



CONSTRUCTION DELAY ANALYSIS USING DAILY WINDOWS TECHNIQUE

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ABSTRACT:

Delays occur commonly in construction projects. Assessing the impact of delay is sometimes a contentious issue. Several delay analysis methods are available but no one method can be universally used over another in all situations. The selection of the proper analysis method depends upon a variety of factors including information available, time of analysis, capabilities of the methodology, and time, funds and effort allocated to the analysis. This paper presents computerized schedule analysis programmed that use daily windows analysis method as it recognized one of the most credible methods, and it is one of the few techniques much more likely to be accepted by courts than any other method. A simple case study has been implemented to demonstrate the accuracy and usefulness of the proposed delay analysis model. The results of the study indicate that the outcomes of delay analyses are often not predictable that each method may yield different results. The study also revealed that depending on the time and resources available, and the accessibility of project control documentation, one method may be more practical or cost-effective.

KEYWORDS: Construction Management, Scheduling, Delay Analysis, Computer Applications, Claims Management, Construction Law.

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INTRODUCTION:

Delays in construction can cause a number of changes in a project such as late completion, lost productivity, acceleration, increased costs, and contract termination. The party experiencing damages from delay needs to be able to recognize the delays and the parties responsible for them in order to recover time and cost. However, in general, delay situations are complex in nature. A delay in an activity may not result in the same amount of project delay. A delay caused by a party may or may not affect the project completion date and may or may not cause damage to another party. A delay can be caused by more than one party; however, it can also be caused by none of the parties (such as unusually severe weather conditions). A delay may occur concurrently with other delays and all of them may impact the project completion date. A delay may sometimes contribute to the formation of other delays. In construction contracts, schedule delay analysis is commonly conducted to demonstrate cause and effect relationships of time-related disputes. Schedule delay analysis makes use of the as-planned schedule, the as-built schedule, and schedule updates. CPM schedules add another dimension to schedule analysis as they provide schedule analysts with a critical path, float consumption, and the opportunity of utilizing what-if methodology. CPM has long been accepted by courts as an effective tool to evaluate the impact of delays (Arditi and Pattanakitchamroon 2006). There are many delay analysis methods that have been used by researchers and practitioners and these are known by different terminologies among practitioners and researchers. The results of delay analysis may be influenced by the method selected and therefore the selection of the most appropriate method is of importance to all parties concerned.

The objective of the study presented in this paper is to introduce a computerized schedule for delay analysis that incorporates daily windows analysis method and also to develop decision support system for selecting the suitable delay analysis method.

DEFINITION OF DELAY:

Time is the essence of a construction contract. A time period is specified as the contract duration. The legal obligations and rights associated with the concept of delay arise from the obligation implied in every contract that one party will not delay, hinder, or interfere with the performance of the

other party (Vento and D'Onofrio 2007). Thus, whether the owner or the contractor (or subcontractor, as the case may be) is legally and, perhaps, financially responsible for the consequences of delay depends upon a determination of the event(s) and party(ies) contributing to the delay.

The term "delay" in construction contracts has no precise technical meaning. It can be used in different sense to mean different conditions in project execution (Pickavance 2005).

Bramble and Callahan (1987) defined delay as "the time during which some part of the construction project has been extended beyond what was originally planned due to an unanticipated circumstance".

Assaf and Al-Hejji (2006) defined construction delay as "the time overrun either beyond the contract date or beyond the date that the parties agreed upon for delivery of a project".

Delay was also defined as "an acts or events that extend the time necessary to finish activities under a contract" (Stumpf 2000).

However, the term delay which will be addressed in this research means any occurrences or events that extend the duration or delay the start or finish of any of the activities of a project resulting in project late completion and that will only occur when the delay lies on the critical path of the programme.

However, in general, delay situations are complex in nature. A delay in an activity may not result in the same amount of project delay. A delay caused by a party may or may not affect the project completion date and may or may not cause damage to another party. A delay such as unusually severe weather conditions can be caused by none of the parties. Delays can occur in any and all activities, and these delays can concurrently or simultaneously cause delays in the project completion (Arditi and Pattanakitchamroon 2008). A delay may sometimes contribute to the formation of other delays. In other words, a project delay is the accumulated effect of the delays in individual activities.

As an example, a delay in the issue of drawings to a contractor can bring about consequences such as out-of-sequence work, work stoppages and poor morale. Shiet al. (2001) presented schematic cause-effect relationship of project delay as shown in Figure 1.

From causation perspective delays may be categorized under the following types:

*** Delays Caused By the Contractor:**

These include delays caused by parties for whom the contractor is responsible in law. Under most contracts the contractor is neither entitled to extension of time nor recovery of loss and/or expense and may have to pay damages/penalties.

*** Delays Caused By the Owner:**

These include delays caused by parties for whom the owner is responsible in law. In most standard forms, the contractor is entitled to extension of time and recovery of loss and/or expense caused by this type of delay.

*** Delays Caused By Neither Party:**

these include delays for which neither the owner nor the contractor is responsible, e.g. exceptionally adverse weather conditions. Most contracts allow the contractor more time to complete but with no corresponding entitlement to recover any loss and/or expense caused and no damages/penalties assessed.

Identifying delay impacts and allocating responsibility for delay events is more often argumentative because it involves one party's gain and the other party's loss. Delay analysis has developed as a means of providing the justification and quantification of the time and/or cost consequences necessary for resolving the different contentions (Braumah and Ndekugri 2009). It involves detailed

investigation of project records, programmes and their updates, often on retrospective basis, and with the aid of a number of different approaches commonly

termed "Delay Analysis Methodologies"

DELAY ANALYSIS METHODS:

There are four methods often mentioned in the literature that are professionally acceptable. They include:

- As-planned versus as-built schedule analysis method,
- Impact as-planned schedule analysis method,
- Collapsed as-built schedule analysis method, and
- Window analysis method, and they are known by different terminologies among practitioners.

The as-planned vs. as-built method is the observation of the difference between an as-planned schedule and an as-built schedule. The method identifies the as-built critical activities, compares these activities with the activities on the as-planned schedule, assesses the impact of delays on the project, identifies the sequences which actually define the duration of the project, and determines the causation and responsibility of delays that impact project completion.

The impact as-planned method uses only an as-planned or baseline schedule for delay analysis. It is based on the theory that the earliest date by which a project is completed can be determined by adding the delays into the as-planned schedule. New activities that represent delays, disruptions, and suspensions are added to the as-planned schedule and are used to demonstrate the reason why the project was completed later than planned. Contractors, who submit claims that involve a time extension, add only owner-caused delays to the as-planned schedule in the appropriate sequence to document the total project delay caused by the owner.

The collapsed as-built method is also referred to as the "but-for" schedule method. This analysis is popular in claim presentations because it is easily understood. SCL defines it as a method where the effects of delays are "subtracted" from an as-built schedule to determine what would have occurred but for those events (SCL 2002). This approach is a method of choice when a contractor lacks an acceptable schedule during the project, or when no as-planned schedule was required in the contract.

The window analysis method breaks the construction period into discrete time increments called "window" and examines the effects of the delays attributable to each of the project participants as the delays occur. It adopts the as-planned schedule as its baseline, but the as-planned schedule is periodically updated at the end of each planned time period. The windows analysis method is distinguished from the impact as-planned and collapsed as-built analyses in the fact that it incorporates both party delays into the analysis. In addition to this advantage, window analysis also provides a disciplined basis for the contractual parties to keep a project schedule up-to-date and properly adjusted. The majority of the viewpoints reviewed in the literature agree that windows analysis yields the most reliable results. In spite of its advantages, this method still has limitations which are summarized as follows:

- Window size can have a significant impact on the results of the analysis.
- Windows analysis has no mechanism for considering owner directed versus contractor acceleration.
- Windows analysis procedures do not include a systematic approach for calculating the responsibility for delays when multiple baseline updates have been used at different construction stages.
- Windows analysis does not consider the impact of resource over-allocation resulting from delays caused by various parties.

Hegazy and Zhang (2005) introduced changes to the traditional windows analysis method in order to resolve some of the above limitations. They proposed a daily windows approach for apportioning concurrent delays and accelerations. The approach uses a window size of one day to account for all fluctuations that occur in the project's critical path(s). However, this approach still does not consider other factors such as the effect of resource over-allocation and multiple baseline updates. To overcome this problem Hegazy and Menesi (2008) introduce improvements to the daily windows analysis in order to ensure that delay analysis considers multiple baseline updates, resource over-allocation and accurately apportions delays and accelerations among project parties.

EASY PLAN PROGRAMME:

Easy Plan (Hegazy 2007) is a computer programme which integrates estimating, scheduling, resource management, and project control. The Easy Plan program has been developed using the VBA language of Microsoft Excel software. Some of Easy Plan's features that facilitate delay analysis are (Menesi 2007):

- It allows the user to specify up to 3 estimates (duration and cost) for each activity.
- It allows the user to enter up to three key resources and to specify the daily limit of these resources.
- It notifies the user if the resource limits are exceeded.
- It allows the user to change the method of executing any activity.
- It permits more than one baseline to be saved.
- It allows the user to enter the daily progress of an activity as a percentage, or as a delay by a certain party.

- It represents the project progress using two bars for each activity: the top represents the baseline, and the bottom represents the progress. Thus, it shows whether the actual progress is faster or slower than that planned.
- It calculates and shows the actual project duration while the daily progress is being entered, taking into consideration all the delays, accelerations, and slowdowns.
- It allows the user to specify the project deadline and notifies the user if the project duration exceeds the deadline.

The application of this schedule analysis programme is described in the following case study. Figure 2 is proposed as the flow chart describing the procedure of Easy Plan programme.

COMPUTERIZED SCHEDULE ANALYSIS MODEL

CASE STUDY: ANALYSIS OF DELAYS, ACCELERATIONS, LOGICAL RELATIONS AND RESOURCE OVER-ALLOCATION

A computerized schedule analysis with enhanced daily windows analysis has been presented in this study to accurately apportion delays and accelerations among the project parties. The model has been incorporated into a computer program, EasyPlan (Hegazy 2007), which integrates estimating, scheduling, resource management, and project control.

CASE OVERVIEW:

A hypothetical eight-activity project is considered as a case study to demonstrate the daily windows analysis. The activities, their optional estimates, their predecessors (logical relationships), and the amount of resources required for each activity are shown in Table 1.

The contractor submitted an initial (as-planned) schedule that satisfied its own resource constraints and met a 15-day deadline, which was accordingly approved by the owner. Actual progress, however, resulted in some schedule changes. Table 2 summarizes delay events during the course of work. An analysis is required to determine if the contractor is entitled for compensation by the owner, and to investigate whether the owner's delay on day 6 warrants a request for compensation to cover the added expenses of accelerating Activity G. Although this



project is simple, the changes due to delays, accelerations, logical relations and resource over-allocation make its delay analysis complicated.

Using the Easy Plan Programme:

Following the case study information, first, the general data for the project were entered; including the start date, working days, the key resource (L1) and its daily limit (6), project deadline duration (15 days), and other contract provisions, such as a \$5,000 (U.S. dollars) daily penalty and a \$50/day (U.S. dollars) indirect cost (Fig. 3). Next, the activities and their optional estimates were specified in an activities sheet, as shown in Fig. 4.

Then, the predecessors of each activity were entered, as shown in Fig. 5. Since the contractor planned to use the first estimate for each activity (the cheap and slow option), the “method used” column, indicates an index of “1.” Accordingly, the project duration became 15 days. This 15-day schedule meets the deadline and also the six L1 resource limit at a total cost of \$ 48,750. Therefore, the schedule was saved as a “baseline” for the project (Fig. 6).

ACTUAL PROGRESS EVENTS:

When the project moved to the construction stage, all progress events, including delays, along with all parties responsible were entered on a daily basis. In the progress sheet of Fig. 7, each activity has two bars: the top bar (light color) represents the baseline indicated as daily percentages (e.g. duration of two days means a progress of 50% for each day). The bottom activity bar (dark color), on the other hand, allows the user to record the actual events that were experienced during the execution of the activity. Initially, the actual bars were set to be the same as the baseline bars. Actual daily events are entered in one of two ways. They can be entered directly on the actual activity bar (bottom) or the user can click on the “daily progress” button.

The daily events for an activity can be entered as either a progress or a delay. For Day 1 (Fig. 6), the project progressed according to the planned. The contractor delayed Activity A on Day

2, Day 3 and Day 4, which extended the project duration from 15 to 18 days as shown in Fig. 5, while Activity E progressed according to its planned duration.

In response to the actual events that took place after Day 4, the contractor decided to run Activity H in parallel with Activity G and immediately after Activity F as a corrective action in order to accelerate the project by three days and finish the work by the planned date (Fig. 8). Since the owner and the contractor agreed to use a new baseline after this logical relationship change, a new baseline was then saved in Easy Plan.

On Day 6, the owner delayed Activity D by one day. Although the delay did not affect the overall project duration, it caused a resource over-allocation at Day 9, as shown in Fig. 9. This over-allocation implied that the owner’s delay on Day 6 would later force the contractor to change the schedule or even delay some activities to avoid exceeding the resource limit. On Day 9, because of the resource limit, the contractor did not start Activity G due to its inability to proceed with the three Activities D, F, and G in parallel. Thus, Activity E and the project duration would be extended to Day 16, as shown in Fig. 10.

To compensate for this 1-day delay, the contractor decided to accelerate Activity G, and accordingly accelerate the overall project by one day, by changing the method of executing Activity G. The faster and more expensive second method reduced the duration of Activity G to six days instead of seven. Consequently, the project duration became 15 days again (Fig. 11). This change also mandated another adjustment and the approval of a new baseline after Day 9.

(Fig. 12) shows the As-built schedule of the project after entering all the events, in which the project finished on Day 17 with 2 days of net delay.

Delay Analysis for the Case Study:

When the user selects “Windows analysis,” as illustrated in Fig. 13, the analysis is conducted, and a small window containing a summary result is presented (Fig. 13).

The results summary indicates that the owner (O) was responsible for half day of excusable compensable delay, which was compensated by his half day of acceleration while the contractor (C) was responsible for five days of non-excusable delays, but he was compensated for four and a half day of them because of his acceleration. On the other hand, the project duration, however, became 17 days due to an excusable (N) delay of one and a half day.

DISCUSSION OF RESULTS:

Detailed results of the delay analysis are presented in an automated report (Fig. 13), providing a detailed day-by-day analysis. For example (Fig. 14) shows the result of Day 5 to Day 8. At the beginning of Day 5, a new baseline was entered because of the contractor’s corrective action. Since the new baseline duration was 15 and the previous baseline duration was 18, a 3-day contractor acceleration was accumulated. At Day 6, the owner caused a delay to Activity D which is critical. Therefore, no (O) was shown in the cumulative results of Day 5. However, the owner’s event on this day would lead to future resource over-allocation as indicated in the extra day of expected project delay (16 days instead of 15 days), as shown in the third column in Fig. 13. Accordingly, one (N) delay was accumulated in this case since it was not caused purely by the contractor (i.e., the owner was the reason). The report thus gives a traceable account of the basis for the results of the analysis. It should be noted that while the programmer suggests that an (N) is considered as a result of the owner’s impact on resource over-allocation (i.e., the contractor is entitled to a time extension but no cost compensation), it is possible to use any other agreed upon option (e.g., considering a compensable owner delay). In the event that the contractor’s own performance is the cause of its resource over-allocation, the presented schedule analysis approach has the advantage of clearly recognizing the situation and its implications on the remaining schedule and eligibility for delay claims.

This validates the programme’s ability to distinguish the parties causing the delay, acceleration, logical relation and resource over-

allocation. As such, it is suitable for decisions related to cost and time compensation.

CONCLUSIONS:

The main study findings and conclusions are summarized as follows:

- The reliability of delay analysis depends on the programming and record keeping practice. An analyst should meticulously review the data obtained from the project records because none of the methods yields reliable results if the information used is invalid.
- There are a number of methodologies available for analyzing delays and these differ from each other based on the type of schedule techniques required, the baseline schedule used and the mode of application in their use. Therefore, a fair and effective evaluation of delay impact is possible if the most appropriate delay analysis method is selected that provides a reliable solution with the information available and within the time and cost allocated for this purpose.
- None of the existing delay analysis methods is perfect as each has its own strengths and weaknesses. Windows analysis method is clearly accepted by the literature as the most reliable delay analysis method among the four standard methods discussed in this research. However, the transient nature of construction projects not often allowing scheduling data being well documented as well as time and budget limitations lead a number of researchers to suggest that the choice of a simpler method may be sensible.
- Daily windows delay analysis method is considered an accurate method and suitable to use as it takes into consideration the effects of baseline Cumulative resource Expected and the effort Results taken Duration contractor to accelerate the project and minimize potential delays as it usually ignored in delay analysis.
- It is necessary for analyst to be very familiar with the capabilities of the software used in project scheduling and progress control in order to be able to generate legitimate schedules for the analysis.

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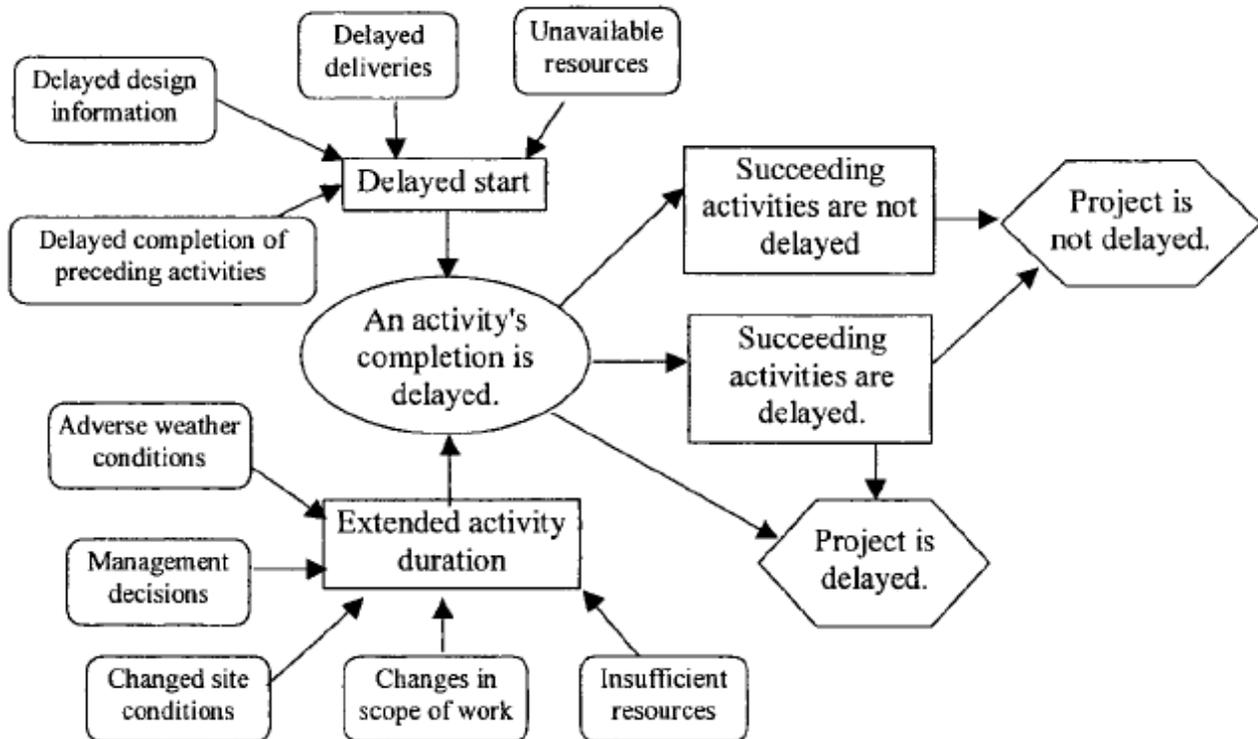


Figure.1 Cause-Effect Relationship of Construction Delays (Shi et al. 2001)

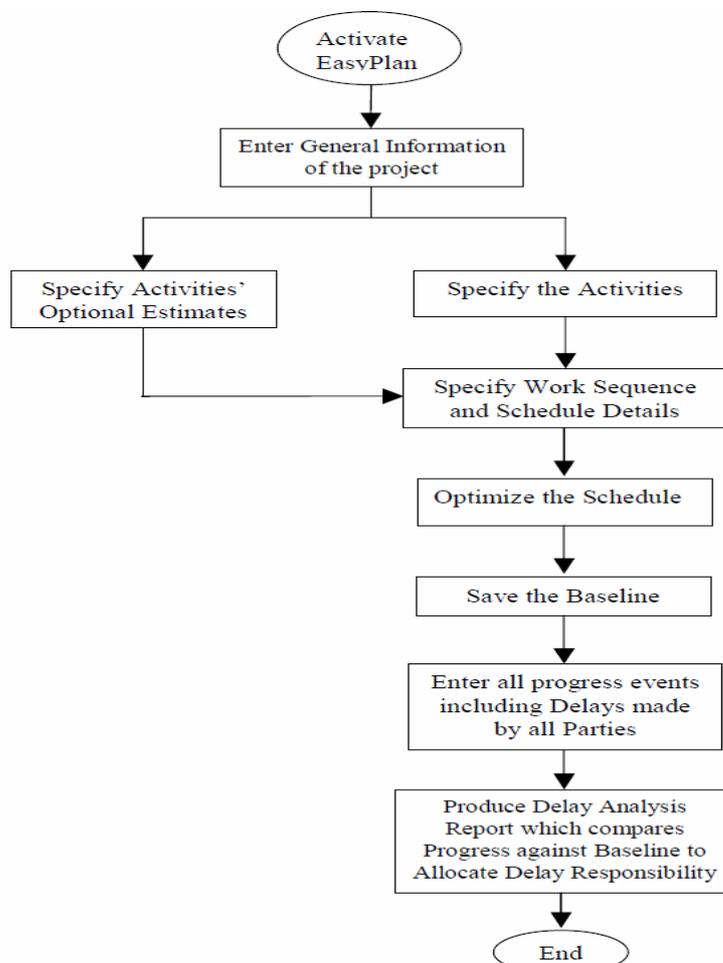


Figure.2 Flow Chart Indicating the Easy Plan's Procedure (Researcher)

**Table 1: The Activities' Estimates and Predecessors**

No.	Activity	Predecessor	Estimate 1			Estimate 2		
			Cost	Duration	Resources	Cost	Duration	Resources
1	A	-	6000	2	3			
2	B	1	6000	3	1	5000	4	1
3	C	1	6000	3	1	5000	4	1
4	D	1	6000	3	2	5000	4	2
5	E	-	6000	5	2	5000	6	2
6	F	2,3,5	6000	4	3	5000	5	3
7	G	2,3,5	6000	7	3	5000	8	3
8	H	4,6,7	6000	3	3			

Table 2: Delay Events and Their Secondary Effects

Day	Description
2,3 and 4	The contractor delayed Activity A (3 days) on Day 2, Day 3 and Day 4, and accordingly, it was expected that the project would finish in 18 days. To recover the three-day delay, the contractor found that the best available option was to run some activities in parallel so that the project duration would be 15 days again.
6	On the sixth day, the owner delayed the start of Activity D, and therefore a resource over-allocation was expected for the next few days.
9	The contractor delayed the start of Activity G to his inability to proceed with three Activities D, F and G in parallel because of the resource limit. Therefore, the contractor voluntarily accelerated the project by using of a more expensive method for Activity G which shortened its duration from 7 days to 6 days.
11	Both the owner and the contractor caused delay to the project. The owner delayed Activity G while the contractor delayed Activity F.
12	The contractor caused delay to both Activities F and G.
14	Activity F was delayed because of the slow progress of the contractor while Activity G was stopped due to inclement weather.
16	The project was accelerated by one-day because of the owner acceleration for Activity G and the contractor acceleration for Activity H.

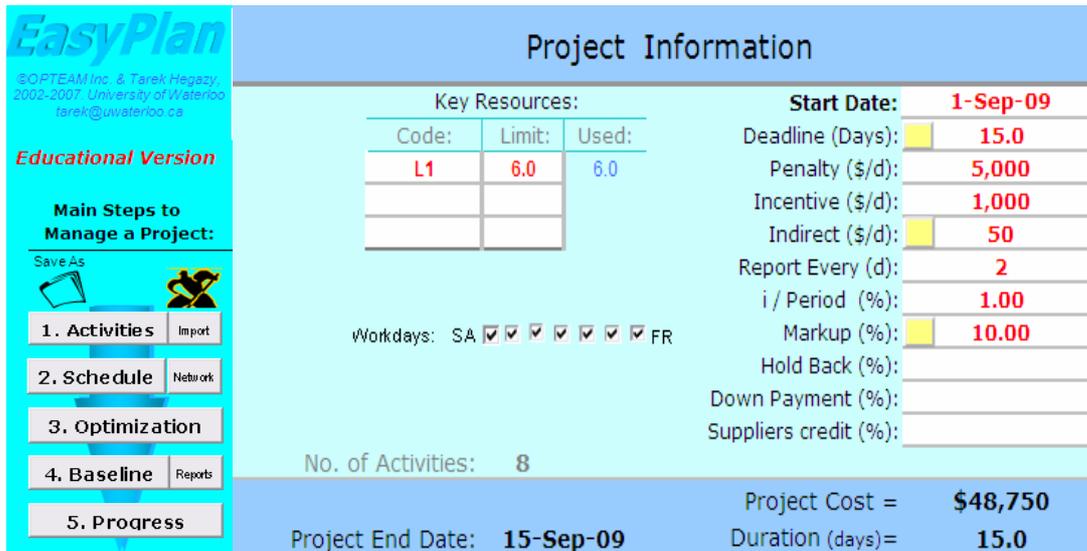
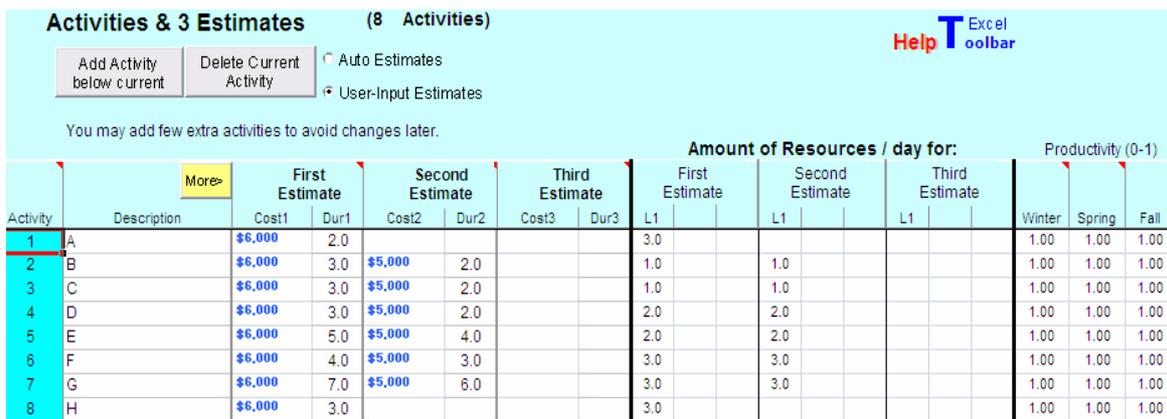


Figure 3: Main Screen of Easy Plan



Slow and cheap option Fast and expensive option

Figure 4: Activities' Estimates

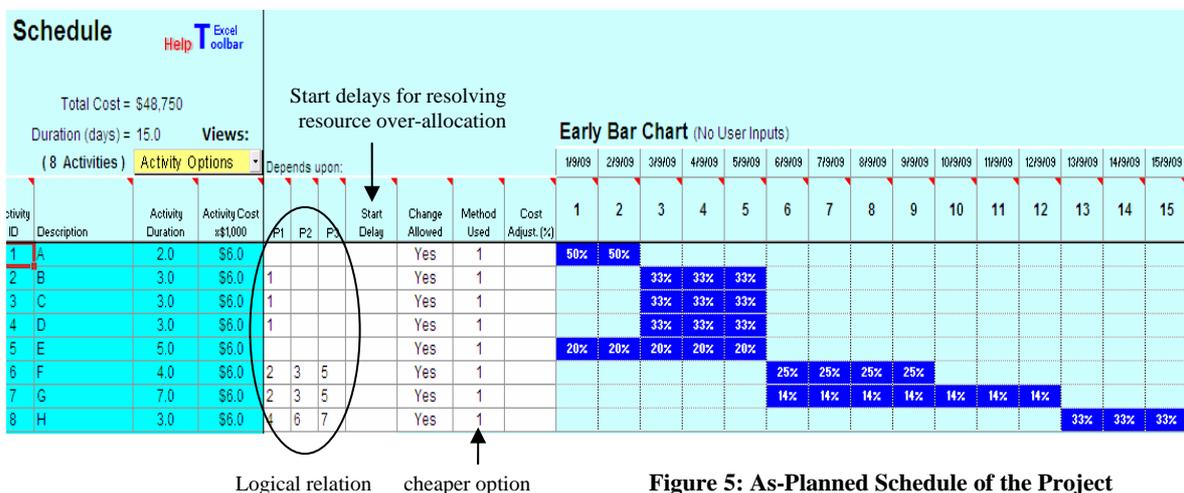


Figure 5: As-Planned Schedule of the Project

is used

First baseline was saved on
September 1 2009

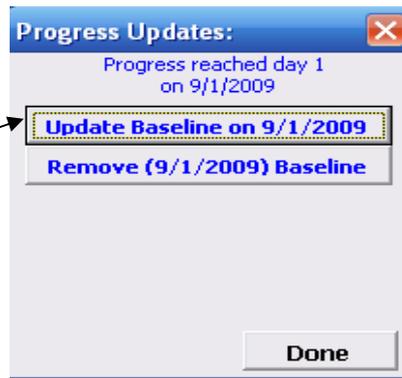


Figure 6: Saving the Project Baseline

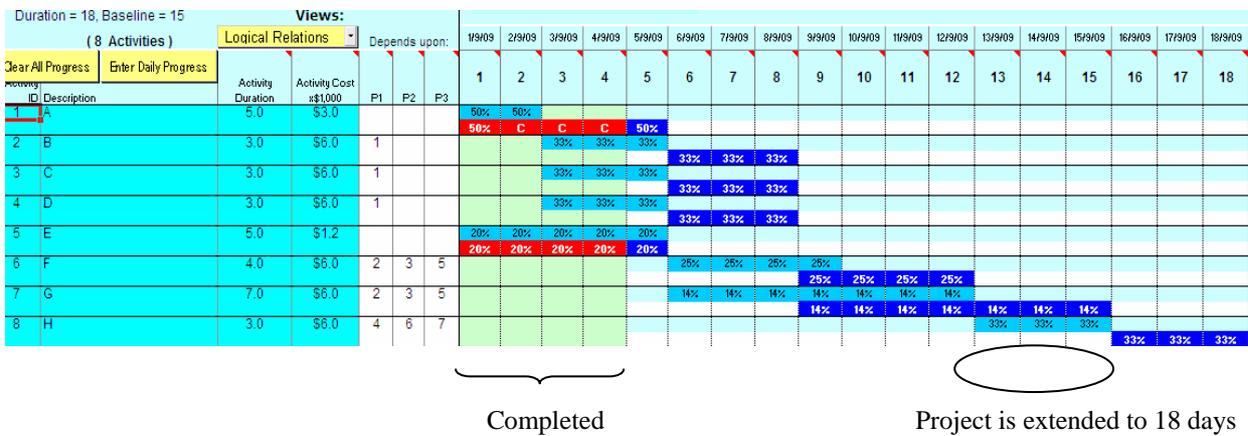
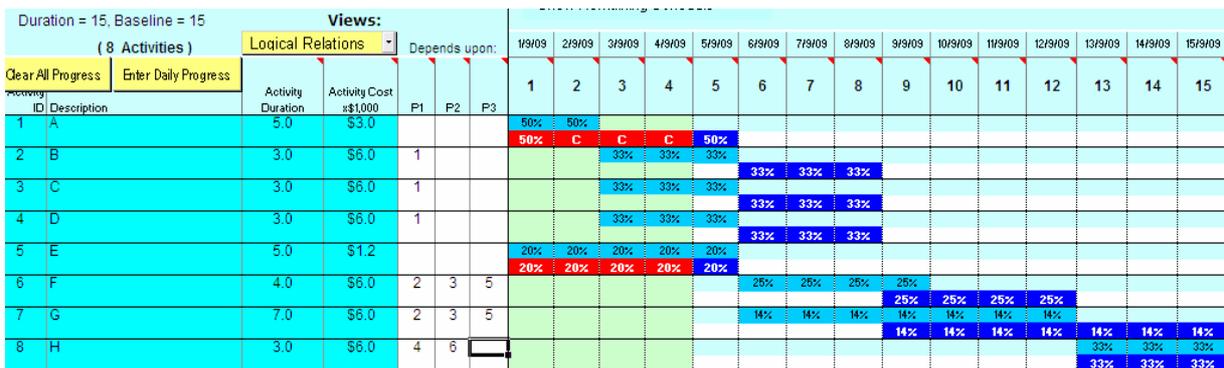


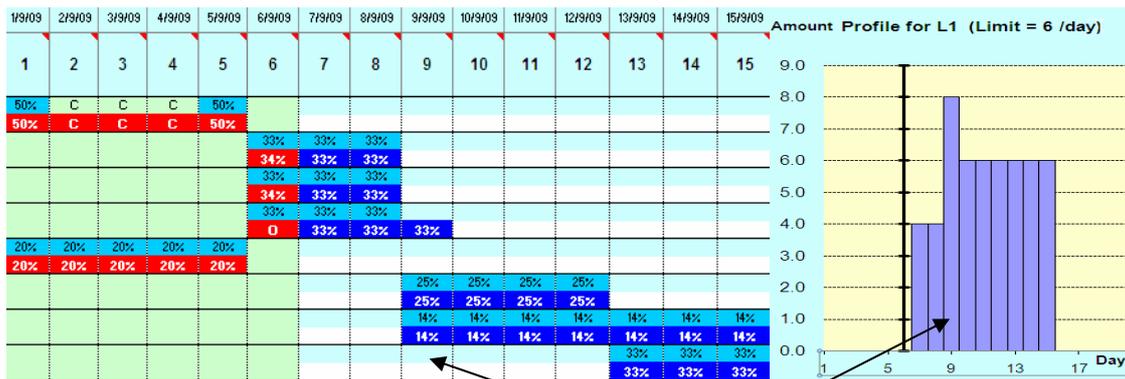
Figure 7: Actual Progress at the end of Day 4



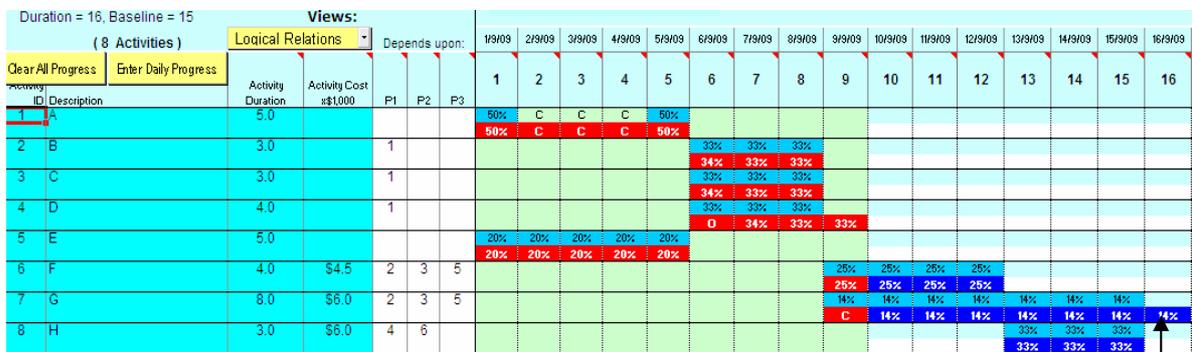
H dependency on G removed

The project duration became 15 days again because of the changed in logical relations

Figure 8: Project Schedule after a Change in the Logical Relations

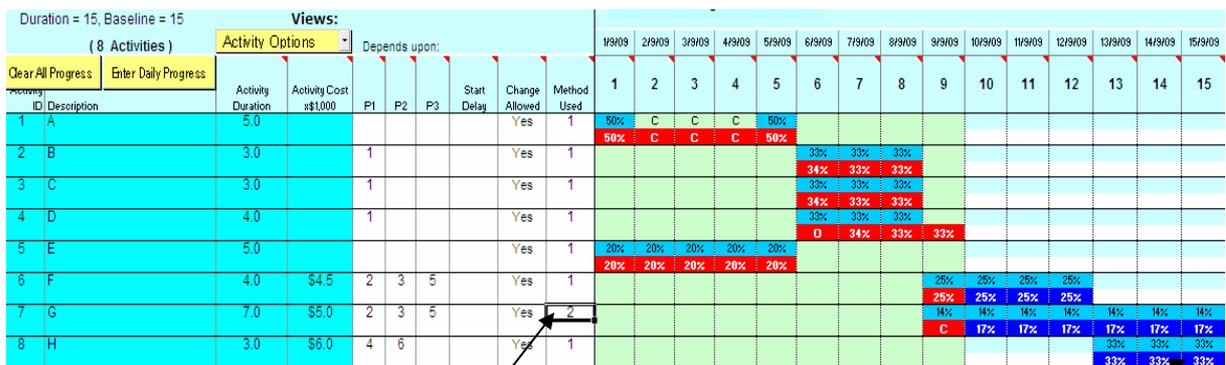


Resource over- allocation at day 9
Figure 9: Actual Progress at the End of Day 5



The project duration becomes 16 days

Figure 10: Actual Progress at the End of Day 9



Choosing a faster method for constructing activity G

The project duration becomes 15 days

Figure 11: Changing the Method of Executing Activity G



Duration = 17, Baseline = 15		Views:			Depends upon:																			
(8 Activities)		Logical Relations	PI	P2	P3	1/9/09	2/9/09	3/9/09	4/9/09	5/9/09	6/9/09	7/9/09	8/9/09	9/9/09	10/9/09	11/9/09	12/9/09	13/9/09	14/9/09	15/9/09	16/9/09	17/9/09		
Clear All Progress	Enter Daily Progress	Activity Duration	Activity Cost \$1,000	PI	P2	P3	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
1	A	5.0					50%	C	C	C	50%													
2	B	3.0		1								34%	33%	33%										
3	C	3.0		1								34%	33%	33%										
4	D	4.0		1								0	34%	33%	33%									
5	E	5.0					20%	20%	20%	20%	20%													
6	F	7.0		2	3	5									25%	25%	25%	25%						
7	G	9.0		2	3	5									25%	25%	C	C	25%	13%	12%			
8	H	2.0		4	6										C	17%	O	C	17%	N	17%	33%	16%	
																			33%	33%	33%		70%	30%

Figure 12: Actual progress at the end of Day 17

The screenshot shows a software interface with a menu bar (Main Screen, File, Project, Resources, Utilities, Quick Jumps, Help) and a toolbar. A 'Windows Analysis' dialog box is open, displaying the following text:

Project As-Built Duration (days) = 17.0
 Compensable Owner delays (O) = 0.50, Owner Acceleration = 0.50.
 Contractor nonexecusable delays (C) = 5.00, Contractor Acceleration = 4.50.
 Execusable other party delays (N) = 1.50.

An 'OK' button is visible at the bottom of the dialog box. In the background, a Gantt chart is partially visible, showing activity durations and progress percentages for activities A through H across dates from 1/9/09 to 17/9/09.

Figure 13: Summary of Delay Analysis Results

Chapter Five Case Study 1 - Notepad	Cumulative Results	Expected Duration
<p>Analysis of days 5 to 9. A new baseline has been entered.</p> <p>Day: 5 (Saturday, Sep 5 2009)</p> <p>The new baseline saves 3 days, which will be credited as Contractor .</p> <p>Previous Duration = 15.0 Current Duration = 15.0</p> <p>Compensable Owner delays (O) = 0.00, Owner Acceleration= 0.00.</p> <p>Contractor delays (C) = 3.00, Contractor Acceleration= 3.00.</p> <p>Execusable delays (N) = 0.00.</p> <p>Considering Resource Allocation: Current Duration = 15.0</p>	<p><u>New Baseline with 3 contractor accelerations</u></p>	<p>15</p>
<p>Day: 6 (Sunday, Sep 6 2009)</p> <p>Previous Duration = 15.0 Current Duration = 15.0</p> <p>Compensable Owner delays (O) = 0.00, Owner Acceleration= 0.00.</p> <p>Contractor delays (C) = 3.00, Contractor Acceleration= 3.00.</p> <p>Execusable delays (N) = 0.00.</p> <p>Considering Resource Allocation: Current Duration = 16.0 Modified (N) Delay= 1.00</p>	<p><u>Effect of Resource over-allocation</u></p>	<p>16</p>
<p>Day: 7 (Monday, Sep 7 2009)</p> <p>Previous Duration = 15.0 Current Duration = 15.0</p> <p>Compensable Owner delays (O) = 0.00, Owner Acceleration= 0.00.</p> <p>Contractor delays (C) = 3.00, Contractor Acceleration= 3.00.</p> <p>Execusable delays (N) = 1.00.</p> <p>Considering Resource Allocation: Current Duration = 16.0</p>	<p><u>No Change</u></p>	<p>16</p>
<p>Day: 8 (Tuesday, Sep 8 2009)</p> <p>Previous Duration = 16.0 Current Duration = 16.0</p> <p>Compensable Owner delays (O) = 0.00, Owner Acceleration= 0.00.</p> <p>Contractor delays (C) = 3.00, Contractor Acceleration= 3.00.</p> <p>Execusable delays (N) = 1.00.</p> <p>Considering Resource Allocation: Current Duration = 16.0</p>	<p><u>No Change</u></p>	<p>16</p>

Figure 14: Daily Windows Analysis Results of the Second Baseline (Days 5 to 8)