1	1	1																						
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3											3	3	3	3	3	3	3															
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	5	5	5	5																
ACT6																		6	6	6	6											
ACT7																				7	7	7										
ACT8																	8	8	8	8	8	8	8	8	8							
ACT9																						9	9	9	9	9						
ACT10																										10	10	10				
Daily delay	1	1	1	0	0	1	1																									
O Delay																																
C Delay		1	1																													
T Delay	1					1	1																									
Cum. Delay	1	2	3	3	3	4	5																									

Note: The third party (EN) delay acting on day 7 in activity 2 was recorded under T delay in the summary because it did affect the overall duration of the project when it was applied alone. (The path 2, 5, 8, 10 was critical at the beginning of day 7.)

End of day 7 (both EN & NE injected)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												3	3	3	3	3	3	3														
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	5	5	5	5																
ACT6																			6	6	6	6										
ACT7																				7	7	7										
ACT8																	8	8	8	8	8	8	8	8	8							
ACT9																							9	9	9	9	9					
ACT10																										10	10	10				
Daily delay	1	1	1	0	0	1	1																									
O Delay																																
C Delay		1	1																													
T Delay	1					1	1																									
Cum. Delay	1	2	3	3	3	4	5																									

Note: Although there was a contractor (NE) delay acting on day 7 in activity 1, this delay was not recorded under C delay in the summary because it did not affect the overall duration of the project (path 1, 3, 6, 9 was not critical at the beginning of day 7). On the other hand, the third-party (EN) delay acting on day 7 in activity 2 was recorded under T delay in the summary because it did affect the overall duration of the project (path 2, 5, 8, 10 was critical at the beginning of day 7). **This end-of-day 7 schedule with all delays injected (NE &EN) will be the baseline for the end-of-day 8 window calculations.**

End of day 12

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												NE	3	3	3	3	3	3	3													
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	5	5	5	5																
ACT6																				6	6	6	6									
ACT7																				7	7	7										
ACT8																	8	8	8	8	8	8	8	8	8							
ACT9																								9	9	9	9	9				
ACT10																										10	10	10				
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0																				
O Delay																																
C Delay		1	1																													
T Delay	1					1	1																									
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5																				

Note: Although there was a contractor (NE) delay acting on day 12 in activity 3, this delay was not recorded under C delay in the summary because it did not affect the overall duration of the project (path 1, 3, 6, 9 was not critical at the beginning of day 12). However, it became critical at the end of day 12.

End of day 13 (NE injected alone)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												NE	NE	3	3	3	3	3	3	3												
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	5	5	5	5																
ACT6																					6	6	6	6								
ACT7																				7	7	7										
ACT8																	8	8	8	8	8	8	8	8	8							
ACT9																									9	9	9	9	9			
ACT10																										10	10	10				
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1																			
O Delay																																
C Delay		1	1										1/2																			
T Delay	1					1	1																									
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6																			

Note: When injecting the NE delays alone, the project duration is affected. This is because the NE delay acting on activity 3 on day 13 when the path (1, 3, 6, 9) was critical at the beginning of day 13. Therefore, this delay is recorded in the summary as C Delay. The value of the C delay is ½ day because there is a concurrency with an EC delay at a parallel critical activity (activity 5).

End of day 13 (EC injected alone)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												NE	3	3	3	3	3	3	3													
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	EC	5	5	5	5															
ACT6																				6	6	6	6									
ACT7																				7	7	7										
ACT8																		8	8	8	8	8	8	8	8	8						
ACT9																								9	9	9	9	9				
ACT10																											10	10	10			
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1																			
O Delay													1/2																			
C Delay		1	1																													
T Delay	1					1	1																									
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6																			

Note: When injecting the EC delay alone, the project duration is affected. This is because the EC delay acting on activity 5 on day 13 while the path (2, 5, 8, 10) was critical at the beginning of day 13. This delay is therefore recorded in the summary as O Delay. The value of the O delay is ½ day because there is a concurrency with an NE delay at a parallel critical activity (activity 3).

End of day 13 (Both NE & EC injected)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												NE	NE	3	3	3	3	3	3	3												
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	EC	5	5	5	5															
ACT6																					6	6	6	6								
ACT7																				7	7	7										
ACT8																		8	8	8	8	8	8	8	8	8						
ACT9																									9	9	9	9	9			
ACT10																											10	10	10			
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1																			
O Delay													1/2																			
C Delay		1	1										1/2																			
T Delay	1					1	1																									
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6																			

Note: Here we have a contractor (NE) delay acting on activity 3 on day 13 that affects (when applied alone) the overall project duration by one day. At the same time (on day 13), we have an owner (EC) delay acting on activity 5 which also affects (when applied alone) the overall project duration by one day. So, the one-day project delay at the end of day 13 will be apportioned between the contractor and the owner, half a day for each. **This end-of-day 13 schedule with all delays injected (NE &EC) will be the baseline for the end-of-day 14 window calculations.**

End of day 14 (NE injected alone)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												NE	NE	NE	3	3	3	3	3	3	3											
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	EC	5	5	5	5															
ACT6																						6	6	6	6							
ACT7																				7	7	7										
ACT8																		8	8	8	8	8	8	8	8	8						
ACT9																										9	9	9	9	9		
ACT10																											10	10	10			
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1	1																		
O Delay													1/2																			
C Delay		1	1										1/2	1/2																		
T Delay	1					1	1																									
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6	7																		

Note: When injecting the NE delays alone, the project duration is affected. This is because the NE delay is acting on activity 3 on day 14 and the path (1, 3, 6, 9) was critical at the beginning of day 14. This delay is therefore recorded in the summary as C Delay. The value of the C delay is ½ day because there is a concurrency with an EC delay at a parallel critical activity (activity 5).

End of day 14 (EC injected alone)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												NE	NE	3	3	3	3	3	3	3												
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	EC	EC	5	5	5	5														
ACT6																					6	6	6	6								
ACT7																				7	7	7										
ACT8																			8	8	8	8	8	8	8	8	8					
ACT9																									9	9	9	9	9			
ACT10																												10	10	10		
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1	1																		
O Delay													1/2	1/2																		
C Delay		1	1										1/2																			
T Delay	1					1	1																									
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6	7																		

Note: When injecting the EC delay alone, the project duration is affected. This is because the EC delay is acting on activity 5 on day 14 and the path (2, 5, 8, 10) was critical at the beginning of day 14. As a result, this delay is recorded in the summary as a O Delay. The value of the O delay is ½ day because there is a concurrency with an NE delay at a parallel critical activity (activity 3).

End of day 14 (Both NE & EC injected)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												NE	NE	NE	3	3	3	3	3	3	3											
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	EC	EC	5	5	5	5														
ACT6																						6	6	6	6							
ACT7																				7	7	7										
ACT8																			8	8	8	8	8	8	8	8	8					
ACT9																										9	9	9	9	9		
ACT10																												10	10	10		
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1	1																		
O Delay													1/2	1/2																		
C Delay		1	1										1/2	1/2																		
T Delay	1					1	1																									
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6	7																		

Note: Here we have a contractor (NE) delay acting on activity 3 on day 14, which affected (when applied alone) the overall project duration by one day. At the same time (on day 14), we have an owner (EC) delay acting on activity 5 which also affected (when applied alone) the overall project duration by one day. So, the one-day project delay at the end of day 14 will be apportioned between the contractor and the owner, half a day for each. **This end-of-day 14 schedule with all delays injected (NE &EC) will be the baseline for the end-of-day 15 window calculations.**

End of day 15

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												NE	NE	NE	EC	3	3	3	3	3	3	3										
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	EC	EC	EC	5	5	5	5													
ACT6																							6	6	6	6						
ACT7																				7	7	7										
ACT8																				8	8	8	8	8	8	8	8	8				
ACT9																											9	9	9	9	9	
ACT10																													10	10	10	
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1																	
O Delay													1/2	1/2	1																	
C Delay		1	1										1/2	1/2																		
T Delay	1					1	1																									
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8																	

Note: The two delays affecting activities 3 and 5 are owner delays, and although each of them (when applied alone) affects the overall project duration, they will be recorded in the summary as 1 day because they belong to the same party (Owner)

End of day 16 (EC injected alone)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												NE	NE	NE	EC	EC	3	3	3	3	3	3	3									
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	EC	EC	EC	5	5	5	5													
ACT6																								6	6	6	6					
ACT7																				7	7	7										
ACT8																				8	8	8	8	8	8	8	8	8				
ACT9																												9	9	9	9	9
ACT10																													10	10	10	
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1																
O Delay													1/2	1/2	1	1/2																
C Delay		1	1										1/2	1/2																		
T Delay	1					1	1																									
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8	9																

Note: When injecting the EC delay alone, the project duration is affected. This is because the EC delay is acting on activity 3 on day 16, and the path (1, 3, 6, 9) was critical at the beginning of day 16. As a result this delay is recorded in the summary as an O Delay. The value of the O delay is ½ day, because there is a concurrency with an NE delay at a parallel critical activity (activity 5).

End of day 16 (NE injected alone)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												NE	NE	NE	EC	3	3	3	3	3	3	3										
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	EC	EC	EC	NE	5	5	5	5												
ACT6																							6	6	6	6						
ACT7																				7	7	7										
ACT8																					8	8	8	8	8	8	8	8	8			
ACT9																											9	9	9	9	9	
ACT10																														10	10	10
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1																
O Delay													1/2	1/2	1																	
C Delay		1	1										1/2	1/2		1/2																
T Delay	1					1	1																									
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8	9																

Note: When injecting the NE delays alone, the project duration is affected. This is because the NE delay is acting on activity 5 on day 16 and the path (2, 5, 8, 10) was critical at the beginning of day 16. As a result, this delay is recorded in the summary as a C Delay. The value of the C delay is ½ day because there is a concurrency with an EC delay at a parallel critical activity (activity 3).

End of day 16 (Both EC & NE injected)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												NE	NE	NE	EC	EC	3	3	3	3	3	3	3									
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	EC	EC	EC	NE	5	5	5	5												
ACT6																								6	6	6	6					
ACT7																				7	7	7										
ACT8																					8	8	8	8	8	8	8	8	8			
ACT9																												9	9	9	9	9
ACT10																														10	10	10
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1																
O Delay													1/2	1/2	1	1/2																
C Delay		1	1										1/2	1/2		1/2																
T Delay	1					1	1																									
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8	9																

Note: Here we have a contractor (NE) delay acting on activity 5 on day 16, which affects (when applied alone) the overall project duration by one day. At the same time (at day 16), we have an owner delay (EC) acting on activity 3, which also affected (when applied alone) the overall project duration by one day. Therefore, the one-day project delay at the end of day 16 will be apportioned between the contractor and the owner, half a day for each. **This end-of-day 16 schedule with all delays injected (NE &EC) will be the baseline for the end-of-day 17 window calculations.**

End of day 22 (EN injected alone)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																									
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																										
ACT3												NE	NE	NE	EC	EC	3	3	3	3	3	3	3													
ACT4											4	4	4	4	4	4	4	4	4	`																
ACT5											5	5	EC	EC	EC	NE	5	5	EN	EN	EN	EN	5	5												
ACT6																								6	6	6	6									
ACT7																				7	7	7														
ACT8																									8	8	8	8	8	8	8	8	8			
ACT9																												9	9	9	9	9				
ACT10																																		10	10	10
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1														
O Delay													1/2	1/2	1	1/2																				
C Delay		1	1										1/2	1/2		1/2																				
T Delay	1					1	1												1	1	1	1														
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8	9	9	9	10	11	12	13														

Note: The third-party (EN) delay acting on day 22 at activity 5 was recorded as a T delay in the summary because it did affect the overall duration of the project when it was applied alone (path 2, 5, 8, 10 was critical at the beginning of day 22).

End of day 22 (EC injected alone)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																									
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																										
ACT3												NE	NE	NE	EC	EC	3	3	3	3	3	3	3													
ACT4											4	4	4	4	4	4	4	4	4	`																
ACT5											5	5	EC	EC	EC	NE	5	5	EN	EN	EN	5	5													
ACT6																								6	6	6	6									
ACT7																				7	7	EC	7													
ACT8																								8	8	8	8	8	8	8	8	8				
ACT9																												9	9	9	9	9				
ACT10																																	10	10	10	
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1	0	0	1	1	1															
O Delay													1/2	1/2	1	1/2																				
C Delay		1	1										1/2	1/2		1/2																				
T Delay	1					1	1												1	1	1															
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8	9	9	9	10	11	12															

Note: When injecting the EC delays alone, the project duration will not be affected. This is because the EC delay is acting on activity 7 on day 22 and the path (2, 4, 7) was not critical at the beginning of day 22. Therefore, this delay was not recorded in the summary.

End of day 22 (Both EN & EC injected)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																									
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																										
ACT3												NE	NE	NE	EC	EC	3	3	3	3	3	3	3													
ACT4											4	4	4	4	4	4	4	4	4	`																
ACT5											5	5	EC	EC	EC	NE	5	5	EN	EN	EN	EN	5	5												
ACT6																								6	6	6	6									
ACT7																				7	7	EC	7													
ACT8																									8	8	8	8	8	8	8	8	8			
ACT9																												9	9	9	9	9				
ACT10																																		10	10	10
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1														
O Delay													1/2	1/2	1	1/2																				
C Delay		1	1										1/2	1/2		1/2																				
T Delay	1					1	1												1	1	1	1														
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8	9	9	9	10	11	12	13														

Note: Although there was an owner delay (EC) on day 22 acting on activity 7, this delay was not recorded under O delay in the summary because it did not affect the overall duration of the project (path 2, 4, 7 was not critical at the beginning of day 22). On the other hand, the third-party (EN) delay acting on day 22 on activity 5 was recorded under T delay in the summary because it did affect the overall duration of the project (path 2, 5, 8, 10 was critical at the beginning of day 22). **This end-of-day 22 schedule with all delays injected (NE &EC) will be the baseline for the end-of-day 23 window calculations.**

End of day 23 (EN injected alone)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																												
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																													
ACT3												NE	NE	NE	EC	EC	3	3	3	3	3	3	3																
ACT4											4	4	4	4	4	4	4	4	4	`																			
ACT5											5	5	EC	EC	EC	NE	5	5	EN	EN	EN	EN	EN	5	5														
ACT6																								6	6	6	6												
ACT7																				7	7	EC	7																
ACT8																										8	8	8	8	8	8	8	8	8					
ACT9																												9	9	9	9	9							
ACT10																																			10	10	10		
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1	1																
O Delay													1/2	1/2	1	1/2																							
C Delay		1	1										1/2	1/2		1/2																							
T Delay	1					1	1												1	1	1	1	1																
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8	9	9	9	10	11	12	13	14																

Note: The third-party delay (EN) acting on day 23 on activity 5 was recorded under T delay in the summary because it did affect the overall duration of the project when it was applied alone (path 2, 5, 8, 10 was critical at the beginning of day 23).

End of day 23 (NE injected alone)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																												
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																													
ACT3												NE	NE	NE	EC	EC	3	3	3	3	3	3	3																
ACT4											4	4	4	4	4	4	4	4	4	`																			
ACT5											5	5	EC	EC	EC	NE	5	5	EN	EN	EN	EN	5	5															
ACT6																								6	6	6	6												
ACT7																				7	7	EC	NE	7															
ACT8																									8	8	8	8	8	8	8	8	8						
ACT9																												9	9	9	9	9							
ACT10																																		10	10	10			
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1	1																
O Delay													1/2	1/2	1	1/2																							
C Delay		1	1										1/2	1/2		1/2																							
T Delay	1					1	1												1	1	1	1	1																
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8	9	9	9	10	11	12	13	14																

Note: When injecting the NE delay alone, the project duration will not be affected. This is because the NE delay is acting on activity 7 on day 23 and the path (2, 4, 7) was not critical at the beginning of day 23. As a result, this delay was not recorded in the summary.

End of day 23 (Both EN & NE injected alone)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																												
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																													
ACT3												NE	NE	NE	EC	EC	3	3	3	3	3	3	3																
ACT4											4	4	4	4	4	4	4	4	4	`																			
ACT5											5	5	EC	EC	EC	NE	5	5	EN	EN	EN	EN	EN	5	5														
ACT6																								6	6	6	6												
ACT7																				7	7	EC	NE	7															
ACT8																										8	8	8	8	8	8	8	8	8					
ACT9																												9	9	9	9	9							
ACT10																																			10	10	10		
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1	1																
O Delay													1/2	1/2	1	1/2																							
C Delay		1	1										1/2	1/2		1/2																							
T Delay	1					1	1												1	1	1	1	1																
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8	9	9	9	10	11	12	13	14																

Note: Although there was a contractor (NE) delay acting on day 23 at activity 7, this delay was not recorded under C delay in the summary because it did not affect the overall duration of the project (path 2, 4, 7 was not critical at the beginning of day 23). On the other hand, the third-party (EN) delay acting on day 23 at activity 5 was recorded under T delay in the summary because it did affect the overall duration of the project (path 2, 5, 8, 10 was critical at the beginning of day 23). **This end-of-day 23 schedule with all delays injected (NE &EN) will be the baseline for the end-of-day 24 window calculations.**

End of day 33 (EC injected alone)

Act - Da	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																													
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																														
ACT3												NE	NE	NE	EC	EC	3	3	3	3	3	3	3																	
ACT4											4	4	4	4	4	4	4	4	4	`																				
ACT5											5	5	EC	EC	EC	NE	5	5	EN	EN	EN	EN	EN	5	5															
ACT6																								EC	EC	6	6	6	6											
ACT7																				7	7	EC	NE	7																
ACT8																										8	8	8	8	EN	8	8	EC	8	8	8				
ACT9																														9	9	EC	9	9	9					
ACT10																																					10	10	10	
Daily de	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1	1	0	0	0	0	0	0	1	0	0	1							
O Delay													1/2	1/2	1	1/2																	1							
C Delay		1	1										1/2	1/2		1/2																								
T Delay	1		0			1	1												1	1	1	1	1							1										
Cum. D	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8	9	9	9	10	11	12	13	14	14	14	14	14	14	14	15	15	15	16							

Note: When injecting the EC delays alone, the project duration is affected. This is because the EC delay is acting on activity 8 at day 33, and the path (2, 5, 8, 10) was critical at the beginning of day 33. This delay was therefore recorded in the summary as an O Delay.

End of day 33 (EN injected alone)

Act - Da	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																													
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																														
ACT3												NE	NE	NE	EC	EC	3	3	3	3	3	3	3																	
ACT4											4	4	4	4	4	4	4	4	4	`																				
ACT5											5	5	EC	EC	EC	NE	5	5	EN	EN	EN	EN	EN	5	5															
ACT6																								EC	EC	6	6	6	6											
ACT7																				7	7	EC	NE	7																
ACT8																										8	8	8	8	EN	8	8	8	8	8					
ACT9																														9	9	EC	EN	9	9	9				
ACT10																																				10	10	10		
Daily de	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1	1	0	0	0	0	0	0	1	0	0								
O Delay													1/2	1/2	1	1/2																								
C Delay		1	1										1/2	1/2		1/2																								
T Delay	1					1	1												1	1	1	1	1							1										
Cum. D	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8	9	9	9	10	11	12	13	14	14	14	14	14	14	14	15	15	15	16							

Note: The third-party delay (EN) acting on day 33 at activity 9 was not recorded under T delay in the summary because it did not affect the overall duration of the project when it was applied alone (path 1, 3, 6, 9 was not critical at the beginning of day 33).

End of day 33 (Both EC & EN injected)

Act - Da	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																													
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																														
ACT3												NE	NE	NE	EC	EC	3	3	3	3	3	3	3																	
ACT4											4	4	4	4	4	4	4	4	4	`																				
ACT5											5	5	EC	EC	EC	NE	5	5	EN	EN	EN	EN	EN	5	5															
ACT6																								EC	EC	6	6	6	6											
ACT7																				7	7	EC	NE	7																
ACT8																										8	8	8	8	EN	8	8	EC	8	8	8				
ACT9																														9	9	EC	EN	9	9	9				
ACT10																																					10	10	10	
Daily d	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1	1	0	0	0	0	0	0	1	0	0	1							
O Delay													1/2	1/2	1	1/2																	1							
C Delay		1	1										1/2	1/2		1/2																								
T Delay	1					1	1												1	1	1	1	1							1										
Cum. D	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8	9	9	9	10	11	12	13	14	14	14	14	14	14	14	15	15	15	16							

Note: Although there was a third-party delay (EN) acting on day 33 at activity 9, this delay was not recorded under T delay in the summary because it did not affect the overall duration of the project (path 1, 3, 6, 9 was not critical at the beginning of day 33). On the other hand, the owner (EC) delay acting on day 33 at activity 8 was recorded under O delay in the summary because it did affect the overall duration of the project (path 2, 5, 8, 10 was critical at the beginning of day 33). **This end-of-day 33 schedule with all delays injected (EN &EC) will be the baseline for the end-of-day 34 window calculations.**

End of day 41 (As-Built)

Act - Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																														
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																															
ACT3												NE	NE	NE	EC	EC	3	3	3	3	3	3	3																		
ACT4											4	4	4	4	4	4	4	4	4	`																					
ACT5											5	5	EC	EC	EC	NE	5	5	EN	EN	EN	EN	EN	5	5																
ACT6																								EC	EC	6	6	6	6												
ACT7																				7	7	EC	NE	7																	
ACT8																										8	8	8	8	EN	8	8	EC	8	8	8					
ACT9																														9	9	EC	EN	EN	NE	NE	9	9	NE	EC	9
ACT10																																					EN	EN	10	10	10
Daily del	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1	1	0	0	0	0	0	0	1	0	0	1	0	0	0	1	1	0	0	0
O Delay													1/2	1/2	1	1/2																	1								
C Delay		1	1										1/2	1/2		1/2																									
T Delay	1					1	1												1	1	1	1	1							1							1	1			
Cum. De	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8	9	9	9	10	11	12	13	14	14	14	14	14	14	14	15	15	15	16	16	16	16	17	18	18	18	18

Results of delay analysis using isolated daily window analysis technique (with equal liability method for concurrency):

Owner (EC) total delay = 1/2+ 1/2 + 1+1/2+1 = 3 1/2 days

Contractor (NE) total delay = 1+1+ 1/2 +1/2+1/2 = 3 1/2 days

Third-party (EN) total delay = 1+1+1+1+1+1+1+1+1+1+1 = 11 days

Project total delay = 3 1/2 + 3 1/2 + 11 = 18days

APPENDIX A-2:

THE 10-ACTIVITIES CASE – IDWAT (REGULAR)

The 10-activity as-planned schedule

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
ACT1	1	1	1	1	1	1	1																																	
ACT2	2	2	2	2	2																																			
ACT3								3	3	3	3	3	3	3																										
ACT4						4	4	4	4	4	4	4	4	4						`																				
ACT5						5	5	5	5	5	5																													
ACT6															6	6	6	6																						
ACT7															7	7	7																							
ACT8												8	8	8	8	8	8	8	8	8																				
ACT9																			9	9	9	9	9																	
ACT10																					10	10	10																	

End of day 2

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	1	1	1	1	1	1	1																							
ACT2	2	2	2	2	2																											
ACT3										3	3	3	3	3	3	3																
ACT4						4	4	4	4	4	4	4	4	4						`												
ACT5						5	5	5	5	5	5																					
ACT6																	6	6	6	6												
ACT7															7	7	7															
ACT8												8	8	8	8	8	8	8	8	8												
ACT9																					9	9	9	9	9							
ACT10																					10	10	10									
Daily delay	1	1																														
O Delay																																
C Delay		1																														
T Delay	1																															
Cum. Delay	1	2																														

End of day 3

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	1	1	1	1																						
ACT2	2	2	NE	2	2	2																										
ACT3											3	3	3	3	3	3	3															
ACT4							4	4	4	4	4	4	4	4	4					`												
ACT5							5	5	5	5	5	5																				
ACT6																		6	6	6	6											
ACT7																7	7	7														
ACT8													8	8	8	8	8	8	8	8	8											
ACT9																						9	9	9	9	9						
ACT10																						10	10	10								
Daily delay	1	1	1																													
O Delay																																
C Delay		1	1																													
T Delay	1																															
Cum. Delay	1	2	3																													

End of day 4

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	1	1	1	1																						
ACT2	2	2	NE	EC	2	2	2																									
ACT3											3	3	3	3	3	3	3															
ACT4								4	4	4	4	4	4	4	4	4				`												
ACT5								5	5	5	5	5	5																			
ACT6																		6	6	6	6											
ACT7																	7	7	7													
ACT8														8	8	8	8	8	8	8	8	8										
ACT9																						9	9	9	9	9						
ACT10																							10	10	10							
Daily delay	1	1	1	0																												
O Delay																																
C Delay		1	1																													
T Delay	1																															
Cum. Delay	1	2	3	3																												

Note: Although there was an owner (EC) delay acting on day 4 at activity 2, this delay was not recorded under O delay in the summary because it did not affect the overall project duration (path 2, 5, 8, 10 was not critical at the beginning of day 4).

End of day 5

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	1	1	1	1																						
ACT2	2	2	NE	EC	EN	2	2	2																								
ACT3											3	3	3	3	3	3	3															
ACT4									4	4	4	4	4	4	4	4	4			`												
ACT5									5	5	5	5	5	5																		
ACT6																		6	6	6	6											
ACT7																		7	7	7												
ACT8															8	8	8	8	8	8	8	8	8									
ACT9																						9	9	9	9	9						
ACT10																								10	10	10						
Daily delay	1	1	1	0	0																											
O Delay																																
C Delay		1	1																													
T Delay	1																															
Cum. Delay	1	2	3	3	3																											

Note: Although there was a third-party (EN) delay acting on day 5 at activity 2, this delay was not recorded under T delay in the summary because it did not affect the overall project duration (path 2, 5, 8, 10 was not critical at the beginning of day 5, but it did become critical at the end of day 5.

End of day 7 – (NE injected alone)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	2	2	2																							
ACT3												3	3	3	3	3	3	3														
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5										5	5	5	5	5	5																	
ACT6																			6	6	6	6										
ACT7																				7	7	7										
ACT8																8	8	8	8	8	8	8	8	8								
ACT9																							9	9	9	9	9					
ACT10																									10	10	10					
Daily delay	1	1	1	0	0	1																										
O Delay																																
C Delay		1	1																													
T Delay	1					1																										
Cum. Delay	1	2	3	3	3	4	5																									

Note: When injecting the NE delays alone, the project duration will not be affected. This is because the NE delay acted on activity 1 on day 7 and the path (1, 3, 6, 9) was not critical at the beginning of day 7. As a result, this delay was not recorded in the summary.

End of day 7- (EN injected alone)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	1	1	1	1																						
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3											3	3	3	3	3	3	3															
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	5	5	5	5																
ACT6																		6	6	6	6											
ACT7																				7	7	7										
ACT8																	8	8	8	8	8	8	8	8	8							
ACT9																						9	9	9	9	9						
ACT10																										10	10	10				
Daily delay	1	1	1	0	0	1	1																									
O Delay																																
C Delay		1	1																													
T Delay	1					1	1																									
Cum. Delay	1	2	3	3	3	4	5																									

Note: The third-party (EN) delay acting on day 7 at activity 2 was recorded under T delay in the summary because it did affect the overall duration of the project when it was applied alone (path 2, 5, 8, 10 was critical at the beginning of day 7).

End of day 7 (both EN & NE injected)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												3	3	3	3	3	3	3														
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	5	5	5	5																
ACT6																			6	6	6	6										
ACT7																				7	7	7										
ACT8																	8	8	8	8	8	8	8	8	8							
ACT9																							9	9	9	9	9					
ACT10																										10	10	10				
Daily delay	1	1	1	0	0	1	1																									
O Delay																																
C Delay		1	1																													
T Delay	1					1	1																									
Cum. Delay	1	2	3	3	3	4	5																									

Note: Although there was a contractor (NE) delay acting on day 7 at activity 1, this delay was not recorded under C delay in the summary because it did not affect the overall duration of the project (path 1, 3, 6, 9 was not critical at the beginning of day 7). On the other hand, the third-party (EN) delay acting on day 7 at activity 2 was recorded under T delay in the summary because it did affect the overall project duration (path 2, 5, 8, 10 was critical at the beginning of day 7). **This end-of-day 7 schedule with all delays injected (NE &EN) will be the baseline for the end-of-day 8 window calculations.**

End of day 12

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												NE	3	3	3	3	3	3	3													
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	5	5	5	5																
ACT6																				6	6	6	6									
ACT7																				7	7	7										
ACT8																	8	8	8	8	8	8	8	8	8							
ACT9																								9	9	9	9	9				
ACT10																										10	10	10				
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0																				
O Delay																																
C Delay		1	1																													
T Delay	1					1	1																									
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5																				

Note: Although there was a contractor (NE) delay acting on day 12 at activity 3, this delay was not recorded under C delay in the summary because it did not affect the overall project duration (path 1, 3, 6, 9 was not critical at the beginning of day 12, although it did become critical at the end of day 12.)

End of day 13 (NE injected alone)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												NE	NE	3	3	3	3	3	3	3												
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	5	5	5	5																
ACT6																					6	6	6	6								
ACT7																				7	7	7										
ACT8																	8	8	8	8	8	8	8	8	8							
ACT9																									9	9	9	9	9			
ACT10																										10	10	10				
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1																			
O Delay																																
C Delay		1	1										1																			
T Delay	1					1	1																									
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6																			

Note: When injecting the NE delays alone, the project duration is affected. This is because the NE delay acted on activity 3 on day 13 and the path (1, 3, 6, 9) was critical at the beginning of day 13, so this NE delay was temporarily recorded in the summary as C Delay. Since there is a concurrency with an EC delay at a parallel critical activity (Activity 5), the C delay of 1 day will eventually be recorded as a third-party delay.

End of day 13 (EC injected alone)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												NE	3	3	3	3	3	3	3													
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	EC	5	5	5	5															
ACT6																				6	6	6	6									
ACT7																				7	7	7										
ACT8																		8	8	8	8	8	8	8	8	8						
ACT9																								9	9	9	9	9				
ACT10																											10	10	10			
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1																			
O Delay													1																			
C Delay		1	1																													
T Delay	1					1	1																									
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6																			

Note: When injecting the EC delay alone, the project duration is affected. Here the EC delay acted on activity 5 on day 13, and the path (2, 5, 8, 10) was critical at the beginning of day 13 -- therefore, this delay is recorded in the summary as O Delay. Because there is a concurrency with an NE delay at a parallel critical activity (Activity 3), the O delay of 1 day will eventually be recorded as a third-party delay.

End of day 13 (Both NE & EC injected)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												NE	NE	3	3	3	3	3	3	3												
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	EC	5	5	5	5															
ACT6																					6	6	6	6								
ACT7																				7	7	7										
ACT8																		8	8	8	8	8	8	8	8	8						
ACT9																									9	9	9	9	9			
ACT10																											10	10	10			
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1																			
O Delay																																
C Delay		1	1																													
T Delay	1					1	1						1																			
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6																			

Note: Here, there is a contractor (NE) delay acting on activity 3 on day 13 which affected (when applied alone) the overall project duration by one day. At the same time (on day 13), there is an owner (EC) delay acting on activity 5 which also affected (when applied alone) the overall project duration by one day. As per the regular method, the one-day project delay at the end of day 13 will be considered as a third-party delay. **`This end-of-day 13 schedule with all delays injected (NE &EC) will be the baseline for the end-of-day 14 window calculations.**

End of day 14 (NE injected alone)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												NE	NE	NE	3	3	3	3	3	3	3											
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	EC	5	5	5	5															
ACT6																						6	6	6	6							
ACT7																				7	7	7										
ACT8																		8	8	8	8	8	8	8	8	8						
ACT9																										9	9	9	9	9		
ACT10																											10	10	10			
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1	1																		
O Delay																																
C Delay		1	1											1																		
T Delay	1					1	1						1																			
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6	7																		

Note: When injecting the NE delays alone, the project duration is affected because the NE delay acted on activity 3 on day 14 and the path (1, 3, 6, 9) was critical at the beginning of day 14. As a result, this delay is recorded in the summary as C Delay. Since there is a concurrency with an EC delay at a parallel critical activity (activity 5), the C delay of one day will eventually be recorded as a third-party delay.

End of day 14 (EC injected alone)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												NE	NE	3	3	3	3	3	3	3												
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	EC	EC	5	5	5	5														
ACT6																					6	6	6	6								
ACT7																				7	7	7										
ACT8																			8	8	8	8	8	8	8	8	8					
ACT9																									9	9	9	9	9			
ACT10																												10	10	10		
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1	1																		
O Delay														1																		
C Delay		1	1																													
T Delay	1					1	1						1																			
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6	7																		

<u>Note:</u> When injecting the EC delay alone, the project duration is affected. This is because the EC delay acted on activity 5 on day 14 and the path (2, 5, 8, 10) was critical at the beginning of day 14. This delay is therefore recorded in the summary as <u>O Delay</u>. Because there is a concurrency with an NE delay at a parallel critical activity (activity 3), the <u>O delay</u> of 1 day will eventually be recorded as a third-party delay.

End of day 14(Both NE & EC injected)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												NE	NE	NE	3	3	3	3	3	3	3											
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	EC	EC	5	5	5	5														
ACT6																						6	6	6	6							
ACT7																				7	7	7										
ACT8																			8	8	8	8	8	8	8	8	8					
ACT9																										9	9	9	9	9		
ACT10																												10	10	10		
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1	1																		
O Delay																																
C Delay		1	1																													
T Delay	1					1	1						1	1																		
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6	7																		

Note: Here, there is a contractor (NE) delay acting on activity 3 on day 14, which affected (when applied alone) the overall project duration by one day. At the same time (on t day 14), we have an owner (EC) delay acting on activity 5 which also affected (when applied alone) the overall project duration by one day. As per the regular method, the one-day project delay at the end of day 14 will be considered as a third-party delay. **This end-of-day 14 schedule with all delays injected (NE &EC) will be the baseline for the end–of-day 15 window calculations.**

End of day 15

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												NE	NE	NE	EC	3	3	3	3	3	3	3										
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	EC	EC	EC	5	5	5	5													
ACT6																							6	6	6	6						
ACT7																				7	7	7										
ACT8																				8	8	8	8	8	8	8	8	8				
ACT9																											9	9	9	9	9	
ACT10																													10	10	10	
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1																	
O Delay															1																	
C Delay		1	1																													
T Delay	1					1	1						1	1																		
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8																	

Note: The two delays affecting activities 3 and 5 are owner delays. Even though each (when applied alone) affects the overall project duration, they are recorded in the summary as 1 day of O delay because they both belong to the Owner.

End of day 16 (EC injected alone)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												NE	NE	NE	EC	EC	3	3	3	3	3	3	3									
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	EC	EC	EC	5	5	5	5													
ACT6																								6	6	6	6					
ACT7																				7	7	7										
ACT8																				8	8	8	8	8	8	8	8	8				
ACT9																												9	9	9	9	9
ACT10																													10	10	10	
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1																
O Delay															1	1																
C Delay		1	1																													
T Delay	1					1	1						1	1																		
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8	9																

Note: When injecting the EC delay alone, the project duration is affected. This is because the EC delay acted on activity 3 on day 16 while the path (1, 3, 6, 9) was critical at the beginning of day 16. This delay is therefore recorded in the summary as O Delay. Because there is a concurrency with an EN delay at a parallel critical activity (activity 5), the O delay of 1 day will eventually be recorded as a third-party delay.

End of day 16 (NE injected alone)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												NE	NE	NE	EC	3	3	3	3	3	3	3										
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	EC	EC	EC	NE	5	5	5	5												
ACT6																							6	6	6	6						
ACT7																				7	7	7										
ACT8																					8	8	8	8	8	8	8	8	8			
ACT9																											9	9	9	9	9	
ACT10																														10	10	10
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1																
O Delay															1																	
C Delay		1	1													1																
T Delay	1					1	1						1	1																		
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8	9																

Note: When injecting the NE delays alone, the project duration is affected. This is because the NE delay is acting on activity 5 on day 16 and the path (2, 5, 8, 10) was critical at the beginning of day 16. This delay is therefore recorded in the summary as C Delay. Because there is a concurrency with an EC delay at a parallel critical activity (activity 3), the C delay of 1 day will eventually be recorded as a third-party delay.

End of day 16 (Both EC & NE injected)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																					
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																						
ACT3												NE	NE	NE	EC	EC	3	3	3	3	3	3	3									
ACT4											4	4	4	4	4	4	4	4	4	`												
ACT5											5	5	EC	EC	EC	NE	5	5	5	5												
ACT6																								6	6	6	6					
ACT7																				7	7	7										
ACT8																					8	8	8	8	8	8	8	8	8			
ACT9																												9	9	9	9	9
ACT10																														10	10	10
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1																
O Delay															1																	
C Delay		1	1																													
T Delay	1					1	1						1	1		1																
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8	9																

Note: Here we have a contractor (NE) delay acting on activity 5 on day 16, which affected (when applied alone) the overall project duration by one day. At the same time (at day 16), we have an owner delay (EC) acting on activity 3 which also affected (when applied alone) the overall project duration by one day. As per the regular method, the one-day project delay at the end of day 16 will be considered as a third-party delay. **This end-of-day 16 schedule with all delays injected (NE &EC) will be the baseline for the end-of-day 17 window calculations.**

End of day 22 (EN injected alone)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																									
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																										
ACT3												NE	NE	NE	EC	EC	3	3	3	3	3	3	3													
ACT4											4	4	4	4	4	4	4	4	4	`																
ACT5											5	5	EC	EC	EC	NE	5	5	EN	EN	EN	EN	5	5												
ACT6																								6	6	6	6									
ACT7																				7	7	7														
ACT8																									8	8	8	8	8	8	8	8	8			
ACT9																												9	9	9	9	9				
ACT10																																		10	10	10
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1														
O Delay															1																					
C Delay		1	1																																	
T Delay	1					1	1						1	1		1			1	1	1	1														
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8	9	9	9	10	11	12	13														

Note: The third-party (EN) delay acting on day 22 at activity 5 was recorded under T delay in the summary because it did affect the overall duration of the project when it was applied alone (path 2, 5, 8, 10 was critical at the beginning of day 22).

End of day 22 (EC injected alone)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																									
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																										
ACT3												NE	NE	NE	EC	EC	3	3	3	3	3	3	3													
ACT4											4	4	4	4	4	4	4	4	4	`																
ACT5											5	5	EC	EC	EC	NE	5	5	EN	EN	EN	5	5													
ACT6																								6	6	6	6									
ACT7																				7	7	EC	7													
ACT8																								8	8	8	8	8	8	8	8	8				
ACT9																												9	9	9	9	9				
ACT10																																	10	10	10	
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1	0	0	1	1	1															
O Delay															1																					
C Delay		1	1																																	
T Delay	1					1	1						1	1		1			1	1	1															
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8	9	9	9	10	11	12															

Note: When injecting the EC delays alone, the project duration will not be affected. This is because the EC delay acted on activity 7 on day 22 and the path (2, 4, 7) was not critical at the beginning of day 22. Therefore, this delay was not recorded in the summary.

End of day 22 (Both EN & EC injected)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																									
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																										
ACT3												NE	NE	NE	EC	EC	3	3	3	3	3	3	3													
ACT4											4	4	4	4	4	4	4	4	4	`																
ACT5											5	5	EC	EC	EC	NE	5	5	EN	EN	EN	EN	5	5												
ACT6																								6	6	6	6									
ACT7																				7	7	EC	7													
ACT8																									8	8	8	8	8	8	8	8	8			
ACT9																												9	9	9	9	9				
ACT10																																		10	10	10
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1														
O Delay															1																					
C Delay		1	1																																	
T Delay	1					1	1						1	1		1			1	1	1	1														
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8	9	9	9	10	11	12	13														

Note: Although there was an owner (EC) delay at day 22 acting on activity 7, this delay was not recorded under O delay in the summary because it did not affect the overall duration of the project since path 2, 4, 7 was not critical at the beginning of day 22. On the other hand, the third-party (EN) delay on day 22 acting on activity 5 was recorded under T delay in the summary, because it did affect the overall duration of the project (path 2, 5, 8, 10 was critical at the beginning of day 22). **This end-of-day 22 schedule with all delays injected (NE &EC) will be the baseline for the end-of-day 23 window calculations.**

End of day 23 (EN injected alone)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																												
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																													
ACT3												NE	NE	NE	EC	EC	3	3	3	3	3	3	3																
ACT4											4	4	4	4	4	4	4	4	4	`																			
ACT5											5	5	EC	EC	EC	NE	5	5	EN	EN	EN	EN	EN	5	5														
ACT6																								6	6	6	6												
ACT7																				7	7	EC	7																
ACT8																										8	8	8	8	8	8	8	8	8					
ACT9																												9	9	9	9	9							
ACT10																																			10	10	10		
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1	1																
O Delay															1																								
C Delay		1	1																																				
T Delay	1					1	1						1	1		1			1	1	1	1	1																
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8	9	9	9	10	11	12	13	14																

Note: The third-party (EN) delay acting on day 23 on activity 5 was recorded under T delay in the summary because it did affect the overall duration of the project when it was applied alone (path 2, 5, 8, 10 was critical at the beginning of day 23).

End of day 23(NE injected alone)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																												
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																													
ACT3												NE	NE	NE	EC	EC	3	3	3	3	3	3	3																
ACT4											4	4	4	4	4	4	4	4	4	`																			
ACT5											5	5	EC	EC	EC	NE	5	5	EN	EN	EN	EN	5	5															
ACT6																								6	6	6	6												
ACT7																				7	7	EC	NE	7															
ACT8																									8	8	8	8	8	8	8	8	8						
ACT9																												9	9	9	9	9							
ACT10																																		10	10	10			
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1	1																
O Delay															1																								
C Delay		1	1																																				
T Delay	1					1	1						1	1		1			1	1	1	1	1																
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8	9	9	9	10	11	12	13	14																

Note: When injecting the NE delay alone, the project duration will not be affected. This is because the NE delay acted on activity 7 at day 23 and the path (2, 4, 7) was not critical at the beginning of day 23, and so this delay was not recorded in the summary.

End of day 23 (Both EN & NE injected alone)

Act - Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																												
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																													
ACT3												NE	NE	NE	EC	EC	3	3	3	3	3	3	3																
ACT4											4	4	4	4	4	4	4	4	4	`																			
ACT5											5	5	EC	EC	EC	NE	5	5	EN	EN	EN	EN	EN	5	5														
ACT6																								6	6	6	6												
ACT7																				7	7	EC	NE	7															
ACT8																										8	8	8	8	8	8	8	8	8					
ACT9																												9	9	9	9	9							
ACT10																																			10	10	10		
Daily delay	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1	1																
O Delay															1																								
C Delay		1	1																																				
T Delay	1					1	1						1	1		1			1	1	1	1	1																
Cum. Delay	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8	9	9	9	10	11	12	13	14																

Note: Although there was a contractor (NE) delay acting on activity 7 on day 23 , this delay was not recorded under C delay in the summary because it did not affect the overall project duration (path 2, 4, 7 was not critical at the beginning of day 23).However, the third-party (EN) delay acting on activity 5 on day 23 was recorded under T delay in the summary because it did affect the overall duration of the project (path 2, 5, 8, 10 was critical at the beginning of day 23). **This end-of-day 23 schedule with all delays injected (NE &EN) will be the baseline for the end-of-day 24 window calculations.**

End of day 33 (EC injected alone)

Act - Da	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																													
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																														
ACT3												NE	NE	NE	EC	EC	3	3	3	3	3	3	3																	
ACT4											4	4	4	4	4	4	4	4	4	`																				
ACT5											5	5	EC	EC	EC	NE	5	5	EN	EN	EN	EN	EN	5	5															
ACT6																								EC	EC	6	6	6	6											
ACT7																				7	7	EC	NE	7																
ACT8																										8	8	8	8	EN	8	8	EC	8	8	8				
ACT9																														9	9	EC	9	9	9					
ACT10																																					10	10	10	
Daily d	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1	1	0	0	0	0	0	0	1	0	0	1							
O Delay															1																		1							
C Delay		1	1																																					
T Delay	1		0			1	1						1	1		1			1	1	1	1	1							1										
Cum. D	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8	9	9	9	10	11	12	13	14	14	14	14	14	14	14	15	15	15	16							

Note: When injecting the EC delays alone, the project duration is affected because the EC delay is acting on activity 8 on day 33 and the path (2, 5, 8, 10) was critical at the beginning of day 33. This delay was therefore recorded in the summary as an O Delay.

End of day 33 (EN injected alone)

Act - Da	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																													
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																														
ACT3												NE	NE	NE	EC	EC	3	3	3	3	3	3	3																	
ACT4											4	4	4	4	4	4	4	4	4	`																				
ACT5											5	5	EC	EC	EC	NE	5	5	EN	EN	EN	EN	EN	5	5															
ACT6																								EC	EC	6	6	6	6											
ACT7																				7	7	EC	NE	7																
ACT8																										8	8	8	8	EN	8	8	8	8	8					
ACT9																														9	9	EC	EN	9	9	9				
ACT10																																				10	10	10		
Daily de	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1	1	0	0	0	0	0	0	1	0	0								
O Delay															1																									
C Delay		1	1																																					
T Delay	1					1	1						1	1		1			1	1	1	1	1							1										
Cum. D	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8	9	9	9	10	11	12	13	14	14	14	14	14	14	14	15	15	15	16							

Note: The third-party delay (EN) acting on day 33 on activity 9 was not recorded under T delay in the summary because it did not affect the overall duration of the project when it was applied alone (path 1, 3, 6, 9 was not critical at the beginning of day 33).

End of day 33 (Both EC & EN injected)

Act - Da	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																													
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																														
ACT3												NE	NE	NE	EC	EC	3	3	3	3	3	3	3																	
ACT4											4	4	4	4	4	4	4	4	4	`																				
ACT5											5	5	EC	EC	EC	NE	5	5	EN	EN	EN	EN	EN	5	5															
ACT6																								EC	EC	6	6	6	6											
ACT7																				7	7	EC	NE	7																
ACT8																										8	8	8	8	EN	8	8	EC	8	8	8				
ACT9																														9	9	EC	EN	9	9	9				
ACT10																																					10	10	10	
Daily d	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1	1	0	0	0	0	0	0	1	0	0	1							
O Delay															1																		1							
C Delay		1	1																																					
T Delay	1					1	1						1	1		1			1	1	1	1	1							1										
Cum. D	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8	9	9	9	10	11	12	13	14	14	14	14	14	14	14	15	15	15	16							

Note: Although there was a third-party (EN) delay acting on activity 9 at day 33, this delay was not recorded under T delay in the summary because it did not affect the overall project duration (path 1, 3, 6, 9 was not critical at the beginning of day 33). However, the owner (EC) delay acting on activity 8 on day 33 at was recorded under O delay in the summary because it did affect the overall duration of the project (path 2, 5, 8, 10 was critical at the beginning of day 33). **This end-of-day 33 schedule with all delays injected (EN &EC) will be the baseline for the end-of-day 34 window calculations.**

End of day 35

Act - Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																														
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																															
ACT3												NE	NE	NE	EC	EC	3	3	3	3	3	3	3																		
ACT4											4	4	4	4	4	4	4	4	4	`																					
ACT5											5	5	EC	EC	EC	NE	5	5	EN	EN	EN	EN	EN	5	5																
ACT6																								EC	EC	6	6	6	6												
ACT7																				7	7	EC	NE	7																	
ACT8																										8	8	8	8	EN	8	8	EC	8	8	8					
ACT9																														9	9	EC	EN	EN	NE	9	9	9			
ACT10																																					10	10	10		
Daily de	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1	1	0	0	0	0	0	0	1	0	0	1	0	0						
O Delay															1																		1								
C Delay		1	1																																						
T Delay	1					1	1						1	1		1			1	1	1	1	1							1											
Cum. De	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8	9	9	9	10	11	12	13	14	14	14	14	14	14	14	15	15	15	16	16	16						

End of day 36

Act - Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																														
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																															
ACT3												NE	NE	NE	EC	EC	3	3	3	3	3	3	3																		
ACT4											4	4	4	4	4	4	4	4	4	`																					
ACT5											5	5	EC	EC	EC	NE	5	5	EN	EN	EN	EN	EN	5	5																
ACT6																								EC	EC	6	6	6	6												
ACT7																				7	7	EC	NE	7																	
ACT8																										8	8	8	8	EN	8	8	EC	8	8	8					
ACT9																														9	9	EC	EN	EN	NE	NE	9	9	9		
ACT10																																					10	10	10		
Daily de	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1	1	0	0	0	0	0	0	1	0	0	1	0	0	0					
O Delay															1																		1								
C Delay		1	1																																						
T Delay	1					1	1						1	1		1			1	1	1	1	1							1											
Cum. De	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8	9	9	9	10	11	12	13	14	14	14	14	14	14	14	15	15	15	16	16	16	16					

End of day 39

Act - Day:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																														
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																															
ACT3												NE	NE	NE	EC	EC	3	3	3	3	3	3	3																		
ACT4											4	4	4	4	4	4	4	4	4	`																					
ACT5											5	5	EC	EC	EC	NE	5	5	EN	EN	EN	EN	EN	5	5																
ACT6																								EC	EC	6	6	6	6												
ACT7																				7	7	EC	NE	7																	
ACT8																										8	8	8	8	EN	8	8	EC	8	8	8					
ACT9																														9	9	EC	EN	EN	NE	NE	9	9	NE	9	
ACT10																																					EN	EN	10	10	10
Daily del.	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1	1	0	0	0	0	0	0	1	0	0	1	0	0	0	1	1	0		
O Delay															1																		1								
C Delay		1	1																																						
T Delay	1					1	1						1	1		1			1	1	1	1	1							1							1	1			
Cum. Del	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8	9	9	9	10	11	12	13	14	14	14	14	14	14	14	15	15	15	16	16	16	16	17	18	18		

End of day 41 (As-Built)

Act - Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
ACT1	EN	NE	NE	1	1	1	NE	1	1	1	1																														
ACT2	2	2	NE	EC	EN	EN	EN	2	2	2																															
ACT3												NE	NE	NE	EC	EC	3	3	3	3	3	3	3																		
ACT4											4	4	4	4	4	4	4	4	4	`																					
ACT5											5	5	EC	EC	EC	NE	5	5	EN	EN	EN	EN	EN	5	5																
ACT6																								EC	EC	6	6	6	6												
ACT7																				7	7	EC	NE	7																	
ACT8																										8	8	8	8	EN	8	8	EC	8	8	8					
ACT9																														9	9	EC	EN	EN	NE	NE	9	9	NE	EC	9
ACT10																																					EN	EN	10	10	10
Daily del	1	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1	1	0	0	0	0	0	0	1	0	0	1	0	0	0	1	1	0	0	0
O Delay															1																		1								
C Delay		1	1																																						
T Delay	1					1	1						1	1		1			1	1	1	1	1							1							1	1			
Cum. De	1	2	3	3	3	4	5	5	5	5	5	5	6	7	8	9	9	9	10	11	12	13	14	14	14	14	14	14	14	15	15	15	16	16	16	16	17	18	18	18	18

Results of delay analysis using the isolated daily window analysis technique (with the regular method for concurrency)

Owner (EC) total delay = 1+1 = 2 days

Contractor (NE) total delay = 1+1 = 2 days

Third party (EN) total delay = 1+1+1+1+1+1+1+1+1+1+1+1+1+1 = 14 days

Project total delay = 2 + 2 + 14 = 18 days

APPENDIX A-3:

THE 7-ACTIVITIES CASE – IDWAT (ELM)

<u>As-planned bar chart</u> (7 activities project with three parallel critical paths and an original duration of 6 days)

Act (Dur.)	Date								
	1	2	3	4	5	6	7	8	9
A (2)									
B (2)									
C (2)									
D (3)									
E (3)									
F (2)									
G(4)									

<u>End of day 1 bar chart</u>

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)									
B (2)									
C (2)									
D (3)									
E (3)									
F(2)									
G(4)									
Daily Delay	0								
Owner	0								
Contractor	0								
Third-party	0								
Cum. delay	0								

End of day 2 bar chart

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (3)		O(EC) C(NE) T(EN)							
B (2)									
C (2)									
D (4)		C(NE) T(EN)							
E (3)									
F(3)		T(EN)							
G(4)									
Daily Delay		1							
Owner		1/3							
Contractor		1/3							
Third-party		1/3							
Cum. delay		1							

End of day 3 bar chart

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A(4)		O(EC) C(NE) T(EN)	O(EC) C(NE)						
B(2)									
C(2)									
D(5)		C(NE) T(EN)	C(NE)						
E(3)									
F(3)		T(EN)							
G(4)									
Daily Delay			1						
Owner			1/2						
Contractor			1/2						
Third-party			0						
Cum. delay			2						

End of day 4 bar chart

Act (Dur)	Date														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
A(5)		O(EC) C(NE) T(EN)	O(EC) C(NE)	O(EC)											
B(2)															
C(2)															
D(6)		C(NE) T(EN)	C(NE)	T(EN)											
E(3)															
F(3)		T(EN)													
G(4)															
Daily Delay				1											
Owner				1/2											
Contractor				0											
Third-party				1/2											
Cum. delay				3											

End of day 5 bar chart

Act (Dur)	Date														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
A(6)		O(EC) C(NE) T(EN)	O(EC) C(NE)	O(EC)	C(NE)										
B(2)															
C(2)															
D(7)		C(NE) T(EN)	C(NE)	T(EN)	T(EN)										
E(3)															
F(3)		T(EN)													
G(4)															
Daily Delay					1										
Owner					0										
Contractor					1/2										
Third-party					1/2										
Cum. delay					4										

<u>End of day 6 bar chart</u>

	Date														
Act (Dur)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
A(7)		O(EC) C(NE) T(EN)	O(EC) C(NE)	O(EC)	C(NE)	O(EC)									
B(2)															
C(2)															
D(7)		C(NE) T(EN)	C(NE)	T(EN)	T(EN)										
E(3)															
F(3)		T(EN)													
G(4)															
Daily Delay						1									
Owner						1									
Contractor						0									
Third-party						0									
Cum. delay						5									

End of day 7 bar chart

Act (Dur)	Date														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
A(8)		O(EC) C(NE) T(EN)	O(EC) C(NE)	O(EC)	C(NE)	O(EC)	O(EC) C(NE)								
B(2)															
C(2)															
D(8)		C(NE) T(EN)	C(NE)	T(EN)	T(EN)		O(EC)								
E(3)															
F(3)		T(EN)													
G(4)															
Daily Delay							1								
Owner							1/2								
Contractor							1/2								
Third-party							0								
Cum. delay							6								

End of day 8 bar chart (As-Built)

Act (Dur)	Date														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
A (9)		O(EC) C(NE) T(EN)	O(EC) C(NE)	O(EC)	C(NE)	O(EC)	**O(EC)** **C(NE)**	O(EC) C(NE)							
B (2)															
C (2)															
D (9)		C(NE) T(EN)	C(NE)	T(EN)	T(EN)		O(EC)	C(NE)							
E (3)															
F (3)		T(EN)													
G (4)															
Daily Delay	0	1	1	1	1	1	1	1							
Owner		1/3	1/2	1/2	0	1	1/2	1/2							
Contractor		1/3	1/2	0	1/2	0	1/2	1/2							
Third-party		1/3	0	1/2	1/2	0	0	**0**							
Cum. delay	0	1	2	3	4	5	6	7	7	7	7	7	7		

Results of delay analysis using the isolated daily window analysis technique (and with the equal liability method for concurrency).

Owner (EC) total delay = 1/3 + 1/2+ 1/2 + 1+1/2+1/2 = 3 1/3 days

Contractor (NE) total delay = 1/3 + 1/2 + 1/2 +1/2+1/2 = 2 1/3 days

Third-party (EN) total delay = 1/3 + 1/2 + 1/2 = 1 1/3 days

Project total delay = 3 1/3 + 2 1/3 + 1 1/3 = 7 days

Note: On day 1 of the project there were no delays. After day 8 there were no further delays.

APPENDIX A-4:

THE 7-ACTIVITIES CASE – IDWAT (REGULAR)

<u>As-planned bar chart</u> (7 activities project with three parallel critical paths and an original duration of 6 days)

	Date								
Act (Dur)	1	2	3	4	5	6	7	8	9
A (2)									
B (2)									
C (2)									
D (3)									
E (3)									
F (2)									
G(4)									

End of day 1 bar chart

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)									
B (2)									
C (2)									
D (3)									
E (3)									
F(2)									
G(4)									
Daily Delay	0								
Owner	0								
Contractor	0								
Third-party	0								
Cum. delay	0								

End of day 2 bar chart

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (3)		O(EC) C(NE) T(EN)							
B (2)									
C (2)									
D (4)		C(NE) T(EN)							
E (3)									
F(3)		T(EN)							
G(4)									
Daily Delay		1							
Owner									
Contractor									
Third-party		1							
Cum. delay		1							

Note: At day 2 there are three types of delays acting concurrently. As per the regular method, the owner and the contractor will carry their own expenses and a time extension will be granted to the contractor. Therefore, the delay day occurring on day 2 will be recorded in the summary as a third-party delay. The owner and the contractor shares will be considered to be zero (will be left blank).

<u>End of day 3 bar chart</u>

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A(4)		O(EC) C(NE) T(EN)	O(EC) C(NE)						
B(2)									
C(2)									
D(5)		C(NE) T(EN)	C(NE)						
E(3)									
F(3)		T(EN)							
G(4)									
Daily Delay		1	1						
Owner									
Contractor									
Third-party		1	1						
Cum. delay			2						

Note: On day 3, there are contractor and owner delays acting concurrently; in accordance with the regular method the delay day will be recorded in the summary as a third-party delay.

End of day 4 bar chart

Act (Dur)	Date														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
A(5)		O(EC) C(NE) T(EN)	O(EC) C(NE)	O(EC)											
B(2)															
C(2)															
D(6)		C(NE) T(EN)	C(NE)	T(EN)											
E(3)															
F(3)		T(EN)													
G(4)															
Daily Delay		1	1	1											
Owner															
Contractor															
Third-party		1	1	1											
Cum. delay		1	2	3											

End of day 5 bar chart

Act (Dur)	Date													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A(6)		O(EC) C(NE) T(EN)	O(EC) C(NE)	O(EC)	C(NE)										
B(2)															
C(2)															
D(7)		C(NE) T(EN)	C(NE)	T(EN)	T(EN)										
E(3)															
F(3)		T(EN)													
G(4)															
Daily Delay		1	1	1	1										
Owner															
Contractor															
Third-party		1	1	1	1										
Cum. delay		1	2	3	4										

End of day 6 bar chart

Act (Dur)	Date														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
A(7)		O(EC) C(NE) T(EN)	O(EC) C(NE)	O(EC)	C(NE)	O(EC)									
B(2)															
C(2)															
D(7)		C(NE) T(EN)	C(NE)	T(EN)	T(EN)										
E(3)															
F(3)		T(EN)													
G(4)															
Daily Delay		1	1	1	1	1									
Owner						1									
Contractor															
Third-party		1	1	1	1										
Cum. delay		1	2	3	4	5									

<u>End of day 7 bar chart</u>

Act (Dur)	Date														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
A(8)		O(EC) C(NE) T(EN)	O(EC) C(NE)	O(EC)	C(NE)	O(EC)	O(EC) C(NE)								
B(2)															
C(2)															
D(8)		C(NE) T(EN)	C(NE)	T(EN)	T(EN)		O(EC)								
E(3)															
F(3)		T(EN)													
G(4)															
Daily Delay		1	1	1	1	1	1								
Owner						1									
Contractor															
Third-party		1	1	1	1		1								
Cum. delay		1	2	3	4	5	6								

Note: At the beginning of day 7 there was one critical path (A, B, C). Also, there are contractor and owner delays on this path acting concurrently at day 7. According to the regular method, the two concurrent delays are recorded in the summary as one day of third-party delay.

<u>End of day 8 bar chart</u> <u>(As-Built)</u>

	Date														
Act (Dur)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
A (9)		O(EC) C(NE) T(EN)	O(EC) C(NE)	O(EC)	C(NE)	O(EC)	**<u>O(EC)</u>** **<u>C(NE)</u>**	O(EC) C(NE)							
B (2)															
C (2)															
D (9)		C(NE) T(EN)	C(NE)	T(EN)	T(EN)		O(EC)	C(NE)							
E (3)															
F (3)		T(EN)													
G (4)															
Daily Delay	0	1	1	1	1	1	1	1							
Owner						1									
Contractor															
Third-party		1	1	1	1		1	1							
Cum. delay	0	1	2	3	4	5	6	7	7	7	7	7	7		

Note: At the beginning of day 8 there was one critical path (A, B, C). Also on this same path, there are contractor and owner delays acting concurrently on day 7. According to the regular method, the two concurrent delays are recorded in the summary as a one-day third-party delay. The contractor delay acting on activity D was not considered because the path (D, E) was not critical at the beginning of day 8.

Results of delay analysis using isolated daily window analysis technique (and with the regular method for concurrency)

Owner (EC) total delay = 1 = 1 day

Contractor (NE) total delay = 0 = 0 day

Third-party (EN) total delay = 1+1+1+1+1+1 = 6 days

Project total delay = 1 + 0 + 6 = 7 days

Note: On day 1 of the project there were no delays. There were also no delays after day 8.

APPENDIX A-5:

THE 7-ACTIVITIES CASE – COST CALCULATION- IDWAT (ELM)

As- planned loaded schedule (loaded with scheduled resource, cost, and production rate data)

Act(Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2) SC= $ 78	LH(Hour)= 5 LC(Cost)$=10 EH(Hour)=2 EC(Cost)$=20 MU(Unit)=1 MC(Cost)$=9 SP(%)=50	LH=5 LC=10 EH=2 EC=20 MU=1 MC=9 SP(%)=50							
B (2) SC= $ 112			LH=4 LC=12 EH=2 EC=24 MU=2 MC=20 SP(%)=50	LH=4 LC=12 EH=2 EC=24 MU=2 MC=20 SP=50					
C (2) SC= $ 22					L=3 LC=6 E=0 EC=0 M=1 MC=5 SP(%)=50	L=3 LC=6 E=0 EC=0 M=1 MC=5 SP(%)=50			
D (3) SC= $ 240	LH=10 LC=40 EH=4 EC=40 MU=0 MC=0 SP(%)=33.33	LH=10 LC=40 EH=4 EC=40 MU=0 MC=0 SP(%)=33.33	LH=10 LC=40 EH=4 EC=40 MU=0 MC=0 SP(%)=33.34						
E (3) SC= $ 30				LH=5 LC=10 EH=0 EC=0 MH=0 MC=0 SP(%)=33.33	LH=5 LC=10 EH=0 EC=0 MH=0 MC=0 SP(%)=33.33	LH=5 LC=10 EH=0 EC=0 MH=0 MC=0 SP(%)=33.34			
F (2) SC= $ 30	LH=3 LC=9 EH=0 EC=0 MU=2 MC=6 SP(%)=50	LH=3 LC=9 EH=0 EC=0 MU=2 MC=6 SP(%)=50							
G(4) SC= $ 392			LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 SP(%)=25	LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 SP(%)=25	LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 SP(%)=25	LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 SP(%)=25			

As-built loaded schedule (loaded with actual resource, cost, and production rate data)

Act (Dur)	Date 1	2	3	4	5	6	7	8	9	10	11	12	13		
A (9) AC= $ 248 ADC(EC)= **$ 90.039**	LH(Hour)= 5 LC(Cost)$=10 EH(Hour)=2 EC(Cost)$=20 MU(Unit)=1 MC(Cost)$=9 AP(%)=50	**O(EC)** C(NE) T(EN) **LH=5** **LC=10** EH=2 EC=20 MU=0 MC=0 AP(%)=0 **DDC(EC)= 10** DC(NE)= 10 DC(EN)= 10 DDC = 30	**O(EC)** C(NE) **LH=3** **LC=6** EH=2 EC=20 MU=0 MC=0 **AP(%)=0** **DDC(EC)= 13** DC(NE)= 13 DDC= 26	**O(EC)** **LH=0** **LC=0** EH=2 EC=20 MU=0 MC=0 AP(%)=0 **DDC(EC)= 20** DDC= 20	**C(NE)** LH=0 LC=0 EH=2 EC=20 MU=0 MC=0 AP(%)=0 DDC(NE)= 20 DDC= 20	**O(EC)** LH=0 LC=0 EH=2 EC=20 MU=0 MC=0 AP(%)=0 **DDC(EC)= 20** DDC= 20	**O(EC)** C(NE) **LH=4** **LC=8** EH=2 EC=20 MU=0.330 MC=3 **AP(%)=16.6** **DDC(EC)=9.026** DC(NE)= 9.026 **DDC= 18.052**	**O(EC)** C(NE) **LH=4** **LC=8** EH=2 EC=20 MU=0.330 MC=3 **AP(%)=16.6** **DDC(EC)= 9.026** DC(NE)= 9.026 **DDC= 18.052**	**LH=4** **LC=8** EH=2 EC=20 MU=0.334 MC=3 **AP(%)=16.7** **DDC(EC)= 8.987** DC(NE)= 8.987 **DDC= 17.974**						
B (2) AC= $ 120 SC= $ 112 **EXC = $ 8** **ASD= 7 days** **DIC= $ 8/7** ADC(EC)= **$ 0** **AIC(EC)= $ 4.38**		**DIC(EC) = 0.381** DIC(NE) = 0.381 DIC (EN)= 0.381	**DIC(EC) = 0.571** DIC(NE) = 0.571	**DIC (EC)= 1.143**		**DIC (EC)= 1.143**	**DIC(EC) = 0.571** DIC(NE) = 0.571	**DIC(EC) = 0.571** DIC (NE)= 0.571		LH=4 **LC=16** EH=2 EC=24 MU=2 MC=20 AP(%)=50	LH=4 **LC=16** EH=2 EC=24 MU=2 MC=20 AP(%)=50				
C (2) AC= $ 28 SC= $ 22 EXC= $6 ASD= 7 days DIC= $ 6/7 ADC(EC)= **$ 0** **AIC(EC)= $ 3.29**		**DIC(EC) = 0.286** DIC(NE) = 0.286 DIC (EN)= 0.286	**DIC (EC)= 0.429** DIC(NE) = 0.429	**DIC (EC)= 0.858**		**DIC (EC)= 0.858**	**DIC(EC) = 0.429** DIC(NE) = 0.429	**DIC(EC) = 0.429** DIC(NE) = 0.429				L=3 **LC=9** E=0 EC=0 M=1 MC=5 AP(%)=50	L=3 **LC=9** E=0 EC=0 M=1 MC=5 AP(%)=50		
D (9) AC= $ 426 ADC(EC)= **$ 58**	LH=10 LC=40 EH=4 EC=40 MU=0 MC=0 AP(%)=33.33	**C(NE)** T(EN) **LH=10** **LC=40** EH=4 EC=40 MU=0 MC=0 AP(%)=0 DDC(NE)= 40 DDC(EN)= 40 DDC= 80	**C(NE)** **LH=5** **LC=20** EH=0 EC=0 MU=0 MC=0 AP(%)=0 DDC(NE)= 20 DDC= 20	**T(EN)** **LH=0** **LC=0** EH=0 EC=0 MU=0 MC=0 AP(%)=0 DDC(EN)= 0 DDC= 0	**T(EN)** LH=0 LC=0 EH=0 EC=0 MU=0 MC=0 AP(%)=0 DDC(EN)= 0 DDC= 0	LH=10 LC=40 **EH=4** **EC=40** MU=0 MC=0 AP(%)=33.33	**O(EC)** **LH=7** **LC=28** **EH=3** **EC=30** MU=0 MC=0 **AP(%)=0** **DDC(EC)= 58** **DDC= 58**	**C(NE)** **LH=6** **LC=24** **EH=3** **EC=30** MU=0 MC=0 **AP(%)=16.67** DDC(NE)= 13.992 **DDC= 13.992**	**LH=6** **LC=24** **EH=3** **EC=30** MU=0 MC=0 **AP(%)=16.67** DDC(NE)=13.992 **DDC= 13.992**						

E (3) AC= $ 45 SC= $30 EXC= $15 ASD= 6 days DIC= $ 15/6 ADC(EC)= **$ 0** **AIC(EC)= $ 2.5**							**DIC (EC)= 2.5**			LH=5 **LC=15** EH=0 EC=0 MH=0 MC=0 AP(%)=33.33	LH=5 **LC=15** EH=0 EC=0 MH=0 MC=0 AP(%)=33.33	LH=5 **LC=15** EH=0 EC=0 MH=0 MC=0 AP(%)=33.33				
F (3) AC= $ 39 ADC(EC)= **$ 0**	LH=3 LC=9 EH=0 EC=0 MU=2 MC=6 AP(%)=50	**T(EN)** LH=3 LC=9 EH=0 EC=0 MU=2 MC=0 AP(%)=0 DC(EN)= 9 DDC= 9	LH=3 LC=9 EH=0 EC=0 MU=2 MC=6 AP(%)=50													
G (4) AC= $ 392 SC= $ 392 EXC= $ 0 ASD= 1 day DIC= $ 0/1 ADC(EC)= **$ 0**				LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 AP(%)=25	LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 AP(%)=25	LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 AP(%)=25	LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 AP(%)=25									
Daily Delay	0	1	1	1	1	1	1	1								
Owner		1/3	1/2	1/2	0	1	1	1								
Contractor		1/3	1/2	0	1/2	0	0	0								
Third party		1/3	0	1/2	1/2	0	0	0								
Cum. delay	0	1	2	3	4	5	6	7	7	7	7	7	7			

Results of delay analysis using the isolated daily window analysis technique (and with the equal liability method for concurrency).

Owner (EC) total delay = 1/3 + 1/2+ 1/2 + 1+1/2+1/2 = 3 1/3 days

Contractor (NE) total delay = 1/3 + 1/2 + 1/2 +1/2+1/2 = 2 1/3 days

Third-party (EN) total delay = 1/3 + 1/2 + 1/2 = 1 1/3 days

Project total delay = 3 1/3 + 2 1/3 + 1 1/3 = 7 days

Legend:

SP: Scheduled production rate of an activity day, usually represented as a percentage (for example, P=12%). For scheduled activities (as-planned), the production rate is assumed to be equal for all days and to be 100 for the duration.

AP: Actual production rate of an activity day usually represented as a percentage. For actual activities (As-built), the summation of all daily production rates of any activity should add up to 100%.

AC: Actual cost of the activity

ACD: Actual cost of the activity day

SC: Scheduled cost of the activity

ASD: Activity start delay (in days) = actual start date – scheduled start date

EXC: Extra cost of the activity = Actual cost of the activity - scheduled cost of the activity = AC- SC

DIC: Daily impact cost = Extra cost of the activity/activity start delay = $ EXC/ASD days = $ /day

AIC (EC): Impact cost of an activity due to a delay of the start date of that activity associated with an EC-type delay.

ACR: Actual cost rate = Actual cost of an activity/100 = Actual activity cost per 1% of the activity work.

SCR: Scheduled cost rate = Scheduled cost of the activity/100 = Scheduled activity cost per 1% of the activity work

SLCR: Scheduled labour cost rate = an activity's scheduled labour cost/100 = Scheduled labour cost per 1% of the activity's work.

SECR: Scheduled equipment cost rate = an activity's scheduled equipment cost/100 = Scheduled equipment cost per 1% of the activity's work.

SMCR: Scheduled material cost rate = an activity's scheduled material cost/100 = Scheduled material cost per 1% of the activity's work.

ALCR: Actual labour cost rate = an activity's actual labour cost/100 = Actual labour cost per 1% of the activity's work.

AECR: Actual equipment cost rate = an activity's actual equipment cost/100 = Actual equipment cost per 1% of the activity's work.

AMCR: Actual material cost rate = an activity's actual material cost/100 = Actual material cost per 1% of the activity's work.

Impacted activity day: an activity day with delay(s) or with an actual production rate less than the scheduled production rate.

DDC: Daily Direct delay cost = **ACD** - **(AP) (SCR) =** Actual cost of labour, equipment and material for an impacted activity day – the earned value for that day: {actual day's production rate X Scheduled cost of the activity/100}

DDC (EC): Daily direct delay cost associated with EC delays. If the EC delay is acting alone it will carry all the DDC value. If the EC delay is acting with other types (concurrency), then it depends on the method. If the ELM is used and EC is acting with one other type, it will carry 0.5 of the DDC, and if it is acting with two other types, then it will carry 0.33 of the DDC. If the regular method is used for concurrency, then there will be no eligibility for direct cost.

ADC (EC): Activity direct delay cost associated with EC delays = SUM of all the DDCs (EC) for all activity days.

LD: Liquidated damages for the owner as a result of contractor's delays.

Sample calculations:

Direct cost:

Act A Day 7

DDC: (Daily Direct delay cost) = $ 31 (actual cost for day 7 of activity A) – {16.6 (actual production rate for day 7 of activity A) X 0.78 (SCR: scheduled activity cost/100) = $ 18.052

DDC (EC): (Daily Direct delay cost associated with EC delay) **= $** 18.052/2 = $ **9.026 (EC is acting with one more type of delay)**

Act A

ADC (EC): (Activity direct delay cost associated with EC delays) = sum of all DDC (EC) of all the days in Act A = $ **90.039**

D = SUM of all ADC(EC) for all project activities = 90.039 + 58 = $ 148.04

Impact cost:

Act B follows Act A and Activity B's actual cost was more than the scheduled cost {(AC=120) > (SC=112)}. And,

Activity B's start was delayed by 7 days. This makes it a candidate for impact cost calculation as per option 1 of the impact cost module . According to this option, we have to go back to the preceding activity, activity A. We have to go backwards for every delayed day in activity A until we accumulate 7 days. For each accumulated delay day, the impact cost will be considered only if the delay day has an EC delay.

The impact cost for each delay day of **activity B is calculated by** dividing the extra cost of activity B over the delay of the activity's start. In the case of activity B, the extra cost (EXC) was $8 and the activity start delay (ASD) was 7 days. Thus, he daily impact cost (DIC) = $8/7days = $1.143

For day 8 of activity A, there was EC delay combined with one other type -- NE delay. So the EC share of the daily impact cost that day 8 of activity A contributed to activity B = **DIC (EC)** = $1.143/2 = **$ 0.571**

AIC (EC) for **Act B** = SUM of all DIC (EC) of all the accumulated delay days in the preceding activity (**Act A**) = **$ 4.38**

I: Project impact delay cost due to delayed activity starts associated with EC delays = SUM of all <u>AIC(EC)</u> for all project activities with delayed starts = 4.38 + 3.29 + 2.5 + 0 = $ 10.17

<u>Office and site overhead cost:</u>

Assume that the amounts of both head office overhead and site overhead are each $ 60. Using the Canadian method, the OH cost of delay will be as follows:

O: OH amount ($ 60)/(6 days of original duration) x No of EC delay days for the whole project (3 1/3 days) = **$ 33.33**

<u>Contractor's Total Project Delay Cost</u> = D + I + O = 148.04 + 10.17 + 33.33 = <u>$ 191.54</u>

<u>Owner's Liquidated damages:</u>

Assuming that the amount of the daily liquidated damages as per the contract is $ 6, the liquidated damages are calculated as follows:

LD: Liquidated damages = daily liquidated damages ($ 6/day) x No of NE delay days for the whole project (2 1/3 days) = **$ 14**

APPENDIX A-6:

THE 7-ACTIVITIES CASE – COST CALCULATION-IDWAT (REGULAR)

As-planned loaded schedule (loaded with scheduled resource, cost, and production rate data)

	Date								
Act(Dur)	1	2	3	4	5	6	7	8	9
A (2) SC= $ 78	LH(Hour)= 5 LC(Cost)$=10 EH(Hour)=2 EC(Cost)$=20 MU(Unit)=1 MC(Cost)$=9 SP(%)=50	LH=5 LC=10 EH=2 EC=20 MU=1 MC=9 SP(%)=50							
B (2) SC= $ 112			LH=4 LC=12 EH=2 EC=24 MU=2 MC=20 SP(%)=50	LH=4 LC=12 EH=2 EC=24 MU=2 MC=20 SP=50					
C (2) SC= $ 22					L=3 LC=6 E=0 EC=0 M=1 MC=5 SP(%)=50	L=3 LC=6 E=0 EC=0 M=1 MC=5 SP(%)=50			
D (3) SC= $ 240	LH=10 LC=40 EH=4 EC=40 MU=0 MC=0 SP(%)=33.33	LH=10 LC=40 EH=4 EC=40 MU=0 MC=0 SP(%)=33.33	LH=10 LC=40 EH=4 EC=40 MU=0 MC=0 SP(%)=33.34						
E (3) SC= $ 30				LH=5 LC=10 EH=0 EC=0 MH=0 MC=0 SP(%)=33.33	LH=5 LC=10 EH=0 EC=0 MH=0 MC=0 SP(%)=33.33	LH=5 LC=10 EH=0 EC=0 MH=0 MC=0 SP(%)=33.34			
F (2) SC= $ 30	LH=3 LC=9 EH=0 EC=0 MU=2 MC=6 SP(%)=50	LH=3 LC=9 EH=0 EC=0 MU=2 MC=6 SP(%)=50							
G(4) SC= $ 392			LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 SP(%)=25	LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 SP(%)=25	LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 SP(%)=25	LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 SP(%)=25			

As-built loaded schedule (loaded with actual resource, cost, and production rate data)

	Date														
Act (Dur)	1	2	3	4	5	6	7	8	9	10	11	12	13		
A (9) AC= $ 248 ADC(EC)= **$ 40**	LH(Hour)= 5 LC(Cost)$=10 EH(Hour)=2 EC(Cost)$=20 MU(Unit)=1 MC(Cost)$=9 AP(%)=50	**O(EC)** C(NE) T(EN) **LH=5** **LC=10** EH=2 EC=20 MU=0 MC=0 AP(%)=0 **DDC(EC)= 0** DC(NE)= 0 DC(EN)= 30 DDC = 30	**O(EC)** C(NE) **LH=3** **LC=6** EH=2 EC=20 MU=0 **MC=0** **AP(%)=0** **DDC(EC)= 0** DC(NE)= 0 DC(EN)=26 DDC= 26	**O(EC)** **LH=0** **LC=0** EH=2 EC=20 MU=0 MC=0 AP(%)=0 **DDC(EC)= 20** DDC= 20	**C(NE)** LH=0 LC=0 EH=2 EC=20 MU=0 MC=0 AP(%)=0 DDC(NE)= 20 DDC= 20	**O(EC)** LH=0 LC=0 EH=2 EC=20 MU=0 MC=0 AP(%)=0 **DDC(EC)= 20** DDC= 20	**O(EC)** C(NE) **LH=4** **LC=8** EH=2 EC=20 MU=0.330 MC=3 **AP(%)=16.6** **DDC(EC)=0** DC(NE)= 0 DC(EN)= 18.052 **DDC= 18.052**	**O(EC)** C(NE) **LH=4** **LC=8** EH=2 EC=20 MU=0.330 MC=3 **AP(%)=16.6** **DDC(EC)= 0** DC(NE)= 0 DC(EN)= 18.052 **DDC= 18.052**	**LH=4** **LC=8** EH=2 EC=20 MU=0.334 MC=3 **AP(%)=16.7** **DDC(EC)= 0** DC(NE)= 0 DC(EN)= 18.052 **DDC= 17.974**						
B (2) AC= $ 120 SC= $ 112 **EXC = $ 8** **ASD= 7 days** **DIC= $ 8/7** ADC(EC)= **$ 0** **AIC(EC)= $ 2.286**		**DIC(EC) = 0** DIC(NE) = 0 DIC (EN)= 1.143	**DIC(EC) = 0** DIC(NE) = 0. DIC (EN)= 1.143	**DIC (EC)= 1.143**	DIC(NE) = 1.143	**DIC (EC)= 1.143**	**DIC(EC) = 0** DIC(NE) = 0 DIC (EN)= 1.143	**DIC(EC) = 0** DIC (NE)= 0 DIC (EN)= 1.143		LH=4 **LC=16** EH=2 EC=24 MU=2 MC=20 AP(%)=50	LH=4 **LC=16** EH=2 EC=24 MU=2 MC=20 AP(%)=50				
C (2) AC= $ 28 SC= $ 22 EXC= $6 ASD= 7 days DIC= $ 6/7 ADC(EC)= **$ 0** **AIC(EC)= $ 1.716**		**DIC(EC) = 0** DIC(NE) = 0 DIC (EN)= 0.858	**DIC (EC)= 0** DIC(NE) = 0 DIC (EN)= 0.858	**DIC (EC)= 0.858**	DIC(NE) = 0.858	**DIC (EC)= 0.858**	**DIC(EC) = 0** DIC(NE) = 0 DIC (EN)= 0.858	**DIC(EC) = 0** DIC(NE) = 0 DIC (EN)= 0.858				L=3 **LC=9** E=0 EC=0 M=1 MC=5 AP(%)=50	L=3 **LC=9** E=0 EC=0 M=1 MC=5 AP(%)=50		
D (9) AC= $ 426 ADC(EC)= **$ 58**	LH=10 LC=40 EH=4 EC=40 MU=0 MC=0 AP(%)=33.33	**C(NE)** T(EN) **LH=10** **LC=40** EH=4 EC=40 MU=0 MC=0 AP(%)=0 DDC(NE)= 40 DDC(EN)= 40 DDC= 80	**C(NE)** **LH=5** **LC=20** EH=0 EC=0 MU=0 MC=0 AP(%)=0 DDC(NE)= 20 DDC= 20	**T(EN)** **LH=0** **LC=0** EH=0 EC=0 MU=0 MC=0 AP(%)=0 DDC(EN)= 0 DDC= 0	**T(EN)** LH=0 LC=0 EH=0 EC=0 MU=0 MC=0 AP(%)=0 DDC(EN)= 0 DDC= 0	LH=10 LC=40 **EH=4** **EC=40** MU=0 MC=0 AP(%)=33.33	**O(EC)** **LH=7** **LC=28** **EH=3** **EC=30** MU=0 MC=0 **AP(%)=0** **DDC(EC)= 58** **DDC= 58**	**C(NE)** **LH=6** **LC=24** **EH=3** **EC=30** MU=0 MC=0 **AP(%)=16.67** DDC(NE)= 13.992 **DDC= 13.992**	**LH=6** **LC=24** **EH=3** **EC=30** MU=0 MC=0 **AP(%)=16.67** DDC(NE)=13.992 **DDC= 13.992**						

E (3) AC= $ 45 SC= $30 EXC= $15 ASD= 6 days DIC= $ 15/6 ADC(EC)= **$ 0** **AIC(EC)= $ 2.5**							**DIC (EC)= 2.5**			LH=5 **LC=15** EH=0 EC=0 MH=0 MC=0 AP(%)=33.33	LH=5 **LC=15** EH=0 EC=0 MH=0 MC=0 AP(%)=33.33	LH=5 **LC=15** EH=0 EC=0 MH=0 MC=0 AP(%)=33.33			
F (3) AC= $ 39 ADC(EC)= **$ 0**	LH=3 LC=9 EH=0 EC=0 MU=2 MC=6 AP(%)=50	**T(EN)** LH=3 LC=9 EH=0 EC=0 MU=2 MC=0 AP(%)=0 DC(EN)= 9 DDC= 9	LH=3 LC=9 EH=0 EC=0 MU=2 MC=6 AP(%)=50												
G (4) AC= $ 392 SC= $ 392 EXC= $ 0 ASD= 1 day DIC= $ 0/1 ADC(EC)= **$ 0**				LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 AP(%)=25	LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 AP(%)=25	LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 AP(%)=25	LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 AP(%)=25								
Daily Delay	0	1	1	1	1	1	1	1							
Owner						1									
Contractor															
Third party		1	1	1	1		1	1							
Cum. delay	0	1	2	3	4	5	6	7	7	7	7	7	7		

Results of delay analysis using isolated daily window analysis technique (with the regular method for concurrency)

Owner (EC) total delay = 1 = 1 day

Contractor (NE) total delay = 0 = 0 day

Third-party (EN) total delay = 1+1+1+1+1+1 = 6 days

Project total delay = 1 + 0 + 6 = 7 days

Note: These delay analysis results will affect the overhead cost of the delay. The direct and impact cost will be calculated on the activity day and activity levels, respectively, as shown in the above actual cost loaded schedule.

Legend: **As in Appendix A-5**

Sample calculations (Regular method):

Direct cost:

Act A Day 7

DDC: (Daily Direct delay cost) = $ 31 (actual cost for day 7 of activity A) – {16.6(actual production rate for day 7 of activity A) X 0.78 (SCR: scheduled activity cost/100) = $ 18.052

DDC(EC): (Daily Direct delay cost associated with EC delay) **=** $ 0. According to the regular method, the daily direct delay cost associated with EC delay = **$ 0** **If EC is acting concurrently with one or two types of delay.**

Act A

ADC (EC): (Activity direct delay cost associated with EC delay) = sum of all DDCs (EC) of all the days in Act A = **$ 40**

D = SUM of all ADC (EC) **for all project activities = 40 + 58 = $ 98**

Impact cost:

Act B

Preceding activity is: Act A

Activity B's actual cost was more than the scheduled cost {(AC=120) > (SC=112)}.

Activity B's start was delayed by 7 days, which makes it a candidate for impact cost calculation as per option 1 of the module. According to this module, we have to go back to the preceding activity, here activity A. We have to go backwards for every delayed day of activity A until we accumulate 7 days. For each accumulated delay day, the impact cost will be considered only if the delay day has an EC delay acting alone on that day (Regular method).

The impact cost of for each delay day of **activity B is calculated by** dividing the extra cost of activity B over the delay in the start of the activity. In the case of activity B, the extra cost (EXC) was $8 and the activity start delay (ASD) was 7 days. Thus, the daily impact cost (DIC) = $8/7days = $1.143

For day 8 of activity A, there was EC delay with one more type (NE). Therefore, the EC share of the daily impact cost which day 8 of activity A contributed to activity B = **DIC(EC)** = $ 0 (Regular method)

For day 6 of activity A, EC acted alone. In this case, the EC will carry the daily impact cost that day 6 of activity A contributed to activity B = DIC (EC) = $ 1.143

AIC (EC) for **Act B** = SUM of all DIC (EC) of all the accumulated delay days in the preceding activity (**Act A**) = **$ 2.286**

I: Project impact delay cost due to delayed activity starts associated with EC delays = SUM of all AIC(EC) for all project activities with delayed start = 2.286 + 1.716 + 2.5 + 0 = $ 6.502

Office and site overhead cost:

Assume that the amounts of both head office overhead and site overhead are $ 60. Using the Canadian method, the OH cost of delay will be calculated as follows:

O: OH amount ($ 60)/(6 days of original duration) x No of EC delay days for the whole project (1 day) = **$ 10**

Contractor's Total Project Delay Cost = D + I + O = 98 + 6.502 + 10 = $ 114.502

Owner's liquidated damages:

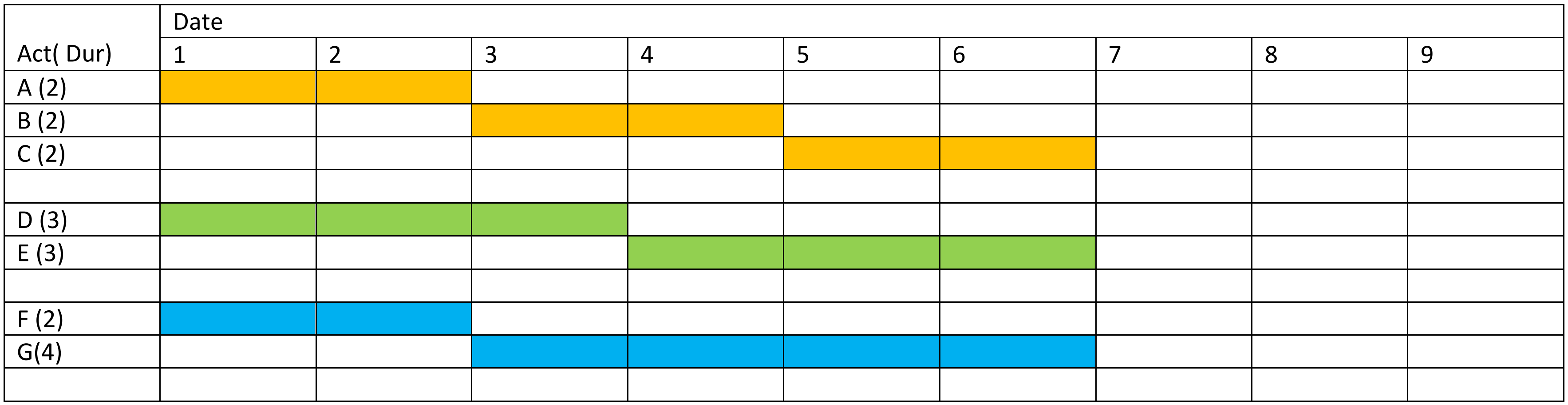
Assuming that the amount of the daily liquidated damages as per the contract is $ 6, the liquidated damages are calculated as follows:

LD: Liquidated damages = daily liquidated damages ($ 6/day) x No of NE delay days for the whole project (0 days) = **$ 0**

APPENDIX A-7:

THE 7-ACTIVITIES CASE – ACCELERATIONS/DELAYS - IDWAT (ELM)

<u>As-planned bar chart</u> (7 activities project with three parallel critical paths and an original duration of 6 days)



End of day 1 bar chart

Act(Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	OA								
B (2)									
C (2)									
D (3)	CA								
E (3)									
F(2)	CA								
G(4)									
Daily impact	-1								
Owner	- 0.5								
Contractor	-0.5								
Third party	0								
Cum. delay	-1								

<u>End of day 2 bar chart</u>

Act(Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	OA								
B (2)		O(EC)							
C (2)									
D (3)	CA	C(NE)							
E (3)									
F(2)	CA								
G(4)		T(EN)							
Daily impact	-1	1							
Owner	- 0.5	1/3							
Contractor	-0.5	1/3							
Third party	0	1/3							
Cum. delay	-1	0							

End of day 3 bar chart

Act(Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	OA								
B (2)		O(EC)	OA						
C (2)									
D (3)	CA	C(NE)	O(EC)						
E (3)									
F(2)	CA								
G(4)		T(EN)							
Daily Impact	-1	1	1						
Owner	- 0.5	1/3	1						
Contractor	-0.5	1/3	0						
Third party	0	1/3	0						
Cum. delay	-1	0	1						

End of day 4 bar chart

Act(Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	OA								
B (2)		O(EC)	OA						
C (2)				O(EC)					
D (3)	CA	C(NE)	O(EC)						
E (3)									
F(2)	CA								
G(4)		T(EN)		C(NE)					
Daily Impact	-1	1	1	0					
Owner	- 0.5	1/3	1	0					
Contractor	-0.5	1/3	0	0					
Third party	0	1/3	0	0					
Cum. delay	-1	0	1	1					

End of day 5 bar chart

Act(Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	OA								
B (2)		O(EC)	OA						
C (2)				O(EC)	O(EC)				
D (3)	CA	C(NE)	O(EC)						
E (3)									
F(2)	CA								
G(4)		T(EN)		C(NE)					
Daily Impact	-1	1	1	0	0				
Owner	- 0.5	1/3	1	0	0				
Contractor	-0.5	1/3	0	0	0				
Third party	0	1/3	0	0	0				
Cum. delay	-1	0	1	1	1				

End of day 6 bar chart

Act(Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	OA								
B (2)		O(EC)	OA						
C (2)				O(EC)	O(EC)	O(EC)			
D (3)	CA	C(NE)	O(EC)						
E (3)									
F(2)	CA								
G(4)		T(EN)		C(NE)		C(NE)			
Daily Impact	-1	1	1	0	0	1			
Owner	- 0.5	1/3	1	0	0	0.5			
Contractor	-0.5	1/3	0	0	0	0.5			
Third party	0	1/3	0	0	0	0			
Cum. delay	-1	0	1	1	1	2			

End of day 7 bar chart (As-built)

Act(Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	OA								
B (2)		O(EC)	OA						
C (2)				O(EC)	O(EC)	O(EC)	OA		
D (3)	CA	C(NE)	O(EC)						
E (3)									
F(2)	CA								
G(4)		T(EN)		C(NE)		C(NE)	OA		
Daily Impact	-1	1	1	0	0	1	-1		
Owner	- 0.5	1/3	1	0	0	0.5	-1		
Contractor	-0.5	1/3	0	0	0	0.5	0		
Third party	0	1/3	0	0	0	0	0		
Cum. delay	-1	0	1	1	1	2	1		

Results of schedule analysis using the isolated daily window analysis technique (IDWAT) (with the equal liability method (ELM) for concurrency)

Owner (EC & OA) total Impact = -1/2 + 1/3 + 1 + 1/2 - 1 = 1/3 days

Contractor (NE & CA) total Impact = -1/2 + 1/3 + 1/2 = 1/3 days

Third-party (EN) total Impact = 1/3 = 1/3 days

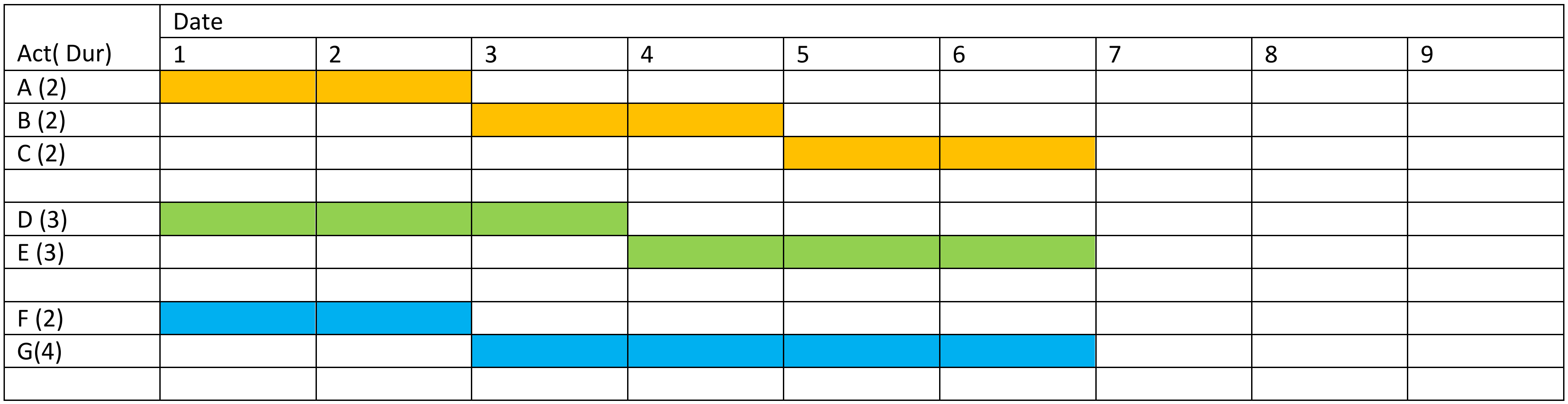
Project total delay = 1/3 + 1/3 + 1/3 = 1 day

Notes: Day 1 of the project was accelerated by both the owner and the contractor. As per the IDWAT, the OA and the CA have to be inserted separately. When the OA is inserted alone, the project will not be accelerated (impact = 0). The same result occurs when contractor accelerations are inserted alone. However, when all the accelerations, i.e. both the OA and the CA, are inserted, the project will be accelerated by one day (Impact = -1). This impact is then apportioned between the owner and the contractor: - 0.5 day of impact for each party. On the other hand, day 7 of the project witnessed two owner accelerations on the only two parallel paths for that day. These two OAs, when inserted alone, resulted in one day of acceleration to the project duration (Impact= -1). Also, on day 3, there was OA on one critical path and an EC delay on a parallel critical path. As per the acceleration rules, the delay will prevail and the impact on the project duration will be one day of delay due to the EC delay (Impact = 1). It is also worth mentioning that at the end of day 1, one day of float was created as a result of accelerating the project due to OA and CA. This one day of float was soon consumed on day two by the delay caused by the three parties (EC, NE, EN). For the purpose of this research, the float is considered as the property of the project and is consumed on a first-come first-consume basis.

APPENDIX A-8:

THE 7-ACTIVITIES CASE – ACCELERATIONS/DELAYS - IDWAT (REGULAR)

As planned bar chart (7 activities project with three parallel critical paths and an original duration of 6 days)



End of day 1 bar chart

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	OA								
B (2)									
C (2)									
D (3)	CA								
E (3)									
F(2)	CA								
G(4)									
Daily impact	-1								
Owner	- 0.5								
Contractor	-0.5								
Third-party	0								
Cum. delay	-1								

End of day 2 bar chart

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	OA								
B (2)		O(EC)							
C (2)									
D (3)	CA	C(NE)							
E (3)									
F (2)	CA								
G (4)		T(EN)							
Daily impact	-1	1							
Owner	- 0.5	0							
Contractor	-0.5	0							
Third-party	0	1							
Cum. delay	-1	0							

End of day 3 bar chart

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	OA								
B (2)		O(EC)	OA						
C (2)									
D (3)	CA	C(NE)	O(EC)						
E (3)									
F (2)	CA								
G (4)		T(EN)							
Daily Impact	-1	1	1						
Owner	- 0.5	0	1						
Contractor	-0.5	0	0						
Third-party	0	1	0						
Cum. delay	-1	0	1						

End of day 4 bar chart

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	OA								
B (2)		O(EC)	OA						
C (2)				O(EC)					
D (3)	CA	C(NE)	O(EC)						
E (3)									
F(2)	CA								
G(4)		T(EN)		C(NE)					
Daily Impact	-1	1	1	0					
Owner	- 0.5	0	1	0					
Contractor	-0.5	0	0	0					
Third-party	0	1	0	0					
Cum. delay	-1	0	1	1					

End of day 5 bar chart

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	OA								
B (2)		O(EC)	OA						
C (2)				O(EC)	O(EC)				
D (3)	CA	C(NE)	O(EC)						
E (3)									
F(2)	CA								
G (4)		T(EN)		C(NE)					
Daily Impact	-1	1	1	0	0				
Owner	- 0.5	0	1	0	0				
Contractor	-0.5	0	0	0	0				
Third-party	0	1	0	0	0				
Cum. delay	-1	0	1	1	1				

End of day 6 bar chart

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	OA								
B (2)		O(EC)	OA						
C (2)				O(EC)	O(EC)	O(EC)			
D (3)	CA	C(NE)	O(EC)						
E (3)									
F (2)	CA								
G (4)		T(EN)		C(NE)		C(NE)			
Daily Impact	-1	1	1	0	0	1			
Owner	- 0.5	0	1	0	0	0			
Contractor	-0.5	0	0	0	0	0			
Third-party	0	1	0	0	0	1			
Cum. delay	-1	0	1	1	1	2			

End of day 7 bar chart (As-Built)

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	OA								
B (2)		O(EC)	OA						
C (2)				O(EC)	O(EC)	O(EC)	OA		
D (3)	CA	C(NE)	O(EC)						
E (3)									
F (2)	CA								
G (4)		T(EN)		C(NE)		C(NE)	OA		
Daily Impact	-1	1	1	0	0	1	-1		
Owner	- 0.5	0	1	0	0	0	-1		
Contractor	-0.5	0	0	0	0	0	0		
Third-party	0	1	0	0	0	1	0		
Cum. delay	-1	0	1	1	1	2	1		

Results of schedule analysis using the isolated daily window analysis technique (with the Regular method for concurrency)

Owner (EC & OA) total Impact = -1/2 + 1 - 1 = - 1/2 days

Contractor (NE & CA) total Impact = -1/2 = - 1/2 days

Third-party (EN) total Impact = 1 + 1 = 2 days

Project total delay = - 1/2 - 1/2 + 2 = 1 day

Notes: Day 1 of the project was accelerated by both the owner and the contractor. As per the IDWAT, OA and CA have to be inserted separately. When the OA is inserted alone, the project will not be accelerated (impact = 0). There is also no project acceleration when the CA is inserted alone. However, when both the OAs and CAs are inserted, the project will be accelerated by one day (impact= -1). This impact is then apportioned between the owner and the contractor: a - 0.5 day impact for each party. On the other hand, day 7 of the project witnessed two OAs on the only two parallel paths for that day. These two owner accelerations, when inserted alone, resulted in one day of acceleration to the project duration (Impact= -1). Also, on day 3, there was OA on one critical path and an EC delay on a parallel critical path. As per the acceleration rules, the delay will prevail and the impact on the project duration will be one day of delay due to the EC delay (impact = 1). It is also worth mentioning that at the end of day 1, one day of float was created as a result of accelerating the project due to OAs and CAs. This one day of float was soon consumed on day two by the delay caused by all three parties (EC, NE, EN). For the purpose of this research, the float is considered to be the property of the project and is consumed on a first-come first-consume basis.

APPENDIX A-9:

THE 7-ACTIVITIES CASE – ACCELERATIONS/DELAYS - COST CALCULATION - IDWAT (ELM)

As-planned loaded schedule (loaded with scheduled resource, cost, and production rate data)

Act(Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2) SC= $ 78	LH(Hour)= 5 LC(Cost)$=10 EH(Hour)=2 EC(Cost)$=20 MU(Unit)=1 MC(Cost)$=9 SP(%)=50	LH=5 LC=10 EH=2 EC=20 MU=1 MC=9 SP(%)=50							
B (2) SC= $ 112			LH=4 LC=12 EH=2 EC=24 MU=2 MC=20 SP(%)=50	LH=4 LC=12 EH=2 EC=24 MU=2 MC=20 SP=50					
C (2) SC= $ 22					L=3 LC=6 E=0 EC=0 M=1 MC=5 SP(%)=50	L=3 LC=6 E=0 EC=0 M=1 MC=5 SP(%)=50			
D (3) SC= $ 240	LH=10 LC=40 EH=4 EC=40 MU=0 MC=0 SP(%)=33.33	LH=10 LC=40 EH=4 EC=40 MU=0 MC=0 SP(%)=33.33	LH=10 LC=40 EH=4 EC=40 MU=0 MC=0 SP(%)=33.34						
E (3) SC= $ 30				LH=5 LC=10 EH=0 EC=0 MH=0 MC=0 SP(%)=33.33	LH=5 LC=10 EH=0 EC=0 MH=0 MC=0 SP(%)=33.33	LH=5 LC=10 EH=0 EC=0 MH=0 MC=0 SP(%)=33.34			
F (2) SC= $ 30	LH=3 LC=9 EH=0 EC=0 MU=2 MC=6 SP(%)=50	LH=3 LC=9 EH=0 EC=0 MU=2 MC=6 SP(%)=50							
G(4) SC= $ 392			LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 SP(%)=25	LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 SP(%)=25	LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 SP(%)=25	LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 SP(%)=25			

As-built loaded schedule (loaded with actual resource, cost, and production rate data)

Act(Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2) AAC = $4	OA **LH=12** **LC=24** EH=4 EC=40 MU=2 MC=18 AP(%)=100 AXC= 4								
B (2) ADC=$12 AAC=$6		O(EC) LH=4 LC=12 EH=0 EC=0 MU=0 MC=0 AP(%)=0 DDC=12	OA LH=10 LC=30 EH=4 EC=48 MU=4 MC=40 AP(%)=100 AXC=6						
C (2) ADC=$6 AAC=$4				O(EC) L=3 LC=6 E=0 EC=0 M=0 MC=0 AP(%)=0 DDC=6	O(EC) L=0 LC=0 E=0 EC=0 M=0 MC=0 AP(%)=0 DDC=0	O(EC) L=0 LC=0 E=0 EC=0 M=0 MC=0 AP(%)=0 DDC=0	OA L=8 LC=16 E=0 EC=0 M=2 MC=10 AP(%)=100 AXC=4		
D (3) ADC=$0	CA LH=22 LC=48 EH=8 EC=80 MU=0 MC=0 AP(%)=66.66	C(NE) LH=5 LC=20 EH=0 EC=00 MU=0 MC=0 AP(%)=0	O(EC) LH=0 LC=0 EH=0 EC=0 MU=0 MC=0 AP(%)=0 DDC=0	LH=10 LC=40 EH=4 EC=40 MU=0 MC=0 AP(%)=33.33					
E (3) **EXC = $ 6** **ASD= 1 days** **DIC= $ 6/1=$6** ADC(EC)= **$ 0** **AIC(EC)= $ 6**			**DIC(EC) = $6**		LH=6 LC=12 EH=0 EC=0 MH=0 MC=0 AP(%)=33.33	LH=6 LC=12 EH=0 EC=0 MH=0 MC=0 AP(%)=33.33	LH=6 LC=12 EH=0 EC=0 MH=0 MC=0 AP(%)=33.33		

F (2)	CA LH=6 LC=18 EH=0 EC=0 MU=4 MC=12 AP(%)=100								
G (4) AAC=$6		T(EN) LH=4 LC=8 EH=0 EC=0 MU=0 MC=0 AP(%)=0	LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 AP(%)=25	C(NE) LH=4 LC=8 EH=0 EC=0 MU=0 MC=0 AP(%)=0	LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 AP(%)=25	C(NE) LH=0 LC=0 EH=0 EC=0 MU=0 MC=0 AP(%)=0	OA LH=30 LC=60 EH=10 EC=120 MU=14 MC=28 AP(%)=50 AXC=6		
Daily Impact	-1	1	1	0	0	1	-1		
Owner	- 0.5	1/3	1	0	0	0.5	-1		
Contractor	-0.5	1/3	0	0	0	0.5	0		
Third-party	0	1/3	0	0	0	0	0		
Cum. delay	-1	0	1	1	1	2	1		

Results of schedule analysis using the isolated daily window analysis technique (with the equal liability method for concurrency).

Owner (EC & OA) total Impact = -1/2 + 1/3 + 1 + 1/2 - 1 = 1/3 days

Contractor (NE & CA) total Impact = -1/2 + 1/3 + 1/2 = 1/3 days

Third-party (EN) total Impact = 1/3 = 1/3 days

Project total delay = 1/3 + 1/3 + 1/3 = 1 day

Legend: As in Appendix A-5

Sample calculations:

Acceleration cost :

Act A on Day 1

AXC: (Daily acceleration cost) = $82 (actual cost for activity A on day 1) – {100 (actual production rate for activity A on day 1) X 0.78 (SCR: Scheduled activity cost/100) = $ 4

AXC (OA): (Daily acceleration cost associated with OA accelerations) **= $** 4

Act A

AAC (OA): (Activity acceleration cost associated with OA accelerations) = sum of all AXCs (OA) of all the days in Act A = $ **4**

A = SUM of all AACs (OA) for all project activities = 4+6+4+6= $ 20

Direct cost :

Act B on Day 2

DDC: (Daily Direct delay cost) = $12 (actual cost for activity B on day 2) – {0 (actual production rate for activity B on day 2) X 1.12 (SCR: Scheduled activity cost/100) = $ 12

DDC (EC): (Daily Direct delay cost associated with EC delay) **= $** 12 **(EC is acting alone on act B on day 2)**

Act B

ADC (EC): (Activity direct delay cost associated with EC delays) = sum of all DDCs (EC) of all the days in Act B = $ **12**

D = SUM of all ADCs (EC) for all project activities = 12 + 6 = $ 18

Impact cost:

Act. E

Preceding activity is: Act. D

Activity E's actual cost was more than the scheduled cost {(AC=36) > (SC=30)} and Activity E's start was delayed by 1 day, which makes it candidate for impact cost calculation as per option 1 of the module. According to this module, we have to go back to the preceding activity, activity D. We have to go backwards for every delayed day of activity D until we accumulate 1 day. For each accumulated delay day, the impact cost will be considered only if the delay day has an EC delay.

The impact cost for each delay day of activity E is calculated by dividing the extra cost of activity E over the delay in the start of the activity. In the case of activity E, the extra cost (EXC) was $6 and the activity start delay (ASD) was 1 day. So, the daily impact cost (DIC) = $6/1day = $ 6.0

For day 3 of activity D, there was EC delay acting alone. So, the EC daily impact cost that day 3 of activity D contributed to activity E = DIC (EC) = $ 6

The AIC (EC) for Act E = SUM of all DIC (EC) of all the accumulated delay days in the preceding activity (Act D) = $ 6.

I: Project Impact delay cost due to delayed activity starts associated with EC delays = SUM of all AICs (EC) for all project activities with delayed starts = 6 = $ 6

Office and site overhead cost:

Assume that the combined amounts of both head office overhead and site overhead are $ 60. Using the Canadian method, the OH cost of delay will be as follows:

O: OH amount ($ 60)/ (6 days of original duration) x No of EC delay days for the whole project (1/3 days) = $ 3.33

Contractor's Total Project Delay Cost = D + I + O = 18 + 6 + 3.33 = $\underline{\$ 27.33}$

Contractor's Total Cost due to owner's impacts (delays/accelerations) = 27.33 + 6 = $ 33.33

Owner's liquidated damages:

Assume that the amount of the daily liquidated damages as per the contract is $ 6; the liquidated damages are calculated as follows:

LD: Liquidated damages = daily liquidated damages ($ 6/day) x No of NE delay days for the whole project (1/3 day) = **$ 2**

APPENDIX A-10:

THE 7-ACTIVITIES CASE – ACCELERATIONS/DELAYS - COST CALCULATION - IDWAT (REGULAR)

As-planned loaded schedule (loaded with scheduled resource, cost, and production rate data)

Act(Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2) SC= $ 78	LH(Hour)= 5 LC(Cost)$=10 EH(Hour)=2 EC(Cost)$=20 MU(Unit)=1 MC(Cost)$=9 SP(%)=50	LH=5 LC=10 EH=2 EC=20 MU=1 MC=9 SP(%)=50							
B (2) SC= $ 112			LH=4 LC=12 EH=2 EC=24 MU=2 MC=20 SP(%)=50	LH=4 LC=12 EH=2 EC=24 MU=2 MC=20 SP=50					
C (2) SC= $ 22					L=3 LC=6 E=0 EC=0 M=1 MC=5 SP(%)=50	L=3 LC=6 E=0 EC=0 M=1 MC=5 SP(%)=50			
D (3) SC= $ 240	LH=10 LC=40 EH=4 EC=40 MU=0 MC=0 SP(%)=33.33	LH=10 LC=40 EH=4 EC=40 MU=0 MC=0 SP(%)=33.33	LH=10 LC=40 EH=4 EC=40 MU=0 MC=0 SP(%)=33.34						
E (3) SC= $ 30				LH=5 LC=10 EH=0 EC=0 MH=0 MC=0 SP(%)=33.33	LH=5 LC=10 EH=0 EC=0 MH=0 MC=0 SP(%)=33.33	LH=5 LC=10 EH=0 EC=0 MH=0 MC=0 SP(%)=33.34			
F (2) SC= $ 30	LH=3 LC=9 EH=0 EC=0 MU=2 MC=6 SP(%)=50	LH=3 LC=9 EH=0 EC=0 MU=2 MC=6 SP(%)=50							
G (4) SC= $ 392			LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 SP(%)=25	LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 SP(%)=25	LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 SP(%)=25	LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 SP(%)=25			

As-built loaded schedule (loaded with actual resource, cost, and production rate data)

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2) AAC = $4	OA **LH=12** **LC=24** EH=4 EC=40 MU=2 MC=18 AP(%)=100 AXC= 4								
B (2) ADC=$12 AAC=$6		O(EC) LH=4 LC=12 EH=0 EC=0 MU=0 MC=0 AP(%)=0 DDC=12	OA LH=10 LC=30 EH=4 EC=48 MU=4 MC=40 AP(%)=100 AXC=6						
C (2) ADC=$6 AAC=$4				O(EC) L=3 LC=6 E=0 EC=0 M=0 MC=0 AP(%)=0 DDC=6	O(EC) L=0 LC=0 E=0 EC=0 M=0 MC=0 AP(%)=0 DDC=0	O(EC) L=0 LC=0 E=0 EC=0 M=0 MC=0 AP(%)=0 DDC=0	OA L=8 LC=16 E=0 EC=0 M=2 MC=10 AP(%)=100 AXC=4		
D (3) ADC=$0	CA LH=22 LC=48 EH=8 EC=80 MU=0 MC=0 AP(%)=66.66	C(NE) LH=5 LC=20 EH=0 EC=00 MU=0 MC=0 AP(%)=0	O(EC) LH=0 LC=0 EH=0 EC=0 MU=0 MC=0 AP(%)=0 DDC=0	LH=10 LC=40 EH=4 EC=40 MU=0 MC=0 AP(%)=33.33					
E (3) **EXC = $ 6** **ASD= 1 days** **DIC= $ 6/1=$6** ADC(EC)= **$ 0** **AIC(EC)= $ 6**			**DIC(EC) = $6**		LH=6 LC=12 EH=0 EC=0 MH=0 MC=0 AP(%)=33.33	LH=6 LC=12 EH=0 EC=0 MH=0 MC=0 AP(%)=33.33	LH=6 LC=12 EH=0 EC=0 MH=0 MC=0 AP(%)=33.33		

F (2)	CA LH=6 LC=18 EH=0 EC=0 MU=4 MC=12 AP(%)=100								
G (4) AAC=$6		T(EN) LH=4 LC=8 EH=0 EC=0 MU=0 MC=0 AP(%)=0	LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 AP(%)=25	C(NE) LH=4 LC=8 EH=0 EC=0 MU=0 MC=0 AP(%)=0	LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 AP(%)=25	C(NE) LH=0 LC=0 EH=0 EC=0 MU=0 MC=0 AP(%)=0	OA LH=30 LC=60 EH=10 EC=120 MU=14 MC=28 AP(%)=50 AXC=6		
Daily Impact	-1	1	1	0	0	1	-1		
Owner	- 0.5	0	1	0	0	0	-1		
Contractor	-0.5	0	0	0	0	0	0		
Third-party	0	1	0	0	0	1	0		
Cum. delay	-1	0	1	1	1	2	1		

Results of schedule analysis using the isolated daily window analysis technique (with the Regular method for concurrency)

Owner (EC & OA) total Impact = -1/2 + 1 - 1 = - 1/2 days

Contractor (NE & CA) total Impact = -1/2 = - 1/2 days

Third-party (EN) total Impact = 1 + 1 = 2 days

Project total delay = - 1/2 - 1/2 + 2 = 1 day

Legend: **As in Appendix A-5**

Sample calculations:

Acceleration cost :

Act A **on Day 1**

AXC: (Daily acceleration cost) = $82 (actual cost for activity A at day 1) – {100 (actual production rate for activity A at day 1) X 0.78 (SCR: scheduled activity cost/100) = $ 4

AXC (OA): (Daily acceleration cost associated with OA accelerations) **= $** 4

Act A

AAC (OA): (Activity acceleration cost associated with OA accelerations) = sum of all AXC (OA) of all the days in Act A = $ **4**

A = SUM of all AAC (OA) for all project activities = 4+6+4+6= $ 20

Direct cost :

Act B **at Day 2**

DDC: (Daily Direct delay cost) = $12 (actual cost for activity B at day 2) – {0 (the actual production rate for activity B at day 2) X 1.12 (the SCR: scheduled activity cost/100)} = $ 12

DDC (EC): (Daily Direct delay cost associated with EC delay) **= $** 12 **(EC is acting alone on act B at day 2)**

Act B

ADC (EC): (Activity direct delay cost associated with EC delays) = sum of all DDCs (EC) of all the days in Act B = $ **12**

D = SUM of all ADCs(EC) for all project activities = 12 + 6 = $ 18

Impact cost:

Act. E

Preceding Activity is: Act. D

Activity E's actual cost was more than the scheduled cost {(AC=36) > (SC=30)}, and Activity E start was delayed by 1 day, which makes it a candidate for impact cost calculation as per option 1 of the module. According to this module, we have to go back to the preceding activity, activity D. We have to go backwards for every delayed day of activity D until we accumulate 1 day. For each accumulated delay day, the impact cost will be considered only if the delay day has an EC delay.

The impact cost for each delay day of activity E is calculated by dividing the extra cost of activity E by the delay in the start of the activity. In the case of activity E, the extra cost (EXC) was $6 and the activity start delay (ASD) was 1 day. So, the daily impact cost (DIC) = $6/1day = $ 6.0

For day 3 of activity D, there was EC delay acting alone. Therefore the EC daily impact cost which day 3 of activity D contributed to activity E = DIC (EC) = $ 6

AIC (EC) for Act E = SUM of all DIC (EC) of all the accumulated delay days in the preceding activity (Act D) = $ 6

I: Project Impact delay cost due to delayed activity starts associated with EC delays = SUM of all AIC (EC) for all project activities with delayed starts = 6 = $ 6

Office and site overhead cost:

Assume that the amount of both head office overhead and site overhead together is $ 60. Using the Canadian method, the OH cost of delay will be as follows:

O: OH amount ($ 60)/(6 days of original duration) x No of EC delay days for the whole project (-1/2 days) = $ -5

Contractor's Total Project Delay Cost = D + I + O = 18 + 6 - 5 = <u>$ 19</u> (1st option, assuming savings in OH cost)

Contractor's Total Project Delay Cost = D + I + O = 18 + 6 + 0 = <u>$ 24</u> (2nd option, assuming 0 increase in OH cost)

Contractor's Total Cost due to owner's impacts (delays/accelerations) = 19 + 6 = $ 25 (based on option 1)

Contractor's Total Cost due to owner's impacts (delays/accelerations) = 24 + 6 = $ 30 (based on option 2)

Owner's Liquidated damages:

Assume that the amount of the daily liquidated damages as per the contract is $ 6; the liquidated damages are calculated as follows:

LD: Liquidated damages = daily liquidated damages ($ 6/day) x No of NE delay days for the whole project (-1/2 day) = **$ - 2 = 0**

(The NE delay was -1/2, which implies there is no damage caused by the contractor.)

APPENDIX A-11:

THE 7-ACTIVITIES CASE – ACCELERATION/DELAY SCENARIOS- TIME - IDWAT (ELM)

<u>As-planned bar chart</u> (7 activities project with three parallel critical paths and an original duration of 6 days)

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)									
B (2)									
C (2)									
D (3)									
E (3)									
F (2)									
G (4)									

End of day 1 bar chart

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	NE								
B (2)									
C (2)									
D (3)	EN								
E (3)									
F (2)	NE								
G (4)									
Daily impact	1								
Owner	0								
Contractor	0.5								
Third-party	0.5								
Cum. delay	1								

<u>End of day 2 bar chart</u>

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	NE	NE							
B (2)									
C (2)									
D (3)	EN								
E (3)									
F (2)	NE	NE							
G (4)									
Daily impact	1	1							
Owner	0	0							
Contractor	0.5	1							
Third-party	0.5	0							
Cum. delay	1	2							

End of day 3 bar chart

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	NE	NE	NE						
B (2)									
C (2)									
D (3)	EN								
E (3)									
F (2)	NE	NE							
G (4)									
Daily impact	1	1	1						
Owner	0	0	0						
Contractor	0.5	1	1						
Third-party	0.5	0	0						
Cum. delay	1	2	3						

Scenario # 1.1: No accelerations as-built bar chart

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	NE	NE	NE						
B (2)									
C (2)									
D (3)	EN								
E (3)									
F (2)	NE	NE							
G (4)									
Daily impact	1	1	1						
Owner	0	0	0						
Contractor	0.5	1	1						
Third-party	0.5	0	0						
Cum. delay	1	2	3						

Results of schedule analysis using the isolated daily window analysis technique (with the equal liability method for concurrency)

Owner (EC & OA) total Impact = 0 days

Contractor (NE & CA) total Impact = 1/2 + 1 + 1 = 2 ½ days

Third-party (EN) total Impact = 1/2 = 1/2 days

Project total delay = 0 + 2 ½ + 1/2 = 3 days

Scenario # 2.1: Acceleration in day 4 (end of day 4 bar chart)

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	NE	NE	NE	CA					
B (2)									
C (2)									
D (3)	EN								
E (3)									
F (2)	NE	NE							
G (4)									
Daily impact	1	1	1	-1					
Owner	0	0	0	0					
Contractor	0.5	1	1	-1					
Third-party	0.5	0	0	0					
Cum. delay	1	2	3	2					

Results of schedule analysis using the isolated daily window analysis technique (with the equal liability method for concurrency)

Owner (EC & OA) total Impact = 0 days

Contractor (NE & CA) total Impact = 1/2 + 1 + 1-1 = 1 ½ days

Third-party (EN) total Impact = 1/2 = 1/2 days

Project total delay = 0 + 1 ½ + 1/2 = 2 days

Scenario # 2.2: Accelerations in days 4 and 5 (end of day 5 bar chart)

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	NE	NE	NE	CA					
B (2)					CA				
C (2)									
D (3)	EN								
E (3)									
F (2)	NE	NE							
G (4)					CA				
Daily impact	1	1	1	-1	-1				
Owner	0	0	0	0	0				
Contractor	0.5	1	1	-1	-1				
Third-party	0.5	0	0	0	0				
Cum. delay	1	2	3	2	1				

Results of schedule analysis using the isolated daily window analysis technique (with the equal liability method for concurrency)

Owner (EC & OA) total Impact = 0 days

Contractor (NE & CA) total Impact = 1/2 + 1 + 1-1-1 = 1/2 days

Third-party (EN) total Impact = 1/2 = 1/2 days

Project total delay = 0 + 1/2 + 1/2 = 1 day

Scenario # 2.3: Accelerations in days 4, 5 and 6 (end of day 6 bar chart)

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	NE	NE	NE	CA					
B (2)					CA				
C (2)						CA			
D (3)	EN								
E (3)						CA			
F (2)	NE	NE							
G (4)					CA	CA			
Daily impact	1	1	1	-1	-1				
Owner	0	0	0	0	0	0			
Contractor	0.5	1	1	-1	-1	-1			
Third-party	0.5	0	0	0	0	0			
Cum. delay	1	2	3	2	1	0			

Results of schedule analysis using the isolated daily window analysis technique (with the equal liability method for concurrency)

Owner (EC & OA) total Impact = 0 days

Contractor (NE & CA) total Impact = 1/2 + 1 + 1-1-1 = - 1/2 days

Third-party (EN) total Impact = 1/2 = 1/2 days

Project total delay = 0 - 1/2 + 1/2 = 0 day

Scenario # 3.1: Accelerations in day 6 (end of day 6 bar chart)

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	NE	NE	NE						
B (2)						CA			
C (2)									
D (3)	EN								
E (3)									
F (2)	NE	NE							
G (4)									
Daily impact	1	1	1						
Owner	0	0	0	0	0	0			
Contractor	0.5	1	1	0	0	-1			
Third-party	0.5	0	0	0	0	0			
Cum. delay	1	2	3	3	3	2			

Results of schedule analysis using the isolated daily window analysis technique (with the equal liability method for concurrency)

Owner (EC & OA) total Impact = 0 days

Contractor (NE & CA) total Impact = 1/2 + 1 + 1-1 = 1 ½ days

Third-party (EN) total Impact = 1/2 = 1/2 days

Project total delay = 0 + 1 ½ + 1/2 = 2 days

Scenario # 3.2: Accelerations in days 6 and 7 (end of day 7 bar chart)

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	NE	NE	NE						
B (2)						CA			
C (2)							CA		
D (3)	EN								
E (3)									
F (2)	NE	NE							
G (4)							CA		
Daily impact	1	1	1						
Owner	0	0	0	0	0	0	0		
Contractor	0.5	1	1	0	0	-1	-1		
Third-party	0.5	0	0	0	0	0	0		
Cum. delay	1	2	3	3	3	2	1		

Results of schedule analysis using the isolated daily window analysis technique (with the equal liability method for concurrency)

Owner (EC & OA) total Impact = 0 days

Contractor (NE & CA) total Impact = 1/2 + 1 + 1-1-1 = 1/2 days

Third-party (EN) total Impact = 1/2 = 1/2 days

Project total delay = 0 + 1/2 + 1/2 = 1 day

Scenario # 4.1: Accelerations in day 8 (end of day 8 bar chart)

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	NE	NE	NE						
B (2)									
C (2)								CA	
D (3)	EN								
E (3)									
F (2)	NE	NE							
G (4)									
Daily impact	1	1	1						
Owner	0	0	0	0	0	0	0	0	
Contractor	0.5	1	1	0	0	0	0	-1	
Third-party	0.5	0	0	0	0	0	0		
Cum. delay	1	2	3	3	3	3	3	2	

Results of schedule analysis using the isolated daily window analysis technique (with the equal liability method for concurrency)

Owner (EC & OA) total Impact = 0 days

Contractor (NE & CA) total Impact = 1/2 + 1 + 1-1 = 1 ½ days

Third-party (EN) total Impact = 1/2 = 1/2 days

Project total delay = 0 + 1 ½ + 1/2 = 2 days

APPENDIX A-12:

THE 7-ACTIVITIES CASE – ACCELERATION/DELAY SCENARIOS- COST - IDWAT (ELM)

As-planned loaded schedule (loaded with scheduled resource cost and production rate data)

	Date								
Act(Dur)	1	2	3	4	5	6	7	8	9
A (2) SC= $ 78	LH(Hour)= 5 LC(Cost)$=10 EH(Hour)=2 EC(Cost)$=20 MU(Unit)=1 MC(Cost)$=9 SP(%)=50	LH=5 LC=10 EH=2 EC=20 MU=1 MC=9 SP(%)=50							
B (2) SC= $ 112			LH=4 LC=12 EH=2 EC=24 MU=2 MC=20 SP(%)=50	LH=4 LC=12 EH=2 EC=24 MU=2 MC=20 SP=50					
C (2) SC= $ 22					L=3 LC=6 E=0 EC=0 M=1 MC=5 SP(%)=50	L=3 LC=6 E=0 EC=0 M=1 MC=5 SP(%)=50			
D (3) SC= $ 240	LH=10 LC=40 EH=4 EC=40 MU=0 MC=0 SP(%)=33.33	LH=10 LC=40 EH=4 EC=40 MU=0 MC=0 SP(%)=33.33	LH=10 LC=40 EH=4 EC=40 MU=0 MC=0 SP(%)=33.34						
E (3) SC= $ 30				LH=5 LC=10 EH=0 EC=0 MH=0 MC=0 SP(%)=33.33	LH=5 LC=10 EH=0 EC=0 MH=0 MC=0 SP(%)=33.33	LH=5 LC=10 EH=0 EC=0 MH=0 MC=0 SP(%)=33.34			
F (2) SC= $ 30	LH=3 LC=9 EH=0 EC=0 MU=2 MC=6 SP(%)=50	LH=3 LC=9 EH=0 EC=0 MU=2 MC=6 SP(%)=50							
G(4) SC= $ 392			LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 SP(%)=25	LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 SP(%)=25	LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 SP(%)=25	LH=12 LC=24 EH=5 EC=60 MU=7 MC=14 SP(%)=25			

(Bar Charts loaded with Actual resource costs and production rate data)

End of day 1 bar chart

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0								
B (2)									
C (2)									
D (3)	EN LH=5 LC=20 EH=0 EC=00 MU=0 MC=0 AP(%)=0								
E (3)									
F (2)	NE LH=3 LC=9 EH=0 EC=0 MU=0 MC=0 AP(%)=0								
G (4)									
Daily impact	1								
Owner	0								
Contractor	0.5								
Third-party	0.5								
Cum. delay	1								

End of day 2 bar chart

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0							
B (2)									
C (2)									
D (3)	EN LH=5 LC=20 EH=0 EC=00 MU=0 MC=0 AP(%)=0								
E (3)									
F (2)	NE LH=3 LC=9 EH=0 EC=0 MU=0 MC=0 AP(%)=0	NE LH=3 LC=9 EH=0 EC=0 MU=0 MC=0 AP(%)=0							
G (4)									
Daily impact	1	1							
Owner	0	0							
Contractor	0.5	1							
Third-party	0.5	0							
Cum. delay	1	2							

End of day 3 bar chart

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0						
B (2)									
C (2)									
D (3)	EN LH=5 LC=20 EH=0 EC=00 MU=0 MC=0 AP(%)=0								
E (3)									
F (2)	NE LH=3 LC=9 EH=0 EC=0 MU=0 MC=0 AP(%)=0	NE LH=3 LC=9 EH=0 EC=0 MU=0 MC=0 AP(%)=0							
G (4)									
Daily impact	1	1	1						
Owner	0	0	0						
Contractor	0.5	1	1						
Third-party	0.5	0	0						
Cum. delay	1	2	3						

Scenario # 1.1: No accelerations- end of day 9 (as-built bar chart)

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0						
B (2)									
C (2)									
D (3)	EN LH=5 LC=20 EH=0 EC=00 MU=0 MC=0 AP(%)=0								
E (3)									
F (2)	NE LH=3 LC=9 EH=0 EC=0 MU=0 MC=0 AP(%)=0	NE LH=3 LC=9 EH=0 EC=0 MU=0 MC=0 AP(%)=0							
G (4)									
Daily impact	1	1	1						
Owner	0	0	0						
Contractor	0.5	1	1						
Third-party	0.5	0	0						
Cum. delay	1	2	3						

Results of schedule analysis using the isolated daily window analysis technique (with the equal liability method for concurrency)

Owner (EC & OA) total Impact = 0 days

Contractor (NE & CA) total Impact = 1/2 + 1 + 1 = 2 ½ days

Third-party (EN) total Impact = 1/2 = 1/2 days

Project total delay = 0 + 2 ½ + 1/2 = 3 days

Acceleration cost (AC1.1) = $ 0

Liquidated damages (LD1.1), {assuming the daily LD = $ 10} = 2 ½ (days) × $ 10 = $25 = LD max

Note: From a contractor perspective, the cost impact of delay-acceleration scenarios will be referred to as the net saving impact (NSI).

NSI = the maximum liquidated damages (LD max) – Liquidated damages of the scenario x (LD x) – Acceleration cost of the scenario x (AC x)

where:

LD max = maximum liquidated damages due to contractor delays (NE) before applying accelerations

LD x = Liquidated damages of scenario x = EN delay days of scenario x (daily LD rate)

AC x = Acceleration cost of scenario x = cost of contractor accelerations (CA) of scenario x (AC x: includes the cost of all accelerated days in the scenario, not only of the last day)

NSI 1.1 = 25-25-0=0 (this indicates that the savings are 0 and the liquidated damages are due in full)

<u>**Scenario # 2.1: Acceleration in day 4 (end of day 4 bar chart)**</u>

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0	CA **LH=12** **LC=24** EH=4 EC=40 MU=2 MC=18 AP(%)=100 AXC= 4					
B (2)									
C (2)									
D (3)	EN LH=5 LC=20 EH=0 EC=00 MU=0 MC=0 AP(%)=0								
E (3)									
F (2)	NE LH=3 LC=9 EH=0 EC=0 MU=0 MC=0 AP(%)=0	NE LH=3 LC=9 EH=0 EC=0 MU=0 MC=0 AP(%)=0							
G (4)									
Daily impact	1	1	1	-1					
Owner	0	0	0	0					
Contractor	0.5	1	1	-1					
Third-party	0.5	0	0	0					
Cum. delay	1	2	3	2					

Results of schedule analysis using the isolated daily window analysis technique (with the equal liability method for concurrency)

Owner (EC & OA) total Impact = 0 days

Contractor (NE & CA) total Impact = 1/2 + 1 + 1-1 = 1 ½ days

Third-party (EN) total Impact = 1/2 = 1/2 days

Project total delay = 0 + 1 ½ + 1/2 = 2 days

Acceleration cost (Scenario 2.1) = $ 4

Liquidated damages (Scenario 2.1, assuming the daily LD = $ 10) = 1 ½ (days) × $ 10 = $15

NSI 2.1 = LD max - LD2.1 – AC2.1 = 25 – 15 – 4 = $ 6 (indicates that spending $ 4 to accelerate the project on day 4 reduced the Liquidated damages by $ 10, producing a net savings of $ 6 on day 4)

Scenario # 2.2: Accelerations in days 4 and 5 (end of day 5 bar chart)

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0	CA **LH=12** **LC=24** EH=4 EC=40 MU=2 MC=18 AP(%)=100 AXC= 4					
B (2)					CA LH=10 LC=30 EH=4 EC=48 MU=4 MC=40 AP(%)=100 AXC=6				
C (2)									
D (3)	EN LH=5 LC=20 EH=0 EC=00 MU=0 MC=0 AP(%)=0								
E (3)									
F (2)	NE LH=3 LC=9 EH=0 EC=0 MU=0 MC=0 AP(%)=0	NE LH=3 LC=9 EH=0 EC=0 MU=0 MC=0 AP(%)=0							
G (4)					CA LH=30 LC=60 EH=10 EC=120 MU=14 MC=28 AP(%)=50 AXC=6				

Daily impact	1	1	1	-1	-1				
Owner	0	0	0	0	0				
Contractor	0.5	1	1	-1	-1				
Third-party	0.5	0	0	0	0				
Cum. delay	1	2	3	2	1				

Results of schedule analysis using the isolated daily window analysis technique (with the equal liability method for concurrency)

Owner (EC & OA) total Impact = 0 days

Contractor (NE & CA) total Impact = 1/2 + 1 + 1-1-1 = 1/2 days

Third-party (EN) total Impact = 1/2 = 1/2 days

Project total delay = 0 + 1/2 + 1/2 = 1 day

AC2.2 = 4 + 6 + 6 = $ 16 (cumulative for days 4 and 5)

LD2.2 = ½ (day) × $ 10 = $ 5

NSI 2.2 = LD max – LD2.2 – AC2.2 = 25 – 5 – 16 = $4 (indicates that spending $ 16 to accelerate the project on Days 4 and 5 reduced the Liquidated damages by $ 20 producing a net savings of $ 4 on day 5)

<u>Scenario # 2.3: Accelerations in days 4, 5 and 6 (end of day 6 bar chart)</u>

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0	CA **LH=12** **LC=24** EH=4 EC=40 MU=2 MC=18 AP(%)=100 AXC= 4					
B (2)					CA LH=10 LC=30 EH=4 EC=48 MU=4 MC=40 AP(%)=100 AXC=6				
C (2)						CA L=8 LC=16 E=0 EC=0 M=2 MC=10 AP(%)=100 AXC=4			
D (3)	EN LH=5 LC=20 EH=0 EC=00 MU=0 MC=0 AP(%)=0								
E (3)						CA LH=12 LC=24 EH=0 EC=0 MH=0 MC=0 AP(%)=66.66 AXC=0			
F (2)	LH=3 LC=9	NE							

	EH=0 EC=0 MU=0 MC=0 AP(%)=0	LH=3 LC=9 EH=0 EC=0 MU=0 MC=0 AP(%)=0							
G (4)					CA LH=30 LC=60 EH=10 EC=120 MU=14 MC=28 AP(%)=50 AXC=6	CA LH=30 LC=60 EH=10 EC=120 MU=14 MC=28 AP(%)=50 AXC=6			
Daily impact	1	1	1	-1	-1				
Owner	0	0	0	0	0	0			
Contractor	0.5	1	1	-1	-1	-1			
Third-party	0.5	0	0	0	0	0			
Cum. delay	1	2	3	2	1	0			

Results of schedule analysis using the isolated daily window analysis technique (with the equal liability method for concurrency)

Owner (EC & OA) total Impact = 0 days

Contractor (NE & CA) total Impact = 1/2 + 1 + 1-1-1 = - 1/2 days

Third-party (EN) total Impact = 1/2 = 1/2 days

Project total delay = 0 - 1/2 + 1/2 = 0 day

AC2.3 = 4 + 6 + 6 + 4 + 0 + 6 = $ 26 (cumulative for days 4, 5 and 6)

LD2.3 = -1/2 (day) × $ 10 = $- 5 = 0 (the contractor net impact was ½ day acceleration. Hence, LD =$0)

NSI 2.3 = LD max – LD2.3 – AC2.3 = 25 – 0 – 26 = - $ 1 (which indicates that spending $ 26 to accelerate

the project on days 4, 5 and 6 reduced the Liquidated damages by $ 25 producing a net loss of $ 1 on day 6)

Scenario # 3.1: Accelerations in day 6 (end of day 6 bar chart)

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0						
B (2)						CA LH=10 LC=30 EH=4 EC=48 MU=4 MC=40 AP(%)=100 AXC=6			
C (2)									
D (3)	EN LH=5 LC=20 EH=0 EC=00 MU=0 MC=0 AP(%)=0								
E (3)									
F (2)	NE LH=3 LC=9 EH=0 EC=0 MU=0 MC=0 AP(%)=0	NE LH=3 LC=9 EH=0 EC=0 MU=0 MC=0 AP(%)=0							
G (4)									
Daily impact	1	1	1						

Owner	0	0	0	0	0	0			
Contractor	0.5	1	1	0	0	-1			
Third-party	0.5	0	0	0	0	0			
Cum. delay	1	2	3	3	3	2			

Results of schedule analysis using the isolated daily window analysis technique (with the equal liability method for concurrency)

Owner (EC & OA) total Impact = 0 days

Contractor (NE & CA) total Impact = 1/2 + 1 + 1-1 = 1 ½ days

Third-party (EN) total Impact = 1/2 = 1/2 days

Project total delay = 0 + 1 ½ + 1/2 = 2 days

AC3.1 = $ 6

LD3.1 = 1 ½ (day) × $ 10 = $15

NSI 3.1 = LD max – LD3.1 – AC3.1 = 25 –15 – 6 = $4 (indicates that spending $ 6 to accelerate the project on day 6 reduced the Liquidated damages by $ 10, producing a net saving of $ 4 on day 6)

Scenario # 3.2: Accelerations in days 6 and 7 (end of day 7 bar chart)

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0						
B (2)						CA LH=10 LC=30 EH=4 EC=48 MU=4 MC=40 AP(%)=100 AXC=6			
C (2)							CA L=8 LC=16 E=0 EC=0 M=2 MC=10 AP(%)=100 AXC=4		
D (3)	EN LH=5 LC=20 EH=0 EC=00 MU=0 MC=0 AP(%)=0								
E (3)									
F (2)	NE LH=3 LC=9 EH=0 EC=0 MU=0 MC=0 AP(%)=0	NE LH=3 LC=9 EH=0 EC=0 MU=0 MC=0 AP(%)=0							
G (4)							CA LH=30		

							LC=60 EH=10 EC=120 MU=14 MC=28 AP(%)=50 AXC=6		
Daily impact	1	1	1						
Owner	0	0	0	0	0	0	0		
Contractor	0.5	1	1	0	0	-1	-1		
Third-party	0.5	0	0	0	0	0	0		
Cum. delay	1	2	3	3	3	2	1		

Results of schedule analysis using the isolated daily window analysis technique (with the equal liability method for concurrency)

Owner (EC & OA) total Impact = 0 days

Contractor (NE & CA) total Impact = 1/2 + 1 + 1-1-1 = 1/2 days

Third-party (EN) total Impact = 1/2 = 1/2 days

Project total delay = 0 + 1/2 + 1/2 = 1 day

AC3.2 = 6 + 4 + 6 = $ 16

LD3.2 = 1/2 (day) × $ 10 = $ 5

NSI 3.2 = LD max – LD3.2 – AC3.2 = 25 – 5 – 16 = $4 (indicates that spending $16 to accelerate the project on days 6 and 7 reduced the Liquidated damages by $ 20, <u>producing a net saving of $ 4 on day 7</u>)

Scenario # 4.1: Accelerations in day 8 (end of day 8 bar chart)

Act (Dur)	Date								
	1	2	3	4	5	6	7	8	9
A (2)	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0	NE LH(Hour)= 3 LC(Cost)$=6 EH(Hour)=1 EC(Cost)$=10 MU(Unit)=0 MC(Cost)$=0 AP(%)=0						
B (2)									
C (2)								CA L=8 LC=16 E=0 EC=0 M=2 MC=10 AP(%)=100 AXC=4	
D (3)	EN LH=5 LC=20 EH=0 EC=00 MU=0 MC=0 AP(%)=0								
E (3)									
F (2)	NE LH=3 LC=9 EH=0 EC=0 MU=0 MC=0 AP(%)=0	NE LH=3 LC=9 EH=0 EC=0 MU=0 MC=0 AP(%)=0							
G (4)									
Daily impact	1	1	1						

Owner	0	0	0	0	0	0	0	0	
Contractor	0.5	1	1	0	0	0	0	-1	
Third-party	0.5	0	0	0	0	0	0		
Cum. delay	1	2	3	3	3	3	3	2	

Results of schedule analysis using the isolated daily window analysis technique (with the equal liability method for concurrency)

Owner (EC & OA) total Impact = 0 days

Contractor (NE & CA) total Impact = 1/2 + 1 + 1-1 = 1 ½ days

Third-party (EN) total Impact = 1/2 = 1/2 days

Project total delay = 0 + 1 ½ + 1/2 = 2 days

AC4.1 = $ 4

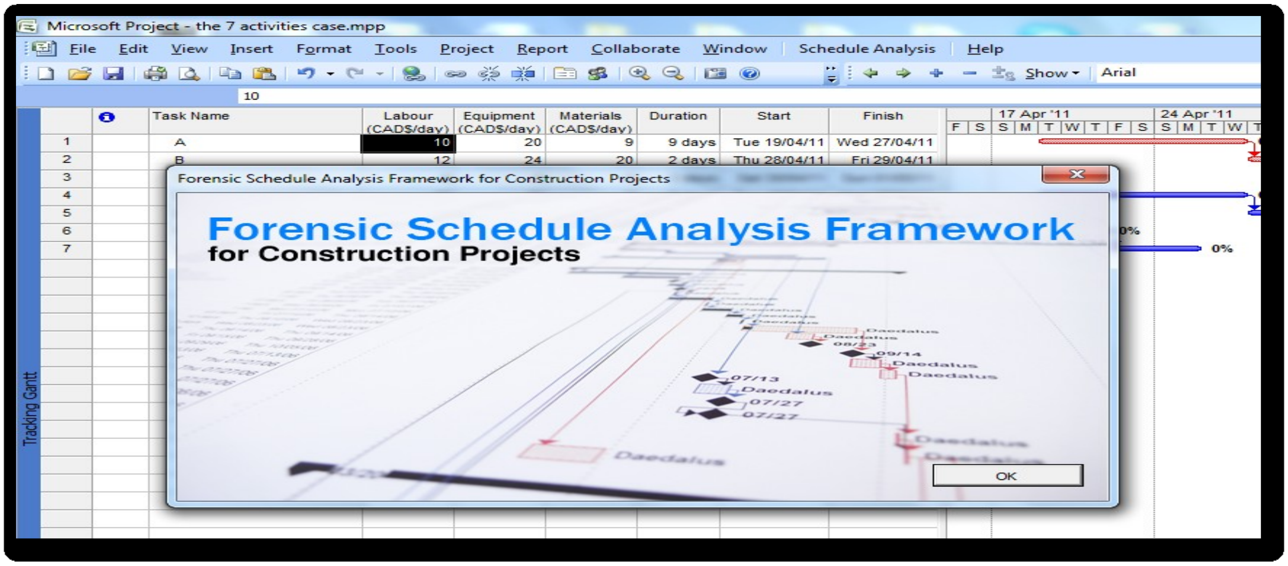
LD4.1= 1 ½ (day) × $ 10 = $15

NSI 4.1 = LD max – LD4.1 – AC4.1 = 25 – 15 – 4 = $6 (indicates that spending $4 to accelerate the project on day 8 reduced the Liquidated damages by $ 10, <u>producing a net saving of $ 6 on day 8</u>)

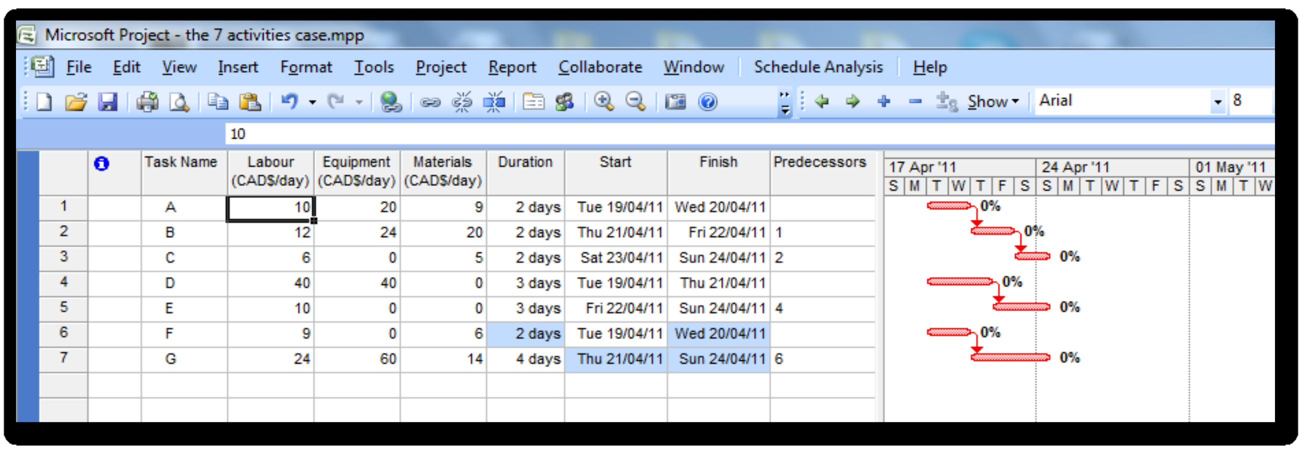
<u>Conclusion:</u> Scenarios 2.1 and 4.1 produced the most net savings impact: $ 6 for each scenario. The contractor has the choice of accelerating day 4 (scenario 2.1) or day 8 (scenario 4.1). Both scenarios have a net savings impact of $ 6 and both will accelerate the project by 1 day. Other scenarios produce either less net savings or a net loss.

Appendix B: Forensic Delay Analysis Framework

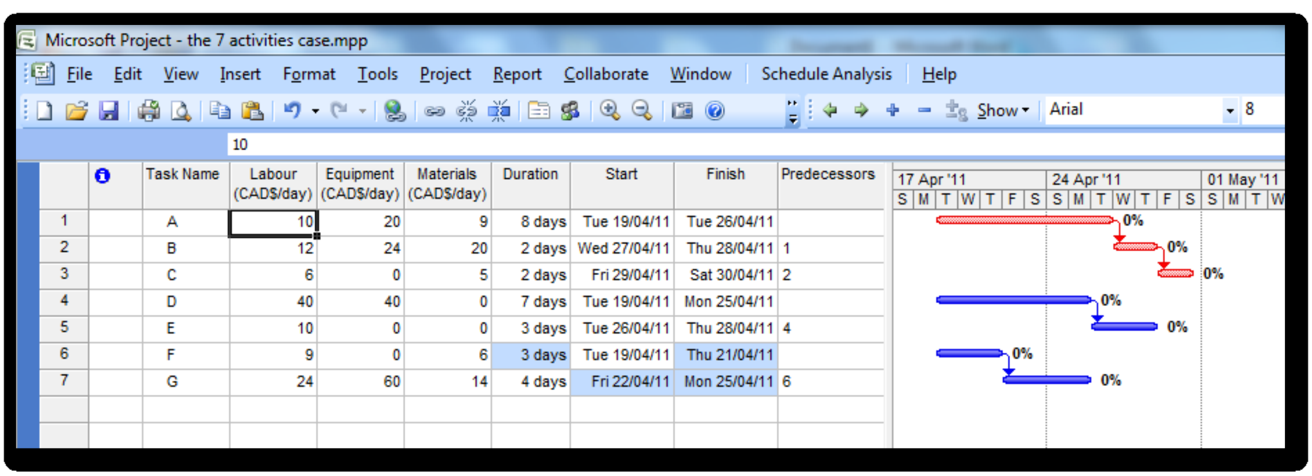
(Screen Shots of the 7-activities case)



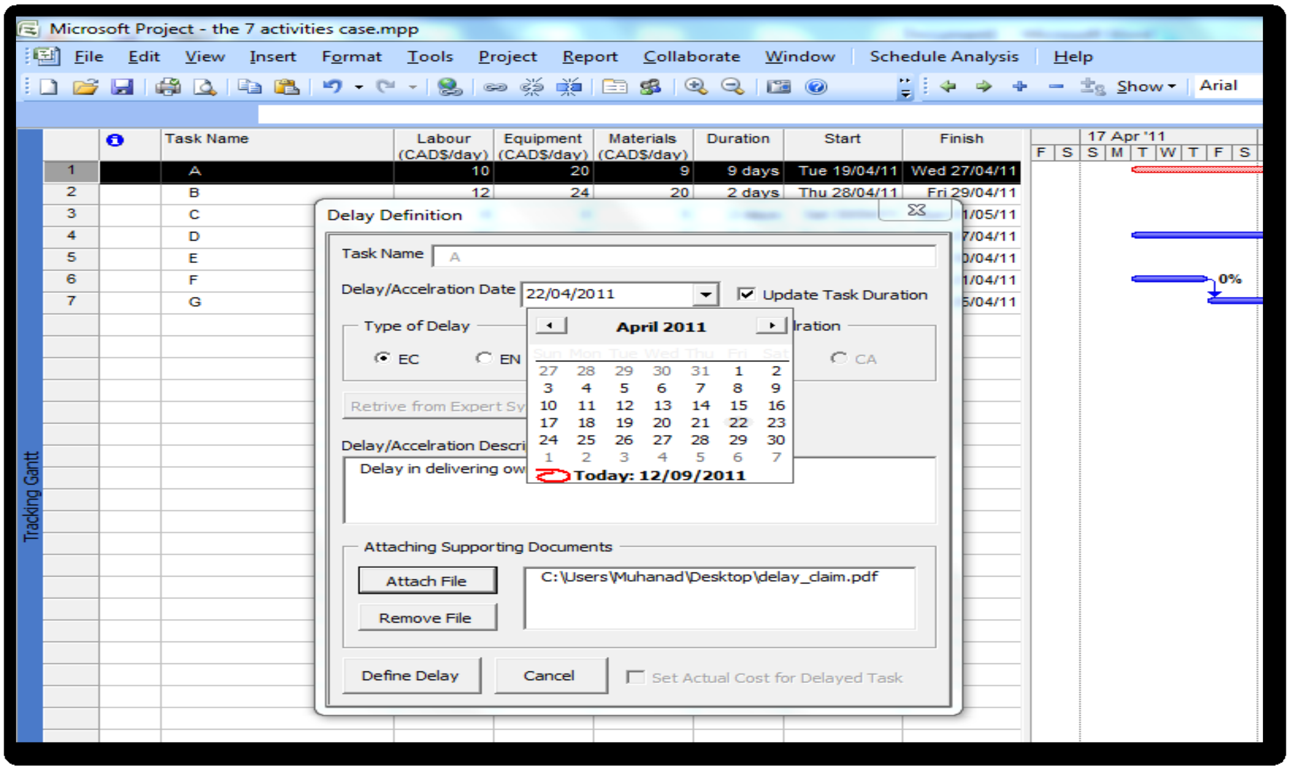
B-1 Framework Activation



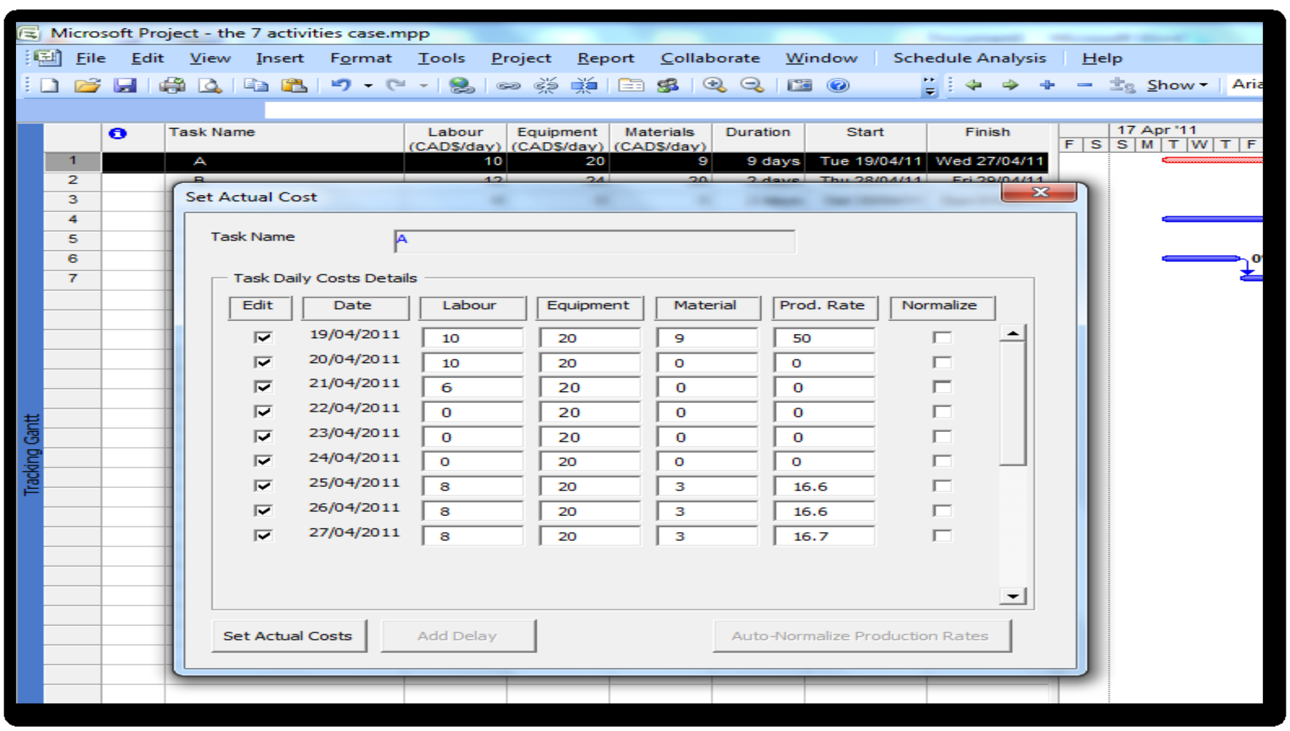
B-2 The 7-activity case – As-planned



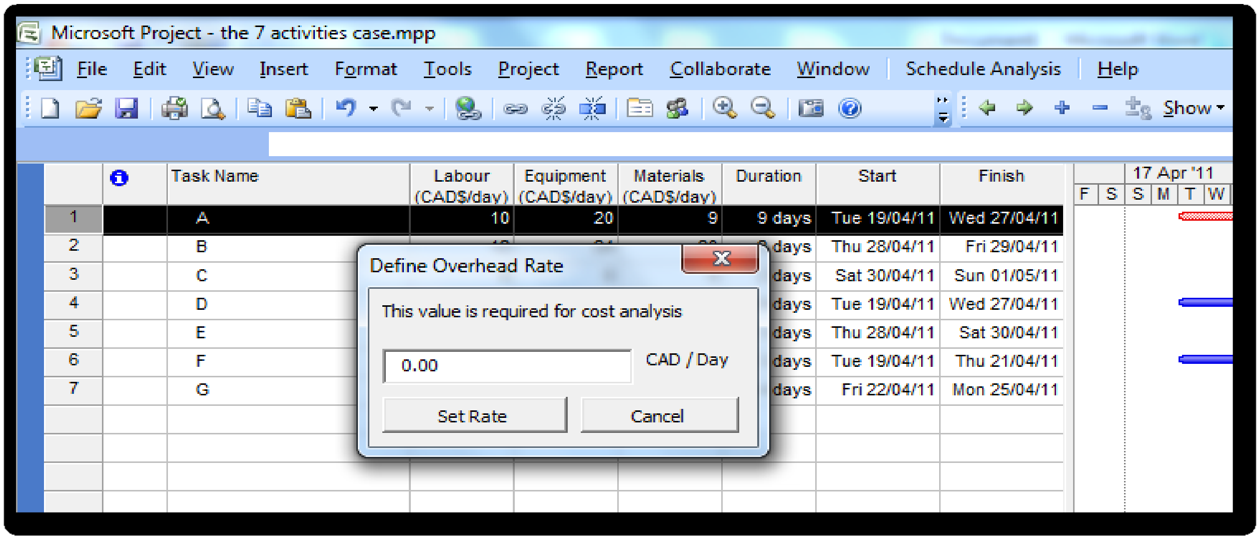
B-3 The 7-activity case – As-built



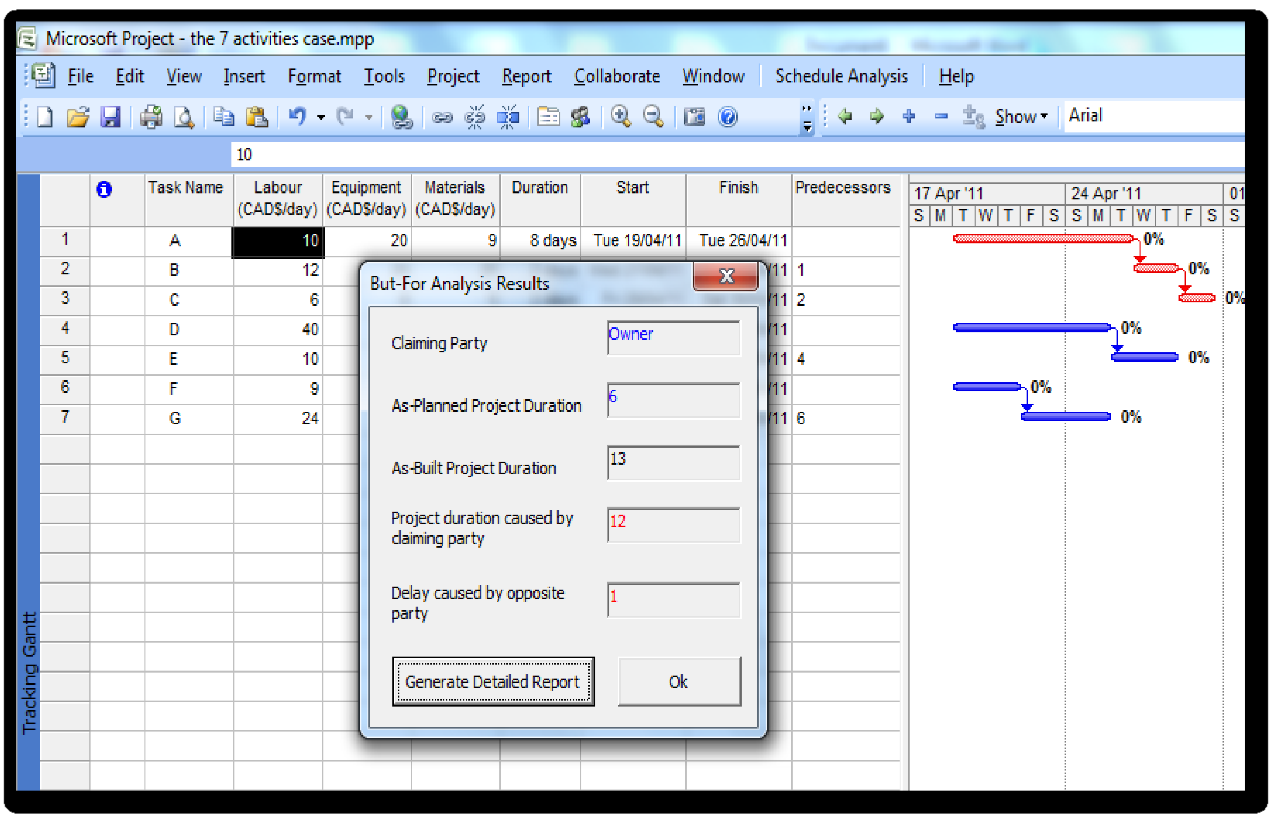
B-4 Delay/Acceleration data documentation form



B- 5 Cost and production data documentation form



B-6 Overhead rate form



B-7 But-for contractor results (owner is the claiming party)

Integrated Delay Analysis System

Information:

Project Name	Report Created On	Analysis Technique	Claiming Party
the 7 activities case.mpp	12/09/2011 1:34:21 AM	But-For Contractor	Owner

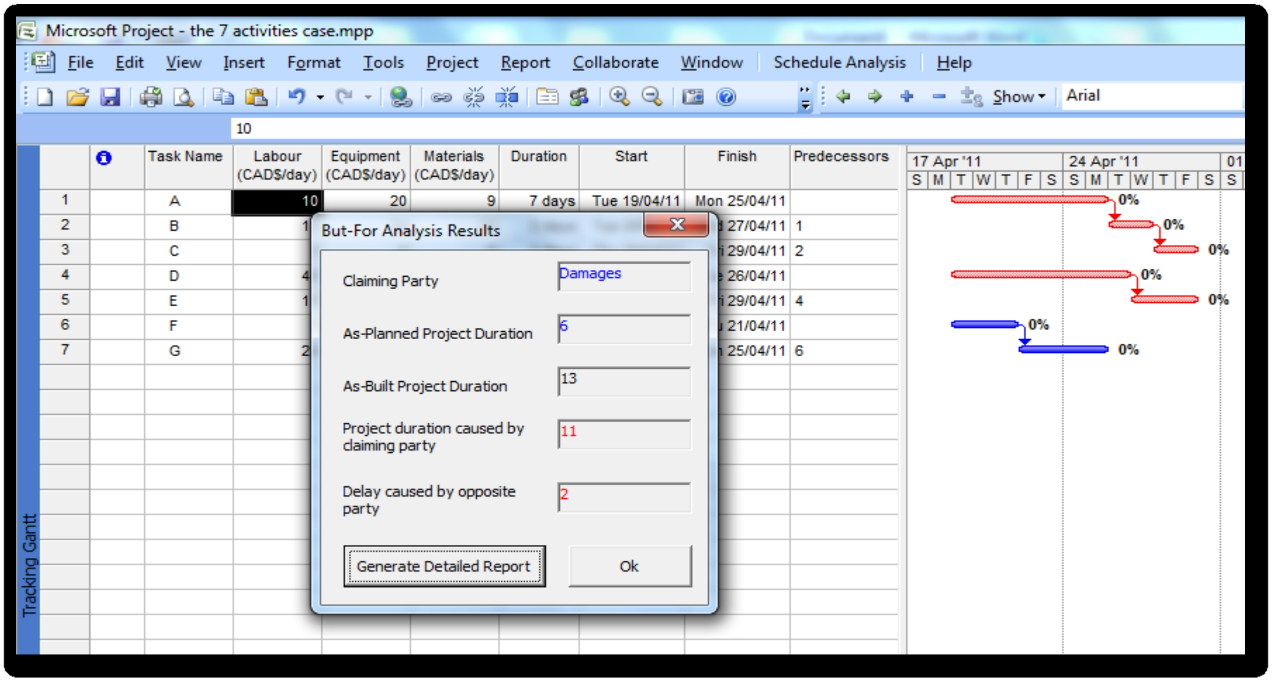
Summary Report:

	As-Planned	As-Built	But-For Contractor Schedule
Start Date	19/04/2011	19/04/2011	19/04/2011
Finish Date	24/04/2011	01/05/2011	30/04/2011
Duration	5 day(s)	12 day(s)	11 day(s)
Delay	7 day(s)		
Contractor Delay	6 day(s)		

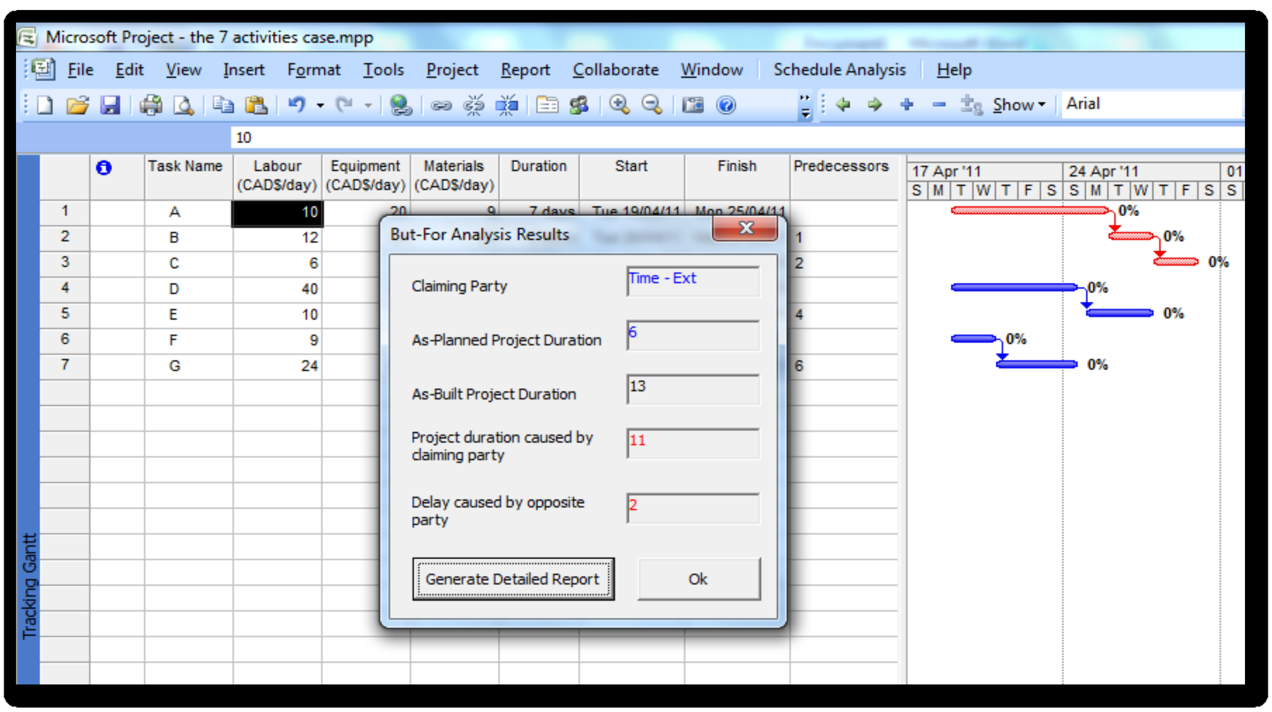
Detailed Report:

Task	Delay Information				
	Type	Duration	Date	Description	Documents
A	EC	1 day	20/04/2011	VOID	Site report
	NE	1 day	20/04/2011	VOID	
	EN	1 day	20/04/2011	VOID	
	EC	1 day	21/04/2011	VOID	
	NE	1 day	21/04/2011	VOID	
	EC	1 day	22/04/2011	VOID	
	NE	1 day	23/04/2011	VOID	

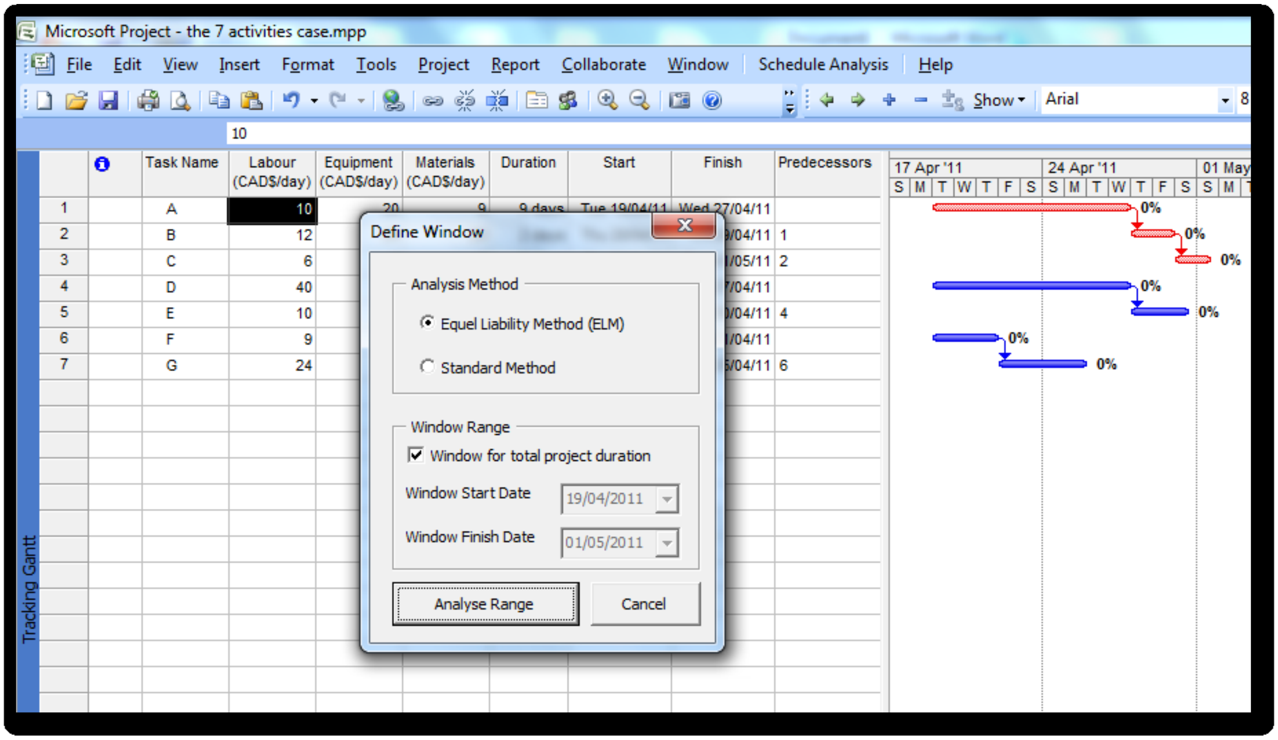
B-8 Sample of the detailed report for the But-for contractor analysis (owner is the claiming party)



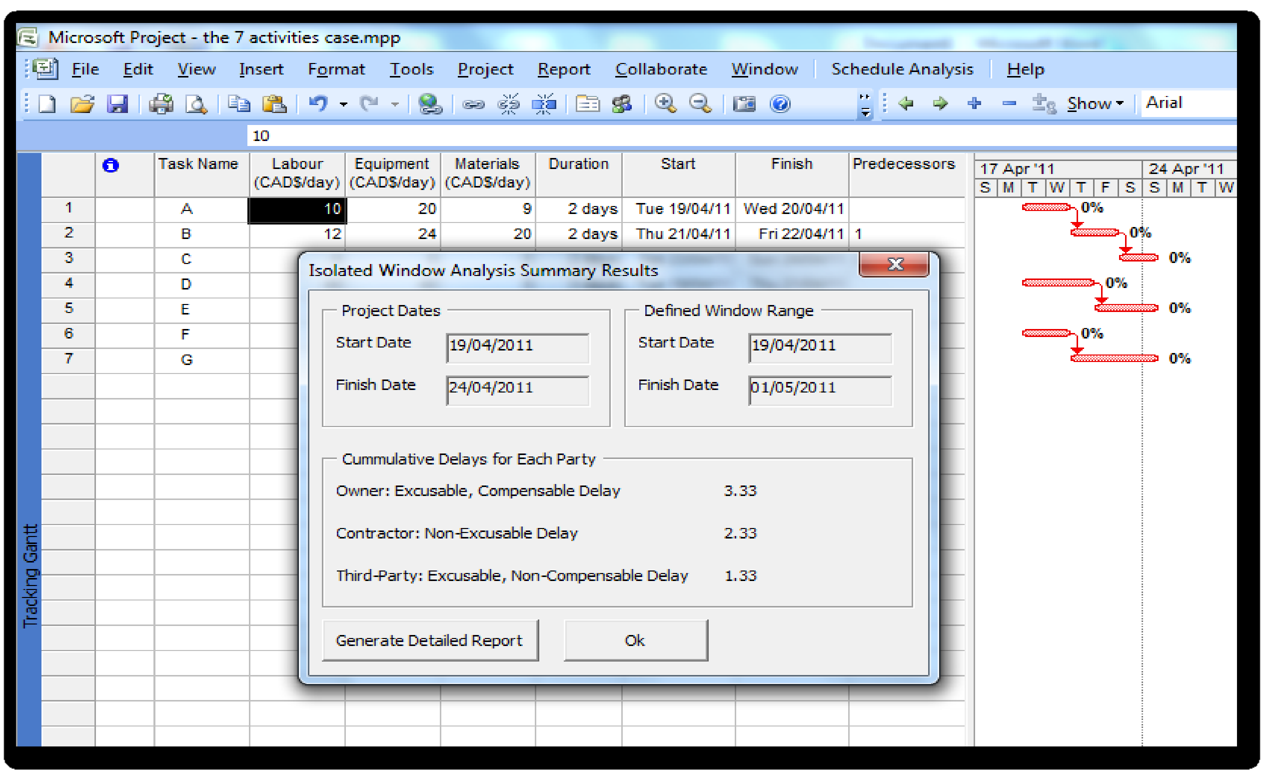
B-9 But-for owner results - damages (Contractor is the claiming party)



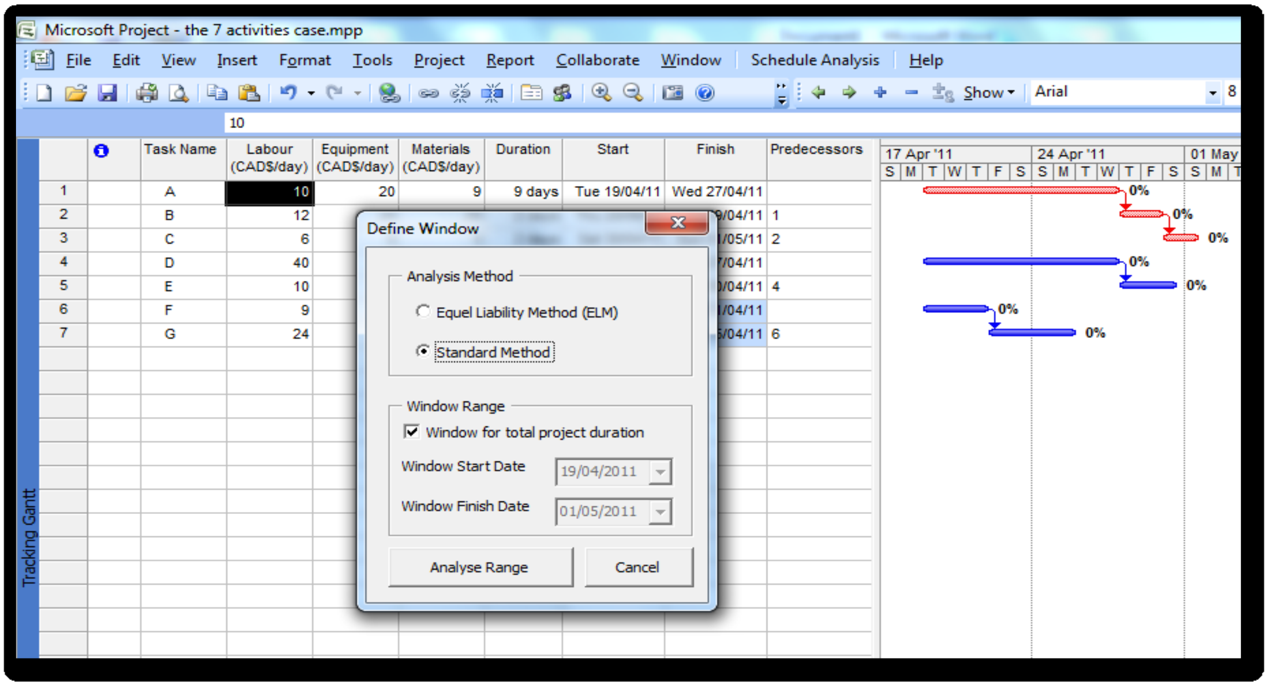
B-10 But-for owner results - EOT (Contractor is the claiming party)



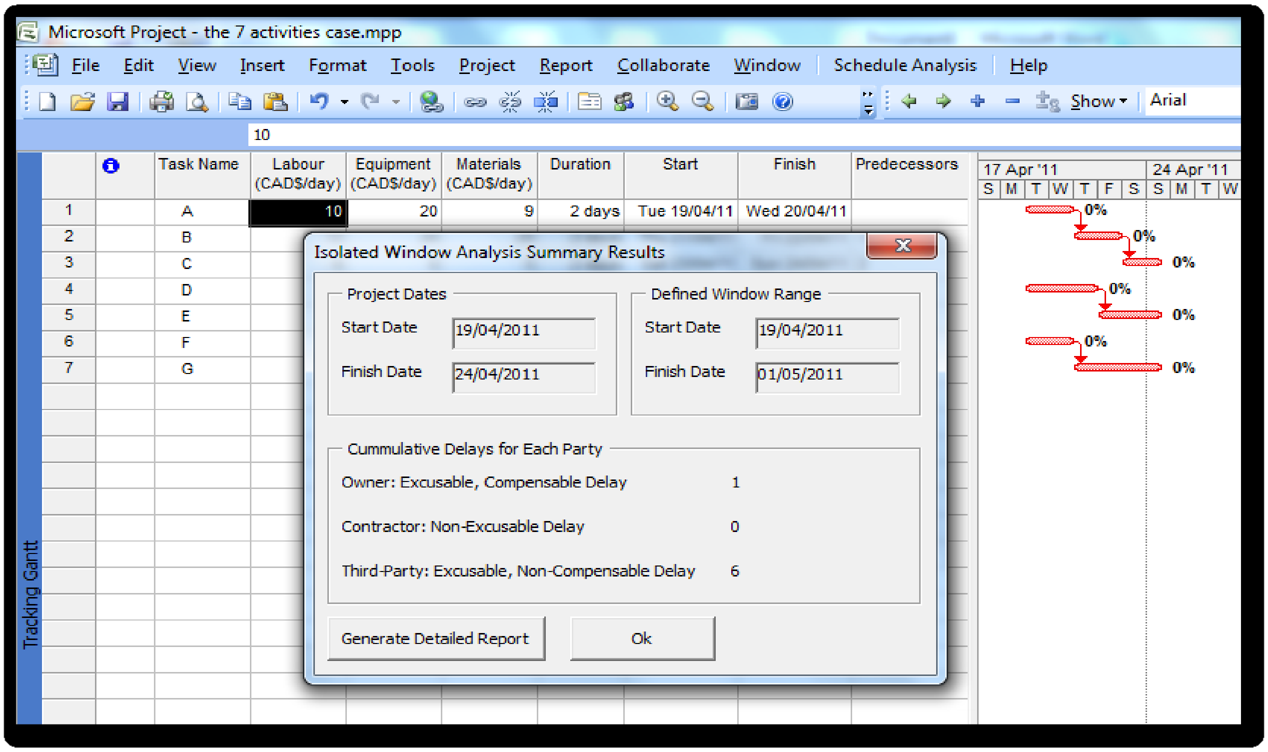
B-11 IDWAT-ELM (window range definition)



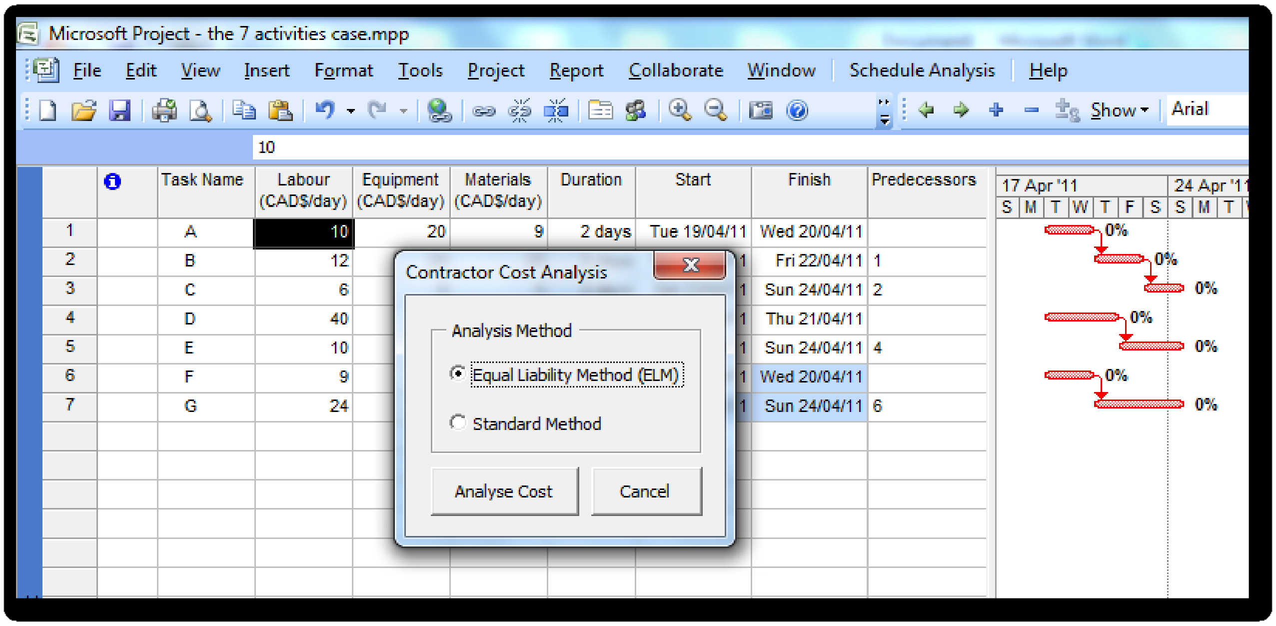
B-12 IDWAT-ELM (delay analysis results)



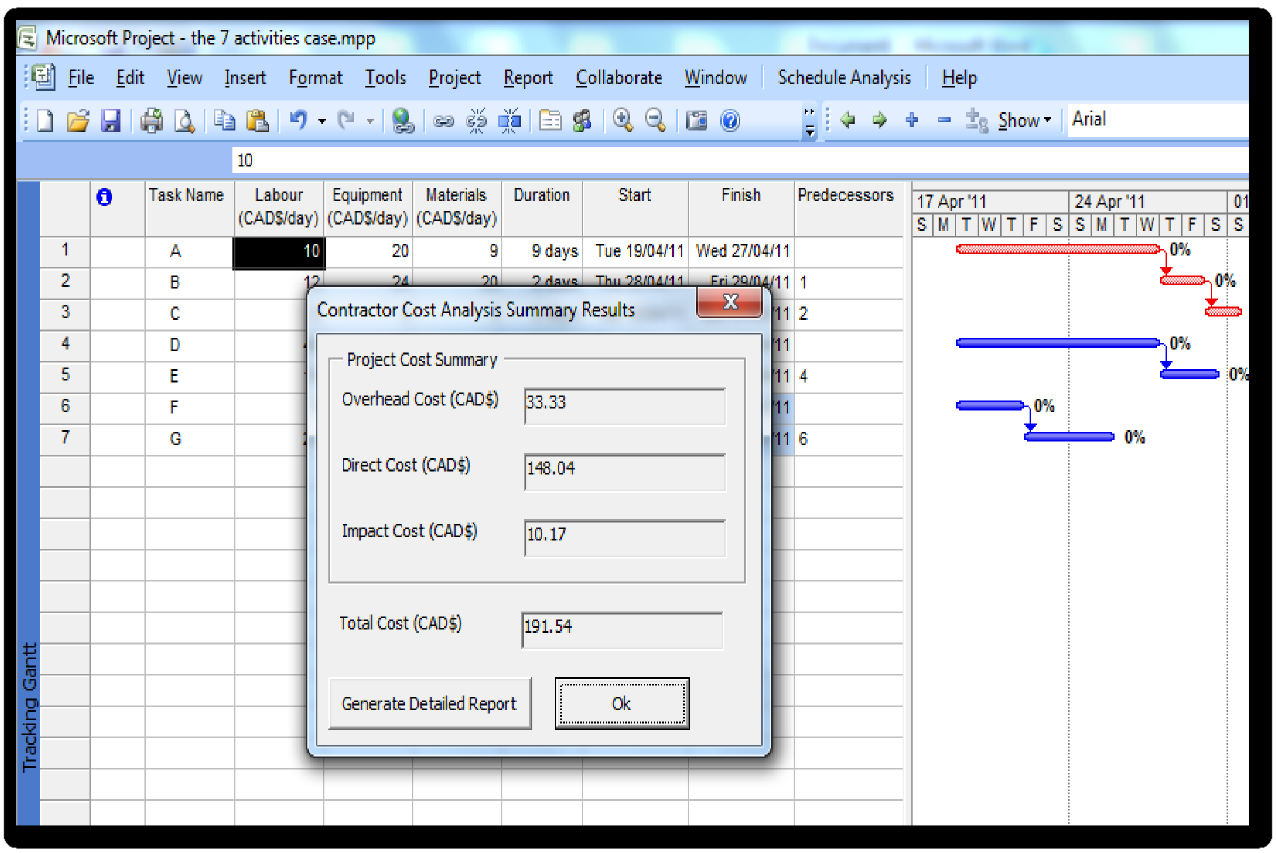
B-13 IDWAT-Regular (window range definition)



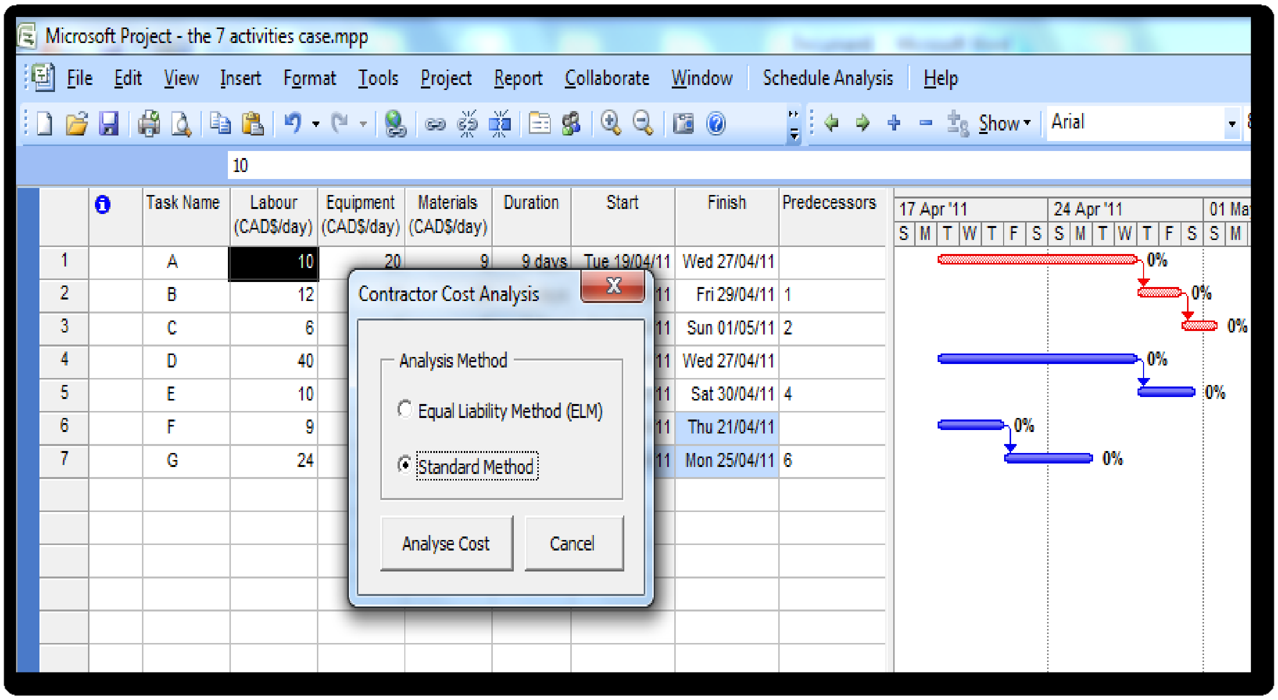
B-14 IDWAT-Regular (delay analysis results)



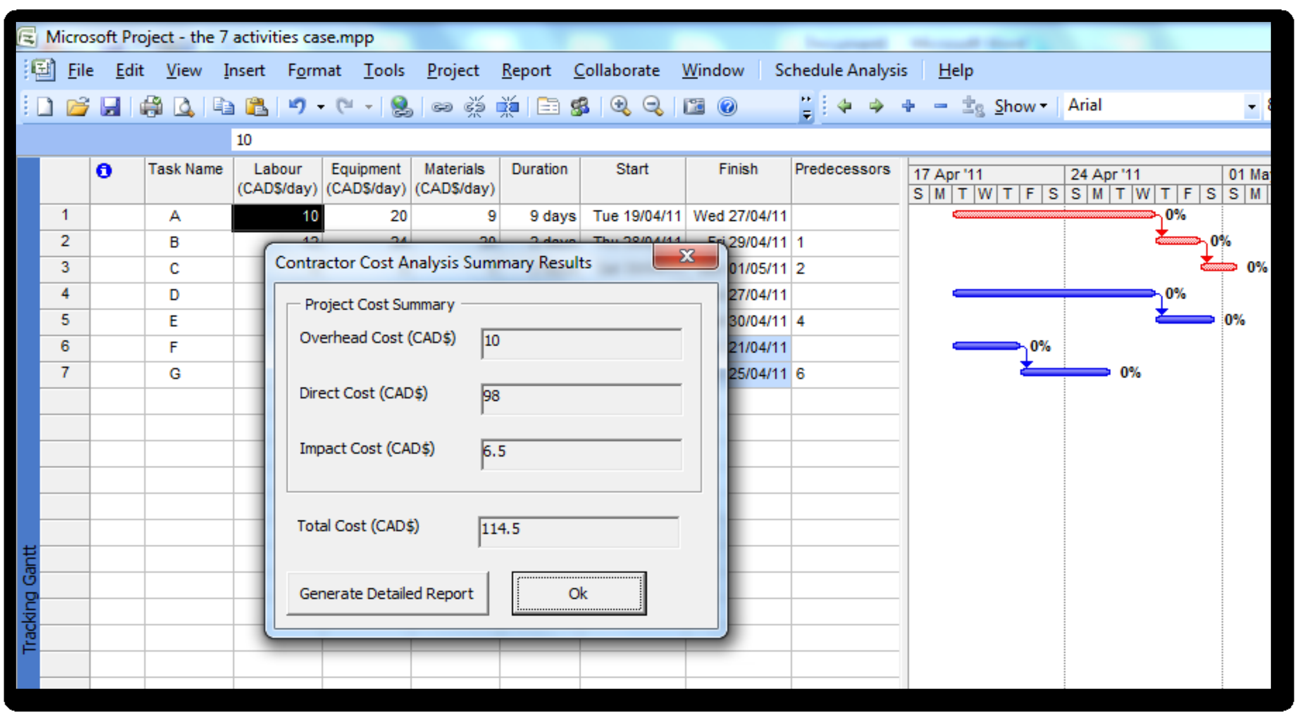
B-15 Contractor Cost Analysis method selection form (IDWAT-ELM)



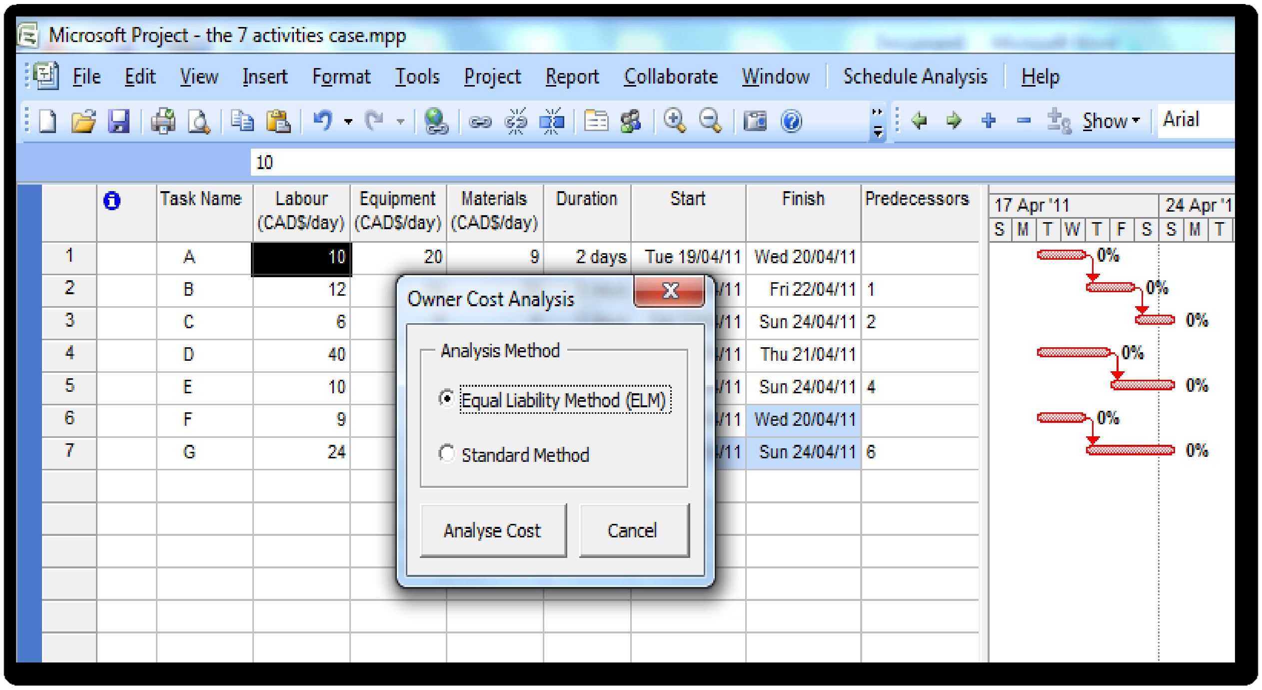
B-16 Contractor Cost Analysis results (IDWAT-ELM)



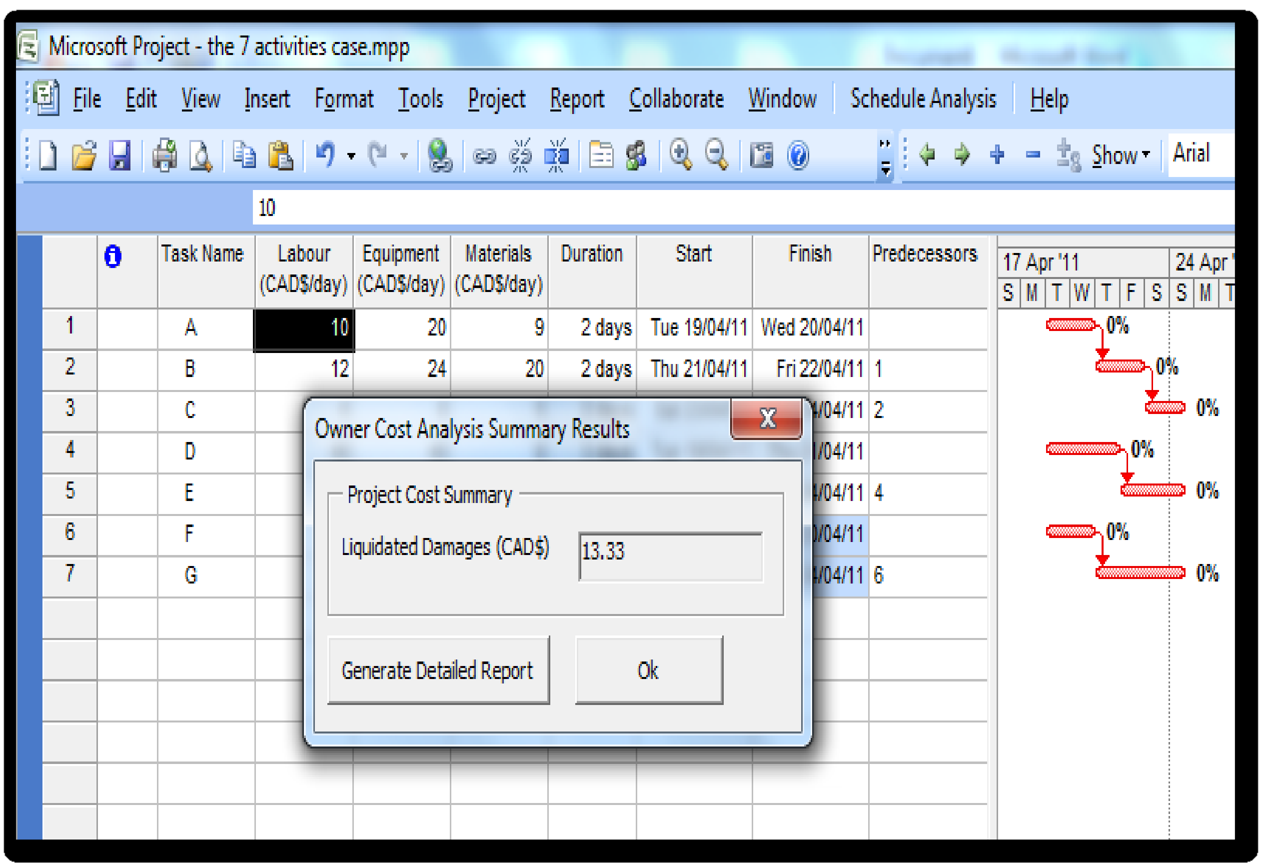
B-17 Contractor Cost Analysis method selection form (IDWAT-Regular)



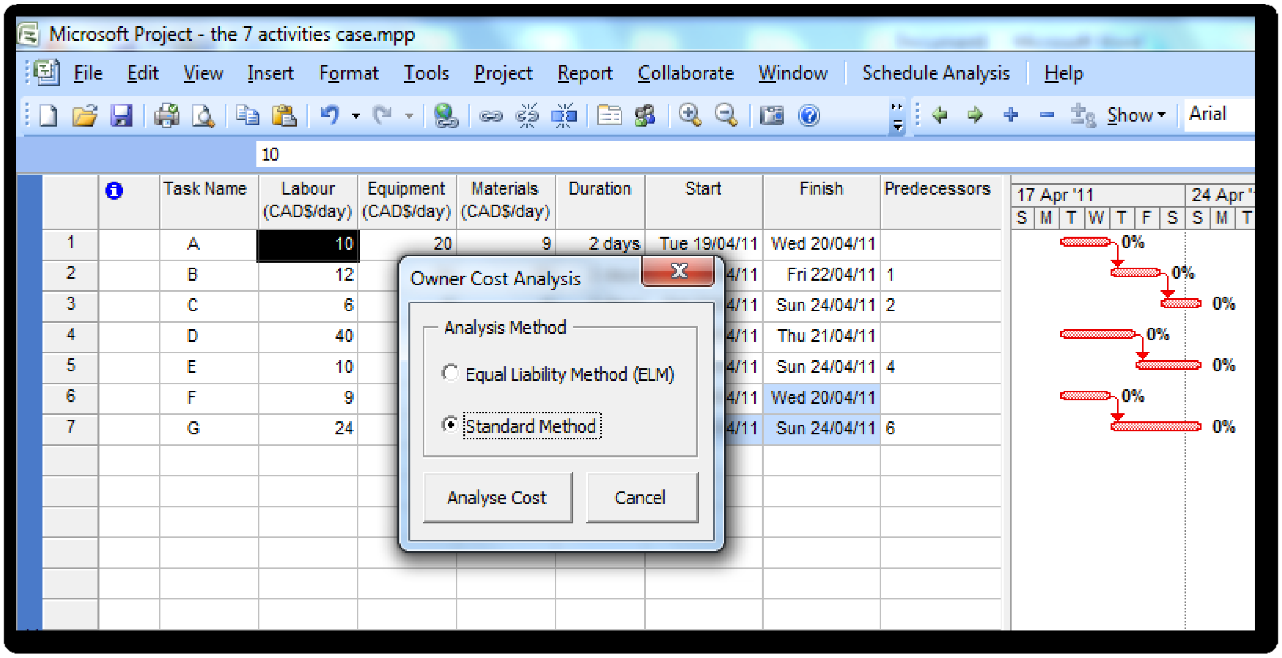
B-18 Contractor Cost Analysis results (IDWAT-Regular)



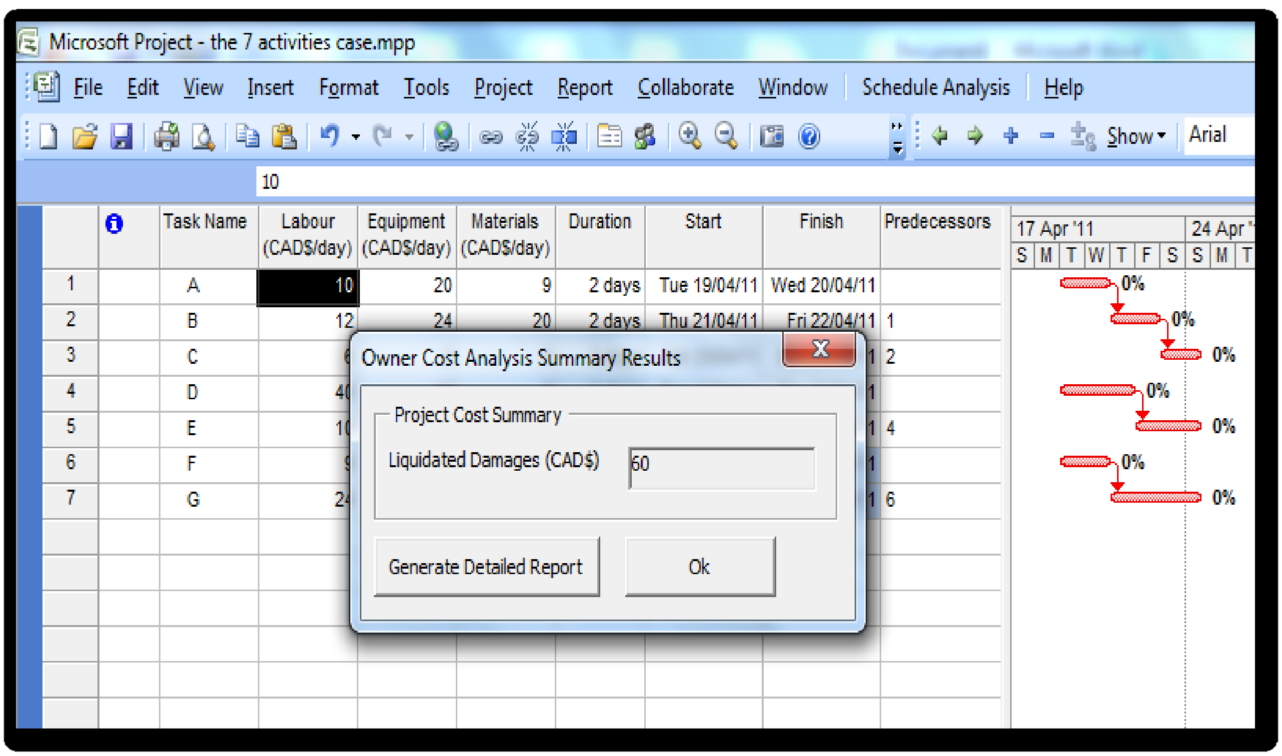
B-19 Owner Cost Analysis method selection form (IDWAT-ELM)



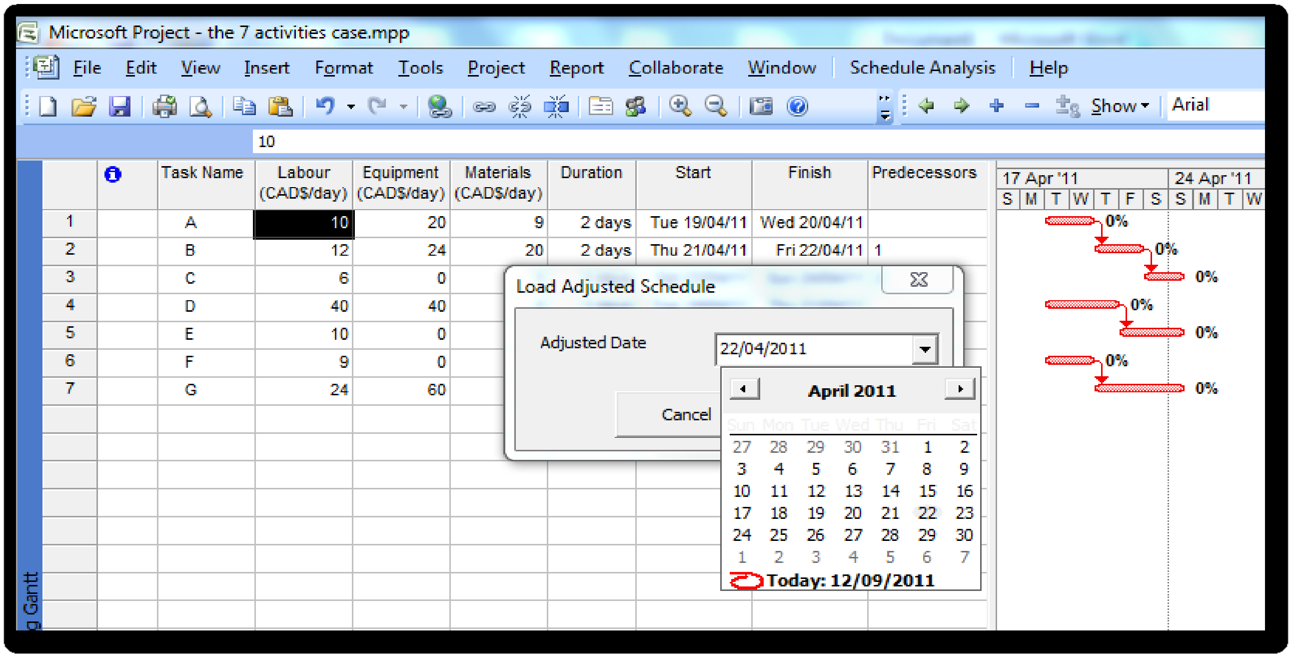
B-20 Owner Cost Analysis results (IDWAT-ELM)



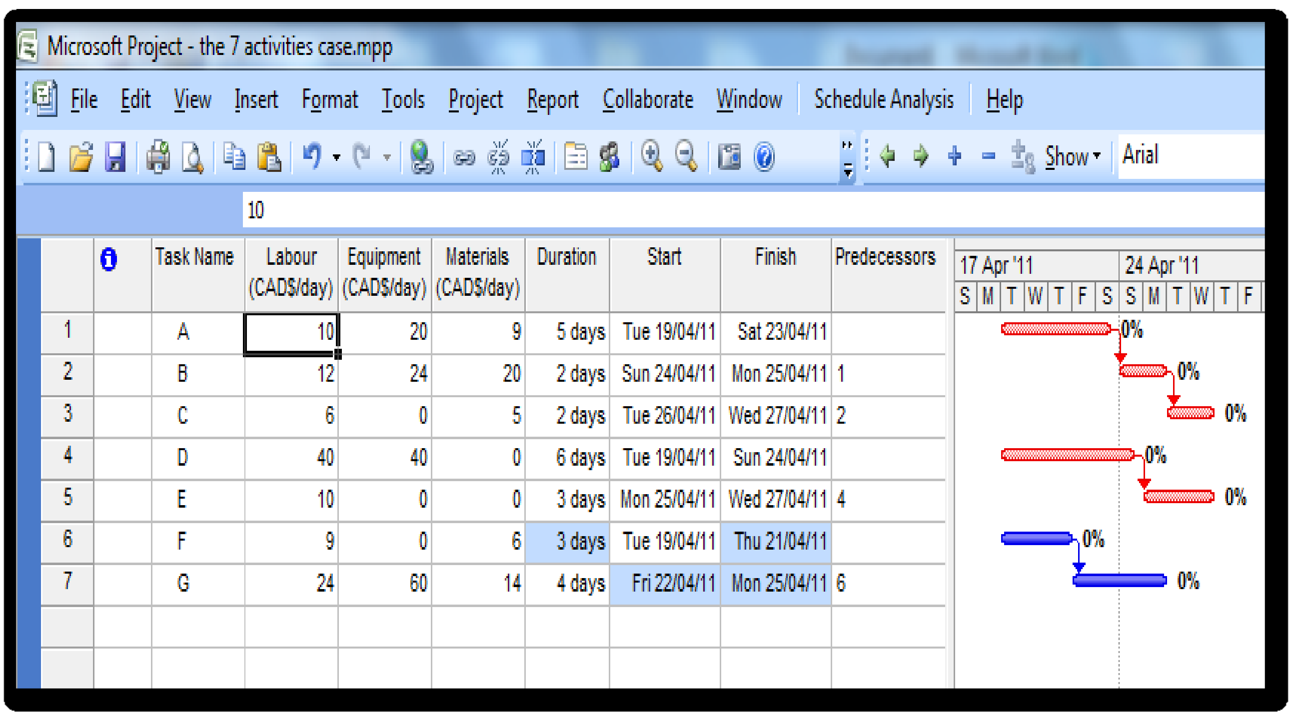
B-21 Owner Cost Analysis method selection form (IDWAT-Regular)



B-22 Owner Cost Analysis results (IDWAT-Regular)



B-23 Adjusted- schedule generating form (Reloading schedule as it was on a specific date)



B-24 Reloaded Adjusted- schedule as it was on April 22, 2011