**A Model to Predict the Impact of Excusable and Non-Excusable
Delays on Selected Residential Construction Projects**

**A thesis submitted to the Faculty of Graduate Studies and Research
in Partial Fulfillment of the requirements for the degree
Master of Applied Science**

Submitted By

Shervin Farzam Behboudi

Department of Civil and Environmental Engineering

Carleton University

Ottawa-Carleton Institute of Civil and Environmental Engineering

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ABSTRACT

Construction duration is a crucial element in any contract between the client and the contractor or between the contractor and sub-contractor.

Unfortunately delays, which are common on construction projects, are also one of the most costly problems. This means that the minimum cost and acceptable performance for projects is affected if the construction time period is extended. In other words, time is money, and a delay on a project means loss of profit for contractor or additional cost to the owner. In this study, a model is proposed that could be used to predict the impact of delays on high-end residential construction projects.

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LIST of ABBREVIATIONS

CP.....Control Project

CPA.....Contemporaneous Period Analysis

CSA.....Canadian Standards Association

CPM.....Critical Path Method

DRM.....Delay Ratio Model

REBO.....Real Estate Board of Ontario

VB.....Visual Basic

Chapter One: Introduction

1.1. Background

All types of construction projects, including high-rise condominiums, residential home buildings or road reconstruction, are subject to completion dates. Yet, even with the most advanced project management techniques, construction projects continue to exceed deadlines, incurring delays and substantial extra costs. The reason for these delays include, but are not limited to, bad weather, material shortages, site conditions, labor disputes, etc.

Delays are the most common and also the most costly problem on construction projects. If the construction time period is extended, higher borrowing costs, inflation and other factors will increase the construction costs. If the construction costs increase, from an economic perspective, the project may no longer be financially viable for the owner or contractor. Thus, the primary objective during the construction process is to complete the project on time and within budget, while meeting established quality requirements and other specifications (Rasdorf et al, 1992). In some cases, delays during construction

can create huge cost damages, and these damages can result in the projects' parties taking legal action against each other through a construction claim.

According to the Canadian Real Estate Board (2007) the value of real estate increased up to 100% across Toronto for the period 2005-2007. The cost of new home construction has followed the same trend with the result that there is an increasing number of homes with a value in excess of \$1 million being built. In the past, delays and claims were often confined to major construction projects. However, there is a heightened investor interest in the high end residential construction business. As result, more delay claims for damages are found in this sector (Tarion, 2005) than ever before.

For example, just two years ago, a custom home builder in Toronto, was sued for a half million dollars by the owner on one of their high-end custom home projects when the project completion was delayed for six months. The corporation hired a specialist to help their lawyers to analyze and classify the delays. In the end, the judge accepted some of the contractor's excuses for delay, and resolved the dispute by having the contractor liable for only forty seven days of delay and not the initial one hundred fifty five days the plaintiff (owner) had claimed.

Usually, the claims for residential projects are premised on two concepts: first, the costs of the late purchase of supplies and materials, which is usually determined at the same rate as inflation; and second, the increased cost of

borrowing, which is counted as interest on the amount of money invested in the project for the duration of the additional time that the project is not ready for use (Alkass et al, 1987). The costs resulting from delays represent a fraction of the overall contract value, thus, the cost of delay would be much greater in larger projects. The effect of the delays is further compounded by the fact that the causes of delays are often multi-faceted.

1.2. Objectives of Research

The extent to which delay claims cause problems in high end residential sector is not well researched, but evidence suggests that it is becoming a significant issue for contactors.

Thus, the goal of this research was to develop a delay impact model that could be used to predict the impact of delays on selected residential construction projects.

In order to reach the goal, several objectives were set:

- review existing delay analysis methods;
- classify and categorize construction delays for selected construction projects;
- identify parties responsible for the delay;
- measure the impact of the delay on the project duration;

- introduce a methodology for quantifying the impact of the delay on the schedule; and
- develop a computer program to assist with project scheduling based on delay impact.

1.3. Scope and Organization of Research

The scope of this research is limited to “ high-end “residential projects located in the City of Toronto, Ontario, Canada, and the period of study is between January 2004 and August 2007. Ten projects were selected for this study.

Chapter 2 contains a literature review of the delay types and delay analysis methods. Chapter 3 provides the methodology of research. Data analysis is presented in Chapter 4. Chapter 5 presents a discussion of the data analysis. Finally, the main conclusions and recommendations of the research are presented in Chapter 6.

Chapter Two: Literature Review

A project is the set of tasks required to accomplish some purpose, such as the construction of a new home. A project is characterized by its scope, quality, time, and cost.

All projects start with a concept stage and end with continued operation stage. These stages comprise the project life cycle (Alkass, 2002) and are illustrated in the Figure below (Fig 2.1) from that work.

Fig 2.1: Project Life Cycle (after Alkass, 2002)

These stages typically occur in the three main phases: planning & scheduling, construction, and utilization.

Risk, naturally, is an important consideration in all project phases. Delay is one of the major risk aspects in the construction phase, and must be considered in decision-making situations such as bidding competitions. If a bid is low enough to win a project, profits can be jeopardized by delays in construction time.

Overruns or time extensions caused by design errors, late deliveries, weather, site conditions, or other reasons can have a major impact on the schedule and the cost of construction. Thus, keeping the construction time and project costs within the estimated parameters is a key to success on a construction project.

To identify the construction delay risk, it is necessary to understand the characteristics of delays by classifying them in delay types. It is also necessary to quantify the delays in order to create the relative delay risk factor. Quantification of the delay cannot occur unless one understands project scheduling & planning.

2.1. Project Scheduling

Alkass (2002) analyzed scheduling using statistical task relationships to estimate optimistic completion time. To compute the expected duration time, the standard formula used to compute the expected duration time is that using a weighted average of times as shown in Eq. (2.1) suggested by Kerzner (2005).

$$E=(O+4M+P)/6 \quad (2.1)$$

Where:

E=Expected duration time

O=Optimistic time

M=Mostly likely time

P=Pessimistic time

The “pessimistic completion time” is the time that the activity will take if everything that can go wrong, does go wrong but the project is still completed. The “mostly likely completion time” is the time required under normal circumstances. It can also be the completion time that has occurred most frequently in similar circumstances. The “optimistic time” is the best time that the activity or task can take to complete on time. For example, if the demolition task takes five days as an optimistic time period (O), but the most likely time is that the task will be done in eight days (M), and the pessimistic time is ten days (P), then by using equation 2.1, the expected time period (E) would be 7.83 days.

There is no guarantee that the expected time is always equal to the mostly likely time. For example if O=3, M=10 and P=11, then E, The expected time is 9 days.

In most construction contracts, task duration is one of the important requirements as delays have serious consequences. As noted previously, there

are many reasons for the delays that may extend the duration of the project. Time-related schedule variance problems can be analyzed and subsequently resolved according to three elements: cause, liability, and damages. The purpose of the analysis is to determine the cause, to estimate the degree of time impacted due to the responsible party, and to determine the corresponding damages. In analyzing the time impact on the project completion date, many scheduling documents are prepared. To evaluate delays, which result from specific events, scheduling techniques such as critical path methods or bar chart methods are normally used.

The as-planned schedule, as-built schedule, adjusted schedule, and as projected schedule are the four types of most common schedules used in construction according to Alkass et al (1991) and Arditi et al (1989).

2.1.1. The As-planned Schedule

At the start of any project, the contractor prepares an original work schedule, known as the as-planned schedule, in accordance with the contract documents (Alkass et al, 1991). This schedule results from the contractor's approach to pursuing the job, and it contains the project start and finish dates, planned activities, their duration, relationships, and the critical path. However, Reams (1990) suggested that in order for this schedule to be accepted in delay analysis, the relationship between the activities must be reasonably valid, the duration be realistic, the planned resource allocation be accessible, and other

conditions such as weather conditions, limits, work restrictions, and time required for inspection and approval be considered in the schedule.

2.1.2. The As-built Schedule

During the construction of a project, new conditions might impact the project duration and, consequently, the schedule is updated in order to recalculate the new project duration. Thus, the schedule that is now in effect at the end of the construction period is the as-built schedule. Alkass et al (1991) stated that this schedule could also be established from the project records by taking the facts from the project's progress reports and documents, so that the as-built schedule is a reflection of the succession of events that occurred up to the completion of the project.

2.1.3. The Adjusted Schedule

A series of adjusted schedules are prepared to explain the sequence of events which transforms the as-planned to the as-built schedule. Hence, these schedules explain the major schedule changes that occurred during the execution of the project. The adjusted schedule is a reflection of how delays, accelerations, or other changes affected the as-planned schedule when they are integrated into the overall schedule (Arditi et al, 1989).

2.1.4. The As-projected Schedule

Arditi et al (1989) stated if a project is not yet completed during the updating process, the as-projected schedule will be carried out to show the expected project completion date. The as-projected schedule contains the as-built records for the completed portion, and the suggested changes for rest of the project.

The difference between the as-projected schedule and the adjusted schedule is based on considering the phases and using the float times within each phase. In adjusted scheduling, the overall schedule would be considered as one phase, but in as-projected scheduling, the project period would be divided in to smaller phases. In other words in as-projected scheduling, each task would be considered as one phase.

Generally, previous as-planned and as-built schedules are the basic data source for the new schedule. However, for predicting project times, it is necessary to calculate the total construction duration by considering each of the anticipated delays and adjusting the schedule accordingly.

2.2. Construction Delays

When delays occur in construction projects, they must be analyzed to determine: (1) what is the cause of the delay. and (2) who is responsible for the

delay. In general, delays are categorized by whether or not a time extension or additional compensation will be given to the contractor because of the delay.

2. 2.1. Impact of Delay on Project Schedule

As Eric Uyttewaal et al (2005) defined in his book; a project is a task or set of tasks to reach a specific goal. A project occurs over an identified period of time known as the project life cycle. In any project, there will be a subset of tasks that form the “critical path”. Any delay in any task on the Critical Path will extend the project time and cause project delay.

Float time or free float is the amount of time that the completion of a task may go beyond its scheduled finish time, without changing the start time of any successor task. The following Figure (Fig 2.2) shows an example of an “As-planned” schedule and a task with float time.

Fig 2.2: As-planned Schedule

In the above chart, task “E” is the predecessor of tasks “C” and “F”. The finish time of task “E” occurs four days before the start of either task “C” or

“F”. Thus, it has four days float time after it finishes and task “C” or “F” begins before it will affect the start time of any other tasks.

Float time is a very valuable element in scheduling as it gives more flexibility to project managers and contractors, and allows them to avoid potential delays by reallocating resources.

The critical path is that set of tasks that have zero float time. That means that if any critical path tasks are delayed, they will cause delays on the whole project. So, any task on the critical path is defined as a critical task. For the as-planned schedule of Fig 2.2 above, the critical path is A, B, C, and D. The following Figure (Fig 2.3) represents the same schedule that has incurred a delay in one task on the critical path.

Fig 2.3: As-built Schedule-Reducing/Extending the Critical Path time

It can be seen that, task “A” is on the critical path and must be finished in five working days. But, task “A” finished in six days, and therefore caused a potential one day delay for the project. However, Task “B”, which is also on the critical path, and had an expected duration of two days, was completed in one

day, and therefore saved one day. In total, the critical path time is unchanged total, with no delay and the critical path and overall schedule are unaffected in this example.

Non-critical tasks may become critical when float time is used up by the delay. The following Figure (Fig 2.4) shows how a non-critical path task may cause a project delay by using all the float time.

Fig 2.4: As-built Schedule-Changing the Critical Path to New One

Task “E” was not initially a critical task. But, after using the entire float time, it becomes a critical task in the as-built schedule. In other words, when the duration of task “E” is extended and causes the finish time of the project to be postponed or delayed, the critical path will change.

In the above example all task delays extended the time period of the project, and not all delays, which cause a late completion of the project, are on the critical path. Thus, it is important to understand the impact of delays on the critical path as well as on tasks that are not on the critical path.

2.2.2. Determining Delay Time

Shi (2001) presented a method for computing task delays, which is based on the difference between as-built and as planned schedule. In this method, he explained how a non-critical-task will become part of critical path. Consider the following definitions:

$$VS = \text{Actual start time} - \text{Planned start time} \quad (2.2)$$

$$VF = \text{Actual finish time} - \text{Planned finish time} \quad (2.3)$$

$$VD = \text{Actual duration} - \text{Planned duration} \quad (2.4)$$

VS and VF represent the variation in start and finish times. When the activity is ahead of the as-planned time, VS and VF will have a negative value. VD symbolizes the variation of activity duration between the as-planned and as-built schedules. A negative value for VD indicates that the time duration is less than the as-planned duration.

In addition to the above relations the following relationships always apply to a project schedule:

$$\text{Actual finish time} = \text{Actual start time} + \text{Actual duration} \quad (2.5)$$

$$\text{Planned finish time} = \text{Planned start time} + \text{Planned duration} \quad (2.6)$$

Therefore,

$$VF = VS + VD \quad (2.7)$$

If a delay happens on any task in the schedule, the starting time for the successor task(s) may be postponed. As this happens, it may cause one or more non-critical tasks to become critical, thus forcing the project to be delayed.

Successive delays can happen when successive tasks, which are related to each other, are delayed. For example, the late delivery of concrete causes delays in the casting of the concrete post. The delay in post construction causes delays in the forming of the roof, and subsequently the roof construction will be postponed. As Brunies (1988) stated, in this kind of delay, the actions of one contractor can cause a series of delays in a number of succeeding activities that may be performed by many different contractors.

2. 2.3. Categorization of Delays and Liabilities

2. 2.3.1. Liability for Delay

O'Brien (1980) apportioned the responsibility for delay in one of the four ways:

- owner responsibility;
- contractor responsibility;
- both owner and contractor responsibility; and
- neither contractor nor owner responsible.

Delays are also classified by the categories of liability and by the cause of the delay.

The major part of delay analysis is finding liable parties in a claim investigation. This is not an easy job for the delay claim consultant. According to Al-Saggaf et al (1998), there are three categories of delay related to liability: excusable compensable, excusable non- compensable, and non-excusable.

Excusable compensable delays are caused by the owner's actions or responsibilities. When contractors come upon this type of delay, they are allowed a time extension. Examples of an excusable compensable delay would be when the owner denies access to the site, or the owner submits a permit application late, or changes are requested by the owner.

Excusable non- compensable delays are delays where neither the owner nor the contractor is responsible. When this type of delay occurs, only a time extension will be justified and there are no grounds for compensation. Some examples of excusable non-compensable delays are unprovoked strikes or severe and unusual weather conditions

Non-excusable delays are delays which result from the contractor's or sub-contractor's actions or responsibility. In other words, the owner is compensated. An example of a non-excusable delay would be when a contractor fails to complete the job on time because he neglected to use appropriate construction equipment. However, this type of delay can result in no

compensation awarded to the owner if it can be proven that the contractor's delay had no effect on the whole project.

From a liability perspective, one or a combination of the above delay categories may apply to a delay. When analyzing delays, each delay is assessed separately and its impact on other activities and the project duration is determined. Rubin et al (1983) suggested the following guidelines for classifying delays in order to help in the analysis of these kinds of concurrent delays:

- If excusable-compensable and non-excusable delays occur concurrently, only a time extension is granted to the contractor;
- If excusable compensable and excusable non-compensable delays occur concurrently, the contractor is entitled to a time extension, but not liable for the damages; and
- If two excusable compensable delays occur concurrently, the contractor is entitled to the time extension, and liable for damages, caused by the delay.

2. 2.3.2. Delay Cause

The most important aspect of delay analysis is to find the cause of the delay that has affected the critical path and the completion time of the project. Identifying the cause of delays can be a difficult task, and is dependent on the project's scale and the availability of construction records. Battikha et al [a]

(1994) proposed that delays are classified by: 1) poor designs; 2) change orders; 3) weather conditions; 4) site conditions; 5) late deliveries; 6) economic conditions; and 7) upgrading. Additionally, each delay-cause has its own delay source. The following table (Table 2.1) presents the delay cause and delay source.

Table 2.1: Delay Cause-Delay Source (Battikha et al [a], 1994)

Delay Cause	Delay Source
Poor design	<ul style="list-style-type: none"> • Defects in plan and specifications • Delay because of defects in shop drawings • Delay because of denial of construction material approval • Lack of information
Change order	<ul style="list-style-type: none"> • Order to stop work • Change orders in any construction stage
Weather condition	<ul style="list-style-type: none"> • Failure to provide heater on job site • Failure to provide cooling system on job site • Snow • Rain • Storm and blizzard
Site condition	<ul style="list-style-type: none"> • Failure to access to site • Stop order because the safety issues • Failure of equipment • Lack of supervision • Earthquakes • Fire and flood • Subcontractor performance
Late delivery	<ul style="list-style-type: none"> • Owner's furnished materials not available • Due to war • Due to strikes • Late delivery by suppliers
Economic condition	<ul style="list-style-type: none"> • Failure to finance the project • Failure to provide the payments • Cash flow limitation • Bankruptcy
Upgrading	<ul style="list-style-type: none"> • Introduction of major changes in requirements • Upgrading work to certain manner • Upgrading the construction standard • Governmental acts and regulations

2. 3. Existing Delay Analysis Methods

In the past, delay analysis was commonly done by comparing the as-planned schedule and the as-built schedule (Battikha et al [b], 1994), without a cause-effect analysis. As a result, none of the parties knew specifically which delays were justified.

By using all relevant available information to schedule the project, prior to the beginning of construction, the risks of the costs incurred by project delay are reduced. The judgment of an experienced engineer can help in choosing the best method for scheduling.

Using the proper method for scheduling entails finding the correct successor(s) for each task, finding the relation between the tasks, and predicting more realistic estimates of the duration of each task. Once the successor relationship between the tasks is determined, they will rarely ever change during the construction period. But predicting the completion time is a completely different story, as the completion time depends on a number of conditions, and numerous developments may change the time period and cause delays. Therefore, in order to more accurately predict the real time of completion, an analysis of the delays and their effect on the project schedule is necessary.

The Critical Path Method (CPM) is widely used in delay analysis methods to analyze and evaluate the effects of delays on the duration of a project. Hohns

(1979) said that CPM is more popular than the bar-chart method in claims situations. CPM analysts compare the as-planned schedule with the as-built schedule in order to discover the amount and the place of the delay in the schedule. The owner or the consulting team creates the as-planned schedule, and estimation is made to determine how long it will take to perform certain tasks. Project costs are broken down into stages, based on the as-planned schedule. Usually, the project manager or site-superintendent provides the as-built schedule from daily construction reports. Fig 2.5 shows a typical as-planned schedule, and Fig 2.6 shows as-built schedule based on working progress and a delay.

Fig2.5: As-planned Schedule

Fig2.6: As-built Schedule

In delay analysis, the float time is usually considered as belonging to the project, not to the client or contractor. If one party uses the float time for his

benefit, even though the project time did not change, schedule adjustment is required. Since free float may reduce the impact of a delay on the whole project duration, the beneficial use of one party having this advantage is equivalent to solving the delay problem at the other party's expense.

However, some government agencies do not care if contractors use the float time. They are also not concerned about how much of the float time is used by each contractor. They are only concerned with the completion time of the project without delay (Kim et al, 2005). In this kind of contract, delay analysts must consider that any delay, which did not cause a delay in the whole project, is not a main concern.

Kim et al (2005), Alkass et al (1991), and Leary et al (1988) all discussed three delay analysis methods that are accepted by courts. These are the what-if method, the but-for method, and the contemporaneous period analysis or CPA method. All three methods follow the same base method. This method measures the delays which affect the project, known as the extended time with delay in CPM, and uses the extended time against the schedule baseline to assign responsibility for the delays. In addition to these three delay analysis methods accepted by courts, there are four more methods used for delay analysis; time impact method, net impact method, adjusted as-built CPM method, and snapshot.

2.3.1. What-if Method

The what-if method is based on the as-planned schedule. The number of days of possible delay for each task is added to the as-planned schedule and the impact on project duration is determined (Leary et al, 1988 and Kim et al, 2005). All tasks that have a possible delay would be processed in the same way.

The what-if method has several advantages and disadvantages. The advantages of this method are simplicity and clarity. One of the disadvantages is that it cannot show the actual project progress. It uses only the as-planned schedule as the baseline schedule for delay analysis, and it does not display how much time the project is ahead of schedule. Therefore, any action to reduce the time will not be recognized. Moreover, if the parties agree to share the damage as a result of delays, the impact of such arrangements on the liability is not considered in this method.

2.3.2. But-for Method

The basis of the but-for method is the as-built schedule. The difference between the completion date of the project on the as-planned schedule, and the completion date on the as-built schedule, is considered the construction delay (Leary et al, 1988 and Kim et al, 2005). The main problem of the "but-for" method is even though the method recognizes the amount of delay on each task, it does not identify the party responsible for the delay (Alkass et al, 1993). There is also

no guarantee that the critical delay is part of the original critical path. As seen before, non-critical tasks may become critical due to delays. However, the result of the “but-for” method is more understandable because the determination of delay on each task helps to display how much time the project is ahead or behind of schedule. So, the tasks that will reduce or extended the time will be recognized.

2.3.3. CPA Method & Collapsing Technique

The CPA method is a method that is based on investigating the construction time schedule in smaller project phases. This method also identifies the responsible party for each delay (Leary et al, 1988, Alkass et al, 1991 and Kim et al, 2005). The CPA method uses a technique known as the collapsing technique, and is based on a combination of the as-built and the as-planned schedule. The collapsing technique effectively characterizes and quantifies delays on the construction project. In this technique, one or both parties propose the as-planned schedule as a baseline. The prepared as-built schedule is based on construction documents, and all delays apply to the as-built schedule based on the responsibility of the parties. At the end, the as-planned and as-built schedules are judged against one another. In other words, the difference between the updated schedule and as-built schedule is the basis of the claims. So, the as-built schedule not only determines the delay for each task, but also documents the responsible party for each delay.

The CPA method overcomes the failure of the what-if method by dealing with changes in project planning and execution during construction. Like other investigation methods that are based on the as-built schedule, such as the but-for method, the CPA method is based on applying the actual record of construction to the schedule (Leary et al, 1988).

2.3.4. Time Impact Method

The time impact method is used to determine the effects of delay at different times in the project (Leary et al, 1988). By using this technique, the time of delay and the cause of the delay can be determined. This technique only focuses on a specific delay. In this technique, the delay is applied to the project and the project schedule is then recalculated to determine a new finish time for the project. At the end, the difference between the as-planned schedule closing time and actual finish time of project will show the delay time.

This method is applicable to every delay that is to be considered and analyzed. The schedule should be updated with actual dates and durations before considering the analyzed delay. This ensures the accuracy of the calculated delay time. The total impact of the delay on the project completion date is determined by adding all delay time analyses. The calculated total delay is then analyzed for appointment between the owner and the contractor (Leary et al, 1988).

2.3.5. Net Impact Method

Alkass (1991) and Leary et al (1988) stated that the “Net Impact” method is the representation of the net effect of all claimed delays on a bar chart. When using this technique, all delays, disruptions, and even change orders are plotted on an as-built schedule. The net impact method focuses on the combined overall effect of all the delays on the completion date of the project. Consequently, only the net effect of the delays is calculated, and the requested time extension is then the difference between the as-planned and as-built completion date. Leary et al, 1988 argues that this method is an attempt to address issues of concurrent delays.

2.3.6. Adjusted As-Built CPM Method

Alkass et al (1993) suggested that the “Adjusted As-Built CPM” technique uses the CPM format to develop an as-built schedule for the project. Delaying events are linked to specific work activities. The critical path(s) are determined twice, once in the as-planned schedule, and once using as-built schedule. The amount of the time that the plaintiff would request compensation for is the difference between the as-planned completion date and the adjusted as-built completion date. The as-built CPM method may neglect insignificant delays which do not affect critical activities.

However, as with the “Net Impact” technique, this technique only shows the net effect of all claimed delays on the project’s completion date (Leary et al, 1988).

2.3.7. Snapshot Method

Oliveros and Ordonez (2005) stated *“The snapshot technique is similar to the Time Impact method”*. The only difference in the “Snapshot” method is that the total project divided into smaller phases. Usually this small time-period-choice is based on changes to the time schedule. Daily, weekly or even monthly duration for time period normally use for this concept. The Snapshot method is used to determine the cause(s) of the delay, the amount of delay that has occurred in a project, and the time when the delay has occurred (Brunies, 1988). This method utilizes the as-planned and as- used and any revised schedules that have been provided during the execution of the project.

The first Snapshot analysis starts with introducing the delays into the as-planned schedule thus generating a new duration. For the next snapshot, the durations and relations of the activities are taken from the as-built schedule. Then these values are inserted into the generated schedule from the previous snapshot, hence an extended duration schedule is created. The difference in duration of the two completion dates is the amount of delay that affected the project due to delay impact(s). Before starting next snapshot, it is required that

the schedule to be revised, if necessary. The revised extended duration schedule becomes the baseline for the next snapshot.

The total delay is calculated by adding up all the delays within each time period. The measurement of the time impact is inclusive of both direct and indirect consequences of a delay-causing event.

2.3.8. Summary of Delay Analysis Techniques

Today, many methods and techniques for schedule delay analysis have been recognized by legal authorities in order to examine the impact of delays on the project duration. Even though there are more methods available for the analysis of the delay, the courts have generally accepted the CPA method for schedule delay analysis because it can identify project delays as compensable delays, non-excusable delays, or excusable non-compensable delays. Thus, this method identifies the party responsible for the delay in any phase of the project when there is a delay.

2.4. Types of Construction Costs

Humphreys and Wilding (1993) noted that construction costs may be classified into two categories, expired costs and un-expired costs. Un-expired costs are continuing costs and expired costs are one-time costs related to purchase of products, materials or services. These costs are classified in Table 2.2.

Table 2.2: Type of Construction Cost

Un-Expired Costs	Expired Costs
Salaries	Raw Materials
Tax, Rent, Insurance	Per hours salaries payments
Equipment	Prepaid costs
Loan and interest payments	Unexpected Cost

Delays in construction will affect the cost of construction. Accordingly, some of the above costs, like interest payments, will increase due to an extension in the construction time. Some other costs, like raw materials, may increase because of inflation.

One of the important subjects in any cost analysis for a delay claim is to know which part of the claim must be calculated based on the inflation rate, and which part will be determined based on the interest rate.

2.5. Types of Delay Cost

Claim calculation depends on the amount of delay per day. Since both parties, owner and contractor, may be involved in the delays, responsibility for the delay must be ascertained as well as the cost of delay. If the owner is responsible for the delay, the contractor will incur extra cost and time to complete the project. But, if the contractor is responsible for the delay, the owner may demand compensation for the damage caused by the delay.

2.5.1. Delay Cost Due to Contractor

The contractor is liable for the actual damages caused by his delay. However, some contractors prefer to spend more money during the construction period rather than pay at the end of the project when it is clear that the delay is their fault. In such situations the following costs may be incurred by the contractor to finish the job on time and avoid litigation:

- extra cost for the rental equipment;
- extra cost to purchases utilities;
- interest on borrowed capital;
- payment for hiring extra skilled workers;
- extended supervisor costs;
- additional operating costs for existing equipment;
- additional extended warranties; and
- extra cost for warehouse rental.

2.5.2. Delay Cost Due to the Owner

Costs due to delays caused by the owner are compensable to the contractor. These costs can be direct, indirect or overhead construction costs. Applicable costs are shown in Table 2.3.

Table 2.3: Owner Delay Cost Type (Battikha et al [b], 1994)

Cost	Type of Cost
Labor	<ul style="list-style-type: none"> • Extra labor • Extended payment for existing labor • Extra insurance cost • Increase labor salary
Material	<ul style="list-style-type: none"> • Extra material • Extra transportation cost • Storage cost
Equipment	<ul style="list-style-type: none"> • Extra equipment purchases cost • Extra equipment rental cost • Extra repair cost • Extra insurance cost • Replacement cost
Supervision	<ul style="list-style-type: none"> • Extra supervision cost • Extended supervision cost • Increase supervisor salary
Office	<ul style="list-style-type: none"> • Extra field office cost • Extra office utility and supplies cost • Leased or rent office cost • Extra heat, water, light cost • Insurance cost • Extra bond cost
Financing	<ul style="list-style-type: none"> • Extra brokerage cost • Interest • Extra interest

2. 6. Cost Impact Analysis Methods

Several methods have been suggested to assess the impact of delay costs as they relate to liability categories. Two common methods are described in this section.

2.6.1. Total Cost Method

For the purpose of estimating the damage resulting from delays, contractors prefer to use the total cost method. This method is based on the original bid and approved extra charges. The “total cost method” is primarily used to calculate damages in all liability categories. However, courts accept this method based on some conditions.

As Dieterle et al (1992) stated, the limitations that must be considered with this method are:

- the bid price must be realistic;
- the actual cost must be reasonable; and
- the extra work must be approved.

2.6.2. Cost Approach Method

The cost approach method is similar to the total cost method and is based on the man-hour technique. In the cost approach method, the cost analyzer makes adjustments to the original bid or the cost estimate. Where the owner is responsible, the analyzer will add the actual cost for extra work, such as change orders. Where the owner is not responsible, the analyzer will deduct the cost from the bid price (Dieterle et al, 1992).

The difference between the “cost approach method” and the “total cost method” is in the method of adjusting the cost of extra work to the original bid or

cost estimating. In the cost approach method, the analyzer will add the actual cost for extra work. This method works better if the project is divided into smaller phases, especially where each task is to be investigated separately. If any delay damages are found, the cost of the damage is conventionally converted to man-hours of work. For example, if rental equipment is required for performing some extra tasks, the rental cost must be converted to man-hour costs.

2. 7. Scheduling Programs

The two most common scheduling programs used by contractors are Microsoft Project ® and Primavera ®. These use the “Day Baseline Scheduling Methods” methodology for scheduling and scheduling analysis (Hussein, 2002). The methodology is based on adjusting the critical path in the working day calendar.

2.8. Gaps in Research in High-End Residential Construction Industry

As mentioned by Kerzner (2005), historically the discussion about scheduling, and finding the delays, is based on large scale construction and commercial construction projects. A major gap in the research in the existing high-end residential construction is the lack of statistics on delay cause.

Another gap in research is in the existing method for measuring the total amount of the delay in projects to determine the equation for the overall time with delay for project. The equations have the form:

$$Y=A+BX \quad (2.8)$$

As shown in Fig 2.8, if the X is the number of days specified in the as-planned schedule, Y will be numbers of days actual in construction. B is the slope of progress of the project. A is a constant which is represented by the amount of delay before starting the job.

Fig2.7: Equation diagram (Al-Momani, 2000)

This method for scheduling has two general problems. It assumes a linear progression, but the CPA shows that progress in real projects are not linear. A further problem with this method is that the equation is applied to the total competition time of the project and does not identify the causes of delay or delay responsibility.

2. 9. Summary

In terms of time and money, each contracting party in a construction project will be impacted if there are delays in construction. In order to determine the impact of delays on completion time, several delay analysis methods exist. By quantifying the delays, the costs due to the delays can be identified. The most frequently used method is the construction break down method known as the CPA method. This method not only calculates a real delay, but also identifies the party responsible for each delay. Identifying the responsible party for the delay is an important part in delay quantification, especially when addressing cost control and damage control.

Delays are categorized as: excusable compensable, excusable non-compensable and non-excusable. If the delay is not excusable, the contractor is liable. On the other hand, if the delay is excusable compensable, the contractor may claim against the owner.

In the terms of delay measurement, the basic method is measuring the extended project duration against the original project schedule. In some situations delay may not necessarily have an effect on the total original project time, but will have an effect on costs. So, full delay reports are required to qualify the impact of delays on costs.

When delays do occur, delay analysis techniques are used to assess the impact and assign liability. Ultimately, it is in the best interest of both the owner and contractor to work together to minimize the impact of the delays on project schedule and reduce the risk of extra cost in project. Thus, a tool that can help the contractor with scheduling and predicting the most likely delays has the potential to minimize the risk of cost and time overruns in the high-end residential construction sector.

Chapter Three: Methodology

3. 1.Study Domain

The regulation of the Canadian home building sector is undertaken by provincial new home warranty corporations and is governed by provincial legislation. In Ontario, the governing legislation is the Ontario New Home Warranties program Act, 1992 which states *“there are guidelines that builders must follow in order to communicate closing delays to home buyers. Specifically, the builder must communicate major and minor construction delays in writing to the new home buyer in accordance with strict timeframes – and if these are not followed, the consumer is eligible for compensation”*.

Tarion Warranty Corporation was established to act as the regulator of the Ontario new home building warranties (<http://www.tarion.com/home>). According to Tarion there were 62,408 new homes registered with the corporation in 2006.

In a typical residential development project the developer is the builder and retains almost total control over each individual home until it is handed over upon completion to the purchaser. The developer designs the home plan, schedules the project and retains control over site access and construction. The purchasers are limited to selection of interior finishes and optional upgrades. This

control does not absolve the builder of the responsibility to complete the construction in a reasonable time however.

In the high-end residential construction sector, the homeowner is the developer. This is similar to small commercial projects where the owner engages an architectural or engineering firm directly to develop the design and then hires the contractor to build. The owner may act as his/her own contract manager or may engage the design firm as his/her agent. This research is focused on the high-end residential construction sector.

The Real Estate Board of Ontario reports for the C12 area of Toronto indicated that for the C12 area of Toronto 1657 houses were sold (new and resale) between 2004 and 2008 (REBO, 2008). Of this total, 125 properties were brand new and had a sale value of more than \$1 million. This represents 7.5% of all properties sold but 36.5% of total value. The sales trends over this period are shown in following figure (Fig.3.1).

Fig 3.1: Toronto C12 Area Houses Sold (REBO, 2008)

3.2. Data Collection

For the purposes of this research, ten housing projects were selected in the period from 2004 to 2007. These projects ranged in sale value from \$1.12 million to \$3.1 million and were between 2100SqF to 6000SqF. Five builders were involved in the projects. Referring to Fig. 3.2, the projects were located in the C12 Area of the Toronto, Ontario zoning map.

Fig 3.2: Toronto Zoning Map, (REBO, 2008)

To investigate project delays, the as-planned and as-built schedules were required. The as-planned schedule is usually provided by the construction company. To obtain the as-built schedule, it was necessary to review items such as the construction specifications, the as-planned schedule, the updated schedule, the inspector's site reports, and the progress report as contained in the construction documents for each project provided by the construction companies.

The inspector's site reports usually cover three aspects: geographic, operations, and technical problems. In the geographic report, the inspector or the

site superintendent defines the location of construction or the inspection area as well as reporting weather conditions, job start time and job finish time. In the operation report, job meetings, equipment break down, material delivery, visitors, new operations, trade and subcontractors are discussed. This report also provides information on change orders, shop drawing changes and design changes. Finally, in the technical problems report, technical problems are identified as well as the party(s) liable for them.

3.3. As-built Schedule Development

The first stage in creating the as-built schedule was to examine and monitor construction tasks for each project and to collect data relevant to the scheduling of these tasks. Site explanations and relevant data were obtained from a review of written construction notes and photos. In addition, reviewing the progress scheduling report and checking the updated schedule helped determine the as-built schedule.

To determine the as-built schedule, project task delays were reviewed and the associated delay time was applied to the related task in the as-planned schedule. An as-built schedule was then created using MS-Project ® software.

3.4. Delay Quantification

After creating the as-built schedule, the next step was to identify and quantify project delays and to provide a basis to show the reason why major milestones could not be achieved.

As previously mentioned, several methods can be used for investigating delays in construction projects. Almost every one of these methods is founded on what-if or but-for assessment techniques, or both of them. All of these techniques are based on the calculated time difference between the as-planned and the as-built schedule.

In this thesis, the collapsing technique was used to investigate delay in the construction schedule. Investigating activities based on the as-built schedule and the monitoring of the actual record of construction in smaller time phases helps identify the responsible party for each delay. So, the as-built schedule not only determines the delay for each task, but also documents the responsible party for each delay.

The best way to investigate delays is to investigate project data on the critical path of both the as-planned and as-built schedules. In order to analyze the delays, one must consider each task separately and identify the problem. This entails finding the delays, and summarizing the delay types and the responsible party. To accomplish this, the construction activities for each housing

project were observed, including excavation, foundations, form-work, concreting, wood framing, installation of prefabricated wooden roof trusses, installation of doors and windows, masonry, fiberglass insulation, electrical rough-in and finishing, plumbing rough-in and finishing, dry walling, painting, carpeting and outside landscaping. Battika's delay source was then used to quantify the delay cause (refer to table 2.3).

As discussed in Chapter Two, delay is categorized in to one of three categories: (1) excusable compensable, which are caused by the owner's actions or responsibilities; (2) excusable non-compensable, which are delays where neither the owner nor the contractor is responsible; and (3) non-excusable, which are delays resulting from the contractors or sub-contractor's actions or responsibilities.

Usually the site report indicated which party was responsible for delay. So, in this study, the "delay-responsible report" provided by the individual builders was used to categorize delay liability.

Some delays may not affect the total project time, or affect the cost of construction directly; however, they may indirectly affect the cost and time of construction. For example, a delay in carpentry causes a delay in plumbing. Extra costs could then apply to plumbing materials if the plumber did not start on time. So, the carpentry delay may not have a direct affect on the overall

construction cost, but by creating a delay on the plumbing task it indirectly affected the total project cost.

3.5. Delay Analysis

All schedule delay impact analysis methods are acceptable in analyzing delays in a given situation. But some methods are more useful than others. In this thesis, a combination of the snapshot and CPA method was used to analyze the delays. By using these two methods, one technique's disadvantages were covered by the other technique's advantages

Delays such as those found in demolition & excavation tasks (like labor shortages) are common from job to job but vary in duration. Because delays and tasks both vary in duration, the best way to quantify the impact of the delay is to get a ratio of delay to total complete task time. In other words:

$$\text{Delay Ratio} = (\text{Original schedule time} + \text{Delay})_{(\text{days})} / \text{Original schedule time}_{(\text{days})} \quad (3.1)$$

For example if task J is scheduled to take 25 days to complete but it finishes in 30 days, it has 5 days delay, and the delay ratio of task J is $(25+5)/25=1.20$.

This same method can be used to obtain a delay ratio for the total project by comparing the total schedule to the total original schedule time.

Another way to present project progress, and thus quantify delay is to present the project progress linearly (Al-Momani, 2000) as:

$$Y=A+BX \quad (3.2)$$

This is shown in Fig 3.3.

Fig 3.3: Project Progress Diagram (Al-Momani, 2000)

Task duration can be presented in the same manner. If the task does not have an initial delay, A will be zero, and if the tasks follow the as-planned schedule, the value of B (i.e., the slope) will be one.

Once the delay ratio is determined, the delay ratio model can be developed.

If all project tasks are assumed to comprise one large task, the project progress line will be linear and after applying the delay ratio factors it will resemble Fig 3.4. But, if the delay ratio is applied to individual tasks, each task will have its own slope and the project progress line will be non-linear as presented in Fig 3.5.

Fig 3.4: Linear Project Progress Diagram

Fig 3.5: Non-linear Project Progress Diagram

The delay associated with each task may be a combination of several delay ratios. These delay ratios can be created based on the relationship between the delay cause and the liability. Relationships can be categorized in 21 classes. As shown in Fig 3.6, a template for the delay ratio model has been created as example. This model and the ratios are explained in chapter 4.

Table 3.1: Delay Ratio Model

		Cause (Ratio)						
		Poor Design	Change Order	Weather Condition	Site Condition	Late Delivery	Economic Condition	Upgrading
Liability	Excusable compensable	1.00	1.10	1.00	1.02	1.16	1.15	1.08
	Excusable non compensable	1.00	1.00	1.11	1.03	1.01	1.00	1.00
	Non-excusable	1.12	1.00	1.00	1.25	1.02	1.07	1.01

It is hypothesized that the relationship between delay cause and responsible party will be as shown in Fig 3.6.

		Cause						
		Poor Design	Change order	Weather Condition	Site Condition	Late Delivery	Economic Condition	Upgrading
Liability	Excusable compensable							
	Excusable non-compensable							
	Non-excusable							

Fig 3.6: Liability – Cause Relationships

In the above figure (Fig 3.6), if the cause affects only one liability category of delay, it is represented by a black cell. For example, the black colored cell for weather condition shows that the liability associated with this delay is always known as excusable non-compensable. If the source of delay affects more than one liability sector, it is represented by a gray cell. For example, site condition may present as an excusable non-compensable or a non-excusable liability depending upon the situation. A white cell means that the type of liability almost never applies to the major source of delay. For example, the white cell indicates that “excusable non-compensable” delays do not apply to delays related to economic conditions.

3.6. Development of Prototype Project scheduling program

Many scheduling programs exist, but the basic versions do not have the ability to apply delay ratio factors which can then be used to better estimate the final as-planned schedule. As part of this research a prototype computer program (Control Project) to do this was created using Microsoft Visual Basic ® programming (VB 6.0®). Control Project (CP) is not only a scheduling program, but it also has the ability to calculate the ratio factors and adjust a schedule automatically. In other words, the biggest advantage of this program compared to basic versions of other scheduling programs (e.g., Microsoft Project) is that it uses the delay ratio model and associated factors to calculate the total delay factor, and then applies that factor to task durations to get a more realistic as-planned schedule.

The CP computer program uses “Day Baseline Scheduling Methods”. This methodology is based on adjusting the critical path by daily or weekly time schedule. Adjusting the critical path by daily or weekly time schedule means that the non-working days are recognized and added to the total tasks time. So, the successor activities start after the previous activity period, plus non-working time (Hussein, 2002).

The CP software comprises three major components: choosing the calendar, choosing the task duration, and choosing the delay ratio factors.

To assist with entry of data several forms were created as shown in Figs. 3.7-3.9. The steps used to enter data are as follows (refer to appendix H for detailed instructions):

Step1-Choose the Calendar: For a regular time schedule it is not necessary to choose a name for the calendar. However, to customize the calendar and choose extra non-working days, it is necessary to create name and set up the non-working days in "Dates" box as shown in Fig 3.7.

Date	Comment
12/07/2007	Not work
12/04/2007	Not Work

Fig 3.7: Dates Window (msp_Calendar) & (msp_Dates)

To customize the calendar to change working days to non-working days, the user needs to choose the non-working date and then enter the comments if necessary. If this is a new day, click on (+) then add a new non-working day to

the list. If the intent is to change a non-working day to a working day, choose the day and apply (–) and the day becomes a working day.

Step 2-Choose task duration: to make a schedule, the user must set up the tasks and link them together. For this purpose, it is necessary to identify the task ID, task name, start date, duration of task, and the predecessor of each task (Fig 3.8). Once the task is added, the user is also to identify the delay ratio (Fig 3.9).

ID	Task	Start	Duration	Factor	Finish	Predecessor
1	s	05/11/2007	3	1.42	12/11/2007	
2	a	13/11/2007	2	1.42	15/11/2007	1
3	as	13/11/2007	1	1.42	13/11/2007	1
4	qw	16/11/2007	1	1.42	16/11/2007	1,2,3

Fig 3.8: Tasks Window (msp_Task)

Steps 1&2 are similar to most basic scheduling programs. Step 3 is where the prototype program allows the user to predict the schedule based on the delay ratio model.

Step 3-Choose delay ratio: To apply the delay ratio for each task, the appropriate ratios from the delay ratio model are entered into the effect factors

window as shown in Fig 3.9. After the delay ratios are entered the user clicks (+) to return to the task screen and the overall delay ratios and finish date for each task will be computed and displayed as “Factor”.

Factor Ratio	Poor Design	Change Order	Weather Condition	Site Condition	Late Delivery	Economical Condition	Upgrading
Excusable-compensable	-	1.1	-	-	1.16	-	-
Excusable-non-compensable	-	-	-	1.03	-	-	-
Non-excusable	1.12	-	-	-	-	-	1.08
*							

Fig 3.9: Effect Factor Window (msp_Factor)

The relationships between the CP tables are shown in Fig 3.10.

Fig 3.10: The CP Program Relationship Diagram

3.7. Summary

Whenever a delaying event is identified as impacting the normal progress of a task, the delay ratio model factor described in this chapter can aid in the analysis of the subsequent effect of the delay on the closing date of the project. An important stage involves documenting site data to create the as-built schedule. The next stage of the model assists in the categorization of delays by utilizing a cause-liability relationship matrix that relates the cause of delays to their corresponding liability.

The last stage is determining the effects of delays on the schedule by evaluating the as-planned, as-built, and task durations with respect to criticality, in order to establish if they will have an impact on the project completion date.

Chapter Four: Data Analysis

The site report and schedules review yielded several findings that could be generalized to all projects. For example, some construction tasks, such as inspections, are found in all projects. These tasks are common and typically have similar durations. Tasks, such as interior finishing, are common to all projects but vary in duration from one project to another, depending on the quantity and the quality of work.

Some tasks, such as pouring foundations, are repetitive in nature and usually follow a standard design. Thus, it could be anticipated that the expected delay duration on this type of task would be similar from one project to another. This is not the case however. Local conditions, weather conditions, or resource availability are the reasons for this difference in task duration or delay duration on different projects for the same tasks. For example, if a contractor uses itinerant subcontractors, they are typically assigned to work on site for a limited time and the contractor has limited controls on when they are available to work. Other contractors hire more established subcontractors for the same tasks on multiple jobs, and thus have better control over their on-site availability. This helps when estimating the delay duration for those specific contractors.

Some task durations may increase because of weather conditions. For example, a snow storm in winter or high temperatures in summer impact the

construction time and cause delays for some tasks such as carpentry and framing. Fig 4.1 shows a construction site during the winter in which a major snow fall caused a delay in the installation of the roof trusses.

Fig 4.1: Winter Conditions in Toronto

44.1. Investigation of As-planned Schedule

Some tasks in high-end residential projects may have different durations depending on the size and quality of the work. The result is that each project has a different schedule. In other words, each project has a unique combination of

tasks that make up the critical path. This is shown in Table 4.1 where the critical paths of projects "A" & "B" are compared.

Table 4.1: Comparison of Critical Paths for Project "A" & "B"

Project "A"		Project "B"	
ID	Task	ID	Task
Id 3	Order lumber	Id 7	Demolition and excavation
Id 15	Carpentry	Id 8	Footing and Foundation
Id 17	Install truss	Id 15	Carpentry
Id 25	Plumbing (rough)	Id 16	Install Exterior doors and Windows
Id 28	Pouring concrete of basement	Id 25	HVAC (rough)
Id 30	Boxing Basement	Id 29	Boxing Basement
Id 35	Insulation and vapor barrier	Id 34	Insulation and vapor barrier
Id 37	Dry wall	Id 36	Dry wall
Id 38	Taping	Id 37	Taping
Id 40	Flooring	Id 38	Painting (rough)
Id 41	Installing Kitchen and Vanity	Id 39	Flooring
Id 46	Finish Painting	Id 40	Installing Kitchen and Vanity
		Id 45	Finish Painting

In general, each project has a specific duration. By using the most likely time, it is possible to estimate the task duration for a similar quantity of work and based on that it is possible to estimate the project duration and /or delay duration of the project.

Fig 4.2 shows the full as-planned schedule for project A. The as-planned schedule for remaining projects can be found in Appendix A.

Fig 4.2: As-planned Schedule for Project "A"

4.2. Investigation of As-built Schedule

There are activities whose as-built duration differs from the as-planned duration. This is because the schedule is affected by a number of delays that occur during the construction period. Examples of common delays observed in the project tasks in this research include:

- **Excavation task:** the contractor encountered unforeseen rock during foundation excavation. Work was temporarily suspended because the owner's consultant had to conduct further tests and redesign the footing. Thus, the excavation task proceeded slowly due to these difficult soil conditions.
- **Foundation task:** the foundation work was delayed because the owner failed to turn the site over on time, or because the subcontractor proceeded more slowly than anticipated.
- **Pouring Basement Slab task:** there was a delay to the start of the task because the owner failed to give access to site (turn the site over) on time.
- **Carpentry task:** the progress of the activity was interrupted because the owner decided to change the layout.
- **Roofing task:** originally, the roofing work was to be performed during good weather; however, snow and rain impacted the start date and the duration of the task.

- Electrical and Mechanical task: a delay occurred due to a change order issued by the owner's architect to modify the type of equipment to be installed.

Although not a task, cost adjustment due to the changing of the cost of the materials also caused delay. For example, the changing cost of metal was a reason for delay because it was necessary to adjust the contract price between the owner and contractors.

In the following Figure (Fig 4.3), the as-built schedule for project A is shown. By comparing the as-planned (Fig 4.2) and as-built schedules of project A, it is can be see that project A was scheduled to finish on Friday 9/11/2006 but the project finished on Saturday 10/13/2006 thereby incurring 32 calendar days or 23 working days delay on the overall project. The causes of this delay will be presented later in this chapter.

The as-built schedules for the remaining projects are located in Appendix B.

The investigation of the as-planned and as-built schedule and the report from the job site for each project facilitated the quantification and categorization of delays. Table 4.2 is an example of delay information for project "A". The remaining reports can be found in Appendix C.

Table 4.2: Delay Information for Project "A"

Job Section	Delay Type	Days	Description
Demolition & excavation & Inspection	Excusable compensable	2	Two days delay for issuing the demolition permit, Owner's responsibility.
Demolition & excavation & Inspection	Excusable non-compensable	6	Two period of rain pouring each 3 days caused the contractor to stop the jobs.
Demolition & excavation & Inspection	Non-excusable	3	The contractor did not show up in job site for 3 days.
Demolition & excavation & Inspection	Non-excusable	3	The site area was eroded and the contractor took 3 days to clean area. The area must be protected by the contractor.
Footing and Foundation	Excusable compensable	1	Delay in requesting inspection
Footing and Foundation	Excusable non-compensable	1	One day delay result of weather condition.
Exterior Wall Construction	Excusable compensable	2	Delay by supplier
Exterior Wall Construction	Non-excusable	5	The contractor took off 2 times during construction. However, they started the jobs 3 days in advance.
Wiring(rough)	Excusable compensable	6	Copper price changed, need to review the price with owner.
Wiring(rough)	Non-excusable	4	The contractor delays.
Plumbing(rough)	Excusable compensable	15	Copper price changed, need justified the price with owner.
Plumbing(rough)	Non-excusable	5	Failed plumbing inspection
HVAC(rough)	Excusable compensable	5	Adding second furnace in second floor.
Pouring concrete of basement & stair& Draining	Non-excusable	4	The contractor delays.
Pouring concrete of basement & stair& Draining	Excusable compensable	3	General contractor(owner) did not remove garbage on-time from basement.
Insulation and vapor barrier	Excusable non-compensable	1	Contractor start the job on Monday because of wet concrete.
Taping	Non-excusable	7	The contractor delays.
Installing Kitchen and Vanity	Excusable compensable	7	Delay by owner because of late order and change kitchen design.
Installing Kitchen and Vanity	Non-excusable	7	The contractor delays.
Finish Plumbing	Excusable compensable	4	Delay by owner because of late order of fixtures.
Installing Interior doors & Finish carpentry	Excusable compensable	5	General contractor(owner) delay in ordering the materials.
Finish Painting	Non-excusable	2	Extra touch ups required.
Landscaping	Excusable non-compensable	5	Weather.
Landscaping	Non-excusable	2	The contractor delays.
Pre-delivery inspection	Excusable compensable	3	Buyer wanted to close the deal on Friday.

Note: Not all tasks listed in table 4.2 are included in the critical path.

4. 3. Delay Analysis

Once the delays are quantified and categorized, an analysis of the delays was undertaken based on delay cause and liable party, and the delay ratio model was created.

4. 3.1 Result of Delay Analysis Based on Delay Cause

As stated in Chapter Two section 2.2.3.2, delay cause can be classified in seven major areas (Battikha et al, 1994): 1) poor design; 2) change order; 3) weather conditions; 4) site conditions; 5) late delivery; 6) economic conditions; and 7) upgrading.

These causes are summarized for project “A” in Table 4.3. It can be seen from the table that some delays have high delay ratios which are most likely to be found in short duration tasks like the pre-delivery task, while long duration tasks have a smaller ratio (i.e. 1.5 or less).

The complete results from the delay analysis can be found in Appendix “D”.

Table 4.3: Delay Cause Investigation for Project "A"

Task	Task Duration (Day)	Poor Design (Day)	Delay Ratio	Change order (Day)	Delay Ratio	Weather Condition (Day)	Delay Ratio	Site Condition (Day)	Delay Ratio	Late Delivery (Day)	Delay Ratio	Economic Condition (Day)	Delay Ratio	Upgrading (Day)	Delay Ratio
Demolition & excavation & Inspection	17.00		1.00		1.00	6.00	1.35	3.00	1.18	2.00	1.12	3.00	1.18		1.00
Footling and Foundation	12.00		1.00		1.00	1.00	1.08		1.00	1.00	1.08		1.00		1.00
Exterior Wall Construction	21.00		1.00		1.00	1.00	1.00	5.00	1.24	2.00	1.10		1.00		1.00
Wiring(rough)	15.00		1.00		1.00		1.00	4.00	1.27		1.00	8.00	1.40		1.00
Plumbing(rough)	15.00	5.00	1.33		1.00		1.00		1.00		1.00	15.00	2.00		1.00
Heating(HVAC)(rough)	15.00		1.00		1.00		1.00		1.00		1.00		1.00	5.00	1.33
Pouring concrete of basement+ stair+ Draining	13.00		1.00		1.00		1.00	4.00	1.31	3.00	1.23		1.00		1.00
Insulation and vapor barrier	3.00		1.00		1.00		1.00	1.00	1.33		1.00		1.00		1.00
Taping	10.00		1.00		1.00		1.00	7.00	1.70		1.00		1.00		1.00
Installing Kitchen and Vanity	7.00		1.00	7.00	2.00		1.00		1.00	2.00	1.29	5.00	1.71		1.00
Finish Plumbing	3.00		1.00		1.00		1.00		1.00	4.00	2.33		1.00		1.00
Installing interior doors + Finish carpentry	10.00		1.00		1.00		1.00		1.00	5.00	1.50		1.00		1.00
Painting	7.00		1.00		1.00		1.00	2.00	1.29		1.00		1.00		1.00
Landscaping	5.00		1.00		1.00	5.00	2.00	2.00	1.40		1.00		1.00		1.00
Pre delivery inspection	1.00		1.00	3.00	4.00		1.00		1.00		1.00		1.00		1.00
Average Ratio			1.02		1.27		1.10		1.18		1.18		1.15		1.02
Total Delay Task		5.00	1.03	10.00	1.08	12.00	1.08	28.00	1.18	19.00	1.12	29.00	1.19	5.00	1.03

Table 4.4 presents the amount of delay by cause for each individual project as well as all projects. This is presented graphically in Fig 4.4.

Table 4.4: Amount of Delay by Cause

Projects	Delay (days)						
	Poor Design	Change order	Weather Condition	Site Condition	Late Delivery	Economic Condition	Upgrading
A	5	10	12	28	19	29	5
B	27	33	5	22	15	54	12
C	44	5	12	10	9	17	19
D	6	25	12	47	20	3	9
E	5	0	4	65	24	26	5
F	5	0	4	65	24	26	5
G	20	0	71	56	37	37	2
H	0	14	13	21	30	7	18
I	8	16	5	20	29	0	0
J	0	0	8	30	23	36	12
Total delay (days)	120	103	146	364	230	235	87
Percentage of total delay	9.34	8.02	11.36	28.33	17.90	18.29	6.77

Fig4.4: Percentage of Delay Cause – All Projects

From Figure 4.4 and Table 4.4, the following observations can be made:

The most common delay cause was “site condition”. It was found that this delay occurred 28% of the time. Most delays in this category were attributable to contractor(s) actions. Examples include: the issuing of a stop order because of safety; failure of equipment; and the lack of supervision of subcontractor performance by a contractor.

The second and third most common delay causes were “economic conditions” and “late delivery” which accounted for 18.3 % and 17.9 % of all delay respectively. The least likely delay cause was upgrading at 6.8%.

One factor that could have affected the frequency of the “economic condition” delay cause was the increase in the price of metal during 2006 and 2007. However, the failures to “provide the payment” and “cash flow limitation” were the main reasons for these types of delays. Late delivery delays were found to be related to the late ordering of materials or equipment by owner.

4. 3.2. Result of delay analysis based on the responsible party

Once the delays durations were determined, it was then possible to calculate the delay ratios for each of the liable parties. The analysis was based on the same method as delay cause.

Project “A” is reviewed as an example in the following table (4.5), the other project analyses can be found in Appendix “E”.

Table 4.5: Delay Liabile Party Investigation for Project "A"

Job Section	Task Duration (days)	Excusable compensable (days)	Delay Ratio	Excusable non- compensable (days)	Delay Ratio	Non-excusable (days)	Delay Ratio
Demolition & excavation & Inspection	17.00	2.00	1.12	6.00	1.35	6.00	1.35
Footing and Foundation	12.00	1.00	1.08	1.00	1.08	0.00	1.00
Exterior Wall Construction	21.00	2.00	1.10	0.00	1.00	5.00	1.24
Wiring(rough)	15.00	6.00	1.40	0.00	1.00	4.00	1.27
Plumbing(rough)	15.00	15.00	2.00	0.00	1.00	5.00	1.33
HVAC (rough)	15.00	5.00	1.33	0.00	1.00	0.00	1.00
Pouring concrete of basement+ stair+ Draining	13.00	3.00	1.23	0.00	1.00	4.00	1.31
Insulation and vapor barrier	3.00	1.00	1.33	0.00	1.00	0.00	1.00
Taping	10.00	0.00	1.00	0.00	1.00	7.00	1.70
Installing Kitchen and Vanity	7.00	7.00	2.00	0.00	1.00	7.00	2.00
Finish Plumbing	3.00	4.00	2.33	0.00	1.00	0.00	1.00
Installing interior doors + Finish carpentry	10.00	5.00	1.50	0.00	1.00	0.00	1.00
Painting	7.00	0.00	1.00	0.00	1.00	2.00	1.29
Landscaping	5.00	0.00	1.00	5.00	2.00	2.00	1.40
Pre delivery inspection	1.00	3.00	4.00	0.00	1.00	0.00	1.00
Average Ratio of Delay By Task			1.56		1.10		1.26
Total Delay Task	154.00	54.00	1.35	12.00	1.08	42.00	1.27

The percentage of each delay by liability of delay is shown by task in the following table (Table 4.6).

Table 4.6: Percentage of Each Delay Responsibility for All Projects

	Job Section	Excusable compensable	Percentage in project	Excusable non-compensable	Percentage in project	Non-excusable	Percentage in project	Percentage in all cases
1	Demolition & excavation & Inspection	5.00	7.14	5.00	20.00	9.00	12.16	11.24
2	Footing and Foundation	7.00	10.00	7.00	28.00	1.00	1.35	8.88
3	Back filling		0.00	1.00	4.00	1.00	1.35	1.18
4	Trusses order	1.00	1.43		0.00		0.00	0.59
5	Carpentry	5.00	7.14	3.00	12.00	7.00	9.46	8.88
6	Ext.Wall Construction	6.00	8.57		0.00	2.00	2.70	4.73
7	Roofing	1.00	1.43		0.00	1.00	1.35	1.18
8	Wiring(rough)	7.00	10.00		0.00	8.00	10.81	8.88
9	Plumbing(rough)	6.00	8.57		0.00	8.00	10.81	8.28
10	Heating(HVAC)(rough)	6.00	8.57		0.00		0.00	3.55
11	Pouring concrete of basement+ stair+ Draining	3.00	4.29	1.00	4.00	5.00	6.76	5.33
12	Insulation and vapor barrier	3.00	4.29		0.00		0.00	1.78
13	Dry wall	2.00	2.86		0.00	2.00	2.70	2.37
14	Taping		0.00	1.00	4.00	6.00	8.11	4.14
15	Flooring	1.00	1.43		0.00		0.00	0.59
16	Installing Kitchen and Vanity	4.00	5.71		0.00	5.00	6.76	5.33
17	Finish Plumbing	3.00	4.29		0.00	1.00	1.35	2.37
18	Installing Interior doors + Finish carpentry	6.00	8.57		0.00	4.00	5.41	5.92
19	Finish Painting	2.00	2.86		0.00	7.00	9.46	5.33
20	Landscaping	1.00	1.43	7.00	28.00	7.00	9.46	8.88
21	Pre delivery inspection	1.00	1.43		0.00		0.00	0.59
	Total case	70.00	100.00	25.00	100.00	74.00	100.00	100.00
	Cases percentage	41.42		14.79		43.79

Fig 4.5: Percentage of Each Delay Liability for All Projects

Fig 4.5 shows that the non-excusable delay liability is almost equal to the excusable compensable delay liability. In other words, the owner of project was as responsible for delays as the contractor of the project.

4.3.3. Analysis of Delay Liability - Cause

The purpose of the delay liability-cause analysis was to determine if the proposed model in Fig 3.7 was valid. Once the delay analysis by cause and liability was complete, the model could be evaluated.

In order to do this, it was necessary to investigate all projects and to find the relationship between the responsible parties and the delay cause based on the percent each delay cause contributed to each liability category. The results

for project A are shown in Table 4.7 and for all projects in Table 4.8. (Refer to Appendix F for the remaining individual project results).

It can be seen from the overall results that the highest percentage of all delays by liability was attributable to site condition (27.5%) and was a non-excusable liability. The second highest delay was due to economic condition and was an excusable compensable liability.

Table 4.7: Liability-cause Relationship by Percentage for Project "A"

Liability	Delay Cause (%)						
	Poor Design	Change order	Weather Condition	Site Condition	Late Delivery	Economic Condition	Upgrading
Excusable compensable	0.00	9.26	0.00	0.93	15.74	19.44	4.63
Excusable non-compensable	0.00	0.00	11.11	0.00	0.00	0.00	0.00
Non-excusable	4.63	0.00	0.00	25.00	1.85	7.41	0.00
Total Percentage	4.63	9.26	11.11	25.93	17.59	26.85	4.63
							100.00

Table 4.8: Liability-cause Relationships by Percentage for All Projects

Liability	Delay Cause (%)						
	Poor Design	Change order	Weather Condition	Site Condition	Late Delivery	Economic Condition	Upgrading
Excusable compensable	0.25	9.50	0.00	2.10	15.34	12.28	6.16
Excusable non-compensable	0.00	0.00	10.38	2.50	0.68	0.29	0.00
Non-excusable	8.92	0.00	0.00	22.91	1.28	5.70	0.97
Total Percentage	9.17	9.50	10.38	27.51	17.30	18.27	7.13
							100.00

It can be seen from the overall results that the excusable compensable delay accounted for 45.6 % of all delays, which was calculated as 41.4% when delay liability was calculated by task and not by cause as shown in Table 4.6. Excusable non-compensable delays accounted for 13.9% of all delays, which in the last section were calculated as 14.8%. Finally, non-excusable delays accounted for 40.5% of all delays, compared to 43.8% in Table 4.6. The reason for these differences is based on the calculation methods. In Table 4.5, the method of calculation is based on comparing the total percentage of delays by task. But in Table 4.8 the method is based on the delay percentage by causes.

Next, the results presented in Tables 4.7 & 4.8 were calculated using the delay ratio method.

The results for project A are shown in Table 4.9. (Refer to Appendix F for the remaining individual project results). The result of the investigation of all projects based on the relationship between the responsible parties and the delay cause based on the average ratio are shown in Table 4.10.

Table 4.9: Liability-cause relationship by delay ratio for Project "A"

Liability	Delay cause (Ratio)					
	Poor Design	Change order	Weather Condition	Site Condition	Late Delivery	Economic Condition
Excusable compensable	1.00	1.06	1.00	1.01	1.11	1.14
Excusable non-compensable	1.00	1.00	1.08	1.00	1.00	1.00
Non-excusable	1.03	1.00	1.00	1.18	1.01	1.05
Total Ratio	1.03	1.06	1.08	1.18	1.12	1.19
						1.03

Table 4.10: Liability-cause Relationship by Delay Ratio for All Projects

Liability	Delay cause (Ratio)						
	Poor Design	Change order	Weather Condition	Site Condition	Late Delivery	Economic Condition	Upgrading
Excusable compensable	1.00	1.10	1.00	1.02	1.16	1.15	1.08
Excusable non-compensable	1.00	1.00	1.11	1.03	1.01	1.00	1.00
Non-excusable	1.12	1.00	1.00	1.25	1.02	1.07	1.01
Total Ratio	1.12	1.10	1.11	1.29	1.18	1.22	1.08

4.4. Determining Schedule Delay

The result of Table 4.8 can be used to determine the potential overall delay due to the delay cause and responsible party. For example, if the duration of task “G” is estimated at ten days, but there is a likelihood that it will be affected by a “weather condition” delay, then from Table 4.8 it can be deduced that the estimated time of the task must be increased by 10.4% to obtain the most likely duration. Therefore, using equation 4.2, task “G” will be finished in 11.4 days:

R= Real task completion time.

E= Estimated task completion time.

P= Additional percentage to complete the task from Table 4.8.

$$R = E + (P \times E/100) \quad (4.2)$$

$$R = 10 + (10 \times 0.104) = 11.4 \text{ Days}$$

In the case of several delays affecting the task, total delay is determined by the sum of all the delay percentages. For example, if task “G” is affected by both a “weather condition” and a non-excusable “site condition” delay, then the total additional time for this task will be 3.3 days (from Table 4.8).

$$R = E + (E \times (P_1 + P_2)/100) \quad (4.3)$$

$$R = 10 + (10 \times (0.104 + 0.23)) = 13.3 \text{ Days}$$

This delay percent method is based on the total percent delay by liability-cause relationships. Therefore, the output from this method will be an approximate value.

Another method is the delay ratio method. This method (Table 4.10) is based on the ratio of the total delay of all the tasks to the total duration of the tasks. As an example of the ratio method, task "G" when delayed by "weather condition", will be finished in 11.1 days based upon the following principle:

R= Real task completion time.

E= Estimated task completion time.

W= Ratio to completion of the task from Table 4.10.

$$R = W \times E \quad (4.3)$$

$$R = 1.11 \times 10 = 11.1 \text{ Days}$$

In the case of several delays affecting the task, total delay is determined by the sum of all delay ratios. For example, if task "G" is affected by both the "weather condition" and non-excusable "site condition" delay, then the total additional time will be 3.5 days (from Table 4.10).

$$R = E \times (W_1 + W_2) \quad (4.4)$$

$$R = 13.5 \text{ Days}$$

4. 4.1.Comparision of Initial and Delay Ratio Model As-planned Schedules

Fig 4.2 and 4.3 showed the Microsoft Project® as-planned and as-built schedules for project “A”. The closing date of the project “A” as-built schedule was compared to the as-planned schedule. According to Fig 4.2 the schedule indicates that the closing date for the project was on 11th September 2006. When compared to the as-built schedule in Fig. 4.3, it can be seen that the project had an actual closing date 13th October 2006. Close to a one month (32 calendar days or 23 working days) delay was not considered in the scheduling of project “A”.

When the delay ratios were applied (table 4.11) and the as-planned schedule created, the estimated time period of each task was affected. The delay “new” as-planned schedule is shown in Fig 4.6. The project closing date according to the model is 24th October 2006. In other words, the difference between actual as-built and the DRM as-planned schedule were 11 days.

The factors used for the DRM as-planned schedule for project “A” in Fig 4.6 can be found in Table 4.11.

Table 4.11: Comparison of As-planned Schedule Delay Ratio Task Durations

	Task Duration	Delay Ratio Factor Combination	Modify Task Duration
Task	Day	Ratio	Day
Demolition & Excavation & Inspection	17	1.13	19
Footing and Foundation	12	1.15	14
Back filling	2	1.43	3
Carpentry	30	1.36	41
Exterior Wall Construction	21	1.59	33
Roofing	14	1.11	16
Wiring (rough)	15	1.35	20
Plumbing (rough)	15	1.63	24
HVAC (rough)	15	1.18	18
Pouring Concrete of Basement	3	1.02	3
Landscaping	5	1.31	7
Insulation and Vapor barrier	3	1.12	3
Painting (rough)	5	1.25	6
Finish (HVAC)	3	1.22	4
Finish Electrical	3	1.22	4
Finish Plumbing	3	1.22	4
Flooring	10	1.49	15
Installing Kitchen and Vanity	7	1.13	8
Installing Interior doors and Finish carpentry	10	1.18	12

Fig 4.6: DRM As-planned Schedule for Project "A"

A comparison of the project closing time for three schedules: the original as-planned schedule, DRM as-planned schedule and as-built schedule for project "A" is shown in Figure 4.7.

Fig 4.7: Compare As-planned Schedule DRM with As-built and Original As-planned for Project "A"

4. 5. Implementation of Prototype program

Many scheduling computer programs exist for planning and scheduling projects. Some programs such as Microsoft Project®, Primavera®, and All Chart Bar® have a graphic solution. Others like Home Schedule® and Base Time® may not have this function, but both give useful results. Microsoft Project or Primavera is more commonly used by the industry.

Once the delay ratio factors were calculated, they could be used in the CP program to adjust the initial as-planned schedule to incorporate anticipated delays.

The methodology to estimate project duration using the delay ratio factors described in chapter 3 was implemented. The scheduler determines the relevant delay cause ratio from the model for each task that experiences a delay to predict project duration and inputs it into the CP program. Fig 4.8 is an example of the application of the CP program with the applied ratios for project A.

Project "A"							
				5/ 1/2008		1	
ID	Task	Start	Duration	Factor	Finish	Predecessor	
1	Start job	16/02/2006	1	1.13	16/02/2006		
2	Ordering	17/02/2006	12	1	06/03/2006	1	
3	Demolition & excavation &	07/03/2006	17	1.13	31/03/2006	1	
4	Footing and Foundation	03/04/2006	12	1.15	20/04/2006	3	
5	Back filling	21/04/2006	2	1.43	25/04/2006	4	
6	Carpentry	21/04/2006	30	1.36	16/06/2006	4	
7	Ext.Wall Construction	19/06/2006	21	1.59	02/08/2006	6	
8	Roofing	19/06/2006	14	1.11	10/07/2006	6	
9	Wiring(rough)	19/06/2006	15	1.35	14/07/2006	6	
10	Plumbing(rough)	19/06/2006	15	1.63	20/07/2006	6	
11	Heating(HVAC)(rough)	19/06/2006	15	1.18	12/07/2006	6	
12	Boxing	21/07/2006	20	1	17/08/2006	6,9,10,11	
13	Pouring concrete of basem	21/07/2006	13	1.02	08/08/2006	10	
21	Landscaping	08/08/2006	5	1.31	16/08/2006	13	
14	Insulation and vapor barri	18/08/2006	23	1.12	22/09/2006	12	
15	Painting	25/09/2006	5	1.25	02/10/2006	14	
16	Finishes(HVAC,Electrical,	03/10/2006	3	1.22	06/10/2006	15	
17	Flooring	03/10/2006	10	1.49	23/10/2006	15	
18	Installing Kitchen and Va	03/10/2006	7	1.18	12/10/2006	15	
19	Installing Interior doors +	03/10/2006	10	1.18	18/10/2006	15	
20	Finish Painting	19/10/2006	2	1	20/10/2006	16,18,19	
22	PDI & Job Finishing	23/10/2006	1	1	23/10/2006	21,20,7	

Fig 4.8: As-planned Schedule for Project "A" with DRM

The DRM schedule, created using the prototype program, was compared to the DRM schedule created using Microsoft Project® to validate the assumptions and programming used in the development of the CP program. The prototype program results differed from the Microsoft Project® results by only one day. This error is due to a rounding error, and is basically negligible over 180 working days.

Chapter Five: Result Analysis

Projects can be delayed for many reasons. These delay causes can be due to change orders, late delivery, weather conditions or several other possible categories as shown in the last chapter. In this chapter, the findings of chapter four are discussed.

5. 1. Delay-Liability Analysis

5. 1.1. Delay by Cause

Limited research has been done on quantifying delays in the residential construction sector. Most of these studies have been undertaken in the Middle East.

Al-Momani (2000) used Battikha's delay cause-delay source model in his research to classify construction delays in the Jordanian construction sector. His results, presented in Table 5.2, identified the occurrence of delay by cause for different types of facilities. Al-Momani's research showed that poor design was the leading cause of delays in the housing sector 36% of the time (4 occurrences out of 11). Site condition was the least important delay cause occurring only 9% of the time. This contrasts with the findings (refer to Table 4.4) of the Toronto

residential construction sector where poor design accounted for only 9.3% of delays, while site condition delay accounted for 28.3% of delays.

Table 5.1: Occurrences of Delay by Cause (After Al-Momani, 2000)

Classification	Poor design	Change orders	Weather	Site condition	Late delivery	Economic condition	Increase in quantity	Total
House	4	1	3	1	0	0	2	11
Office	8	5	4	2	1	4	5	29
School	10	8	6	5	4	2	3	38
Medical centers	6	4	2	0	3	2	1	18
Communication facilities	4	2	1	0	2	0	1	10
Total	32	20	16	8	10	8	12	106

Following Al-Momani, a summary of research on project delays was undertaken by Sweis et al (2008). This work indicated that slow preparation and approval of shop drawings were the reasons for the poor design delay cause in the Middle East region.

One reason that delays due to shop drawings were the primary delay source in Middle East projects is that a contractor receives a less complete design package than would occur in the Toronto construction sector. In addition, in the Middle East, the approval of shop drawings is the mandate of the local municipality. Therefore, the contractor has limited ability to influence the speed at which approvals are granted. In the City of Toronto, the approval of shop drawings lies with a professional engineer or architect, not the municipality. The municipality's role is that of verification.

Site condition delays in the Middle Eastern projects were due mainly to a shortage of labor. While labor shortages were common to both sectors the stop

work order delays are most prevalent in Toronto due to the more stringent occupational health & safety legislation in Canada as compared to the Middle East. As an example, a stop work order would be issued in Toronto for an unorganized, unclean site. This would not normally occur in the Middle East.

5. 1. 2. Delay by Liability

Due to complications in determining the relationship between different parties in residential construction projects, delay by liability is very hard to determine. Several studies have been done on quantifying delays in the residential construction sector; however, delay by liability has not been studied. Alkass et al (1987) quantified the liability of delays in the broader construction sector. Their findings show that the share of “Excusable compensable” and “Non-excusable” delays in other construction sectors was almost equal. This is confirmed by the findings in this research, as well.

5. 1. 3. Mitigation of Delay Cause

As noted previously, stop work orders and a shortage of labor were the primary cause of “site condition” delay in Toronto, accounting for 28% of all delays. To reduce the risk of the delay, contractors must try to eliminate the source of delay such as “stop work orders due to safety issues” and “shortage of labor”. To reduce delays resulting from stop work orders, general contractors must do a better job of training and monitoring subcontractors when it comes to

occupational health & safety to ensure compliance with the legislation. Simple acts such as holding the site superintendent and crew leader accountable for site safety and holding safety “tool box” talks have been shown to be very effective in reducing health and safety infractions.

Other sources of site condition delays such as fire can also be mitigated by the contractor. If the contractor educates employees on fire prevention and protection, he/she can reduce the risk of fire on the job site. As with health and safety, education and management buy-in are key.

Finally, failure of equipment is another delay cause that can be controlled by the contractor. Regular maintenance of equipment is critical to reducing the likelihood of failure during construction. Contractors may believe they are saving money by ignoring equipment maintenance; however, one day’s delay due to failure can be far more costly to a contractor than the money saved by deferring maintenance. For example, the cost of maintenance for a jackhammer is approximately \$150/year, the cost to replace a jackhammer is over \$2,000 plus the associated delay costs incurred while the task is stopped awaiting the new hammer.

The second most frequent delay cause, economic condition, is mostly due to the owner’s cash flow problems which the contractor cannot mitigate directly. However, the contractors can reduce the effect of this kind of delay cause on project duration. When cash flow is limited due to the owner’s failure to pay

promptly, the contractor may reduce the risk of delay due to lien or strike by trying to negotiate a flexible payments schedule with the subcontractors. Ideally, this should be discussed in advance.

Late delivery delays are primarily due to the failure to obtain permits in the housing industry. The owners or their representatives are responsible for obtaining all construction related permits, and often they delay obtaining the permits. To avoid this kind of delay, owners should make this task part of the contract terms and conditions as is done in other construction sectors. This transfers the delay risk to contractor

The likelihood of weather conditions causing an excusable non-compensable delay can be estimated by examining historical weather records to look for trends. For example, the roofing task is affected by temperature, wind and precipitations. By incorporating the potential delay due to weather into the schedule, the risk of this kind of delay may be reduced through better planning.

The last important delay cause that involves the contractor is “poor design”. In this study, this turned out to be because of unapproved materials. Unfortunately, contractors often try to reduce the cost of construction to their benefit, by using materials that are cheaper in price but are not necessarily approved by any authority such as the Canadian Standards Association (CSA). To reduce the risk of delay because of “denial of construction material approval”,

contractors should use the material that has been approved. The owner also bears responsibility not to encourage contractors to use unapproved materials.

5. 1. 4. Proposed changes to Battikha's Delay Cause-Delay Source Model

While Battikha's cause-delay model has been used by many researchers, the findings of this research showed that several modifications need to be made to the model, specifically to the weather condition, site condition, late delivery and economic condition delay causes.

The weather condition delay cause was modified to change the "storm and blizzard" delay source to just "storm", as this includes all severe weather such as blizzard, hail & wind storms. The previous term specified blizzard but not other storm conditions such as hail, tornadoes, etc. Therefore, it was felt that storm was a more meaningful term.

The site condition delay cause was modified to "site occurrence" as this better reflects that the delay source is due to an "on site" event as opposed to a site condition. The term site condition is contractually taken in the construction industry to mean the physical condition of the site. In addition "shortage of labor and supplies" was added as a delay source. This includes all events such as a labor strike or damaged material on the job site.

Delays due to war was removed as this was not, and has not been, a factor in the last 50 years in the Canadian construction sector.

The late delivery delay cause was modified to add “delay in obtaining the permit”. As noted in the last section, in the housing industry, the owner or his/her representative is responsible for “obtaining the permit” for each stage of construction such as demolishing, constructing, plumbing and heating. Battikha’s model does not reflect this.

The economic condition delay cause was also modified to include additional delay sources. The first, “failure to manage the payments to subcontractors” is an important aspect and includes liens or other legal actions of subcontractor against the contractor and owner. The second added source was “material price change”. In the current volatile market metal price changes, especially copper and steel, were one of the major sources of delay as they forced up the price of construction and thus, the contractor had to negotiate with owner to obtain additional funds to allow extra costs.

Finally, the “bankruptcy” delay source was changed to “insolvency” as this term includes all severe economic conditions, ranging from cash flow, liquidity and potentially bankruptcy that could be experienced by contractor.

The changes proposed above are highlighted in revised model shown in Table 5.2:

Table 5.2: Modified Delay Cause-Delay Source Model

Delay Cause	Delay Source
Poor design	<ul style="list-style-type: none"> • Defects in plan and specifications • Delay because of defects in shop drawings • Delay because of denial of construction material approval • Lack of information
Change order	<ul style="list-style-type: none"> • Order to stop work • Change orders in any construction stage
Weather condition	<ul style="list-style-type: none"> • Failure to provide heater on job site • Failure to provide cooling system on job site • Storm
Site occurrence	<ul style="list-style-type: none"> • Failure to access to site • On site condition • Shortage of labor and supplies • Stop order due to safety issues • Failure of equipment • Lack of supervision • Earthquakes • Fire and flood • Subcontractor performance
Late delivery	<ul style="list-style-type: none"> • Owner's furnished materials not available • Delay in obtaining the permit • Due to strikes • Late delivery by suppliers
Economic condition	<ul style="list-style-type: none"> • Failure to finance the project • Failure to manage payments to subcontractors • Material price change • Failure to provide the payments • Cash flow limitation • Insolvency
Upgrading	<ul style="list-style-type: none"> • Introduction of major changes in requirements • Upgrading work to certain manner • Upgrading the construction standard • Governmental acts and regulations

5. 2. Discussion of liability-cause Relationships Table

Based on the results of the liability-cause relationships, the relationships proposed in Fig 3.7 were validated. The results of the liability-cause relationships based on percentage results (Table 4.8) are shown in Fig 5.1.

		Cause						
		Poor Design	Change order	Weather Condition	Site Condition	Late Delivery	Economic Condition	Upgrading
Liability	Excusable compensable							
	Excusable non-compensable							
	Non-excusable							

Fig 5.1: Revised Delay Liability - Cause Relationships Based on Percentage Results

The results of the liability-cause relation based on the ratio results are shown in Fig 5.2.

		Cause						
		Poor Design	Change order	Weather Condition	Site Condition	Late Delivery	Economic Condition	Upgrading
Liability	Excusable compensable							
	Excusable non-compensable							
	Non-excusable							

Fig 5.2: Revised Delay Liability - Cause Relationships Based on Ratio Results

It can be seen in Fig 5.2 that five types of delays were consistent with Fig. 5.1. Only poor design and economic condition differed. This difference is based on the method of calculation. Each of these causes contributed less than 0.3% to the overall delay occurrence, however. This difference is considered insignificant and thus the delay ratio result (Fig 5.2) is chosen to compare to the hypothesized model.

This model presents relationships between delay causes and liable party that differ from what was hypothesized in Fig 3.7. These are: poor design (excusable compensable), site condition (excusable compensable); late delivery (excusable non- compensable); and upgrading (non-excusable).

The first delay cause (poor design) was found not to occur frequently enough to be of consequence in the delay ratio. This can be accounted for by the good quality of the design packages for the projects studied in this research. The site condition and late delivery delay causes did not occur with great frequency; however, they did still occur due to specific events that occurred during the study period such as a transportation strike and denial of access to site by the owner.

The final difference is in the delay due to upgrading. This was not hypothesized as a cause because upgrading is typically the owner's choice (e.g. upgrading countertops from laminate to granite). It was found in this research however, that upgrading of mechanical systems under the contract were required due to the contractor's tendency to cut corners and reduce costs. Thus, the

revised model in Fig. 5.2 more accurately reflects the delay liability-cause relationships found in high-end residential construction.

5. 3. Application of Delay Ratio Model

The DRM was applied to as-planned task durations to determine an overall DRM project duration which could then be compared to as-built project duration. As can be seen in Table 5.3, the model was quite good at predicting a more realistic project duration for project A, C, D, E, F, and J. in these projects the difference between the DRM as-planned and as-built schedule was less than 10%.

Table 5.3: Comparison of As-planned Schedule with DRM with As-built and Original As-planned for All Projects

	As-planned	As-planned with DRM	As-built	Delay	DRM
Projects	Days	Days	Days	Percent	Percent
A	122	168	160	31.1%	-4.8%
B	100	134	166	66.0%	23.9%
C	100	134	142	42.0%	6.0%
D	105	137	135	28.6%	-1.5%
E	105	145	143	36.2%	-1.4%
F	121	159	153	26.4%	-3.8%
G	109	142	161	47.7%	13.4%
H	144	191	213	47.9%	11.5%
I	128	170	227	77.3%	33.5%
J	122	160	146	19.7%	-8.8%
Average	115.6	154	164.6	42.3%	6.9%

The model underestimated the duration for projects B, G, H, and I by amounts ranging from 13.4% to 33.5%. After further analysis, it was found that

these projects all had a delay in the starting time. When the start delays were removed for these projects, the results of the DRM improved dramatically as the DRM does not take into account the delays in starting. The resulting changes are highlighted in the revised model shown in Table 5.4:

Table 5.4: Comparison of As-planned Schedule DRM with As-built and Original As-planned, Corrected for Starting Delays

	As-planned	As-planned with DRM	As-built	Delay	DRM
Projects	Days	Days	Days	Percent	Percent
A	122	168	160	31.1%	-4.8%
B	100	134	147	47.0%	9.7%
C	100	134	142	42.0%	6.0%
D	105	137	135	28.6%	-1.5%
E	105	145	143	36.2%	-1.4%
F	121	159	153	26.4%	-3.8%
G	109	142	138	26.6%	-2.8%
H	144	191	196	36.1%	2.6%
I	128	170	167	30.5%	-1.8%
J	122	160	146	19.7%	-8.8%
Average	115.6	154	152.7	32.4%	-0.8%

5. 4. Application of CP Program

As shown in Table 5.4, the difference between the as-built and the DRM as planned schedule was reduced to 1% when the non-linear DRM was applied. The DRM developed in this study was used as the basis of the CP program. The program allows the user to apply the delay ratio factors at the start of the project. The program then does the calculation automatically and presents an amended as-planned schedule.

The program is a prototype of comprehensive scheduling software which calculates and applies delay ratios automatically. However, it requires future development to be used in the broader construction sector.

A model to predict the impact of delay has been developed for the scheduling of construction projects. While the methodology behind the model is basically general, for this thesis it has been tuned to the construction of high-end residences.

5. 5. Benefits of the DRM

Two kinds of cost damages due to delays may have an impact on a the contractor: damages due to late payments, and damages associated with the delay of the project completion (known as delay claim).

In high-end residential construction, contractors are paid based on the progress of the project. The owner usually finances the project through a financial institution (e.g. bank). These institutions set up payment to the owner based on the as-planned schedule and project progress. A delay in the project means that the owner would not receive funds in time to pay the contractor. In other words, the contractor will be paid late if there are delays in the project. Thus, it is beneficial for the contractor to avoid this kind of problem by scheduling the project more realistically so that he will not cause the owner cash flow problems.

In some contracts, the contractor may receive extra payment due to early project closing, or be penalized with costs due to a late finish depending on the contract's terms and conditions. In many delay claim cases, a party may succeed in proving a delay claim only to learn later that the claim amount has been reduced because of a lack of proof of damage (e.g. the court case *G.M. Shupe Vs. United States*, Barry et al ,1999). To minimize the delay claim, the contractor should provide a schedule that has considered the effects of unexpected events on the project duration.

The DRM proposed in this research allows a contractor to develop a more realistic as-planned schedule with the potential to avoid the above situations.

Chapter Six: Conclusions and Recommendations

The general view of high-end residential construction projects is that they are more likely to be completed late, rather than early or on time. Typically, financial trouble, either due to lost profit or to increased project costs, will apply to the construction project if the actual project time goes beyond the expected completion date. Delays on the project completion date commonly produce financial claims by one party against another because of perceived contractual violations.

In recent years, the nature of delays in construction has been studied. The challenges in delay-analysis are focused on finding the links between delay causes and damage. In other words, the impact of the extended time of each task on the schedule must be discovered to determine the real delay on the project. Penalties for delays can range from an agreed extension of the project time, depending on who is responsible for the delays, to outright fines and legal action.

The costs of legal action and damage to reputations have become obvious in the last few years. All parties in the high-end residential construction industry have been trying to mitigate the risk of late closings of projects so that project costs can be more manageable.

6.1 Summary

A model to predict the impact of delay has been developed for the scheduling of construction projects. While the methodology behind the model is basically general, for this thesis it has been tuned to the construction of high-end homes. For the purposes of this research, ten housing projects were selected in the period from 2004 to 2007.

The development of the model is based on three stages: analysis, design, and performance. The first stage is the analysis stage and its purpose is to outline delay relationships and the effect on the sequence of operations that occur in the model. This stage required using the existing site information to get the real as-built schedule for the project. The analysis stage also involved the identification of potential delay causes.

The second stage in the development of the present model was the design stage. In this stage, described in chapter 4, 21 delay classes were identified in order to create a "Liability-Major Cause" delay table as a model. The combination of classes of this model may be applied to the project schedule in order to estimate the new completion time for project.

During the design stage, a number of charts and tables were developed in order to perform the necessary scheduling calculations, including: 1) the major delay causes table and chart; 2) charts and tables for recognizing the responsible

party involved in the delays; and 3) Liability vs. Major Cause table. Creating the Liability vs. Major Cause table dealt with the development of procedures to estimate the expected duration of delay, by means of evaluating the liability of delays and the causes of delays.

The third and last stage in the development of the model was the performance stage. For this stage, a prototype computer program was developed. This program can be used to simulate delays of any given duration during the life of a project. The advantage of the program that integrates the delay ratio model includes the fact that it can:

1. reduce the manual effort of scheduling, in the case of complex delay factors applying to the schedule; and
2. calculate the delay related to each party.

In order to use the model, it is necessary to understand the basic scheduling methods of scheduling and also to make educated guesses about what kinds of delay may apply to the tasks, depending on the time of the year and the location of the project.

In the most cases, several delays may be applied to a project. The easiest way to use the model is as follows: first schedule the project with no delay then choose the right delay ratios (by using engineering judgment) and apply them to each task. In other words the new duration of each task is determined from the

original as-plan time and the estimated delay. The new finishing time will be the most likely completion time for the project.

General findings included the following:

1. delays in High-end residential projects do not differ from other sectors;
2. major delay causes are site condition, economic condition and late delivery;
3. delay Ratio Model (DRM) provides better approximation of as-planned schedule; and
4. simple CP program demonstrated how calculation of DRM can be automated.

6.2 Contributions

The overall contribution of the DRM developed in this thesis is to provide a tool for project managers or contractors who are involved in the home-construction industry. The tool would enable such project managers or contractor to monitor the expected completion date for their project schedule by anticipating likely delays in development of the as-planned schedule. This tool also helps the relevant parties to manage the financial aspects of the project in order to reduce the risk of financial penalties associated with late project closing.

The DRM created for this thesis also overcomes the shortcomings of existing present-day methods used in high-end-home construction scheduling.

Present-day construction scheduling techniques fail to anticipate the effect of exceptional events occurring during construction.

6.3 The Limitations of the Research

This research has some limitations. The main limitation was related to creating real as-built schedules by reviewing and analyzing the site report. In some instances, the base information was incomplete, or details were not clear. In this case, assumptions and judgment were required to determine the source of delay, or responsible party(s).

Another limitation is, that the DRM model does not take into consideration, tasks that might be completed before the stipulated deadline. Another limitation is number of cases used to develop the DRM.

6.4 Recommendation for Future Research

This study has presented a DRM for high-end residential construction projects. The model is flexible and can be applied to all types of repetitive housing projects in the Greater Toronto Area (GTA). However, in order to expand the potential applications of the model, the following recommendations for future research are made:

1. Increase numbers of cases to improve accuracy of model;

2. Expanded model to other locations; and
3. Use model for other type of construction.

CP program also requires further development to be used in the broader construction sector.

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Appendix A

As-planned Schedule

Fig.A.1: As-planned schedule for project "A"

FigA.2: As-planned schedule for project "B"

Fig.A.3: As-planned schedule for project "C"

Fig.A.4: As-planned schedule for project "D"

FigA.5: As-planned schedule for project "E"

Fig.A.6: As-planned schedule for project "F"

Project: As planned Project "F"

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FigA.7: As-planned schedule for project "G"

FigA.8: As-planned schedule for project "H"

Project As planned Project"

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FigA.9: As-planned schedule for project "I"

FigA.10: As-planned schedule for project "J"

Appendix B

As-built Schedule

FigB.1: As-built schedule for project "A"

FigB.2: As-built schedule for project "B"

FigB.3: As-built schedule for project "C"

FigB.4: As-built schedule for project "D"

FigB.5: As-built schedule for project "E"

Project As built Project "E"

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FigB.6: As-built schedule for project "F"

FigB.7: As-built schedule for project "G"

FigB.8: As-built schedule for project "H"

FigB.9: As-built schedule for project "I"

FigB.10: As- Built schedule for project "J"

Appendix C

Delay Information

TableC.1: Delay Information for Project "A"

Job Section	Delay Type	Days	Description
Demolition & excavation & Inspection	Excusable compensable	2	Two days delay for issuing the demolition permit, Owner's responsibility.
Demolition & excavation & Inspection	Excusable non-compensable	6	Two period of rain pouring each 3 days caused the contractor to stop the jobs.
Demolition & excavation & Inspection	Non-excusable	3	The contractor did not show up in job site for 3 days.
Demolition & excavation & Inspection	Non-excusable	3	The non-protected area was eroded and the contractor took 3 days to clean area. The area must be protected by the contractor.
Footing and Foundation	Excusable compensable	1	One day delay for requesting the inspection.
Footing and Foundation	Excusable non-compensable	1	One day delay result of weather condition.
Ext. Wall Construction	Excusable compensable	2	Delay by supplier
Ext. Wall Construction	Non-excusable	5	The contractor took off 2 times during construction. However, they started the jobs 3 days in advance.
Wiring(rough)	Excusable compensable	6	Copper price changed, need justified the price with owner.
Wiring(rough)	Non-excusable	4	The contractor delays.
Plumbing(rough)	Excusable compensable	15	Copper price changed, need justified the price with owner.
Plumbing(rough)	Non-excusable	5	delay because the inspector did not pass the plumbing job. So need to be fixed.
Heating(HVAC)(rough)	Excusable compensable	5	Updating the system by owner. Adding second furnace in second floor.
Pouring concrete of basement+stair+Drainage	Non-excusable	4	The contractor delays.
Pouring concrete of basement+ stair+ Draining	Excusable compensable	3	General contractor did not remove garbage on-time from basement.
Insulation and vapour barrier	Excusable compensable	1	Contractor start the job on Monday because of wet concrete.
Taping	Non-excusable	7	The contractor delays.
Installing Kitchen and Vanity	Excusable compensable	7	Delay by owner because of late order and change kitchen design.
Installing Kitchen and Vanity	Non-excusable	7	The contractor delays.
Finish Plumbing	Excusable compensable	4	Delay by owner because of late order of fixtures.
Installing Interior doors + Finish carpentry	Excusable compensable	5	Lack of materials. General contractor delay in ordering the materials.
Finish Painting	Non-excusable	2	Some extra touch ups.
Landscapeing	Excusable non-compensable	5	Weather Condition.
Landscapeing	Non-excusable	2	The contractor delays.
Pre delivery inspection	Excusable compensable	3	Owner wanted close the deal on Friday.

TableC.2: Delay Information for Project "B"

Job Section	Delay Type	Days	Description
Demolition & excavation & Inspection	Excusable compensable	12	Tree cutting permit, Owner's responsibility.
Demolition & excavation & Inspection	Non-excusable	3	The contractor did not show up in job site for 3 days.
Footing and Foundation	Excusable non-compensable	5	Delay result of weather condition.
Carpentry	Excusable compensable	3	Lack of material.
Carpentry	Excusable compensable	10	Owner economical condition.
Carpentry	Non-excusable	27	Contractor delay.Lack of knowledge.
Ext.Wall Construction	Excusable compensable	34	Owner economical condition.
Roofing	Excusable compensable	12	Owner change order.
Roofing	Excusable compensable	7	Copper price changed, need justified the price with owner.
Wiring(rough)	Excusable compensable	6	Owner change order.
Wiring(rough)	Non-excusable	13	The contractor delays.
Plumbing(rough)	Excusable compensable	15	Owner change order.
Plumbing(rough)	Non-excusable	2	Contractor delay.Lack of man power.
Heating(HVAC)(rough)	Excusable compensable	12	Updating the system by owner. Adding Heat flooring.
Taping	Non-excusable	7	The contractor delays.

TableC.3: Delay Information for Project "C"

Job Section	Delay Type	Days	Description
Demolition & excavation & Inspection	Excusable non-compensable	8	Rain pouring caused the contractor to stop the jobs.
Demolition & excavation & Inspection	Non-excusable	5	The contractor did not show up in job site for 5 days.
Demolition & excavation & Inspection	Non-excusable	3	The non-protected area was eroded and the contractor took 3 days to clean area. The area must be protected by the contractor.
Footing and Foundation	Excusable compensable	4	4 day delay for requesting the inspection.
Footing and Foundation	Excusable non-compensable	3	3 day delay result of weather condition.
Ext.Wall Construction	Excusable compensable	2	Delay by supplier
Wiring(rough)	Excusable compensable	6	Copper price changed, need justified the price with owner.
Wiring(rough)	Non-excusable	6	The contractor delays.
Plumbing(rough)	Excusable compensable	15	Copper price changed, need justified the price with owner.
Plumbing(rough)	Non-excusable	3	delay because the inspector did not pass the plumbing job. So need to be fixed.
Heating(HVAC)(rough)	Excusable compensable	4	Updating the system by owner. Adding second furnace in second floor.
Pouring concrete of basement+stair+Drainage	Non-excusable	1	The contractor delays.
Pouring concrete of basement+ stair+ Draining	Excusable compensable	5	General contractor did not remove garbage on-time from basement.
Insulation and vapour barrier	Excusable compensable	2	Contractor start the job on Monday because of wet concrete.
Taping	Non-excusable	4	The contractor delays.
Installing Kitchen and Vanity	Non-excusable	5	The contractor delays.
Finish Plumbing	Excusable compensable	10	Delay by owner because of late order of fixtures.
Finish Painting	Non-excusable	2	Some extra touch ups.
Landscaping	Excusable non-compensable	12	Weather Condition.
Landscaping	Non-excusable	4	The contractor delays.

TableC.4: Delay Information for Project "D"

Job Section	Delay Type	Days	Description
Footing and Foundation	Excusable compensable	2	Delay for requesting the inspection.
Footing and Foundation	Excusable compensable	5	Owner change order result of changing the design.
Carpentry	Excusable compensable	7	Lack of Material.
Carpentry	Non-excusable	17	Contractor delay because of mistake in construction.
Wiring(rough)	Non-excusable	6	Low voltage wiring delay.
Wiring(rough)	Non-excusable	14	Inspector did not pass the inspection.
Plumbing(rough)	Non-excusable	5	delay because the inspector did not pass the plumbing job. So need to be fixed.
Heating(HVAC)(rough)	Excusable compensable	5	Updating the system by owner. Adding second furnace in second floor.
Taping	Non-excusable	7	The contractor delays.
Painting	Excusable compensable	9	Owner change the color after painting.
Painting	Non-excusable	4	The contractor delays.
Installing Kitchen and Vanity	Non-excusable	4	The contractor delays.
Installing Interior doors + Finish carpentry	Non-excusable	8	Contractor delay because of mistake in construction.
Installing Interior doors + Finish carpentry	Non-excusable	12	Contractor lost and damage the materials and caused to order material again.
Landscaping	Non-excusable	6	The contractor delays.

TableC.5: Delay Information for Project "E"

Job Section	Delay Type	Days	Description
Demolition & excavation & Inspection	Excusable compensable	2	Owner did not remove the oil tank on time.
Demolition & excavation & Inspection	Non-excusable	3	The contractor did not show up in job site for 3 days.
Footing and Foundation	Excusable compensable	1	Delay for requesting the inspection and approval of PEO.
Footing and Foundation	Excusable compensable	1	One day delay for requesting the inspection.
Carpenter	Excusable compensable	2	Lack of materials.
Carpenter	Excusable compensable	12	Change the design.
Carpenter	Excusable non-compensable	3	Weather Condition.
Carpenter	Non-excusable	21	Contractor delay.
Wiring(rough)	Excusable compensable	6	Copper price changed, need justified the price with owner.
Plumbing(rough)	Excusable compensable	15	Copper price changed, need justified the price with owner.
Taping and dry wall	Excusable compensable	7	Owner late payment.
Installing Kitchen and Vanity	Excusable compensable	7	Delay by owner because of late order and change kitchen design.
Finish Plumbing	Non-excusable	10	Contractor make damage on fasets.re-ordering.
Installing Interior doors + Finish carpentry	Excusable compensable	5	Owner late payment.
Landscaping	Excusable non-compensable	7	Site Condition.
Landscaping	Excusable non-compensable	5	Weather Condition.
Landscaping	Non-excusable	2	The contractor delays.

TableC.6: Delay Information for Project "F"

Job Section	Delay Type	Days	Description
Demolition & excavation & Inspection	Excusable non-compensable	2	Rain pouring caused the contractor to stop the jobs.
Demolition & excavation & Inspection	Excusable non-compensable	6	High Table water Caused the contractor to stop the jobs.
Demolition & excavation & Inspection	Non-excusable	3	The contractor did not ignore to rent pump for 3 days.
Footing and Foundation	Excusable compensable	5	One day delay for requesting the PEO inspection.
Footing and Foundation	Excusable non-compensable	2	2 days delay result of site condition.
Ext.Wall Construction	Excusable compensable	1	Delay by supplier
Ext.Wall Construction	Non-excusable	3	The contractor stop the job for 3 days.
Roofing	Non-excusable	3	Need to fix
Wiring(rough)	Excusable compensable	4	Updating system by owner, need justified the price with owner.
Wiring(rough)	Non-excusable	8	The contractor delays.
Plumbing(rough)	Excusable compensable	5	Updating system by owner, need justified the price with owner.
Plumbing(rough)	Non-excusable	5	delay because the inspector did not pass the plumbing job. So need to be fixed.
Heating(HVAC)(rough)	Excusable compensable	10	Changing the design. The designed furnace was not in market.
Pouring concrete of basement+stair+Draining	Excusable non-compensable	2	Water penetration in basement. Water needed to pump out.
Pouring concrete of basement+stair+Draining	Non-excusable	4	The contractor delays.
Pouring concrete of basement+ stair+ Draining	Excusable compensable	2	General contractor did not remove garbage on-time from basement.
Insulation and vapour barrier	Excusable compensable	3	Contractor did the job again because water penetration from roof.
Taping	Excusable non-compensable	5	Taping did not dry because of weather condition.
Installing Kitchen and Vanity	Excusable compensable	15	Delay by owner because of change kitchen design.
Finish Plumbing	Excusable compensable	2	Delay by supplier.
Installing Interior doors + Finish carpentry	Excusable compensable	10	Lack of materials.General contractor delay in ordering the materials.
Installing Interior doors + Finish carpentry	Non-excusable	14	The contractor delays.
Finish Painting	Non-excusable	3	Some extra touch ups.
Landscaping	Excusable non-compensable	5	Weather Condition.

TableC.7: Delay Information for Project "G"

Job Section	Delay Type	Days	Description
Demolition & excavation & Inspection	Excusable compensable	10	Delay for getting permit from neighbours . Owner's responsibility.
Demolition & excavation & Inspection	Non-excusable	7	The non-protected area was eroded and the contractor took 7 days to clean area. The area must protected by the contractor.
Order Trusses	Excusable compensable	14	Delay because of late ordering.
Carpenter	Non-excusable	21	The contractor took off 2 times total 21 days during construction.
Wiring(rough)	Excusable compensable	6	Copper price changed, need justified the price with owner.
Wiring(rough)	Non-excusable	4	The contractor delays.
Plumbing(rough)	Excusable compensable	15	Copper price changed, need justified the price with owner.
Plumbing(rough)	Non-excusable	5	delay because the inspector did not pass the plumbing job. So need to be fixed.
Heating(HVAC)(rough)	Excusable compensable	5	Updating the system by owner. Adding second furnace in second floor.
Dry wall	Non-excusable	5	The contractor delays.
Taping	Non-excusable	3	The contractor delays.
Installing Kitchen and Vanity	Non-excusable	7	The contractor delays.
Installing Interior doors + Finish carpentry	Non-excusable	5	Lack of man power.
Finish Painting	Non-excusable	5	Re-painting.
Landscaping	Excusable non-compensable	4	Weather Condition.
Landscaping	Non-excusable	13	The contractor delays.

TableC.8: Delay Information for Project "H"

Job Section	Delay Type	Days	Description
Demolition & excavation & Inspection	Excusable compensable	10	Two days delay for issuing the demolition permit, Owner's responsibility.
Demolition & excavation & Inspection	Excusable non-compensable	6	snow pouring caused the contractor to stop the jobs.
Demolition & excavation & Inspection	Non-excusable	5	Lack of equipments. Contractor responsibilities.
Footing and Foundation	Excusable compensable	10	Delay because of PEO approval.
Footing and Foundation	Excusable non-compensable	15	Delay result of weather condition.
Back filling	Excusable non-compensable	15	Weather condition.
Carpenter	Excusable non-compensable	30	Weather condition.
Carpenter	Excusable compensable	10	Lack of Material.
Carpenter	Non-excusable	15	Contractor delay because of mistake in construction.
Ext.Wall Construction	Excusable compensable	2	Delay by supplier
Wiring(rough)	Excusable compensable	2	System upgrade.
Wiring(rough)	Non-excusable	8	The contractor delays.
Plumbing(rough)	Non-excusable	5	delay because the inspector did not pass the plumbing job. So need to be fixed.
Pouring concrete of basement+stair+Drainage	Non-excusable	4	The contractor delays.
Drywall	Excusable compensable	14	Owner late payments.
Drywall	Non-excusable	6	The contractor delays.lack of man power.
Taping	Non-excusable	7	The contractor delays.
Installing Kitchen and Vanity	Non-excusable	7	The contractor delays.
Installing Interior doors + Finish carpentry	Excusable compensable	5	Lack of materials.General contractor delay in ordering the materials.
Installing Interior doors + Finish carpentry	Non-excusable	10	The contractor delays.
Painting	Non-excusable	17	Lack man power.
Landscaping	Excusable non-compensable	5	Weather Condition.
Landscaping	Excusable non-compensable	3	Site condition.
Landscaping	Non-excusable	12	The contractor delays.

TableC.9: Delay Information for Project "I"

Job Section	Delay Type	Days	Description
Demolition & excavation & Inspection	Excusable non-compensable	3	Rain pouring caused the contractor to stop the jobs.
Demolition & excavation & Inspection	Excusable non-compensable	7	Need to PEO approved the soil condition.
Demolition & excavation & Inspection	Non-excusable	3	The contractor did not show up in job site for 3 days.
Footing and Foundation	Excusable compensable	8	Need to PEO approved the soil condition.
Back filling	Non-excusable	3	Contractor did not use the right equipment.
Carpenter	Excusable compensable	5	Lack of materials.
Carpenter	Excusable compensable	8	Change the design.
Carpenter	Excusable non-compensable	4	Weather Condition.
Carpenter	Non-excusable	9	Contractor delay.
Footing and Foundation	Excusable non-compensable	1	One day delay result of weather condition.
Ext.Wall Construction	Excusable compensable	5	Delay by supplier
Pouring concrete of basement+stair+Drainage	Non-excusable	4	The contractor delays.
Painting	Excusable compensable	6	Change the colors.
Installing Kitchen and Vanity	Excusable compensable	7	Delay by owner because of he did not protect the vanities.
Installing interior doors + Finish carpentry	Excusable compensable	5	Lack of materials.General contractor delay in ordering the materials.
Finish Painting	Non-excusable	10	Upgrading the design to painting.
Landscaping	Excusable compensable	8	Owner change the design the landscaping.
Landscaping	Excusable non-compensable	5	Weather Condition.
Landscaping	Non-excusable	2	The contractor delays.

TableC.10: Delay Information for Project "J"

Job Section	Delay Type	Days	Description
Demolition & excavation & Inspection	Non-excusable	5	Contractor did not back fill by Bob-Cat.
Footing and Foundation	Non-excusable	5	Inspector did not pass the footing structure.
Footing and Foundation	Excusable non-compensable	5	Delay result of weather condition.
Carpenter	Non-excusable	8	Contractor delay.
Carpenter	Non-excusable	3	Contractor did not use lifter for truss.
Wiring(rough)	Non-excusable	4	The contractor delays.
Plumbing(rough)	Non-excusable	3	delay because the inspector did not pass the plumbing job. So need to be fixed.
Flooring	Excusable compensable	16	Owner change the hard wood.
Installing Interior doors + Finish carpentry	Excusable compensable	9	Lack of materials.General contractor delay in ordering the materials.

Appendix D

Project Investigation

By Delay Cause

Table D.1: Delay cause investigation Project "A"

Task	Task Duration (Day)	Poor Design (Day)	Delay Ratio	Changes order (Day)	Delay Ratio	Weather Condition (Day)	Delay Ratio	Site Condition (Day)	Delay Ratio	Late Delivery (Day)	Delay Ratio	Economic Condition (Day)	Delay Ratio	Upgrading (Day)	Delay Ratio
Demolition & excavation & inspection	17.00		1.00		1.00	6.00	1.35	3.00	1.18	2.00	1.12	3.00	1.18		1.00
Footling and Foundation	12.00		1.00		1.00	1.00	1.08		1.00	1.00	1.08				1.00
Exterior Wall Construction	21.00		1.00		1.00	1.00	1.00	5.00	1.24	2.00	1.10				1.00
Wiring(rough)	15.00		1.00		1.00	1.00	1.00	4.00	1.27		1.00				1.00
Plumbing(rough)	15.00	5.00	1.33		1.00	1.00	1.00		1.00		1.00				1.00
Heating(HVAC)(rough)	15.00		1.00		1.00	1.00	1.00		1.00		1.00				1.33
Pouring concrete of basement+ stair+ Draining	13.00		1.00		1.00	1.00	1.31	4.00	1.31	3.00	1.26			5.00	1.00
Insulation and vapor barrier	3.00		1.00		1.00	1.00	1.33	1.00	1.33		1.00				1.00
Tiling	10.00		1.00		1.00	1.00	1.00	7.00	1.70		1.00				1.00
Installing Kitchen and Vanity	7.00		1.00	7.00	2.00	2.00	1.00		1.00	2.00	1.29				1.00
Finish Plumbing	3.00		1.00		1.00	1.00	1.00		1.00	4.00	2.33				1.00
Installing Interior doors + Finish carpentry	10.00		1.00		1.00	1.00	1.00		1.00	5.00	1.50				1.00
Painting	7.00		1.00		1.00	1.00	1.00	2.00	1.29		1.00				1.00
Landscaping	5.00		1.00		1.00	5.00	2.00	2.00	1.40		1.00				1.00
Pre delivery inspection	1.00		1.00	3.00	4.00		1.00		1.00		1.00				1.00
Average Ratio			1.02		1.27		1.10		1.18		1.18				1.02
Total Delay Task		5.00	1.03	10.00	1.06	12.00	1.08	28.00	1.18	19.00	1.12	29.00	1.19	5.00	1.03

Table D.2: Delay cause investigation Project "B"

Task	Task Duration (Day)	Poor Design (Day)	Delay Ratio	Change order (Day)	Delay Ratio	Weather Condition (Day)	Delay Ratio	Site Condition (Day)	Delay Ratio	Late Delivery (Day)	Delay Ratio	Economic Condition (Day)	Delay Ratio	Upgrading (Day)	Delay Ratio
Demolition & excavation & Inspection	5.00		1.00		1.00		1.00		1.00	12.00	3.40		1.60		1.00
Excavating and Foundation	18.00		1.00		1.00	5.00	1.28		1.00		1.00		1.00		1.00
Concreting	28.00	27.00	1.00		1.00		1.00		1.00	3.00	1.11	10.00	1.38		1.00
External Construction	13.00		1.00		1.00		1.00		1.00		1.00	34.00	2.92		1.00
Formwork	14.00		1.00	12.00	1.00		1.00		1.00		1.00	7.00	1.00		1.00
Roofing	5.00		1.00	6.00	1.00		1.00	13.00	3.60		1.00		1.00		1.00
Plumbing (rough)	5.00		1.00	2.20	1.00		1.00	2.00	1.60		1.00		1.00		1.00
Plumbing (finish)	8.00		1.00	15.00	1.00		1.00	2.00	1.00		1.00		1.00		1.00
Heating (HVAC rough)	10.00		1.00		1.00		1.00	7.00	1.70		1.00		1.00	12.00	2.50
Painting			1.00		1.00		1.00		1.00		1.00		1.00		1.00
Average Ratio			1.11		1.56		1.03		1.41		1.28		1.45		1.17
Total Delay Task	108.00	27.00	1.25	33.00	1.31	5.00	1.05	22.00	1.21	15.00	1.14	54.00	1.51	12.00	1.11

Table D.3: Delay cause investigation Project "C"

Task	Task Duration (Day)	Poor Design (Day)	Change order (Day)	Delay Ratio	Weather Condition (Day)	Delay Ratio	Site Condition (Day)	Delay Ratio	Late Delivery (Day)	Delay Ratio	Economic Condition (Day)	Delay Ratio	Upgrading (Day)	Delay Ratio
Demolition & excavation & inspection	5.00			1.00	8.00		3.00	1.60	0.00	1.00		2.00		1.00
Footing and Foundation	20.00			1.00	3.00			1.00	4.00	1.20		1.00		1.00
Ext.Wall Construction	13.00			1.00				1.00	2.00	1.15		1.00		1.00
Wiring(rough)	5.00			1.00			6.00	2.20			6.00	2.20		1.00
Plumbing(rough)	3.00	3.00		2.00			1.00	1.00		1.00	15.00	6.00		1.00
Heating/HVAC(rough)	8.00			1.00				1.00		1.00		1.00	4.00	1.50
Pouring concrete of basement* slabs* Draining	6.00			1.00			1.00	1.17	5.00	1.83		1.00		1.00
Insulation and vapor barrier	5.00			1.00			2.00	1.40		1.00		1.00		1.00
Taping	10.00			1.00			2.00	1.20		1.00	2.00	1.20		1.00
Installing Kitchen and Vanity	2.00			1.00				1.00		1.00	5.00	3.50		1.00
Finish Plumbing	3.00			1.00				1.00	10.00	4.33		1.00		1.00
Painting	5.00			1.00			2.00	1.40		1.00		1.00		1.00
Landscaping	7.00			1.00	6.00		4.00	1.57	2.00	1.29	2.00	1.29		1.00
Average Ratio				1.00				1.27		1.37		1.78		1.04
Total Delay Task	92.00	3.00	0.00	1.03	17.00		20.00	1.22	23.00	1.25	35.00	1.38	4.00	1.04

Table D.4: Delay cause investigation Project "D"

Task	Task Duration (Day)	Poor Design (Day)	Change order (Day)	Delay Ratio	Weather Condition (Day)	Delay Ratio	Site Condition (Day)	Delay Ratio	Late Delivery (Day)	Delay Ratio	Economic Condition (Day)	Delay Ratio	Upgrading (Day)	Delay Ratio
Footling and Foundation	12.00		5.00	1.00	1.42	1.00	1.00	1.00	2.00	1.00		1.00	5.00	1.42
Carpentry	30.00	17.00		1.57	1.00	1.00	1.00	1.00	7.00	1.23		1.00		1.00
Wiring(rough)	3.00	14.00		5.67	1.00	1.00	6.00	1.00		1.00		1.00		1.00
Plumbing(rough)	4.00	5.00		2.25	1.00	1.00	1.00	1.00		1.00		1.00		1.00
Heating(HVAC)(rough)	6.00			1.00	1.00	1.00	1.00	1.00		1.00		1.00		1.00
Taping	7.00			1.00	1.00	1.00	1.00	1.00		1.00		1.00		1.83
Installing Kitchen and Vanity	2.00			1.00	1.00	1.00	1.00	1.00		1.00	7.00	2.00		1.00
Installing Interior doors + Finish carpentry	10.00	8.00		1.80	1.00	1.00	12.00	1.00		1.00	4.00	1.00		1.00
Painting	5.00			1.00	1.00	1.00	4.00	1.00		1.00		1.00	9.00	2.80
Landscaping	3.00			1.00	1.00	1.00	1.00	1.00		1.00	6.00	3.00		1.00
Average Ratio				1.73	1.04	1.00	22.00	1.40		1.27	17.00	1.50		1.31
Total Delay Task	82.00	44.00	5.00	1.54	0.00	1.00		1.21	9.00	1.11		1.21	19.00	1.23

Table D.5: Delay cause investigation Project "E"

Task	Task Duration (Day)	Poor Design (Day)	Change order (Day)	Delay Ratio	Weather Condition (Day)	Delay Ratio	Site Condition (Day)	Delay Ratio	Late Delivery (Day)	Delay Ratio	Economic Condition (Day)	Delay Ratio	Upgrading (Day)	Delay Ratio
Demolition & excavation & inspection	5.00			1.00		1.00		1.00	2.00	1.40	3.00	1.60		1.00
Footing and Foundation	16.00			1.00		1.00		1.00	2.00	1.13		1.00		1.00
Carpentry	28.00			1.00	3.00	1.11	21.00	1.75	2.00	1.07		1.00	12.00	1.43
Wiring(coudb)	3.00			1.00		1.00		1.00		1.00	6.00	3.00		1.00
Plumbing(coudb)	4.00			1.00		1.00		1.00		1.00	15.00	1.00		1.00
Taping	10.00			1.00		1.00		1.00		1.00	7.00	4.75		1.00
Installing Kitchen and Vanity	2.00			1.00		1.00		1.00	7.00	4.50		1.70		1.00
Finish Plumbing	1.00			1.00		1.00		1.00	10.00	11.00		1.00		1.00
Installing Interior doors + Finish carpentry	10.00			1.00		1.00		1.00		1.00	5.00	1.50		1.00
Landscaping	7.00			1.00	5.00	1.71	9.00	2.29		1.00		1.00		1.00
Average Ratio				1.00		1.08		1.20		2.41		1.76		1.04
Total Delay Task	86.00	0.00	0.00	1.00	8.00	1.69	30.00	0.35	23.00	1.27	38.00	1.42	12.00	1.14

Table D.6: Delay cause investigation Project "F"

Task	Task Duration (Day)	Poor Design (Day)	Change order (Day)	Weather Condition (Day)	Site Condition (Day)	Late Delivery (Day)	Economic Condition (Day)	Upgrading (Day)	Delay Ratio
Demolition & excavation & inspection	5.00	1.00	1.00	2.00	1.40	2.20	1.00	1.80	1.00
Foundation	18.00	1.00	1.00	1.00	5.00	1.11	1.38	1.00	1.00
Ex-Wall Construction	20.00	1.00	1.00	1.00	3.00	1.15	1.05	1.00	1.00
Roofing	20.00	1.15	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Wiring(rough)	3.00	1.00	1.00	1.00	8.00	3.87	1.00	4.00	2.33
Plumbing(rough)	4.00	2.35	1.00	1.00	1.00	1.00	1.00	5.00	2.35
Plumbing(Finish)	6.00	1.00	2.57	1.00	1.00	1.00	1.00	1.00	1.00
Pouring concrete of Basement- stair- Draining	8.00	1.00	1.00	1.00	6.00	2.00	1.33	1.00	1.00
Insulation and vapor barrier	3.00	1.00	1.00	1.00	3.00	2.00	1.00	1.00	1.00
Trapping	1.00	1.00	1.00	5.00	1.80	1.00	1.00	1.00	1.00
Installing Kitchen and Vanity	2.00	1.00	4.75	1.00	1.00	1.00	1.00	1.00	1.00
Finish Plumbing	2.00	1.00	1.00	1.00	1.00	2.00	2.00	1.00	1.00
Installing interior doors + Finish carpentry	10.00	1.00	1.00	1.00	14.00	2.40	2.00	1.00	1.00
Painting	9.00	1.00	1.00	1.00	3.00	1.38	1.00	1.00	1.00
Landscaping	7.00	1.00	1.00	5.00	1.71	1.00	1.00	1.00	1.00
Average Ratio		1.09	1.36	1.42	1.11	1.53	1.18	1.04	1.17
Total Delay Test	126.00	8.00	25.00	12.00	45.00	20.00	3.00	9.00	1.29

Table D.7: Delay cause investigation Project "G"

Task	Task Duration (Day)	Poor Design (Day)	Delay Ratio	Change order (Day)	Delay Ratio	Weather Condition (Day)	Delay Ratio	Site Condition (Day)	Delay Ratio	Late Delivery (Day)	Delay Ratio	Economic Condition (Day)	Delay Ratio	Upgrading (Day)	Delay Ratio
Demolition & excavation & Inspection	5.00		1.00		1.00		1.00	7.00	1.00	2.40	1.00		1.00		1.00
Order Trusses	27.00		1.00		1.00		1.00	21.00	1.00	1.00	1.52		1.00		1.00
Carpentry	28.00		1.00		1.00		1.00	4.00	1.00	1.75	1.00		1.00		1.00
Wiring(rough)	5.00		1.00		1.00		1.00	5.00	1.00	1.80	1.00	6.00	2.20		1.00
Plumbing(rough)	4.00		1.00		1.00		1.00	5.00	1.00	2.25	1.00	15.00	4.75		1.00
Heating(HVAC)(rough)	6.00		1.00		1.00		1.00	5.00	1.00	1.00	1.00		1.00	5.00	1.83
Drywall	8.00		1.00		1.00		1.00	5.00	1.00	1.63	1.00		1.00		1.00
Taping	10.00		1.00		1.00		1.00	3.00	1.00	1.30	1.00		1.00		1.00
Installing Kitchen and Vanity	2.00		1.00		1.00		1.00	7.00	1.00	4.50	1.00		1.00		1.00
Installing interior doors + Finish carpentry	10.00		1.00		1.00		1.00		1.00	1.00	1.00	5.00	1.50		1.00
Painting	5.00	5.00	2.00		1.00		1.00		1.00	1.00	1.00		1.00		1.00
Landscaping	7.00		1.00		1.00	4.00	1.00	13.00	1.57	2.86	1.00		1.00		1.00
Average Ratio			1.08		1.00		1.00		1.05	1.87	1.21		1.45		1.07
Total Delay Task	117.00	5.00	1.04	0.00	1.00	4.00	1.00	65.00	1.03	24.00	1.21	26.00	1.22	5.00	1.04

Table D.8: Delay cause investigation Project "H"

Task	Task Duration (Day)	Poor Design (Day)	Delay Ratio	Weather Condition (Day)	Delay Ratio	Site Condition (Day)	Delay Ratio	Late Delivery (Day)	Delay Ratio	Economic Condition (Day)	Delay Ratio	Upgrading (Day)	Delay Ratio
Demolition & excavation & Inspection	14.00		1.00	6.00	1.43	5.00	1.36	10.00	1.71		1.00		1.00
Footings and Foundation	19.00		1.00	15.00	1.79		1.00	10.00	1.53		1.00		1.00
Back Filling	4.00		1.00	15.00	4.75		1.00		1.00		1.00		1.00
Carpentry	40.00	15.00	1.38	30.00	1.75		1.00	10.00	1.25		1.00		1.00
Ext.Wall Construction	21.00		1.00		1.00	1.00	1.00	2.00	1.10		1.00		1.00
Wiring(rough)	6.00		1.00		1.00	8.00	2.33		1.00		1.00	2.00	1.33
Plumbing(rough)	7.00	5.00	1.71		1.00	1.00	1.00		1.00		1.00		1.00
Pouring concrete of basement+ stair+ Draining	12.00		1.00		1.00	4.00	1.33		1.00		1.00		1.00
Dry Wall	20.00		1.00		1.00	1.00	1.00		1.00	20.00	2.00		1.00
Tile	10.00		1.00		1.00	7.00	1.70		1.00		1.00		1.00
Installing Kitchen and Vanity	5.00		1.00		1.00	2.00	2.40		1.00		1.00		1.00
Installing interior doors + Finish carpentry	16.00		1.00		1.00	10.00	1.63	5.00	1.31		1.00		1.00
Painting	7.00		1.00		1.00		1.00		1.00	17.00	3.43		1.00
Landscaping	3.00		1.00	5.00	2.67	15.00	6.00		1.00		1.00		1.00
Average Ratio			1.08		1.53		1.70		1.14		1.24		1.02
Total Delay Task	184.00	20.00	1.11	71.00	1.39	56.00	1.30	37.00	1.20	37.00	1.20	2.00	1.01

Table D.9: Delay cause investigation Project "I"

Task	Test Duration (Day)	Poor Design (Day)	Delay Ratio	Change order (Day)	Delay Ratio	Weather Condition (Day)	Delay Ratio	Site Condition (Day)	Delay Ratio	Late Delivery (Day)	Delay Ratio	Economic Condition (Day)	Delay Ratio	Upgrading (Day)	Delay Ratio
Demolition & excavation & inspection	5.00		1.00		1.00	3.00	1.60		1.00	7.00	2.40	3.00	1.60		1.00
Footings and Foundation	15.00		1.00		1.00	1.00	1.07		1.00	8.00	1.53		1.00		1.00
Back fill	4.00		1.00		1.00	1.00	1.00	3.00	1.75		1.00		1.00		1.00
Carpentry	40.00		1.00		1.00	4.00	1.10	9.00	1.23	5.00	1.13		1.00	8.00	1.20
Ext Wall Construction	21.00		1.00		1.00	1.00	1.00	1.00	1.00	5.00	1.24		1.00		1.00
Pouring concrete of basement+ stair+ Draining	12.00		1.00		1.00	1.00	1.00	1.00	1.00		1.00	4.00	1.33		1.00
Painting	7.00		1.00	6.00	1.85	1.00	1.00	1.00	1.00	1.00	1.00		1.00	10.00	2.43
Installing Kitchen and Vanity	5.00		1.00		1.00	1.00	1.00	7.00	2.40		1.00		1.00		1.00
Installing interior doors + Finish carpentry	16.00		1.00		1.00	1.00	1.00	1.00	1.00	5.00	1.31		1.00		1.00
Landscaping	3.00		1.00	6.00	3.67	5.00	2.67	2.00	1.67		1.00		1.00		1.00
Average Ratio			1.00		1.35		1.24		1.30		1.28		1.06		1.16
Total Delay Task	128.00	0.00	1.00	14.00	1.11	13.00	1.10	21.00	1.16	30.00	1.23	7.00	1.05	18.00	1.14

Table D.10: Delay cause investigation Project "J"

Task	Task Duration (Day)	Poor Design (Day)	Delay Ratio	Change order (Day)	Delay Ratio	Weather Condition (Day)	Delay Ratio	Site Condition (Day)	Delay Ratio	Late Delivery (Day)	Delay Ratio	Economic Condition (Day)	Delay Ratio	Upgrading (Day)	Delay Ratio
Demolition & excavation & inspection	8.00		1.00		1.00		1.00		2.00		1.00		1.00		1.00
Founding and Foundation	18.00	5.00	1.28		1.00	5.00	1.28		1.00		1.00		1.00		1.00
Carpentry	35.00		1.00		1.00		1.00	11.00	1.81		1.00		1.00		1.00
Wiring(rough)	3.00		1.00		1.00		1.00	4.00	2.83		1.00		1.00		1.00
Plumbing(rough)	4.00	3.00	1.75		1.00		1.00		1.00		1.00		1.00		1.00
Flooring	5.00		1.00	16.00	4.20		1.00		1.00		1.00		1.00		1.00
Installing interior doors + Finish carpentry	10.00		1.00		1.00		1.00		1.00	9.00	1.90		1.00		1.00
Average Ratio			1.15		1.46		1.04		1.38		1.13		1.00		1.00
Total Delay Task	80.00	8.00	1.10	16.00	1.20	5.00	1.06	20.00	1.25	9.00	1.11	0.00	1.00	0.00	1.00

Appendix E

Project Investigation

By Liability

Table E.1: Delay cause investigation Project "A"

Job Section	Task Duration (days)	Excusable compensable (days)	Delay Ratio	Excusable non-compensable (days)	Delay Ratio	Non-excusable (days)	Delay Ratio
Demolition & excavation & inspection	17.00	2.00	1.12	6.00	1.35	6.00	1.35
Footling and Foundation	12.00	1.00	1.08	1.00	1.08	0.00	1.00
Exterior Wall Construction	21.00	2.00	1.10	0.00	1.00	5.00	1.24
Wiring(rough)	15.00	6.00	1.40	0.00	1.00	4.00	1.27
Plumbing(rough)	15.00	15.00	2.00	0.00	1.00	5.00	1.33
HVAC (rough)	15.00	5.00	1.33	0.00	1.00	0.00	1.00
Pouring concrete of basement+ stair+ Draining	13.00	3.00	1.23	0.00	1.00	4.00	1.31
Insulation and vapor barrier	3.00	1.00	1.33	0.00	1.00	0.00	1.00
Taping	10.00	0.00	1.00	0.00	1.00	7.00	1.70
Installing Kitchen and Vanity	7.00	7.00	2.00	0.00	1.00	7.00	2.00
Finish Plumbing	3.00	4.00	2.33	0.00	1.00	0.00	1.00
Installing Interior doors + Finish carpentry	10.00	5.00	1.50	0.00	1.00	0.00	1.00
Painting	7.00	0.00	1.00	0.00	1.00	2.00	1.29
Landscaping	5.00	0.00	1.00	5.00	2.00	2.00	1.40
Pre delivery inspection	1.00	3.00	4.00	0.00	1.00	0.00	1.00
Average Ratio of Delay By Task			1.56		1.10		1.26
Total Delay Task	154.00	54.00	1.35	12.00	1.08	42.00	1.27

Table E.2: Delay cause investigation Project "B"

Job Section	Task Duration (days)	Excusable compensable (days)	Delay Ratio	Excusable non-compensable (days)	Delay Ratio	Non-excusable (days)	Delay Ratio
Demolition & excavation & inspection	5.00	12.00	3.40		1.00	3.00	1.60
Footling and Foundation	18.00		1.00	5.00	1.28		1.00
Carpentry	28.00	13.00	1.46	0.00	1.00	27.00	1.96
Ext.Wall Construction	13.00	34.00	3.62		1.00		1.00
Roofing	14.00	19.00	2.36		1.00		1.00
Wiring(rough)	5.00	6.00	2.20		1.00	13.00	3.60
Plumbing(rough)	5.00	15.00	4.00		1.00	2.00	1.40
Heating(HVAC)(rough)	8.00	12.00	2.50		1.00		1.00
Taypling	10.00		1.00		1.00	7.00	1.70
Average Ratio			2.39		1.03		1.58
Total Delay Task	106.00	111.00	2.05	5.00	1.05	52.00	1.49

Table E.3: Delay cause investigation Project "C"

Job Section	Task Duration (days)	Excusable compensable (days)	Delay Ratio	Excusable non-compensable (days)	Delay Ratio	Non-excusable (days)	Delay Ratio
Demolition & excavation & inspection	5.00	0.00	1.00	8.00	2.60	8.00	2.60
Footling and Foundation	20.00	4.00	1.20	3.00	1.15	0.00	1.00
Ext.Wall Construction	13.00	2.00	1.15	0.00	1.00	0.00	1.00
Wiring(rough)	5.00	6.00	2.20	0.00	1.00	6.00	2.20
Plumbing(rough)	3.00	15.00	6.00	0.00	1.00	3.00	2.00
Heating(HVAC)(rough)	8.00	4.00	1.50	0.00	1.00	0.00	1.00
Pouring concrete of basement+ stair+ Draining	6.00	5.00	1.83	0.00	1.00	1.00	1.17
Insulation and vapour barrier	5.00	2.00	1.40	0.00	1.00	0.00	1.00
Taping	10.00	0.00	1.00	0.00	1.00	4.00	1.40
Installing Kichen and Vanety	2.00	0.00	1.00	0.00	1.00	5.00	3.50
Finish Plumbing	3.00	10.00	4.33	0.00	1.00	0.00	1.00
Painting	5.00	0.00	1.00	0.00	1.00	2.00	1.40
Landscaping	7.00	0.00	1.00	12.00	2.71	4.00	1.57
Average Ratio			1.89		1.27		1.60
Total Delay Task	92.00	48.00	1.52	23.00	1.25	33.00	1.36

Table E.4: Delay cause investigation Project "D"

Job Section	Task Duration (days)	Excusable compensable (days)	Delay Ratio	Excusable non-compensable (days)	Delay Ratio	Non-excusable (days)	Delay Ratio
Footings and Foundation	12.00	7.00	1.58	0.00	1.00	0.00	1.00
Carpentry	30.00	7.00	1.23	0.00	1.00	17.00	1.57
Wiring(rough)	3.00	0.00	1.00	0.00	1.00	20.00	7.67
Plumbing(rough)	4.00	15.00	4.75	0.00	1.00	5.00	2.25
Heating(HVAC)(rough)	6.00	5.00	1.83	0.00	1.00	0.00	1.00
Taping	7.00	0.00	1.00	0.00	1.00	7.00	2.00
Installing Kitchen and Vanity	2.00	0.00	1.00	0.00	1.00	4.00	3.00
Installing Interior doors + Finish carpentry	10.00	0.00	1.00	0.00	1.00	20.00	3.00
Painting	5.00	9.00	2.80	0.00	1.00	4.00	1.80
Landscaping	3.00	0.00	1.00	0.00	1.00	6.00	3.00
Average Ratio			1.72		1.00		2.63
Total Delay Task	82.00	43.00	1.52	0.00	1.00	83.00	2.01

Table E.5: Delay cause investigation Project "E"

Job Section	Task Duration (days)	Excusable compensable (days)	Delay Ratio	Excusable non-compensable (days)	Delay Ratio	Non-excusable (days)	Delay Ratio
Demolition & excavation & Inspection	5.00	2.00	1.40		1.00	3.00	1.60
Footings and Foundation	16.00	2.00	1.13		1.00		1.00
Carpentry	28.00	15.00	1.54	3.00	1.11	21.00	1.75
Wiring(rough)	3.00	6.00	3.00		1.00		1.00
Plumbing(rough)	4.00	15.00	4.75		1.00		1.00
Taping	10.00	7.00	1.70		1.00		1.00
Installing Kitchen and Vanity	2.00	7.00	4.50		1.00		1.00
Finish Plumbing	1.00		1.00		1.00	10.00	11.00
Installing Interior doors + Finish carpentry	10.00	5.00	1.50		1.00		1.00
Landscaping	7.00		1.00	12.00	2.71	2.00	1.29
Average Ratio			2.15		1.18		2.16
Total Delay Task	86.00	59.00	1.69	15.00	1.17	36.00	1.42

Table E.6: Delay cause investigation Project "F"

Job Section	Task Duration (days)	Excusable compensable (days)	Delay Ratio	Excusable non-compensable (days)	Delay Ratio	Non-excusable (days)	Delay Ratio
Demolition & excavation & Inspection	5.00	2.00	1.40	6.00	2.20	3.00	1.60
Footings and Foundation	18.00	5.00	1.28	2.00	1.11	0.00	1.00
Ext.Wall Construction	20.00	1.00	1.05	0.00	1.00	3.00	1.15
Roofing	20.00	0.00	1.00	0.00	1.00	3.00	1.15
Wiring(rough)	3.00	4.00	2.33	0.00	1.00	8.00	3.67
Plumbing(rough)	4.00	5.00	2.25	0.00	1.00	5.00	2.25
Heating(HVAC)(rough)	6.00	10.00	2.67	0.00	1.00	0.00	1.00
Pouring concrete of basement+ stair+ Draining	6.00	2.00	1.33	4.00	1.67	2.00	1.33
Insulation and vapour barrier	3.00	3.00	2.00	0.00	1.00	0.00	1.00
Taping	10.00	0.00	1.00	5.00	1.50	0.00	1.00
Installing Kitchen and Vanity	4.00	15.00	4.75	0.00	1.00	0.00	1.00
Finish Plumbing	2.00	2.00	2.00	0.00	1.00	0.00	1.00
Installing Interior doors + Finish carpentry	10.00	10.00	2.00	0.00	1.00	14.00	2.40
Painting	8.00	0.00	1.00	0.00	1.00	3.00	1.38
Landscaping	7.00	0.00	1.00	5.00	1.71	0.00	1.00
Average Ratio			1.80		1.21		1.46
Total Delay Task	126.00	59.00	1.47	22.00	1.17	41.00	1.33

Table E.7: Delay cause investigation Project "G"

Job Section	Task Duration (days)	Excusable compensable (days)	Delay Ratio	Excusable non-compensable (days)	Delay Ratio	Non-excusable (days)	Delay Ratio
Demolition & excavation & Inspection	5.00	10.00	3.00	0.00	1.00	7.00	2.40
Order Trusses	27.00	14.00	1.52	0.00	1.00	0.00	1.00
Carpentry	28.00	0.00	1.00	0.00	1.00	21.00	1.75
Wiring(rough)	5.00	6.00	2.20	0.00	1.00	4.00	1.80
Plumbing(rough)	4.00	15.00	4.75	0.00	1.00	5.00	2.25
Heating(HVAC)(rough)	6.00	5.00	1.83	0.00	1.00	0.00	1.00
Dry wall	8.00	0.00	1.00	0.00	1.00	5.00	1.63
Taping	10.00	0.00	1.00	0.00	1.00	3.00	1.30
Installing Kitchen and Vanity	2.00	0.00	1.00	0.00	1.00	7.00	4.50
Installing Interior doors + Finish carpentry	10.00	0.00	1.00	0.00	1.00	5.00	1.50
Painting	5.00	0.00	1.00	0.00	1.00	5.00	2.00
Landscaping	7.00	0.00	1.00	4.00	1.57	13.00	2.86
Average Ratio			1.69		1.05		2.00
Total Delay Task	117.00	50.00	1.43	4.00	1.03	75.00	1.64

Table E.8: Delay cause investigation Project "H"

Job Section	Task Duration (days)	Excusable compensable (days)	Delay Ratio	Excusable non-compensable (days)	Delay Ratio	Non-excusable (days)	Delay Ratio
Demolition & excavation & Inspection	14.00	2.00	1.14	6.00	1.43	5.00	1.36
Footing and Foundation	19.00	10.00	1.53	15.00	1.79	0.00	1.00
Back Filling	4.00		1.00	15.00	4.75		1.00
Carpentry	40.00	10.00	1.25	30.00	1.75	15.00	1.38
Ext.Wall Construction	21.00	2.00	1.10	0.00	1.00	0.00	1.00
Wiring(rough)	6.00	2.00	1.33	0.00	1.00	8.00	2.33
Plumbing(rough)	7.00	0.00	1.00	0.00	1.00	5.00	1.71
Pouring concrete of basement+ stair+ Draining	12.00	0.00	1.00	0.00	1.00	4.00	1.33
Dry Wall	20.00	14.00	1.70	0.00	1.00	6.00	1.30
Taping	10.00	0.00	1.00	0.00	1.00	7.00	1.70
Installing Kitchen and Vanity	5.00	0.00	1.00	0.00	1.00	7.00	2.40
Installing Interior doors + Finish carpentry	16.00	5.00	1.31	0.00	1.00	10.00	1.63
Painting	7.00	0.00	1.00	0.00	1.00	17.00	3.43
Landscaping	3.00	0.00	1.00	8.00	3.67	12.00	5.00
Average Ratio			1.17		1.60		1.90
Total Delay Task	184.00	45.00	1.24	74.00	1.40	96.00	1.52

Table E.9: Delay cause investigation Project "I"

Job Section	Task Duration (days)	Excusable compensable (days)	Delay Ratio	Excusable non-compensable (days)	Delay Ratio	Non-excusable (days)	Delay Ratio
Demolition & excavation & Inspection	5.00		1.00	10.00	3.00	3.00	1.60
Footing and Foundation	15.00	8.00	1.53	1.00	1.07		1.00
Back fill	4.00		1.00		1.00	3.00	1.75
Carpentry	40.00	13.00	1.33	4.00	1.10	9.00	1.23
Ext.Wall Construction	21.00	5.00	1.24		1.00		1.00
Pouring concrete of basement+ stair+ Draining	12.00		1.00		1.00	4.00	1.33
Painting	7.00	6.00	1.86		1.00	10.00	2.43
Installing Kitchen and Vanity	5.00	7.00	2.40		1.00		1.00
Installing Interior doors + Finish carpentry	16.00	5.00	1.31		1.00		1.00
Landscaping	3.00	8.00	3.67	5.00	2.67	2.00	1.67
Average Ratio			1.63		1.38		1.40
Total Delay Task	128.00	52.00	1.41	20.00	1.16	31.00	1.24

Table E.10: Delay cause investigation Project "J"

Job Section	Task Duration (days)	Excusable compensable (days)	Delay Ratio	Excusable non-compensable (days)	Delay Ratio	Non-excusable (days)	Delay Ratio
Demolition & excavation & Inspection	5.00		1.00		1.00	5.00	2.00
Footing and Foundation	18.00		1.00	5.00	1.28	5.00	1.28
Corpentary	35.00		1.00		1.00	11.00	1.31
Wiring(rough)	3.00		1.00		1.00	4.00	2.33
Plumbing(rough)	4.00		1.00		1.00	3.00	1.75
Flooring	5.00	16.00	4.20		1.00		1.00
Installing Interior doors + Finsh carpentry	10.00	9.00	1.90		1.00		1.00
Average Ratio			1.59		1.04		1.53
Total Delay Task	80.00	25.00	1.31	5.00	1.06	28.00	1.35

Appendix F

Reliability-Cause Relation

Table F.1: Reliability-cause relation for Project "A"

	Poor Design	Change order	Weather Condition	Site Condition	Late Delivery	Economic Condition	Upgrading	Total Percentage
Excusable compensable	0.00	9.26	0.00	0.93	15.74	19.44	4.63	50.00
Excusable non-compensable	0.00	0.00	11.11	0.00	0.00	0.00	0.00	11.11
Non-excusable	4.63	0.00	0.00	25.00	1.85	7.41	0.00	38.89
Total Percentage	4.63	9.26	11.11	25.93	17.59	26.85	4.63	100.00

	Poor Design	Change order	Weather Condition	Site Condition	Late Delivery	Economic Condition	Upgrading
Excusable compensable	1.00	1.06	1.00	1.01	1.11	1.14	1.03
Excusable non-compensable	1.00	1.00	1.08	1.00	1.00	1.00	1.00
Non-excusable	1.03	1.00	1.00	1.18	1.01	1.05	1.00
Total Ratio	1.03	1.06	1.08	1.18	1.12	1.19	1.03

Table F.2: Reliability-cause relation for Project "B"

	Poor Design	Change order	Weather Condition	Site Condition	Late Delivery	Economic Condition	Upgrading	Total Percentage
Excusable compensable	0.00	19.64	0.00	0.00	7.14	30.36	7.14	64.29
Excusable non-compensable	0.00	0.00	2.98	0.00	0.00	0.00	0.00	2.98
Non-excusable	16.07	0.00	0.00	13.10	1.79	1.79	0.00	32.74
Total Percentage	16.07	19.64	2.98	13.10	8.93	32.14	7.14	100.00

	Poor Design	Change order	Weather Condition	Site Condition	Late Delivery	Economic Condition	Upgrading
Excusable compensable	1.00	1.31	1.00	1.00	1.11	1.48	1.11
Excusable non-compensable	1.00	1.00	1.05	1.00	1.00	1.00	1.00
Non-excusable	1.25	1.00	1.00	1.21	1.03	1.03	1.00
Total Ratio	1.25	1.31	1.05	1.21	1.14	1.51	1.11

Table F.3: Reliability-cause relation for Project "C"

	Poor Design	Change order	Weather Condition	Site Condition	Late Delivery	Economic Condition	Upgrading	Total Percentage
Excusable compensable	0.00	0.00	0.00	1.92	22.12	20.19	3.85	48.08
Excusable non-compensable	0.00	0.00	16.35	5.77	0.00	0.00	0.00	22.12
Non-excusable	2.88	0.00	0.00	13.46	0.00	13.46	0.00	29.81
Total Percentage	2.88	0.00	16.35	21.15	22.12	33.65	3.85	100.00

	Poor Design	Change order	Weather Condition	Site Condition	Late Delivery	Economic Condition	Upgrading
Excusable compensable	1.00	1.00	1.00	1.02	1.25	1.23	1.04
Excusable non-compensable	1.00	1.00	1.18	1.07	1.00	1.00	1.00
Non-excusable	1.03	1.00	1.00	1.15	1.00	1.15	1.00
Total Ratio	1.03	1.00	1.18	1.24	1.25	1.38	1.04

Table F.4: Reliability-cause relation for Project "D"

	Poor Design	Change order	Weather Condition	Site Condition	Late Delivery	Economic Condition	Upgrading	Total Percentage
Excusable compensable	0.00	3.97	0.00	0.00	7.14	0.00	15.08	26.19
Excusable non-compensable	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-excusable	34.92	0.00	0.00	17.46	0.00	13.49	0.00	65.87
Total Percentage	34.92	3.97	0.00	17.46	7.14	13.49	15.08	92.06

	Poor Design	Change order	Weather Condition	Site Condition	Late Delivery	Economic Condition	Upgrading
Excusable compensable	1.00	1.06	1.00	1.00	1.11	1.00	1.23
Excusable non-compensable	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Non-excusable	1.54	1.00	1.00	1.27	1.00	1.21	1.00
Total Ratio	1.54	1.06	1.00	1.27	1.11	1.21	1.23

Table F.5: Reliability-cause relation for Project E”

	Poor Design	Change order	Weather Condition	Site Condition	Late Delivery	Economic Condition	Upgrading	Total Percentage
Excusable compensable	0.00	0.00	0.00	0.00	11.93	30.28	11.01	53.21
Excusable non-compensable	0.00	0.00	7.34	6.42	0.00	0.00	0.00	13.76
Non-excusable	0.00	0.00	0.00	21.10	9.17	2.75	0.00	33.03
Total Percentage	0.00	0.00	7.34	27.52	21.10	33.03	11.01	100.00

	Poor Design	Change order	Weather Condition	Site Condition	Late Delivery	Economic Condition	Upgrading
Excusable compensable	1.00	1.00	1.00	1.00	1.15	1.38	1.14
Excusable non-compensable	1.00	1.00	1.09	1.08	1.00	1.00	1.00
Non-excusable	1.00	1.00	1.00	1.27	1.12	1.03	1.00
Total Ratio	1.00	1.00	1.09	1.35	1.27	1.42	1.14

Table F.6: Reliability-cause relation for Project “F”

	Poor Design	Change order	Weather Condition	Site Condition	Late Delivery	Economic Condition	Upgrading	Total Percentage
Excusable compensable	2.46	20.49	0.00	2.46	16.39	0.00	7.38	49.18
Excusable non-compensable	0.00	0.00	9.84	11.48	0.00	0.00	0.00	21.31
Non-excusable	4.10	0.00	0.00	25.41	0.00	0.00	0.00	29.51
Total Percentage	6.56	20.49	9.84	39.34	16.39	0.00	7.38	100.00

	Poor Design	Change order	Weather Condition	Site Condition	Late Delivery	Economic Condition	Upgrading
Excusable compensable	1.02	1.20	1.00	1.02	1.16	1.00	1.07
Excusable non-compensable	1.00	1.00	1.10	1.11	1.00	1.00	1.00
Non-excusable	1.04	1.00	1.00	1.25	1.00	1.00	1.00
Total Ratio	1.06	1.20	1.10	1.38	1.16	1.00	1.07

Table F.7: Reliability-cause relation for Project “G”

	Poor Design	Change order	Weather Condition	Site Condition	Late Delivery	Economic Condition	Upgrading	Total Percentage
Excusable compensable	0.00	0.00	0.00	0.00	18.60	16.28	3.88	38.76
Excusable non-compensable	0.00	0.00	3.10	0.00	0.00	0.00	0.00	3.10
Non-excusable	3.88	0.00	0.00	50.39	0.00	3.88	0.00	58.14
Total Percentage	3.88	0.00	3.10	50.39	18.60	20.16	3.88	100.00

	Poor Design	Change order	Weather Condition	Site Condition	Late Delivery	Economic Condition	Upgrading
Excusable compensable	1.00	1.00	1.00	1.00	1.21	1.18	1.04
Excusable non-compensable	1.00	1.00	1.03	1.00	1.00	1.00	1.00
Non-excusable	1.04	1.00	1.00	1.56	1.00	1.04	1.00
Total Ratio	1.04	1.00	1.03	1.56	1.21	1.22	1.04

Table F.8: Reliability-cause relation for Project “H”

	Poor Design	Change order	Weather Condition	Site Condition	Late Delivery	Economic Condition	Upgrading	Total Percentage
Excusable compensable	0.00	0.00	0.00	0.00	16.59	6.28	0.90	23.77
Excusable non-compensable	0.00	0.00	31.84	1.35	0.00	0.00	0.00	33.18
Non-excusable	8.97	0.00	0.00	23.77	0.00	10.31	0.00	43.05
Total Percentage	8.97	0.00	31.84	25.11	16.59	16.59	0.90	100.00

	Poor Design	Change order	Weather Condition	Site Condition	Late Delivery	Economic Condition	Upgrading
Excusable compensable	1.00	1.00	1.00	1.00	1.20	1.08	1.01
Excusable non-compensable	1.00	1.00	1.39	1.02	1.00	1.00	1.00
Non-excusable	1.11	1.00	1.00	1.29	1.00	1.13	1.00
Total Ratio	1.11	1.00	1.39	1.30	1.20	1.20	1.01

Table F.9: Reliability-cause relation for Project "I"

	Poor Design	Change order	Weather Condition	Site Condition	Late Delivery	Economic Condition	Upgrading	Total Percentage
Excusable compensable	0.00	13.59	0.00	6.80	22.33	0.00	7.77	50.49
Excusable non-compensable	0.00	0.00	12.62	0.00	6.80	2.91	0.00	22.33
Non-excusable	0.00	0.00	0.00	13.59	0.00	3.88	9.71	27.18
Total Percentage	0.00	13.59	12.62	20.39	29.13	6.80	17.48	100.00

	Poor Design	Change order	Weather Condition	Site Condition	Late Delivery	Economic Condition	Upgrading
Excusable compensable	1.00	1.11	1.00	1.05	1.18	1.00	1.06
Excusable non-compensable	1.00	1.00	1.10	1.00	1.05	1.02	1.00
Non-excusable	1.00	1.00	1.00	1.11	1.00	1.03	1.08
Total Ratio	1.00	1.11	1.10	1.16	1.23	1.05	1.14

Table F.10: Reliability-cause relation for Project "J"

	Poor Design	Change order	Weather Condition	Site Condition	Late Delivery	Economic Condition	Upgrading	Total Percentage
Excusable compensable	0.00	27.59	0.00	8.62	15.52	0.00	0.00	51.72
Excusable non-compensable	0.00	0.00	8.62	0.00	0.00	0.00	0.00	8.62
Non-excusable	13.79	0.00	0.00	25.86	0.00	0.00	0.00	39.66
Total Percentage	13.79	27.59	8.62	34.48	15.52	0.00	0.00	100.00

	Poor Design	Change order	Weather Condition	Site Condition	Late Delivery	Economic Condition	Upgrading
Excusable compensable	1.00	1.20	1.00	1.06	1.11	1.00	1.00
Excusable non-compensable	1.00	1.00	1.06	1.00	1.00	1.00	1.00
Non-excusable	1.10	1.00	1.00	1.19	1.00	1.00	1.00
Total Ratio	1.10	1.20	1.06	1.25	1.11	1.00	1.00

Appendix G

Compare the result of different As-planned schedule

Fig.G.1. Compare the result of different As-planned schedule for project "A"

Fig.G.2. Compare the result of different As-planned schedule for project "B"

Fig.G.3.Compare the result of different As-planned schedule for project "C"

Fig.G.4.Compare the result of different As-planned schedule for project "D"

Fig.G.5.Compare the result of different As-planned schedule for project “E”

Fig.G.6.Compare the result of different As-planned schedule for project “F”

Fig.G.7.Compare the result of different As-planned schedule for project "G"

Fig.G.8.Compare the result of different As-planned schedule for project "H"

Fig.G.9.Compare the result of different As-planned schedule for project "I"

Fig.G.10.Compare the result of different As-planned schedule for project "J"

Appendix H

Working Instruction for

Control Project scheduling

program

Menu bar: Any program has a part to control the program. In PC, the menu bar is the easiest way to access to the core of controlling box of the program.

Fig 6.1: Menu bar

File menu: the file menus used to set up the project schedule. It has following parts:

Fig 6.2: File Menu

- To create a new schedule, click on Project and New.
- to access to old files, click on Project and Open.
- To create the calendar with non-working days, click on Calendar.
- To introduce the scope of each task, click on Task.

- Exit for exit.

New Project window:

The image shows a 'New Project' window with the following fields:

- Project Name :** A text input field.
- Calendar :** A dropdown menu.
- Effect Factor :** A dropdown menu with the following options:
 - For all project
 - For each task
 - None

Fig 6.3: New project window

The following elements are presented in this section:

- **Project Name:** Introduce new project names.
- **Calendar:** To choose the created calendar.
- **Effect Factor:** Can choose in three conditions: "For all project" known as linear," for each task" known as non-linear, and "None" for non-effective factor.

Open Project window:

Fig 6.4: Open project window

In this section, the user may choose old projects to review or edit. Also in this section, old projects can be deleted.

Calendar window:

Fig 6.5: Calendar window

For regular time schedule it is not necessary to choose a name. However, to customize the calendar and choose extra Non-working days, it is necessary to choose name and set up the non-working day in Dates part as Fig 6.6.

Date window:

Dates

Note : Determine the dates of days that are not the dates of working days .

Calendar : call

Define date of day

Date : 12/04/2007 Comment :

+ -

Date	Comment
12/07/2007	Not work
12/04/2007	Not Work

Fig 6.6: Dates window

To customize the calendar, you need to choose the non-working day and then put the comments in it. For adding a new day, click on + then add new non-working day to the list. Some non-working days may become working day, by choosing the day and apply – on it the day becomes a working day.

Task window:

The Task window displays the following information:

ID: Task: Start Date: 12/7/2007 Duration: 1 day
 Project: p2 Predecessors:

ID	Task	Start	Duration	Factor	Finish	Predecessor
1	s	05/11/2007	3	1.42	12/11/2007	
2	a	13/11/2007	2	1.42	15/11/2007	1
3	as	13/11/2007	1	1.42	13/11/2007	1
4	qw	16/11/2007	1	1.42	16/11/2007	1,2,3

Fig 6.7: Tasks window

For making a schedule, you must set up the task and relate them together.

For this purpose, it is necessary to identify the task ID, Task name, Start date, Duration of task, and the predecessor of each task.

Affect Factor window:

The Affect Factor window displays the following information:

Factor Ratio	Poor Design	Change Order	Weather Condition	Site Condition	Late Delivery	Economical Condition	Upgrading
Excusable-compensable	1	-	1	-	-	-	-
Excusable-non-compensable	-	-	-	0.2	-	-	-
Non-excusable	-	-	-	-	0.3	-	-

Project: Edit + -

Fig 6.8: Effect factor window

Some amount of ratio factor may apply to each relation box. The applied amount depends on the case and methodology of ratio factor, which we find out in the last chapter.