Construction Delay Analysis under Multiple Baseline Updates

By

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I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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ABSTRACT

Due to the inherent risks and increasing complexity of modern construction projects, delays and cost overruns have become common facts in the industry. Researchers and practitioners have used many techniques to assess project delays and apportion delay responsibility among the parties involved. Windows delay analysis has been recognized as one of the most credible techniques for analyzing construction delays. Despite its benefits, windows analysis can produce different results depending on the window size, it does not consider owner and contractor acceleration, it does not systematically consider the impact of several baseline updates made due to changes in the duration and logical relationships of the activities, and it does not consider the impact of the progress events on resource over-allocation and its consequent delays.

This study proposes a computerized schedule analysis model that considers multiple baseline updates and resource over-allocation. The model uses a daily window size in order to consider all fluctuations in the critical path(s) and uses a legible representation of progress information to accurately apportion delays and accelerations among project parties. To facilitate its use, the model has been incorporated into a computer tool, EasyPlan, which integrates estimating, scheduling, resource management, and project control. A simple case study has been implemented on the proposed delay analysis model in order to demonstrate its accuracy and usefulness.

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Above all, praise is to God.

To My Parents

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CHAPTER 1
INTRODUCTION

1.1 Construction Delays

Delays are one of the biggest problems construction firms face. Delays can lead to many negative effects such as lawsuits between owners and contractors, increased costs, loss of productivity and revenue, and contract termination. According to Bordoli and Baldwin (1998) and the World Bank (1990), for 1627 projects completed worldwide between 1974 and 1988, the overrun varied between 50% and 80%.

The construction companies in many countries around the world experience significant delays. In the past few years, the number of claims submitted to the American Arbitration Association (AAA) reached almost 25% of the 1.7 million claims submitted over the past 74 years (Kassab et al., 2006). In the United Kingdom (U.K.), a 2001 report by the National Audit Office, entitled “Modernising Construction”, revealed that 70% of the projects undertaken by government departments and agencies were delivered late, and a recent research by Building Cost Information Service (BCIS) found that nearly 40% of all studied projects had overrun the contract period (Lowsley and Linnett, 2006). In India, a study conducted by the Infrastructure and Project Monitoring Division of the Ministry of Statistics and Programme Implementation in 2004 reported that out of 646 central sector projects costing about $50 trillion, approximately 40% are behind schedule, with delays ranging from 1 to 252 months (Lyer and Jha, 2006). In the United Arab Emirates (UAE), where construction contributes 14% to the gross domestic product (GDP), a study by Faridi and El-Sayegh (2006) revealed that 50% of construction projects encounter delays.

To recover the damage caused by delays, both the delays and the parties responsible for them should be identified. However, delay situations are complex in nature because multiple delays can occur concurrently and because they can be caused by more than one party, or by none of the principal parties. One delay may contribute to the formation of other delays (Arditi and Pattanakitchamroon, 2006). The analysis of these delays involves not only the calculation of the delay time but also the identification of the root causes and the responsibility for delays, Such an analysis therefore becomes a basis for the financial calculations that determine penalties or other damages to be assigned to the parties responsible for the delays.

1.2 Research Motivation

Schedule delays must be analyzed in order to apportion responsibility for the duration of the delay among the project participants (owner, contractor, and/or third party). There are various methods that exist for schedule delay analysis. However, different analysis techniques provide different results for the same circumstances depending on the time and resources available for the analysis and the accessibility of project control documentation. The same technique may also yield inconsistent results when the points of views of different parties are considered (Hegazy and Zhang, 2005).

Of the methods available, the windows delay analysis is recognized as the most credible method, and it is one of the few techniques much more likely to be accepted by courts than any other method (Arditi and Pattanakitchamroon, 2006; Finke, 1999; Hegazy and Zhang, 2005; Kartam, 1999; Stumpf, 2000). Windows analysis breaks the project into a number of sequential periods, called windows, and analyzes the delays that occurred in each window successively. In spite of its advantages, this method still has limitations which are summarized in the following subsections.

1.2.1 Problem with Window Size

When windows analysis is performed, attention is paid to the critical path(s) that exist(s) at the end of each window, and the fluctuations in the critical path(s) within the window are overlooked. Therefore, the selection of a window size can have a significant impact on the results of the analysis, especially when concurrent delays are involved. Hegazy and Zhang (2005) discussed this problem and proposed a daily windows approach in an attempt to overcome it. 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.

1.2.2 Inadequate Consideration of Acceleration

The windows analysis has no mechanism for taking into account time-shortened activities that reduce the total project duration. Hegazy and Zhang (2005) proposed a new approach for representing and analyzing acceleration in windows analysis. This approach uses daily windows and deals with acceleration as a negative delay attributable to the party who creates it. In another effort, Kim et al. (2005) introduced a new concept called “contractor’s float” in order to solve the problem of handling time-shortened activities that contribute to a reduction in the total duration of the project. When the total project duration is reduced by time-shortened activities because of the contractor’s efforts, the time reduced could be utilized by the contractor as a safety margin against future delays.

1.2.3 Inadequate Consideration of Baseline Changes Along the Project

Since the windows approach uses the as-planned schedule as its baseline, it may produce inaccurate results when approved schedule updates are not taken into consideration when the baseline is modified. According to Stumpf (2000), the courts will not uphold a windows analysis that is based only on questionable schedule updates. Stumpf gave an example of a case in which there was a change in the logic. The scheduling analysis expert used windows analysis to evaluate the delay, but the change in logic was not considered. As a consequence, the Board of Contract Appeals said that the scheduling expert failed to use a current critical path method (CPM) schedule to evaluate the delay on the project. Current windows analysis procedures do not include a systematic approach for calculating the responsibility for delays when there are multiple baseline updates.

1.2.4 No Consideration of Resource Over-Allocation in Delay Analysis

Some delays may result in unrealistic resource allocation in the succeeding work, which in turn, may further delay the project. Therefore, resource over-allocation should be considered in the schedule analysis in order to arrive at an accurate apportionment of the delay responsibility (Ibbs and Nguyen, 2007). The windows analysis method does not capture the possible extended effect of the delay due to resource over-allocation. While a number of studies have focused on project resource allocation (e.g. Chua and Shen, 2005; Davis, Fondahl, 1991; 1974; Hegazy, 1999; Kim and de la Garza, 2003; 2005; Wiest, 1967; Willis, 1985), only one study (Ibbs and Nguyen, 2007) have indicated the importance of the effect of resource allocation in delay analysis. The effort by Ibbs and Nguyen (2007), however, neither provided a structured calculation procedure nor addressed the issues discussed in the subsections 1.2.1, 1.2.2, and 1.2.3.

1.3 Research Objectives and Scope

The main objective of this research is to introduce improvements to the windows method for construction delay analysis. Detailed objectives are as follows:

- Develop a new delay analysis model that considers contractors' corrective actions and the consequent baseline changes along the project.
- Introduce improvements to the new delay analysis model to consider resource over-allocation in the analysis.
- Develop a systematic daily windows analysis procedure that incorporates the two above items.

- Develop a computer prototype and validate the algorithm functionality, usefulness, and practicality through an example application.

1.4 Research Methodology

To achieve the above research objectives, the following methodology was followed:

- Conduct a comprehensive literature review of delay analysis techniques.
- Identify the limitations of the windows delay analysis method and propose improvements.
- Propose and describe an effective and logical method based on the windows approach for evaluating construction delays considering baseline and logic changes.
- Design and implement a modified daily windows approach that reads the as-built data and apportions delays that occur in the critical path(s) by taking the effect of resource over-allocation into consideration.
- Present case studies to validate the results of the improved method.

1.5 Thesis Organization

The thesis consists of 5 additional chapters. Chapter 2 is a literature review of the causes of delays and the traditional techniques for delay analysis in construction. The history of the development of delay analysis techniques is reviewed, including the modified techniques and recent approaches mentioned in the literature.

Chapter 3 introduces developments to the daily windows analysis that will allow the analysis of schedules with multiple baseline updates. A systematic procedure for a daily windows analysis with a multiple baseline approach is established. In this approach, the contractor’s corrective actions (i.e., changes in the logical relations between the activities and the changes in the activities’ duration) are considered in the analysis as contractor’s acceleration.

Chapter 4 shows that delay analysis without considering resource allocation may affect the results of the analysis. A modified daily windows method is introduced along with its algorithm. The modified daily windows analysis is shown to be more accurate and reliable since it takes the effect of resource allocation into consideration in the analysis.

Chapter 5 describes a hypothetical case study which is used to validate the proposed computer model of the modified daily windows analysis, and to demonstrate that this model is able to analyze schedules under multiple baseline updates, taking into consideration the effect of resource allocation.

In chapter 6, a summary of the study and some of the areas for possible future research are presented.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Delays happen in most construction projects, whether simple or complex. In construction, delay could be defined as the time overrun either beyond the contract date or beyond the date that the parties agreed upon for delivery of a project (Assaf and Al-Hejji, 2006). A project consists of a collection of activities. Delays can occur in any or all of these activities, and these delays can concurrently cause delays in the completion of the project. A project delay is the accumulated effect of the delays in the individual activities. Delay analysis is used to determine the cause(s) of the delay in order to ascertain whether an extension of time should be awarded. An extension of time relieves the contractor from the liability for damages (Lowsley and Linnett, 2006).

The analysis of delays in construction projects is difficult and complicated because of the large number of individual activities that have to be dealt with, even for a relatively simple project. A medium-sized project may consist of hundreds of activities, many of which may take place at different times and with different durations than originally planned (Shi et al., 2001). Some activities may be delayed or accelerated, and such changes may partially or fully, or may not, affect the project completion date.

2.2 Causes of Delays

Researchers have studied the many causes of delay in the construction industry. Lo et al. (2006) summarized some of the studies that took place from 1971 to 2000 (Table 2.1).

Table 2.1: Summary of Previous Studies of the Causes of Delays in Construction Projects

Researchers	Country	Major causes of delay
Baldwin et al. (1971)	United States	- inclement weather - shortages of labour supply - subcontracting system
Arditi et al. (1985)	Turkey	- shortages of resources - financial difficulties faced by public agencies and contractors - organizational deficiencies - delays in design work - frequent changes in orders/design - considerable additional work
Okpala and Aniekwu (1988)	Nigeria	- shortages of materials - failure to pay for completed work - poor contract management
Dlakwa and Culpin (1990)	Nigeria	- delays in payment by agencies to contractors - fluctuations in materials, labour and plant costs
Mansfield et al. (1994)	Nigeria	- improper financial and payment arrangements - poor contract management - shortages of materials - inaccurate cost estimates - fluctuations in cost
Semple et al. (1994)	Canada	- increases in the scope of the work - inclement weather - restricted access
Assaf et al. (1995)	Saudi Arabia	- slow preparation and approval of shop drawings - delays in payments to contractors - changes in design/design error - shortages of labour supply - poor workmanship

Table 2.1 (Cont.): Summary of Previous Studies of the Causes of Delays in Construction Projects

Ogunlana et al. (1996)	Thailand	- shortages of materials - changes of design - liaison problems among the contracting parties
Chan and Kumaraswamy (1996)	Hong Kong	- unforeseen ground conditions - poor site management and supervision - slow decision making by project teams - client-initiated variations
Al-Khal and Al-Ghafly (1999)	Saudi Arabia	- cash flow problems/financial difficulties - difficulties in obtaining permits -"lowest bid wins" system
Al-Momani (2000)	Jordan	- poor design - changes in orders/design - inclement weather - unforeseen site conditions - late deliveries
Lo et al. (2006)	Hong Kong	- inadequate resources - unforeseen ground conditions - exceptionally low bids - inexperienced contractor - work in conflict with existing utilities - poor site management and supervision -unrealistic contract duration
Faridi and El-Sayegh (2006)	UAE	- slowpreparation and approval of drawings - inadequate early planning of the project - slowness of owner's decision making - shortage of manpower - poor site management and supervision - low productivity of manpower
Assaf and Al-Hejji (2006)	Saudi Arabia	- change in orders by the owner during construction - delay in progress payment - ineffective planning and scheduling - shortage of labor - difficulties in financing on the part of the contractor

2.3 Types of Delays

Delays are classified into two different types according to liability: excusable and inexcusable (Fig. 2.1). When the contractor is responsible for the cause of the delay, it is called an inexcusable delay. Examples include failure to coordinate work, too few workers, and low productivity. The contractor can not obtain a time extension for inexcusable delays. The contractor is also liable for damages incurred by the owner as a result of the inexcusable delay.

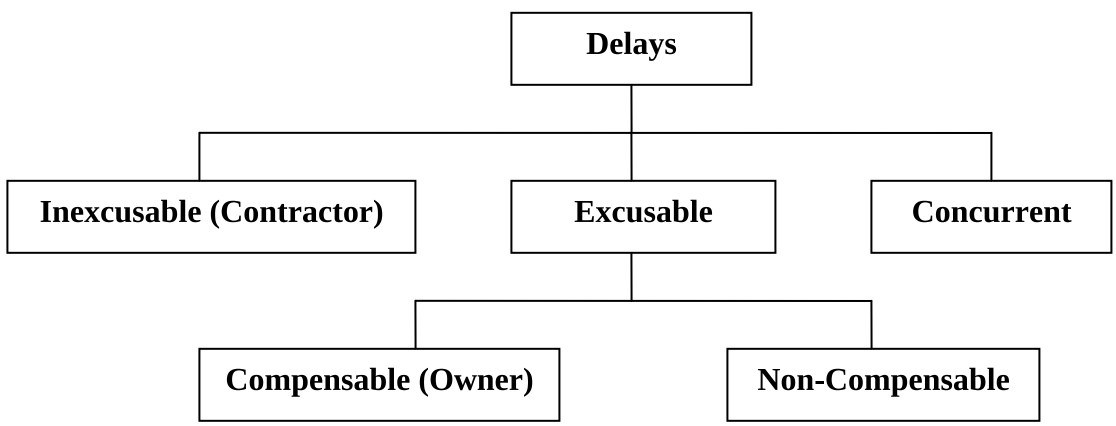


Fig. 2.1: Types of Delays

The second type of delays, excusable delays, can be farther broken down into compensable and non-compensable delays. Compensation is required when the owner is the major cause of the delay. Examples include changes in the scope of work and the owner’s failure to grant site access. When neither the owner nor the contractor is responsible for the delay, it is called excusable-non-compensable delay. Examples include severe weather and acts of God. The contractor is entitled to a time extension if this type of delay increases the overall project duration.

When more than one type of delay happens at the same time and both, either together or independently, impact the project's critical path, a concurrent delay occurs (Arditi and Robinson 1995; Ostrowski and Midgette, 2006). Concurrent delays add more complexity to the delay analysis. Mohan and Al-Gahtani (2006) indicated that the three major difficulties in calculating concurrent delay are as follows:

1. It is difficult to agree on the concurrency period of two or more delay events. The concurrent delay events may occur with respect to two or more concurrent activities which have different start and finish dates; thus only portions of these activities are concurrent.
2. New critical paths could be formed because of consuming the total floats for noncritical activities.
3. If the concurrent delays are on critical paths, and if the owner delays the critical path, the contractor can decelerate his work on the parallel critical paths in order to be critical.

2.4 Types of Schedules Used in Delay Analysis

The purpose of the delay analysis is to calculate the contribution of each party to the total project delay. Generally the as-planned and as-built schedules are the basic data source for delay analysis (Bubshait and Cunningham, 1998; Kim et al, 2005).

The as-planned schedule is a graphical representation of the contractor's original intentions for the completion of the project. It shows the different critical paths as well as the planned activities and their sequence.

The as-built schedule shows the actual sequence and progress of the activities in the project as they occurred in real life, including the slowdowns, work stopages, and accelerations. The as-built schedule provides evidence to substantiate an assessment of liability for any delays.

2.5 Recording Site Events for Delay Analysis

Daily recording of the actions performed by all parties on a construction site is necessary for delay analysis. Site events involve a large amount of data related to weather, staffing, resource use, work accomplished, inspections, accidents, delivery of materials, and changes in orders.

Daily site events are recorded in a variety of media, including daily site diaries, notes from progress meetings, daily weather records, photographs, and weekly progress reports. Therefore, compiling these data for delay analysis purposes is difficult. Usually, in practice, only after construction is completed, existing site records are used to form a detailed as-built bar chart that reflects major events during construction.

Delay analysis requires progress-related data, which include start and finish times, work completed, resources used, idle times, and work disruption periods. For realistic analysis of delays, the recorded site data should be sufficient to define the progress of activities as slow, stopped, or accelerated. Slow progress occurs when the work production is less than planned. Acceleration, on the other hand, means that more work is produced than was planned, and should be defined as contractor-desired acceleration or owner-forced acceleration (Hegazy et al., 2005).

Although the daily site report is an important document for following the progress of an activity, it is often given the least attention (Pogorilich, 1992). Some researchers have been interested in developing computerized systems for daily site reporting. Scott (1990) developed a bar chart as a graphical form for progress reporting. In his bar chart (Fig. 2.2), the daily status of each activity is recorded as one of the following four conditions:

- X - Activity working all day

- H - Activity working half day
- W - Activity not working all day due to weather
- R - Activity not working half day due to weather

Code	Activity Description	June 90														
		5	6	7	8	9	12	13	14	15	16	19	20	21	22	23
E101	Excavate topsoil	X														
E102	General Excavation		X	R	X											
E103	Excavate pier					X										
E104	Excavate S abut					X	H									
E105	Excavate N abut					H	X									
E106	Backfill S abut															
E107	Backfill N abut															
S101	Blind S pier								W	H		H				
S102	Blind N pier								X	W	H	X	X	X	H	

Legend: X: Activity working all day H: Activity working half day
W: Activity not working all day due to weather R: Activity not working half day due to weather

Fig. 2.2: Recording Site Data in a Bar Chart (Based on Scott 1990)

Stumpf (2000) presented an approach that manipulates existing software to facilitate the analysis. His approach simulates each delay by adding a separate activity with a duration equal to the delay period, as shown in Fig. 2.3. For example, the activity “Excavation” in Fig. 2.3 experienced an owner-caused delay (due to unexpected rock) for 2 days. This situation is represented by the addition of a new activity for the delay and the splitting of the original activity into two parts (a and b). The activity then becomes 3 components that are manually linked by appropriate logical relations.

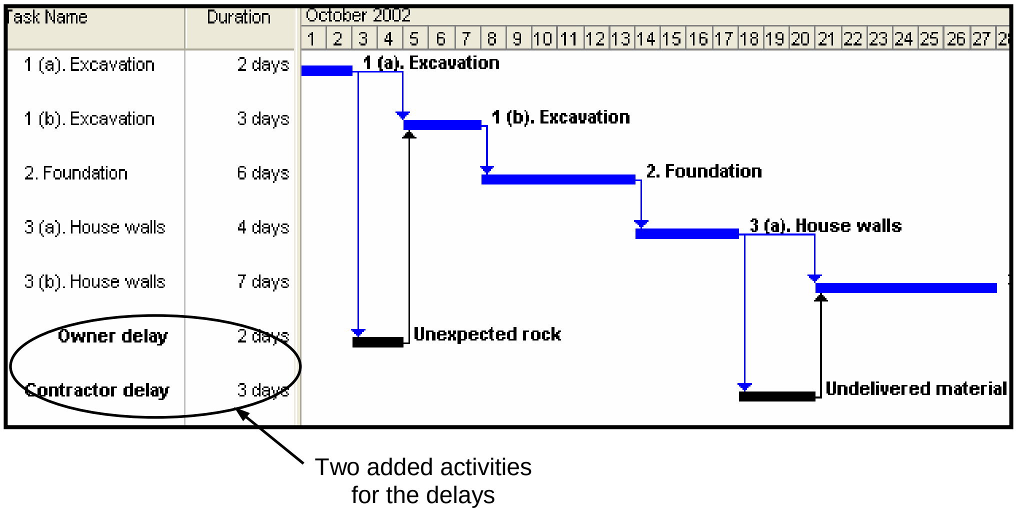
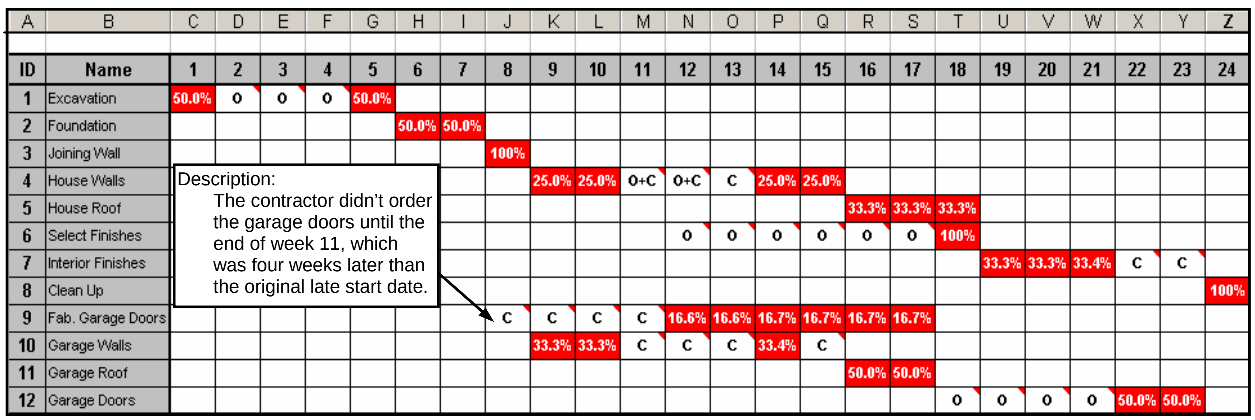


Fig. 2.3: Representing Delays on Commercial Scheduling Software (based on Stumpf, 2000)

Hegazy et al. (2005) showed that the evolution of the progress of the project can be accurately indicated by recording the daily percentage completed (can be calculated from the start and finish dates) for each activity and then comparing it to the planned percentage. Accordingly, slow progress can be identified when actual progress proceeds with lower productivity than planned; acceleration, when work proceeds with higher productivity than planned; and suspension, when work is completely stopped. The authors presented a bar chart made of spreadsheet cells, each representing one day or one week, or any unit of time for an activity. The activities are thus represented not in bars (as in commercial software) but as a group of adjacent cells making up the duration of the activity. The proposed bar chart records the daily percentage completed of each activity, the delays, the party responsible for the delay, and any other related data.

Delays are recorded on the bar chart on the day they occur. As shown in Fig. 2.4, if an activity is delayed for owner-related reasons, an “O” is shown for that day. In the same manner, if the delay is contractor-related, a “C” is shown. In the case of delays that are not attributable to the owner or contractor (e.g., weather), an “N” is shown. If a concurrent delay occurs, a combination of these three letters is shown (e.g., “O+N” or “O+C”). The reasons for delays are also recorded as text comments in the delay cells.



A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
ID	Name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	Excavation	50.0%	O	O	O	50.0%																			
2	Foundation						50.0%	50.0%																	
3	Joining Wall								100%																
4	House Walls									25.0%	25.0%	O+C	O+C	C	25.0%	25.0%									
5	House Roof																33.3%	33.3%	33.3%						
6	Select Finishes												O	O	O	O	O	O	100%						
7	Interior Finishes																			33.3%	33.3%	33.4%	C	C	
8	Clean Up																								100%
9	Fab. Garage Doors								C	C	C	C	16.6%	16.6%	16.7%	16.7%	16.7%	16.7%							
10	Garage Walls									33.3%	33.3%	C	C	C	33.4%	C									
11	Garage Roof																50.0%	50.0%							
12	Garage Doors																		O	O	O	O	50.0%	50.0%	

Fig. 2.4: Recording Site Data Using an Intelligent Bar Chart (based on Hegazy et al., 2005)

It is essential that progress-related data be recorded daily so that the responsibility for the delay is known, and compensation can be calculated accurately with less disagreement among parties.

2.6 Delay Analysis Techniques

Delay analysis is an analytical process in which the critical path method is employed together with a review of project documentation and site records in order to evaluate and apportion the effects of delays and events that have an impact on the project schedule (Holloway, 2002). Several methods are available for delay analysis; the selection of the proper method depends upon a variety of factors including the value of the dispute, the time available, the records available, and the funds and effort allocated to the analysis. The four methods often mentioned in the literature are described briefly in the following subsections

2.6.1 The As-Planned Versus As-Built Comparison

Comparing the as-planned with the as-built schedule is the simplest method of analysing schedule delays. The majority of the researchers do not recommend using this method because it simply determines a net impact of all delay events as a whole rather than studying each individual delay event separately.

2.6.2 The Impacted As-Planned Method (What-If approach)

The impacted as-planned method adopts the as-planned schedule as its baseline. The delays caused by either the contractor or the owner are added to the as-planned schedule, and the impact on the project duration is calculated. The impacted as-planned schedule reflects how the as-planned schedule could have been impacted as a result of owner or contractor-caused delays being inserted into the schedule. For example, contractors who submit claims that involve a time extension add only owner-caused delays to the as-planned schedule in the appropriate sequence.

2.6.3 The Collapsed As-Built Method (but-for method)

The collapsed as-built method is used by the contractors to demonstrate a schedule that they could have achieved "but for" the actions of the owner. This method adopts the as-built schedule as its baseline. The delays attributable to the owner are subtracted from the as-built schedule. The compensable delay is the difference between the as-built schedule and the but-for schedule. The collapsed as-built method is a very practical approach since it offers a good combination of benefits (Lovejoy, 2004). But-for schedules are frequently used for delay analysis because of the following advantages:

- This method is more reliable than several other delay analysis methods.
- It requires less time and efforts than windows analysis to be performed.
- It costs less than windows analysis.
- It is accepted by courts and boards.

On the other hand, the collapsed as-built method has the following drawbacks:

- Concurrent delays cannot be recognized.
- It does not consider the dynamic nature of the project's critical paths.
- It is highly subjective and subject to manipulation.
- It is restricted by its inability to identify resequencing, redistribution of resources or acceleration (Lowsley and Linnett, 2006).

In conclusion, the collapsed as-built analysis can be used when the time and resources available for detailed analysis are limited, but it should be used with an awareness of its limitations and weaknesses.

2.6.4 The Contemporaneous Period Analysis Method (window analysis)

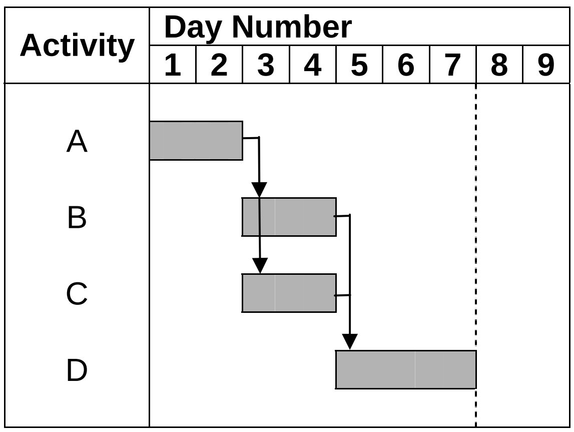
The windows method breaks the construction period into discrete time increments and examines the effects of the delays attributable to each of the project participants as the delays occur. It adopts the as-planned schedule as its baseline, but the as-planned schedule is periodically updated at the end of each planned time period. Ideally, the windows method schedule analysis can be followed during the course of construction. It is distinguished from the but-for method by the fact that it incorporates delays attributable to both parties into the analysis and by its consideration of the dynamic nature of the project's critical paths. Some researchers have developed computer implementations of the traditional windows technique using commercial scheduling software (e.g., Alkass et al., 1995; Lucas, 2002).

The majority of the viewpoints reviewed in the literature agree that windows analysis yields the most reliable results. Despite these advantages windows analysis requires significant time and effort. Since it requires a large amount of information and the schedule needs to be periodically updated, this method may not be appropriate for projects that lack strict administrative procedures and updated schedules. Arditi and Pattanakitchamroon (2006) presented the views of some of the researchers and practitioners who wrote about standard delay analysis methods from years 1987 to 2004. The comments of these researchers and practitioners on windows analysis are summarized in Table 2.2.

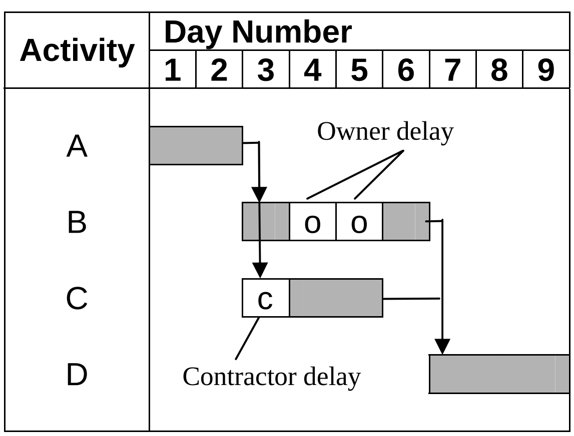
Table 2.2: Comments on the Windows Delay Analysis (Based on Arditi and Pattanakitchamroon 2006)

References	**Comments**
Lovejoy (2004)	Very good
Sagarlata and Brasco (2004)	Useful for prospective analyses, but minimal utility supporting claims
Sandlin et al. (2004)	Overcomes some disadvantages of others
Gothand (2003)	Reliable
SCL (2002)	Most reliable when available
Harris and Scott (2001)	Make some use by claims consultants
Zack (2001)	Accurate but expensive
Fruchtman (2000)	Contemporaneous basis, but not future changes considered
Stumpf (2000)	Reliable, but time consuming
Finke (1999, 1997)	Most reasonable and accurate
McCullullough (1999)	Dependent on baseline schedule, accurate
Zack (1999)	Suitable
Bubshait and Cunningham (1998)	Acceptable, dependent on availability of data
Levin (1998)	Dependent on how the method is applied
Alkass et al. (1996)	Some drawbacks/propose modified method
Schumacher (1995)	Effective method
Baram (1994)	Most desirable approach
Wickwire et al. (1991)	Recommended

The windows analysis method can be demonstrated by an example reported in Hegazy and Zhang (2005). Fig. 2.5 shows the as-planned and the as-built schedules of a simple 4-activity case study. According to the relationships shown, activities B and C both follow activity A and are then followed by activity D. The as-planned duration is seven days, while the as-built duration is nine days; thus, the project delay is two days.



(a) As-Planned Bar Chart



(b) As-Built Bar Chart

Fig. 2.5: Bar Charts for a Small Example of Windows Analysis

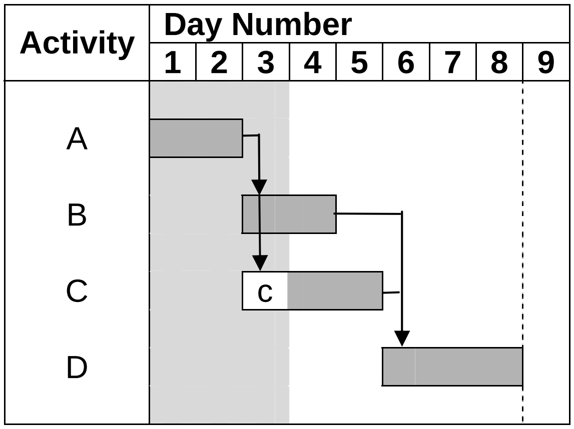
a- Windows Analysis Using One Window of Nine Days

Since two owner delays (O) occurred on the final critical path A-B-D, the two days of project delay are attributed to the owner.

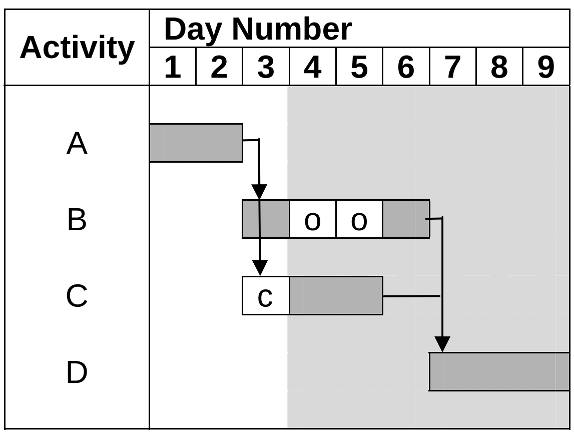
b- Windows Analysis Using Two Windows, Ending at Days 3 and 9

In the first window (Fig. 2.6a), the shaded part to the left of day 4 represents the actual progress of the project. Looking at the window's critical path A-C-D, one day of contractor delay (C) occurred, leading to a one-day project delay. This window becomes the basis for the next window.

In the second window (Fig. 2.6b), the critical path becomes A-B-D which exhibits two days of owner delay, causing the project duration to become nine days. One day of the two-day owner delays at current critical path did not affect project duration since there was a one-day project delay from the previous window. Therefore, only one-day owner delay is decided at the second window. Thus the analysis concludes that the two-day project delay should be allocated as one day of contractor delay and one day of owner delay.



(a) Window Ending at Day 3



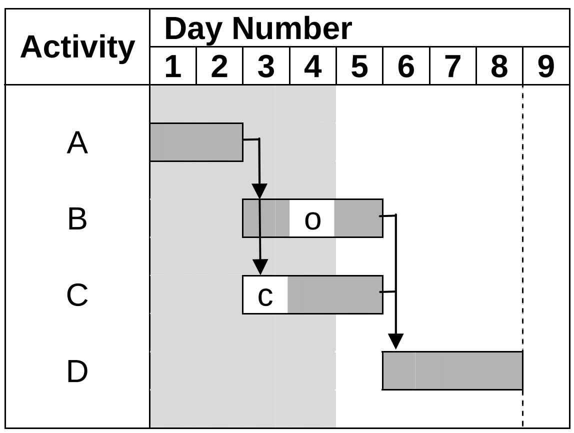
(b) Window Ending at Day 9

Fig. 2.6: Windows Analysis Method with Two Windows, Ending at Days 3 and 9

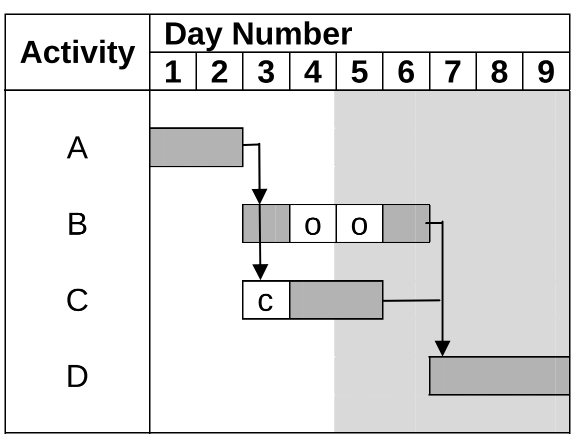
b- Windows Analysis Using Two Windows (Ending at Days 4 and 9):

In the first window shown in Fig. 2.7a, the two paths A-B-D and A-C-D are critical, with one day of owner delay on the path A-B-D and one day of contractor delay on the path A-C-D resulting in an eight-day project duration. Although the delays occurred at different dates, the one-day delay is equally attributed to both.

In the second window (Fig. 2.7b), the project duration becomes nine days and the one-day delay is attributed to the owner. Thus, the final conclusion of the analysis is a one-day delay shared by the owner and the contractor and a one-day owner delay.



(a) Window Ending at Day 4



(b) Window Ending at Day 9

Fig. 2.7: Windows Analysis Method with Two Windows, Ending at Days 4 and 9

This simple example shows that windows analysis may overlook critical path fluctuations, and using different window sizes to analyze the same case may result in different conclusions as shown in Table 2.3.

Table 2.3: Comparison of the Results of Different Window Sizes

Window Sizes	Delay Responsibility	
	Owner (O)	Contractor (C)
One window ending at day 9	-	2
Two windows ending at day 3 and 9	1	1
Two windows ending at day 4 and 9	1.5	0.5

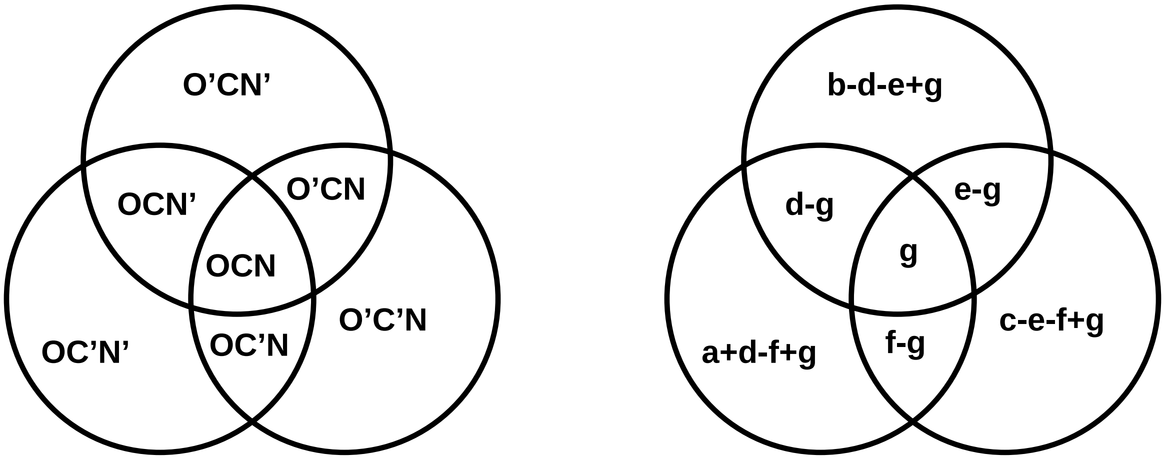
The pros and cons as well as detailed background about the above techniques are available in studies such as (Alkass et al., 1996; Arditi and Pattanakitchamroon, 2006; Finke, 1999; Ibbs and Nguyen, 2007; Kim et al., 2005; Lovejoy, 2004).

2.7 New Developments

Of the traditional techniques, the but-for and the windows analysis are preferred for delay analysis. Courts are much more likely to accept the windows delay analysis or but-for method than they are to accept other methods (Finke, 1999; Hegazy and Zhang, 2005; Kartam, 1999; Stumpf, 2000). Since both techniques still have drawbacks, researchers have attempted to either improve them or introduce new approaches to schedule delay analysis.

2.7.1 Improved But-for Analysis

The traditional but-for method considers only one party's point of view and does not distinguish between critical, non-critical and concurrent delays. Mbabazi et al. (2005) proposed three improvements to the existing but-for delay analysis method, including new representation of disruption of an activity, new representation of possible interactions among concurrent critical delays, and a new delay analysis method that reconsiders and reconciles the points of views of all parties. Through the manipulation of the features of Microsoft project software, an activity is split into two activities at the delay date, and then a new activity is inserted between the two parts to represent the delay. The inserted delay activity is then given an identifier to indicate the responsible party. A Venn diagram representation, as shown in Fig.2.8 (a), was introduced to represent the possible critical delay interactions among three parties (owner, contractor, and neither party), with a naming notation for each segment. An example of a one-party delay is OC'N', i.e., owner delay. Similarly, an example of a two-party concurrent delay is OCN', i.e., owner and contractor delay. The modified but-for method presents a mathematical basis for reconciling the varying results associated with the individual parties' points of view (Fig.2.8b).



(a) (b)

Fig. 2.8: Concurrent Delay Representation Using a Venn Diagram

2.7.2 Improved Windows Analysis

Hegazy and Zhang (2005) summarized the drawbacks of traditional windows analysis. They proved that different window sizes may produce different results. The use of large windows may overlook the fluctuations in the critical path(s) within the window and therefore the decision related to delay responsibility will differ. They proposed using a daily window size that would accurately consider the changes in the critical path(s), slowdowns, accelerations, and work stoppages. They utilized an intelligent bar chart (IBC) to represent the progress information and any delays as a project evolves. The daily windows analysis and its proposed improvements are discussed through a case study in chapter 3.

Kim et al. (2005) presented a new method for analyzing and apportioning responsibility for schedule delays. This method builds on the windows delay analysis. The authors investigated three currently accepted methods, namely, the what-if, but-for, and windows methods. The authors pointed out that the present methods of evaluating construction delays are not adequate and have two limitations: inadequate accounting for concurrent delay and inadequate accounting for time-shortened activities (acceleration). They introduced two new concepts: delay section and contractor's float. The as-built schedule is divided into various delay sections. The delay sections are categorised as "no delay", "single delay", and "two or more delays" section. Using the delay sections, the concurrent delays can be divided into a single delay section and two or more delays sections. This technique uses the as-planned schedule which is updated after evaluating every delay section. The delay sections are evaluated based on the minimum total float of the succeeding activities.

2.7.3 Other Approaches

Shi et al. (2001) proposed a computation method that consists of a set of equations for computing activity delays and assessing their contribution to the total project delay. This method uses the as-planned schedule as the basis of analysis and is not based on the criticality of activities. Therefore, the as-planned schedule does not need to be updated. This method was developed based only on the finish-to-start relationship and is not applicable for other relationships.

Oliveros et al. (2005) proposed a fuzzy logic approach for schedule updating and delay analysis. The basis of this approach is the use of fuzzy logic for estimating the impact of activity delays, for calculating revised activities, and for recalculating the project schedule. However, the presented model is partially computerized; to efficiently analyze the information that results from daily site recordings, it needs to be fully automated.

Lee et al. (2005) suggested that lost productivity is one of the factors that cause delays in construction projects. They proposed a method for converting lost productivity into equivalent delay durations. Their study focuses on labour productivity, assuming that it represents all kinds of productivity. The methodology used introduced several concepts regarding delay and productivity, such as planned and actual work duration, and impact factors. Based on those concepts, a delay analysis process and equations for calculating “the loss of duration due to lost productivity” are developed. Thereafter the responsibility for lost duration is assigned through the use of any other appropriate method.

2.8 Conclusions

This chapter discussed the major delay analysis techniques: as-planned versus as-built, impacted as-planned, collapsed as-built or but-for, and windows analysis. Although the windows analysis and the but-for methods are the techniques most often used, they still have serious drawbacks and may yield inconsistent results. Some researchers have proposed improvements to the existing techniques to overcome their drawbacks, while others have introduced new methods for delay analysis. These improved methods and recent approaches have been also discussed in this chapter.

CHAPTER 3

DAILY WINDOWS ANALYSIS WITH MULTIPLE BASELINE UPDATES

3.1 Introduction

The original as-planned schedule represents one of the many possibilities of the way the work may progress. It is a representation of the contractor's best guess for the execution of the work based on his or her experience and the available information. In reality, it is unlikely that the work will be undertaken strictly in accordance with this schedule, and at various points throughout the project the contractor is likely to revise the as-planned schedule to ensure that the updated schedule reflects the contractual date for completion (Lowsley and Linnett, 2006). Effective delay analysis must include provision for these updates (multiple baseline updates).

In this chapter, the traditional daily windows delay analysis is illustrated through an example, and then a further sample case illustrates the daily windows analysis with multiple baseline updates. A systematic procedure for the proposed approach is also developed in order to facilitate its computer implementation.

3.2 Daily Windows Analysis

Zhang (2003) introduced changes to the traditional windows analysis method in order to resolve some of its drawbacks. To capture and consider all the fluctuations in the critical path(s), he used a window size of one day. The simple example from chapter 2 (Fig. 2.5) can be used to demonstrate this new daily windows analysis. The relationships show that activities B and C both follow activity A and are then followed by activity D. The as-planned duration is 7 days, while the as-built duration is 9 days, thus exercising a two-day project delay. It is important to apportion the two-day delay accurately among the parties responsible.

The daily windows analysis uses a window size of one day. In this process, all delays and work stops caused by the different parties are first removed from the as-built schedule so that the process will begin with the as-planned schedule. Then, the events of each day are entered as shown in Fig. 3.1. It is assumed in this representation of daily progress that the work stop caused by each party (c or o) is for a full-day and progress is stopped in this case. The case of partial progress and partial interruption of work by the parties is not considered.

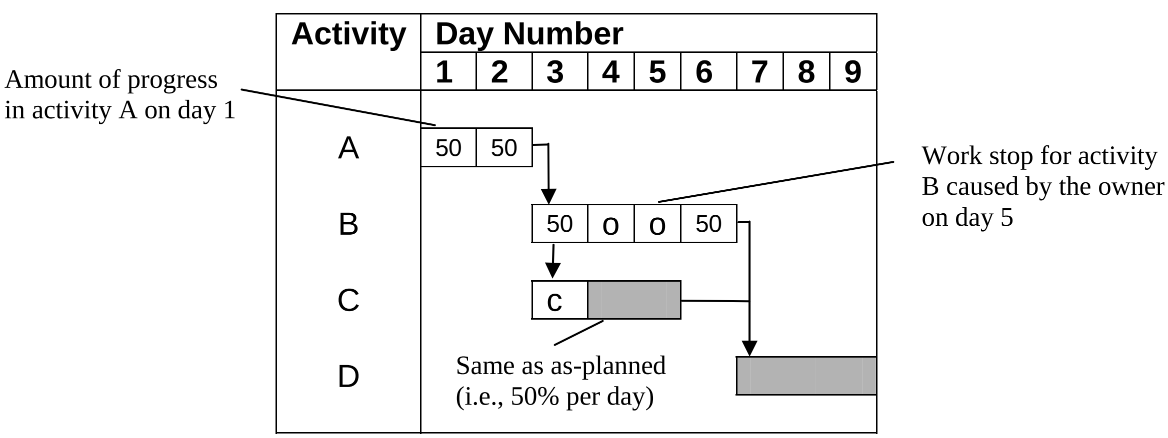


Fig. 3.1: Entering the Daily Events

The notations used in the daily site events shown on the as-built bar chart are as follows:

- Small letters (o), (c), (n), or combinations of them (e.g., o+c) on an activity bar chart represent work stops for a given day on a specific activity, as caused by the party indicated (o = owner, c = contractor, n = neither).
- A percentage (e.g., 30%) on an activity bar chart represents the amount of work done by the contractor on a given day for this specific activity. The absence of a percentage on the activity as-built bar indicates that the planned and as-built percentages are the same.

In addition, capital letters (O, C, and N) indicate the delay analysis results apportioned to the indicated party. The values are calculated as a result of the analysis and are not shown on the as-built bar chart.

Following the daily windows process in this example yields nine windows which are analyzed as follows:

Days 1 and 2: The project did not experience any delays, so the project duration remains seven days.

Day 3 (Fig. 3.2): The critical path A-C-D exhibits a one-day contractor delay (c), which extended the project duration to eight days. Therefore, this window is one day longer than the previous window, indicating a project delay of one day. An examination of the critical path A-C-D reveals that this one-day project delay was caused by the contractor's (c) event. Accordingly, a contractor delay (C) is accumulated.

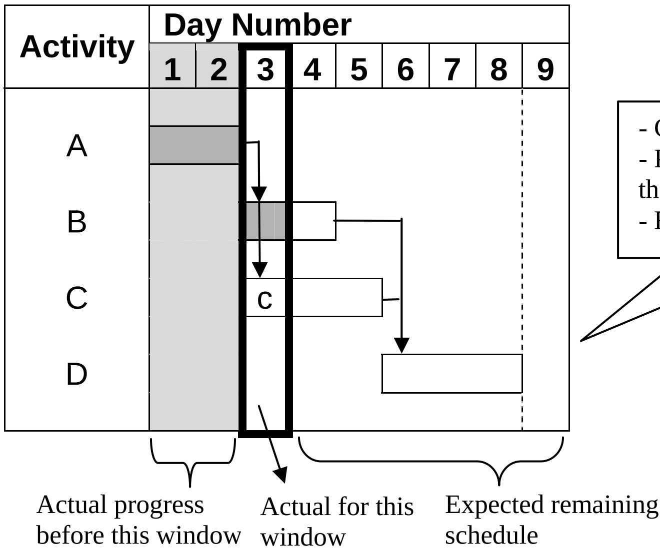


Fig. 3.2: Daily Windows Analysis Showing the Window of Day 3

Day 4 (Fig. 3.3): The window of the fourth day shows a one-day owner delay on the path A-B-D, but the project duration remains eight days, as in the previous window.

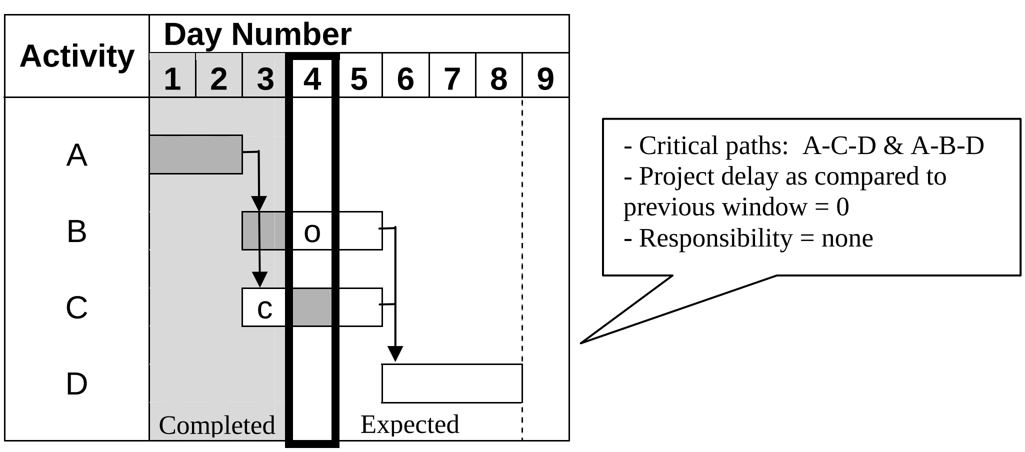


Fig. 3.3 Daily Windows Analysis Showing the Window of Day 4

Day 5 (Fig. 3.4): The project experiences a one-day delay due to the owner's delay on the critical path A-B-D, leading to the project duration becoming nine days.

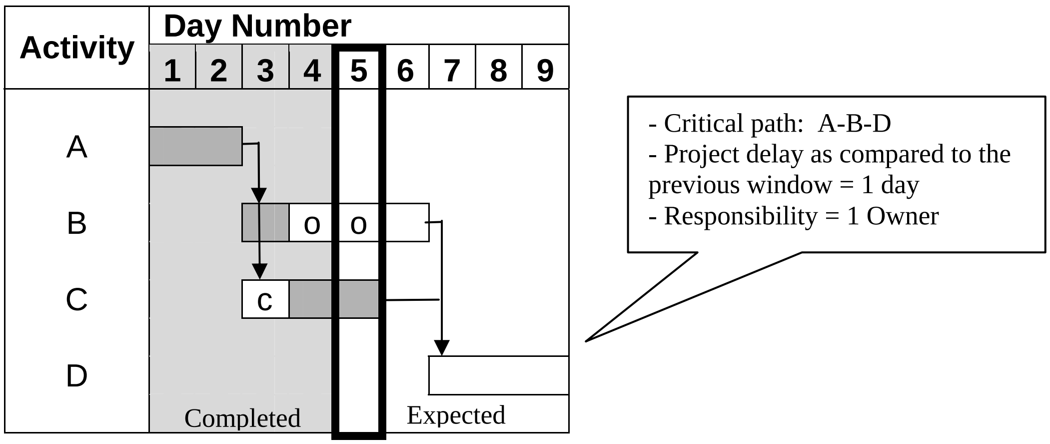


Fig. 3.4: Daily Windows Analysis Showing the Window of Day 5

Days 6 to 9: No additional delays occurred, so the project duration remains at nine days.

Therefore, the conclusions of the daily windows analysis are as follows:

- One-day contractor delay (1 C)
- One-day owner delay (1 O)

As demonstrated by this simple example, the daily windows analysis considers every change in the critical path(s). Some of these changes would be overlooked if traditional windows analysis was used to analyze the same case. However, daily windows analysis still needs improvement as it does not take into consideration other factors, such as multiple baseline updates.

3.3 Baseline Updates

The as-planned schedule can be changed for many reasons: work delays, additional work requested by the owner, changes in the logical relationships between the activities, or changes in the duration of the activities. Delay analysis that does not consider such changes in the schedule may yield inaccurate results.

When the as-planned schedule is updated with progress events, the remaining work is generally rescheduled based on the logical sequence previously set for the as-planned schedule. Midway through the project, the parties may agree on a schedule update, which then becomes a new baseline for measuring progress. In this case, the earlier portion of the project is measured against the first baseline, while the portion that occurs after the update is measured against the new baseline. Therefore, a systematic procedure for delay analysis is needed in order to account for varying baselines, particularly when baseline updates involve changes to the duration of an activity and to logical relationships.

3.4 Case Study Involving Multiple Baseline Updates

Fig. 3.5 illustrates the as-planned schedule and the as-built schedule of a simple five-activity case study. Both the as-planned and the as-built durations are 10 days. Therefore, the project was completed as planned. However, the project experienced delays and accelerations during the course of the work. These delays and accelerations should be analyzed and apportioned among the parties in order to allocate any time-related costs.

Activity	**Predecessor**	**Days**									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
A	-	50%	50%								
B	A			33%	33%	34%					
C	A			25%	25%	25%	25%				
D	B						33%	33%	34%		
E	C,D									50%	50%

(a) As-planed Schedule

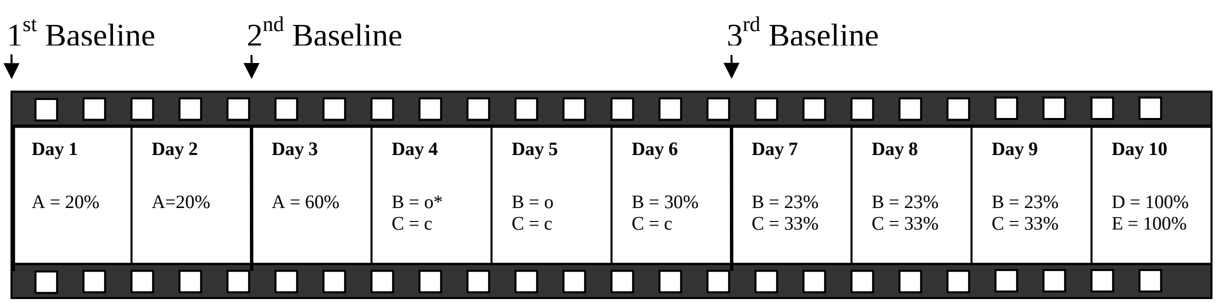
Activity	**Predecessor**	**Days**									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
A	-	20%	20%	60%							
B	A				o	o	30%	23%	23%	24%	
C	A				c	c	c	33%	33%	34%	
D	B										100%
E	C										100%

(b) As-Built Schedule

Fig. 3.5: Planned and Actual Progress of the Sample Case

The initial duration of 10 days was satisfactory to both parties and the baseline was agreed upon, but the as-built schedule did not run smoothly. For the first two days, the contractor was slow, and accordingly, at that time, the project was expected to finish in 12 days. The owner found the duration of 12 days unacceptable and asked the contractor either to speed up some activities or to run some of them in parallel, such as the electrical and mechanical activities, in order to accelerate the project and finish it within the original 10 days. After investigating the various options, the contractor decided to run some activities in parallel, so that activity E would run in parallel with activity D. This change reduced the expected project duration to 10 days, as originally planned.

In the next few days, both the owner and the contractor caused delays to the project, and again the contractor had to take corrective actions and accelerate the project upon the owner's request. The contractor changed the method of construction of some activities to shorten the duration of these activities so the project would be finished in 10 days. As shown in Fig. 3.6, some of the events were caused by the owner, so an analysis is required to determine if the contractor is entitled to compensation by the owner.



* c = contractor delay; o = owner delay

Fig. 3.6: Representation of Project Timeline as a Film Strip

Applying the daily windows analysis for this case study, a total of 10 windows are analyzed. For each window, the left side is the actual progress until the window date, while the right side is the anticipated remaining project duration, calculated based on the planned schedule. As shown in Fig. 3.5, there are two bars for each activity: the top bar represents the baseline, while the shaded bottom bar illustrates the actual progress.

As shown in the window of the first day (Fig. 3.7), the contractor finished only 20% of activity A instead of the planned 50%. As such without accelerating this activity, the remaining 80% of the activity can not be finished in one day, and activity A will not be completed within the planned two days. Rather, the remaining duration of activity A is calculated as

Remaining Duration = (100 – Percent Complete) / Planned activity production per day ……………………………………………………….. (3.1)

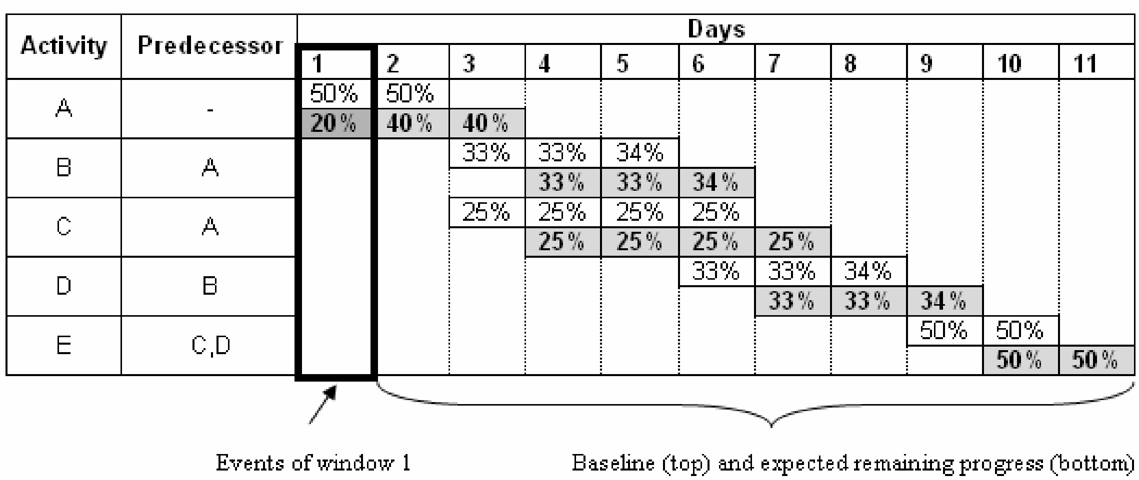


Fig. 3.7: Delay Analysis with Multiple Baseline Updates (window of day 1)

Therefore, the new planned duration of activity A becomes three days (one completed and two remaining), not the original planned duration of two days. Since this activity is critical at this window, the project duration will change from 10 days to 11 days. Accordingly, the analysis of day 1 shows that the contractor is responsible for one day of project delay (1 C) because of his or her slow progress.

On the second day (Fig. 3.8), the progress of activity A was again slower than planned (20% as opposed to 50%). Thus, the project will be delayed another day (current window duration = 12, previous window = 11) because of the contractor’s slowdown. However, as shown in Fig. 3.9, the contractor decided to run activity E in parallel with activity D and immediately after activity C as a corrective action in order to accelerate the project by two days and finish the work within the planned duration. Consequently, a two-day acceleration is accumulated. The baseline is updated on day 2, and the new baseline duration is again10 days.

Activity	Predecessor	Days											
		1	2	3	4	5	6	7	8	9	10	11	12
A	-	50%	50%										
		20%	20%	30%	30%								
B	A			33%	33%	34%							
						33%	33%	34%					
C	A			25%	25%	25%	25%						
						25%	25%	25%	25%				
D	B						33%	33%	34%				
									33%	33%	34%		
E	C,D									50%	50%		
												50%	50%

Fig. 3.8: Delay Analysis with Multiple Baseline Updates Showing the Window of day 2 before the Baseline is Updated

Activity	Predecessor	Days										
		1	2	3	4	5	6	7	8	9	10	11
A	-	20%	20%	30%	30%							
		20%	20%	30%	30%							
B	A					33%	33%	34%				
						33%	33%	34%				
C	A					25%	25%	25%	25%			
						25%	25%	25%	25%			
D	B								33%	33%	34%	
									33%	33%	34%	
E	C									50%	50%	
										50%	50%	

Fig. 3.9: Delay Analysis with Multiple Baseline Updates (window of day 2)

The window of the third day (Fig. 3.10) shows an acceleration of one day in activity A, reducing the project duration to nine days. Accordingly, a one-day acceleration is accumulated. On the fourth day (Fig. 3.11), the project experienced a concurrent (O+C) delay, causing the project completion time to be 10 days rather than 9 days.

Activity	Predecessor	Days										
		1	2	3	4	5	6	7	8	9	10	11
A	-	20%	20%	30%	30%							
		20%	20%	60%								
B	A					33%	33%	34%				
					33%	33%	34%					
C	A					25%	25%	25%	25%			
					25%	25%	25%	25%				
D	B								33%	33%	34%	
								33%	33%	34%		
E	C									50%	50%	
									50%	50%		

Fig. 3.10: Delay Analysis with Multiple Baseline Updates (window of day 3)

Activity	Predecessor	Days										
		1	2	3	4	5	6	7	8	9	10	11
A	-	20%	20%	30%	30%							
		20%	20%	60%								
B	A					33%	33%	34%				
					o	33%	33%	34%				
C	A					25%	25%	25%	25%			
					c	25%	25%	25%	25%			
D	B								33%	33%	34%	
									33%	33%	34%	
E	C									50%	50%	
										50%	50%	

Fig. 3.11: Delay Analysis with Multiple Baseline Updates (window of day 4)

In the window of the fifth day (Fig. 3.12), another concurrent delay is experienced in activities B and C leading to the project duration becoming 11 days. Continuing the analysis to the sixth day, the contractor delayed activity C and made a slowdown in activity B to further delay the project duration to 12 days. On the other hand, the contractor made another corrective action by speeding up activities C, D, and E to finish the project in just 10 days as shown in Fig. 3.13. Accordingly, two-day acceleration is decided. The baseline is updated on day 6, and the new baseline duration becomes 10 days again.

Activity	Predecessor	Days										
		1	2	3	4	5	6	7	8	9	10	11
A	-	20%	20%	30%	30%							
		20%	20%	60%								
B	A					33%	33%	34%				
					o	o	33%	33%	34%			
C	A					25%	25%	25%	25%			
					c	c	25%	25%	25%	25%		
D	B								33%	33%	34%	
										33%	33%	34%
E	C									50%	50%	
											50%	50%

Fig. 3.12: Delay Analysis with Multiple Baseline Updates (window of day 5)

Activity	Predecessor	Days 1	2	3	4	5	6	7	8	9	10	11
A	-	20%	20%	60%								
		20%	**20%**	**60%**								
B	A				o	o	30%	23%	23%	24%		
					o	**o**	**30%**	**23%**	**23%**	**24%**		
C	A							33%	33%	34%		
					c	**c**	c	**33%**	**33%**	**34%**		
D	B										100%	
											100%	
E	C										100%	
											100%	

Fig. 3.13: Delay Analysis with Multiple Baseline Updates (window of day 6)

After the sixth day, the project progressed according to the new baseline and did not experience any further delays or accelerations (Fig. 3.14). Therefore, the conclusion of the analysis is five days of contractor acceleration, four days of contractor delay, and one day of owner delay.

Activity	Predecessor	Days 1	2	3	4	5	6	7	8	9	10	11
A	-	20%	20%	60%								
		20%	**20%**	**60%**								
B	A				o	o	30%	23%	23%	24%		
					o	**o**	**30%**	**23%**	**23%**	**24%**		
C	A				c	c	c	33%	33%	34%		
					c	**c**	**c**	**33%**	**33%**	**34%**		
D	B										100%	
											100%	
E	C										100%	
											100%	

Fig. 3.14: Delay Analysis with Multiple Baseline Updates (window of day 10)

As demonstrated by this simple case study, the contractor may take corrective actions to accelerate the project and meet the deadlines. He or she may make changes in the logical relationships between the activities and/or changes in the durations of the activities, which might not be considered when the traditional windows analysis is used. Daily windows analysis with multiple baseline updates considers every change in the relationships and durations of the activities because of its legible representation and its ability to analyze the schedule using multiple baselines, and thus can arrive at more accurate results.

3.5 Detailed Procedure

To facilitate computer implementation of daily windows analysis with multiple baseline updates, a systematic procedure was set up as follows:

1. After recording all site events, form the as-built schedule and determine the project duration. Save a copy of the as-built schedule before clearing the actual progress.
2. Clear all progress data and determine the as-planned duration.
3. In each day (*i*), starting from day 1 to the last day of the project, the following steps are performed:

1) Determine the initial project duration and calculate the smallest float S_F at the start of this day.
2) If the current day corresponds with a baseline update, then perform the following steps:
   a. Calculate the previous baseline duration B_{old} and load the baseline date.
   b. Update the baseline, including the logical relations between activities, start delays, and activity durations.
   c. Calculate the new baseline duration B_{new}.

d. If the project exercises acceleration (i.e., $B_{new} < B_{old}$), apportion the project acceleration amount (B_{old} - B_{new}) on the current day according to the causation of the acceleration(s) to the owner and/or the contractor.

e. If the project is delayed (i.e., $B_{new} > B_{old}$), apportion the project delay amount ($B_{new} – B_{old}$) on the current day according to the causation of the delay(s) to the owner and/or the contractor.

3) Perform modified daily windows analysis for this as discussed in chapter 4.

4) Advance the counter to the next day.

This detailed procedure for daily windows analysis with multiple baseline changes is also shown in a flowchart in Fig. 3.15.

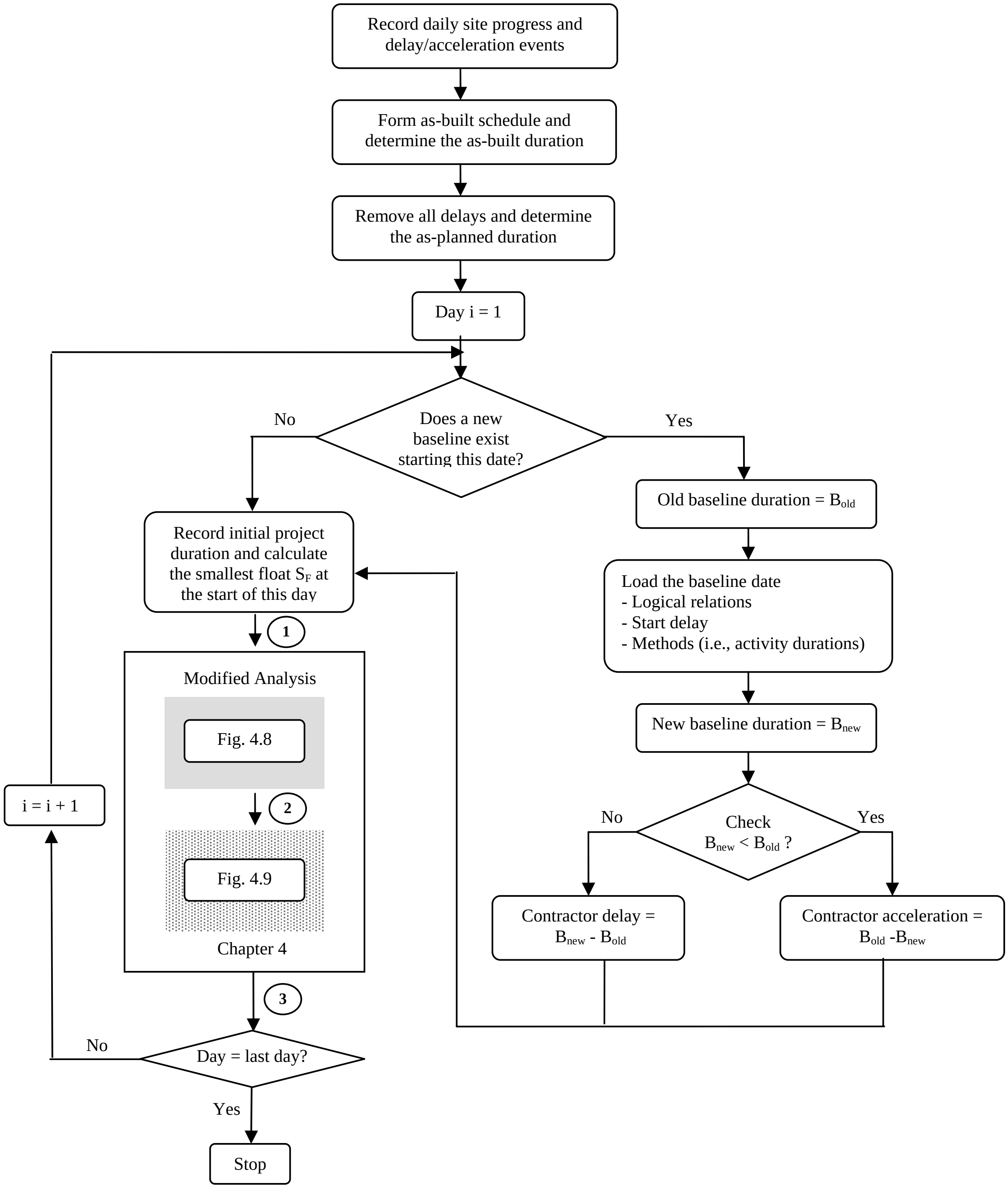


Fig. 3.15: Daily Windows Analysis with Multiple Baseline Updates Procedure

3.6 Conclusion

As the project progresses, the baseline can be updated due to changes in the duration and logical relationships of the activities in order to reflect the progress achieved. The traditional windows delay analysis can produce inaccurate results since it does not consider baseline updates.

This chapter has presented a delay analysis approach that considers multiple baseline updates and accurately apportions delays and accelerations among project parties. The approach uses a daily window size to consider all fluctuations in critical path(s) and uses a legible representation of progress information. A detailed procedure for the proposed delay analysis approach has been described in this chapter along with an example to demonstrate its accuracy and usefulness.

CHAPTER 4

DAILY WINDOWS DELAY ANALYSIS WITH RESOURCE ALLOCATION

4.1 Introduction

Many delay analysis methods are available in the construction industry; none of these methods provides a structured calculation procedure for apportioning delays and accelerations among the parties responsible and also considers the effect of resource allocation. In most practical situations, there is a limit on the amount of resources available, particularly when resources are shared by multiple activities or even multiple projects (Lu and Li, 2003).

Traditional delay analysis techniques study the effect of an event or several events on the critical path(s) of the project in order to evaluate and apportion the delays. However, some events not only change the critical path(s) of the project but also disorganize the planned resource allocation for the remaining work, which in turn, may introduce more delays to the project because of the resource rescheduling required. It has been proven, therefore, that the apportionment of responsibility for the delay may be inaccurate unless the impact of the resource allocation is considered in the analysis (Ibbs and Nguyen, 2007). Unfortunately, available delay analysis methods, including the windows analysis, do not capture the possible extended effect of such events due to the reallocation of resources.

This chapter presents a systematic procedure for considering the impact of resource allocation on the apportionment of the responsibility for the delay. The presented approach modifies the daily windows analysis method to include resource allocation both in the case of delay and acceleration.

4.2 Resolving Resource Over-Allocation

Resource allocation (sometimes referred to as constrained-resource scheduling) is among the top challenges in project management. It attempts to schedule the project activities so that a limited number of resources can be efficiently utilized while the unavoidable extension of the project is kept to a minimum.

Limited-resource allocation algorithms deal with a difficult problem that mathematicians refer to as a “large combinatorial problem”. The objective is to find the shortest-duration schedule consistent with specified resource limits. Optimization methods for solving the resource allocation problem were used as early as the late 1960s (e.g., Wiest, 1964). Various approaches have been formulated to solve the problem optimally, including Integer Programming, branch-and-bound, and Dynamic Programming (Gavish and Pirkul, 1991). None of these, however, is computationally tractable for any real-life problem size, rendering them impractical (Allam, 1988; Moselhi and Lorterapong, 1993).

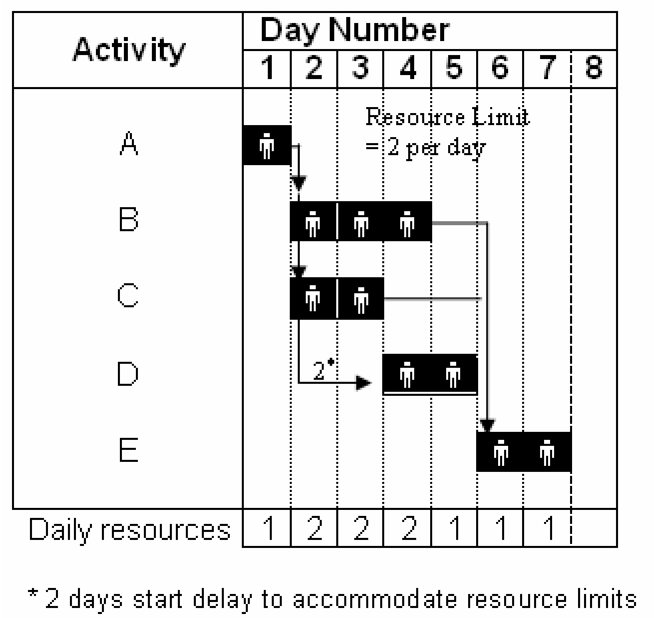
Alternatively, heuristic approaches have been proposed for solving the resource allocation problem. These approaches apply selected heuristic (rules) that are based on activity characteristics, such as the “minimum total-float” rule, to prioritize the activities that compete for the limited resource. Accordingly, the resource is given to the top-ranked activities and the others are delayed. When ties occur during the implementation of a rule (e.g., when two or more activities have the same total float), another rule, such as “shortest duration” can be used to break the tie. The scheduling process thus begins with the project’s start time, identifies eligible activities according to the network logic, and resolves the over-allocation of resources using the selected set of heuristic rules. The process, therefore, ensures that all project activities are scheduled without violating the logical relationships or the resource constraints. This benefit, however, comes at the expense of the total project duration, which often exceeds the duration determined by the original CPM analysis. Therefore, because it can affect project duration, this scheduling process should be considered when project delays are analyzed.

Heuristic rules have the advantage of being simple to understand, easy to apply, and very inexpensive to use in computer programs. They are able to rationalize the scheduling process and make it manageable for practical-sized projects (Talbot and Patterson, 1979). Furthermore, research has identified rules such as the “least total-float” and the “earliest late-start”, which generally provide good solutions (Davis and Patterson, 1975). Almost all commercial software for planning and scheduling, therefore, utilize heuristic rules to provide resource allocation capabilities. Despite these benefits, however, heuristic rules perform with varying effectiveness when used on different networks and there are no hard guidelines that help in the selection of the best heuristic rule to use for a given network. Accordingly, they cannot guarantee optimum solutions. Furthermore, their drawbacks have contributed to large inconsistencies in the resource-constrained capabilities of commercial project-management software, as reported in recent surveys (Johnson, 1992; Hegazy and El-Zamzamy, 1998).

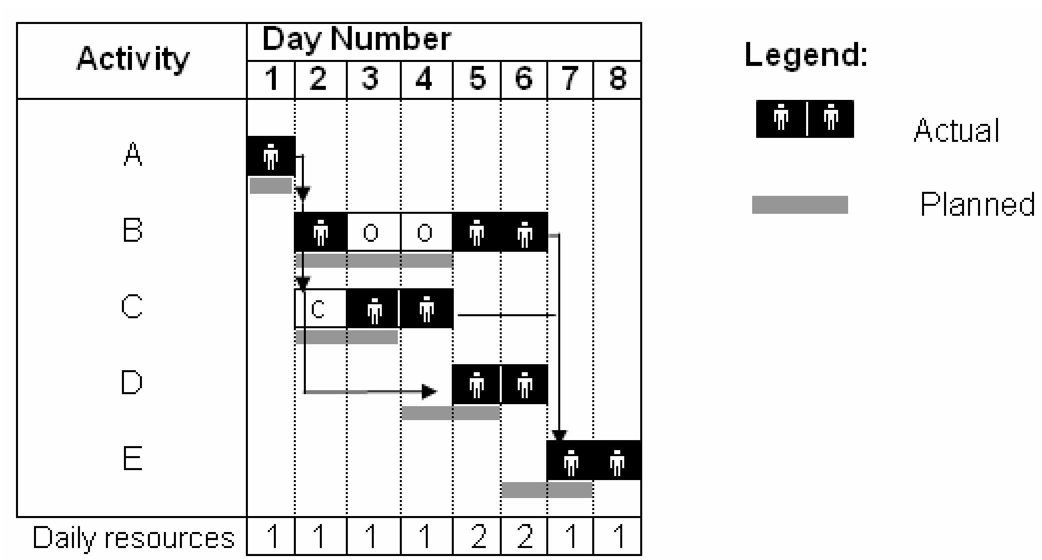
Since it is not possible to select an optimum heuristic rule for a given project network, one common procedure is to try a series of heuristic rules and then select the schedule with the minimum duration. In the present study, five heuristic rules have been used in the modified daily windows analysis to solve resource over-allocation: earliest late-start, shortest duration, longest duration, smallest ID, and longest ID rules. To show that the effect of resource allocation should not be neglected in delay analysis, a simple case study is presented.

4.3 Delay Analysis with Resource Allocation

Fig. 4.1 shows the as-planned and the as-built schedules of a simple case study. The project has an as-planned duration of 7 days. The contractor has a limit of two resources per day. The daily resource needs for each activity are shown on the activities' bars. The as-planned schedule shows how the contractor adjusted the start time of activity D to avoid resource over-allocation. During the course of the actual work, the contractor caused a delay of one day for activity C, while the owner caused a delay of two days for activity B. The total project was delayed one day (ends at day 8, as opposed to day 7 of the as-planned). It is important to correctly analyze which party is responsible for the project delay.



(a) As-Planned Schedule



(b) As-Built Schedule

Fig. 4.1: As-Planned and As-Built Schedules for a Simple Case Study

4.3.1 Analysis Using the Traditional Daily Windows Analysis

For the traditional daily windows analysis, a total of 8 windows are analyzed. The windows of days 2, 3, and 4 are shown in Fig. 4.2, 4.3, and 4.4, respectively. In the window of the first day, the project advances according to the baseline schedule, and the project duration remains seven days. The analysis of the windows of days 2, 3, and 4 is as follows:

Window of day 2 (Fig. 4.2): Activity C exhibits a one day contractor delay, but the project duration remains seven days, without considering the effect of resource allocation.

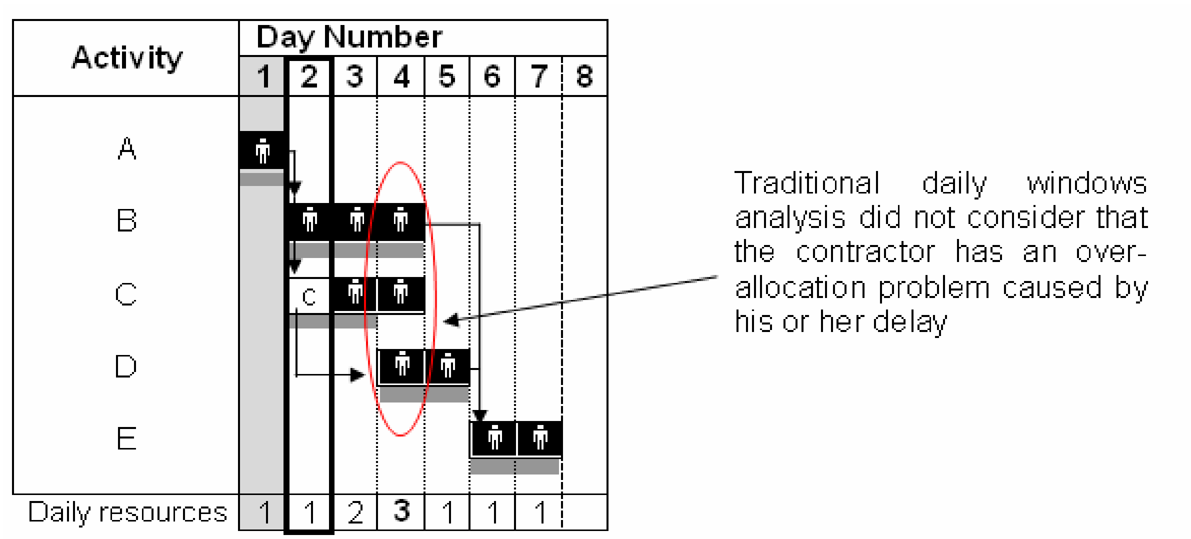


Fig. 4.2: Traditional Daily Windows Analysis (window of day 2)

Window of day 3 (Fig. 4.3): Although the window of the third day shows a one-day owner delay for activity B, the project duration remains seven days.

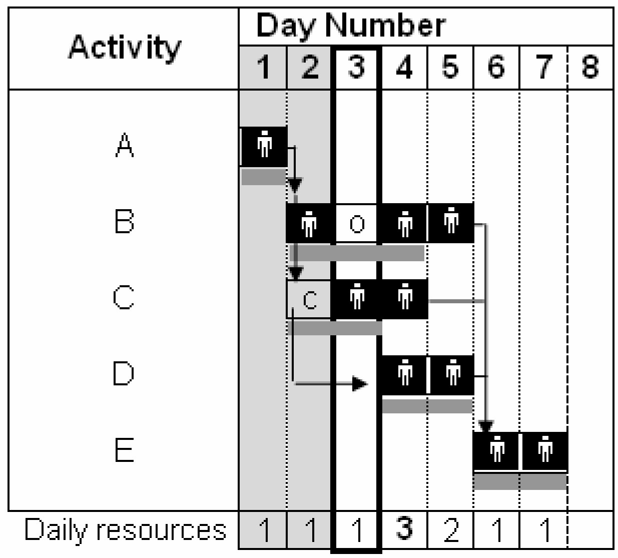


Fig. 4.3: Traditional Daily Windows Analysis (window of day 3)

Window of day 4 (Fig. 4.4): In the window of the fourth day, the project experiences a one-day owner delay, leading to the project duration becoming eight days. Therefore, the conclusion of the daily windows analysis is a one-day owner delay.

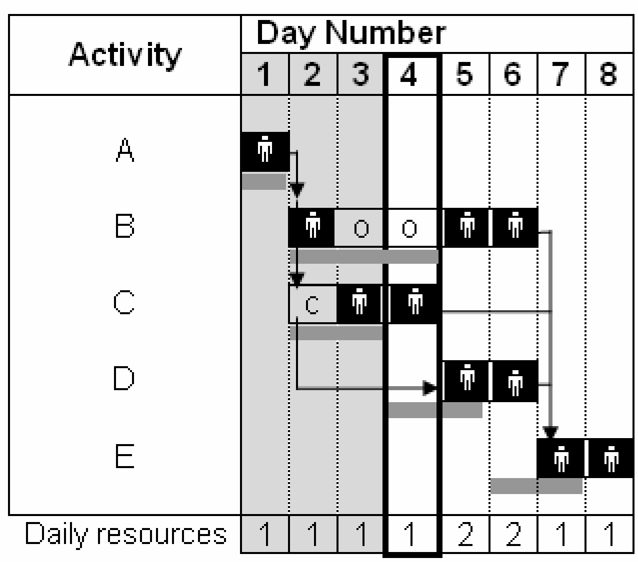


Fig. 4.4: Traditional Daily Windows Analysis (window of day 4)

This simple example shows that the daily windows analysis may produce inaccurate results because it does not consider the resource allocation in the analysis. In this research, therefore, changes to the daily windows analysis have been introduced in order to consider the effect of resource allocation. The modified daily windows analysis requires rescheduling and resequencing the remaining part of the project in order to reflect resource availability and allocation practice.

4.3.2 Analysis Using the Modified Daily Windows Analysis

Applying the modified daily windows analysis, a total of 8 windows are analyzed. The windows of days 2, 3 and 4 are shown in Fig. 4.5, 4.6, and 4.7, respectively. In the window of the first day, the project advances according to baseline schedule and the project duration remains seven days. Analysis of the windows of days 2, 3 and 4 is as follows:

Window of day 2 (Fig. 4.5b): Activity C exhibits a one day contractor delay. Although the delay did not affect the critical path, it made the initial resource allocation for the remaining work impractical. As shown in Fig. 4.5(a) the resource would be over-allocated at day 4. Thus, the project would have to be rescheduled to meet the resource limits. After rescheduling, the project duration would become eight days (Fig. 4.5b). Accordingly, the contractor becomes responsible for a one-day delay.

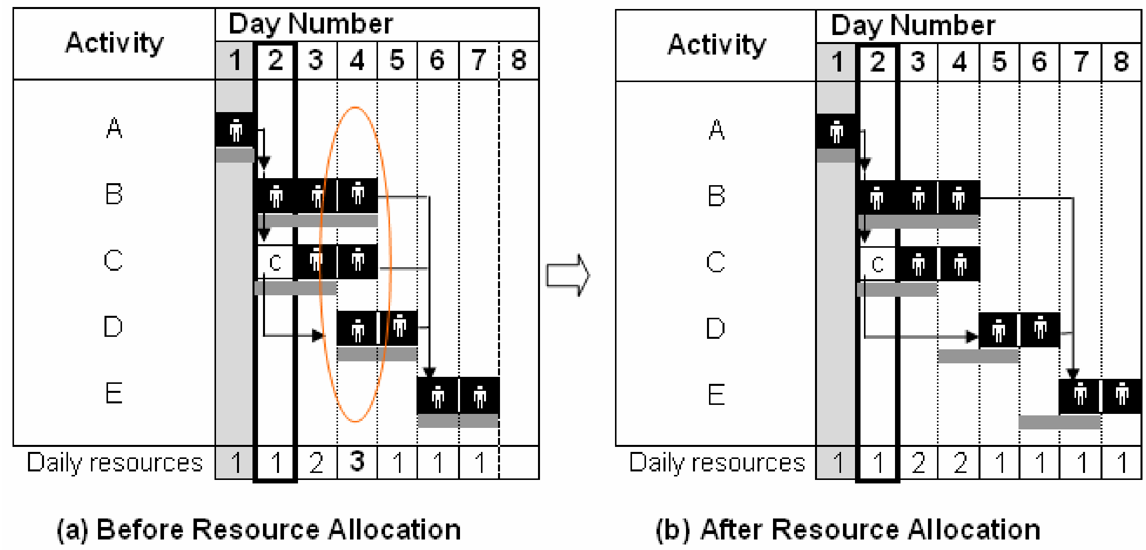


Fig. 4.5: Modified Window of Day 2

The window of day 3 (Fig. 4.6): The owner delayed activity B by one day, but that delay affected neither the critical path nor the resource allocation.

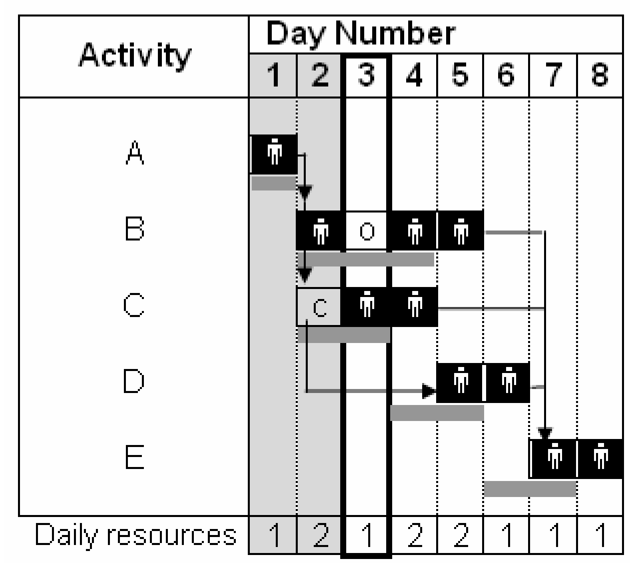


Fig. 4.6: Modified Window of Day 3

The window of the day 4 (Fig. 4.7): The owner caused another one-day delay with respect to activity B, and again this delay did not affect the overall project duration.

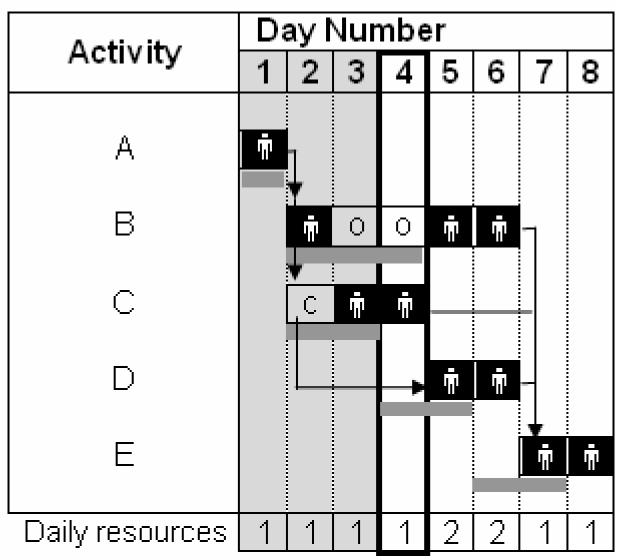


Fig. 4.7: Modified Window of Day 4

Continuing the process for the remaining windows (the fifth day to the eighth day), the project duration remains at eight days. Therefore, the conclusion of the modified daily windows analysis is a one-day contractor delay since the contractor would have delayed the project one day even the owner had not caused the further delay. A comparison of the modified versus the traditional daily windows results is shown in Table 4.1.

Table 4.1: Results of the Traditional and Modified Daily Windows Analysis

Approach	Delay Responsibility	
	Owner (O)	Contractor (C)
Traditional Daily Windows	1	0
Modified Daily Windows	0	1

4.4 Detailed Procedure

To facilitate computer implementation of the modified daily windows analysis that considers delays, accelerations, and resource allocation, a systematic procedure is set up as follows:

1. A copy of the as-built schedule is saved, and then all actual progress is cleared to get the as-planned schedule.

2. For each day (*i*), starting from day 1 to the last day of the project, the following steps are performed:

    1) Critical path(s) and near critical path(s) are identified, and the smallest float S_F among all the non-critical path(s) is calculated.

    2) The actual events (percentage completed or delays) of day (i) are added to the project baseline at that day and the remaining schedule is calculated.

    3) The project duration after adding the actual events is compared with the initial duration. Any change in the project duration (delay or acceleration)

is analyzed and apportioned, including concurrent delays and accelerations, among the parties, as follows:

a. If the project experiences a delay as compared to the previous day's analysis, the current day's critical path(s) and near-critical path(s) are analyzed as follows:

    1. If the delay $D(i) <= S_F(i)$, the smallest float $S_F(i)$ is equally attributed to the new critical path(s) only.

    2. If $D(i) > S_F(i)$, $S_F(i)$ is equally attributed to the new critical path(s) only, and $(D(i) - S_F(i))$ is equally attributed to the new critical path(s) and the near-critical path.

    3. According to the causation of delay(s) on critical path(s) and near-critical path(s), the project delay is apportioned to the owner, the contractor and/or a third party.

b. If the project experiences acceleration as compared to the previous day's analysis, the current day's critical path(s) and near-critical path(s) are analyzed as follows:

    1. If the project acceleration $A(i) <= S_F(i)$, the project acceleration $A(i)$ is equally attributed to the original critical path(s) only.

    2. If $A(i) > S_F(i)$, $S_F(i)$ is equally attributed to the original critical path(s) only, and $(A(i) - S_F(i))$ is equally attributed to the original critical path(s) and the near-critical path.

3. According to the causation of the acceleration(s) on the critical path(s) and near-critical path(s), the project acceleration is apportioned to the owner and/or the contractor.

4) The resource allocation for the remaining work is checked.
5) If the resources are over-allocated in the remaining schedule, the remaining activities are rescheduled and resequenced to meet the resource limits.
6) The remaining schedule is calculated again after the reallocation.
7) The project duration after rescheduling is compared with the base duration. Any change in the project duration is analyzed and apportioned among the parties.
8) The counter is incremented to the next day.

3. At the end of the process, the total accumulated owner, contractor, and third-party delays and the owner and contractor acceleration are presented as the final conclusion of the analysis. Decisions about time and cost compensation can be based on these values.

The analysis procedure for the modified windows analysis is also illustrated in the flowcharts of Fig.4.8 and Fig. 4.9. These flowcharts represent the details of the analysis section of the overall flowchart in chapter 3 (Fig. 3.15).

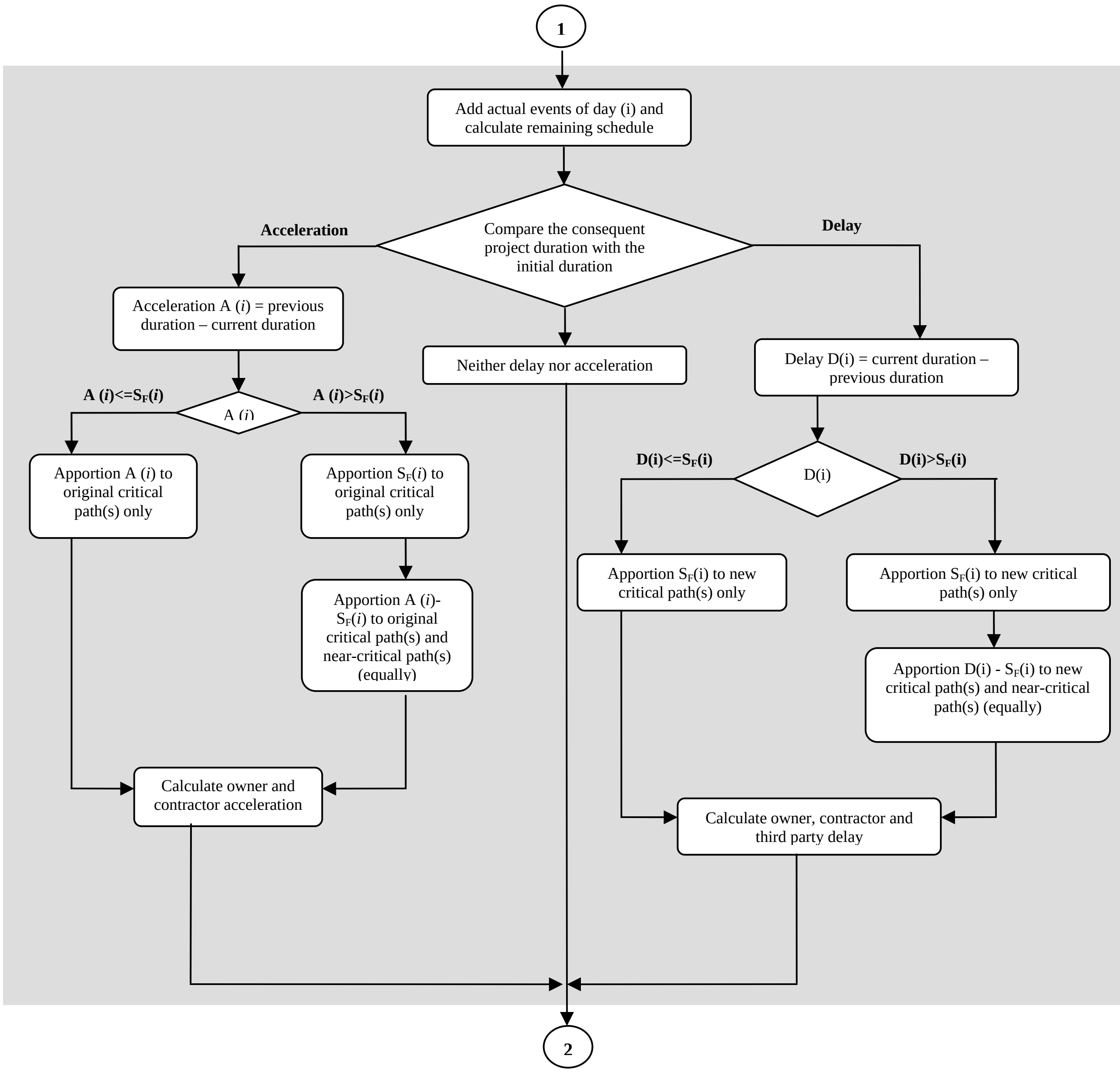


Fig. 4.8: Daily Windows Procedure without Considering Resource Allocation

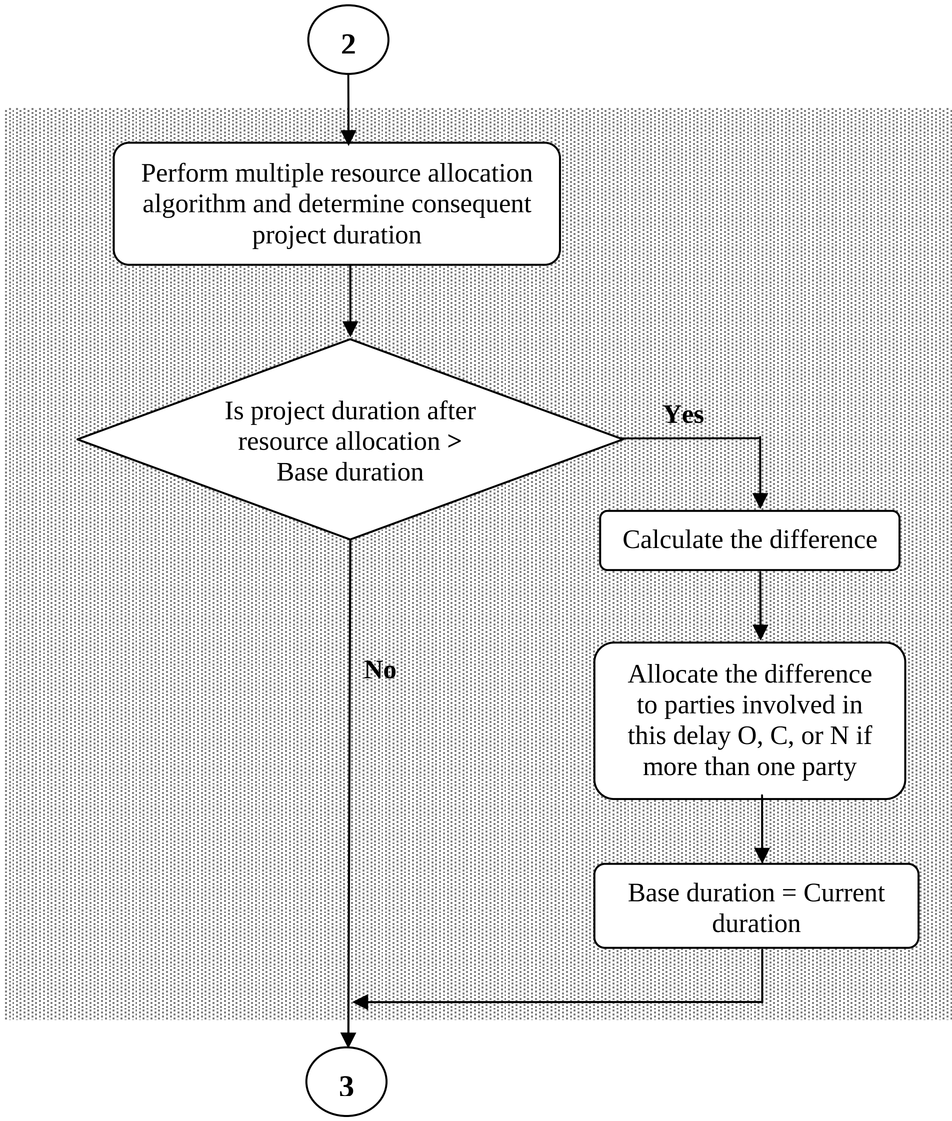


Fig. 4.9: Considering Resource Allocation in the Analysis

4.5 Conclusion

In this chapter, improvements to the daily windows analysis are proposed in order to ensure that delay analysis considers the impact of resource allocation. The modified daily windows approach identifies any changes in the resource allocation for the remaining work due to any delays or slowdowns and takes the impact of these changes on the project duration into consideration in the analysis. A systematic procedure for a daily windows delay analysis that considers resource allocation is presented in order to facilitate its computer implementation. A simple case study was used to compare the methods and results of the traditional and the modified daily windows analysis.

CHAPTER 5

INTEGRATED MODEL: PROTOTYPE AND A CASE STUDY

5.1 Introduction

This chapter presents prototype computer software for a Modified Daily Windows Analysis (MDWA) that incorporates both multiple baseline updates and resource allocation. To validate the proposed prototype and demonstrate its accuracy and usefulness, a hypothetical case study of a small project is presented.

5.2 Case Study

A hypothetical six-activity project is considered as a case study to demonstrate the modified daily windows analysis prototype developed in this research. The activities, their optional estimates, their predecessors (logical relationships), and the amount of resources required for each activity are shown in Table 5.1, while the activities' CPM network is shown in Fig. 5.1.

Table 5.1: The Activities' Estimates and Predecessors

			Estimate 1			Estimate 2		
No.	**Activity**	**Depends on**	**Cost**	**Duration**	**Resources**	**Cost**	**Duration**	**Resources**
1	A	-	5000	2	2			
2	B	1	5000	3	2	6000	2	2
3	C	1	5000	3	2	6000	2	2
4	D	2	5000	3	2	6000	2	2
5	E	2	5000	5	2	6000	4	2
6	F	3,4,5	5000	2	2			

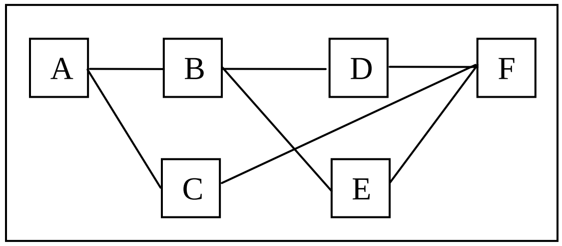


Fig. 5.1: CPM Network for the Case Study

The contractor submitted an initial schedule that satisfies his own resource constraints and meets a 12-day deadline. The owner therefore approved the schedule. However, the actual progress experienced some schedule changes. For the first two days, the progress of activity A was slower than planned because of the late arrival of resources, and accordingly, it was expected to finish the project in 14 days. Since the agreement was to finish the project in only 12 days, the contractor had to accelerate the project to recover the two-day delay. The contractor found that the best available option was to run some activities in parallel so that the project duration would be 12 days. On the fifth day, the owner delayed the start of activity C, and therefore, a resource over-allocation was expected for the next few days. To avoid delays, the contractor voluntarily accelerated the project by shortening the duration of activity E from 5 days to 4 days through the use of a more expensive method. At the end, therefore, the project was completed in 12 days, but the contractor is investigating whether the owner's delay on day 5 warrants a request for compensation to cover the added expenses of accelerating activity E.

Although this project is simple, the changes in logical relations and resource over-allocation make its delay analysis complicated.

5.3 Modified Daily Windows Prototype

This study has developed a computerized schedule analysis model to consider multiple baseline updates and resource allocation in order to accurately apportion delays and accelerations among project parties. The model has been incorporated into a computer tool, EasyPlan (Hegazy, 2007), which integrates estimating, scheduling, resource management, and project control. The EasyPlan program has been developed using the VBA language of Microsoft Excel software. Some of EasyPlan's features that facilitate delay analysis are:

- 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 the schedule analysis model to the case study is described in the following sub-sections.

5.3.1 Activities and Schedule

Following the case study information, the general data for the project was entered, including the start date; the working days; the key resource (L1) and its daily limit (4); the project deadline duration (12 days); and other contract provisions such as a $ 5000 daily penalty (Fig. 5.2). Then, the activities and their estimates were specified on the activities sheet, as shown in Fig. 5.3.

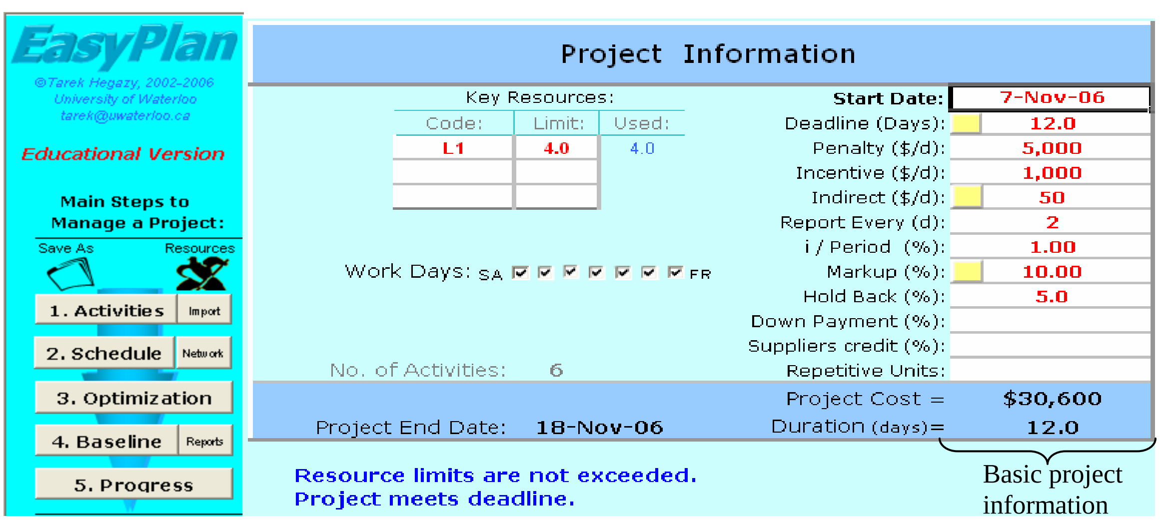
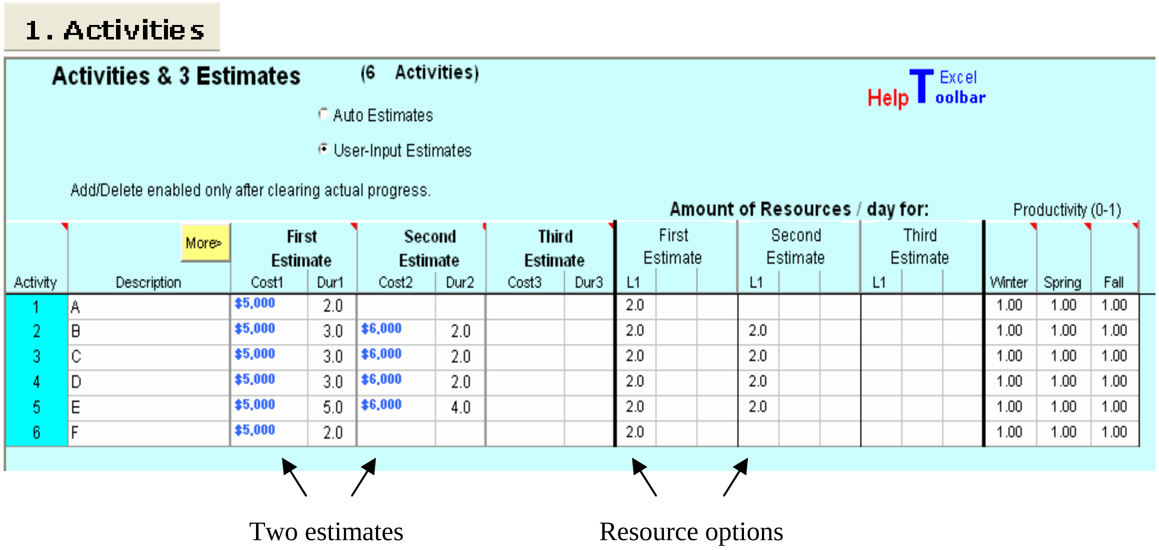


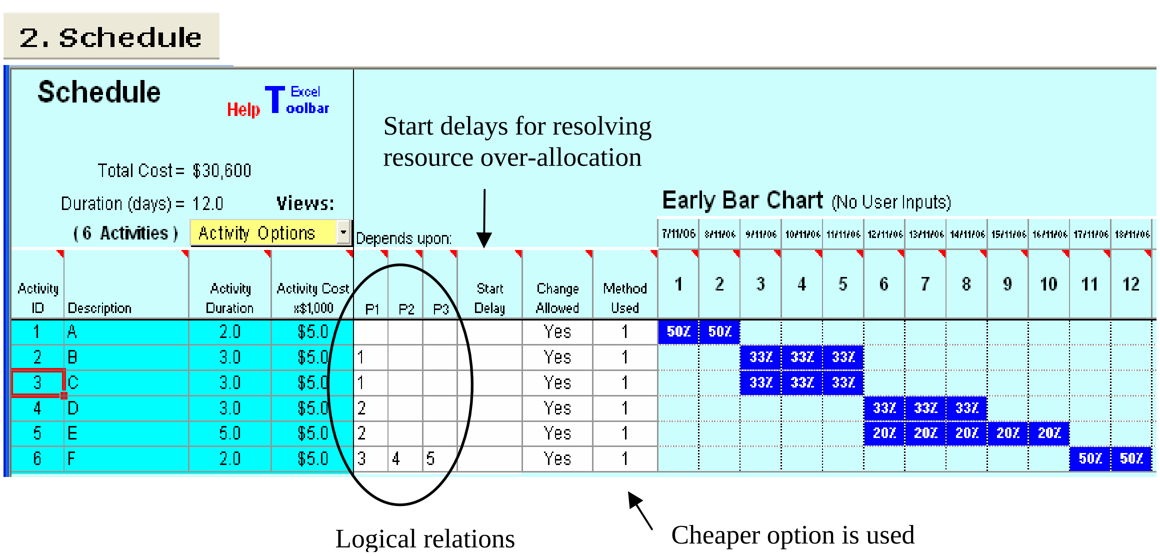
Fig. 5.2: Main Screen of EasyPlan



Activity	Description	First Estimate Cost1	Dur1	Second Estimate Cost2	Dur2	Third Estimate Cost3	Dur3	First Estimate L1	Second Estimate L1	Third Estimate L1	Winter	Spring	Fall
1	A	$5,000	2.0					2.0			1.00	1.00	1.00
2	B	$5,000	3.0	$6,000	2.0			2.0	2.0		1.00	1.00	1.00
3	C	$5,000	3.0	$6,000	2.0			2.0	2.0		1.00	1.00	1.00
4	D	$5,000	3.0	$6,000	2.0			2.0	2.0		1.00	1.00	1.00
5	E	$5,000	5.0	$6,000	4.0			2.0	2.0		1.00	1.00	1.00
6	F	$5,000	2.0					2.0			1.00	1.00	1.00

Fig. 5.3: Activities' Estimates

Next, in the schedule sheet, the predecessors to each activity were entered as shown in Fig. 5.4. Since the contractor was using the first estimate for each activity (the cheap and slow option), the "Method Used" column indicates an index of "1". Accordingly, the project duration becomes 12 days.



Activity ID	Description	Activity Duration	Activity Cost x$1,000	P1	P2	P3	Start Delay	Change Allowed	Method Used	1	2	3	4	5	6	7	8	9	10	11	12
1	A	2.0	$5.0					Yes	1	50%	50%										
2	B	3.0	$5.0	1				Yes	1			33%	33%	33%							
3	C	3.0	$5.0	1				Yes	1			33%	33%	33%							
4	D	3.0	$5.0	2				Yes	1						33%	33%	33%				
5	E	5.0	$5.0	2				Yes	1						20%	20%	20%	20%	20%		
6	F	2.0	$5.0	3	4	5		Yes	1											50%	50%

Fig. 5.4: As-Planned Schedule of the Project

This 12-day schedule meets the deadline and also the four L1 resource limit at a total cost of $ 30,600, as shown in Fig 5.5. Therefore, the schedule was saved as a “baseline” for the project (Fig. 5.6). This baseline was approved by the owner and is used for progress evaluation and delay analysis.

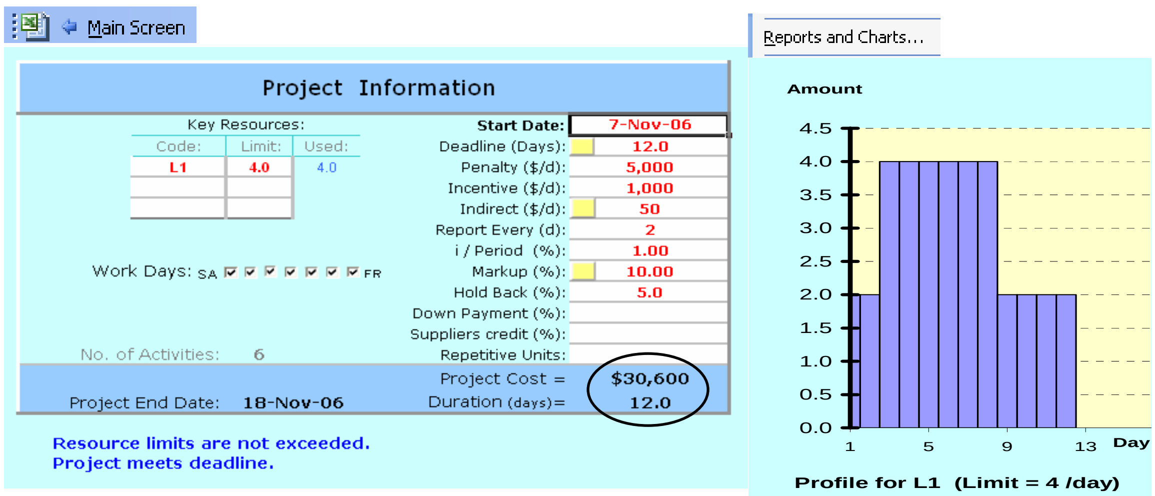


Fig. 5.5: Schedule Meets Deadline and Resource Limit

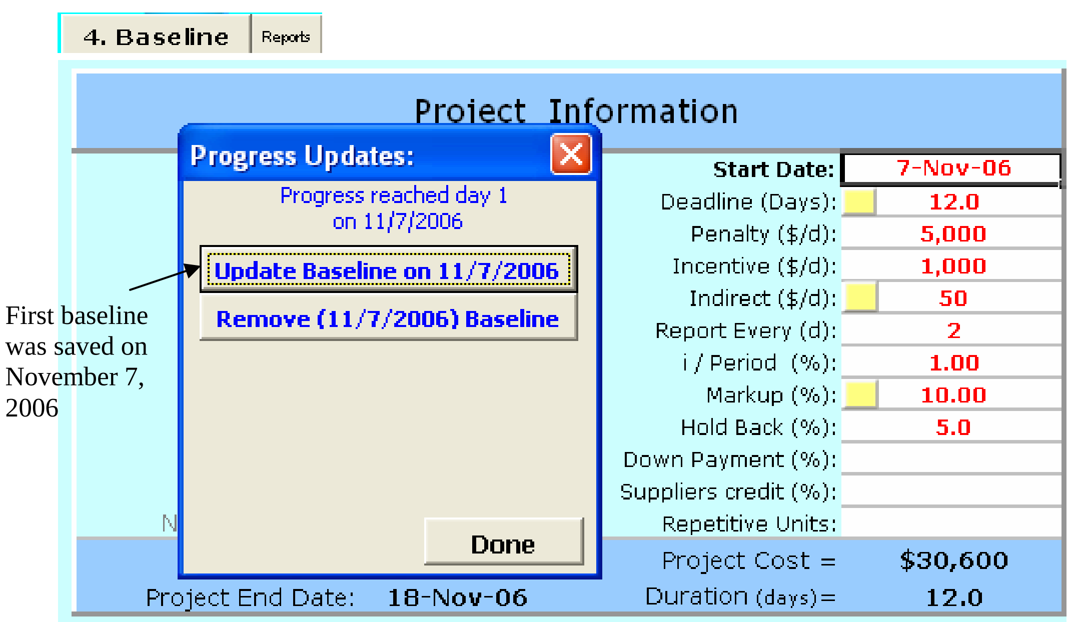


Fig. 5.6: Saving the Project Baseline

5.3.2 Actual Progress Events

In the construction stage, all progress events, including delays caused by all parties, were entered on a daily basis. In the progress sheet shown in Fig. 5.7, each activity has two bars: the top bar (light colour) represents the baseline indicated as daily percentages (e.g., a duration of two days means a progress of 50% for each day). The activity bottom bar (dark colour), on the other hand, allows the user to record the actual events that were experienced during the execution of the activity (initially actual bars are set to be the same as the baseline bars, as shown in Fig. 5.7). The actual daily events are then entered either directly on the actual activity bar (bottom) or through the use of the “Enter Daily Progress” button on the progress sheet, as shown in Fig. 5.7. When this button is used, a form is presented (Fig. 5.8) in which the events that took place on that day can be entered.

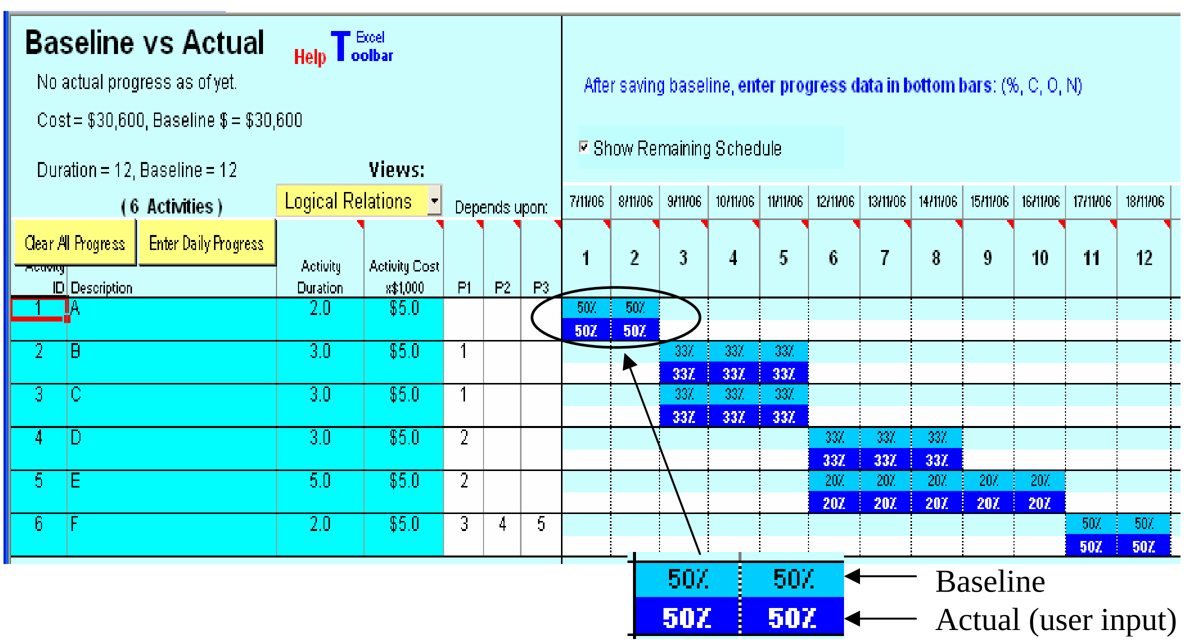


Fig. 5.7: Representation of Progress in the Progress Sheet

Activity daily events can be entered as either a progress or a delay. For day 1 (Fig. 5.8), a progress of 20% percent complete was assigned to activity A. Since this progress is less than the baseline progress for this activity (50%), an explanation is given, as shown in Fig. 5.8.

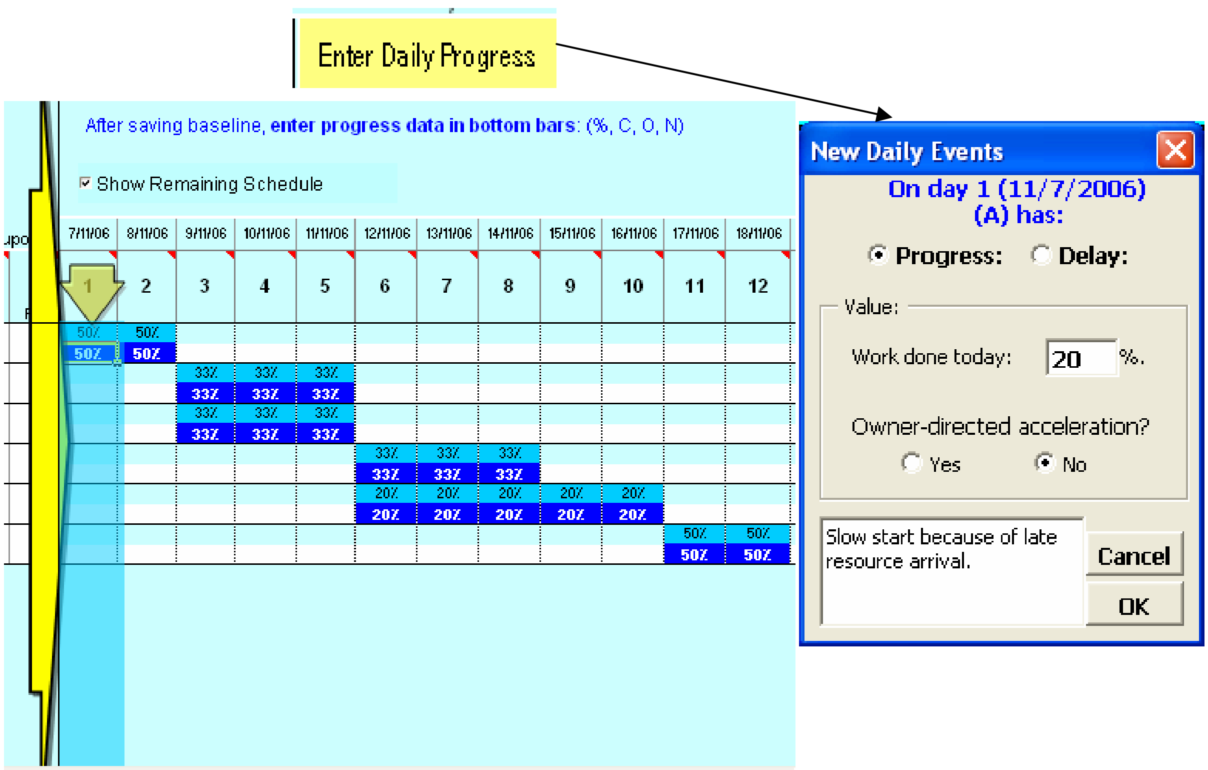


Fig. 5.8: Entering the Progress Events of Day 1

For day 2, the contractor's progress was also slow (20% as opposed to the planned 50%), as shown in Fig. 5.9. Therefore, activity A will require two additional days of duration (calculated using Equation 3.1), resulting in activity A becoming four days, as shown in Fig. 5.9. Accordingly, the project was delayed two days and not be completed until day 14.

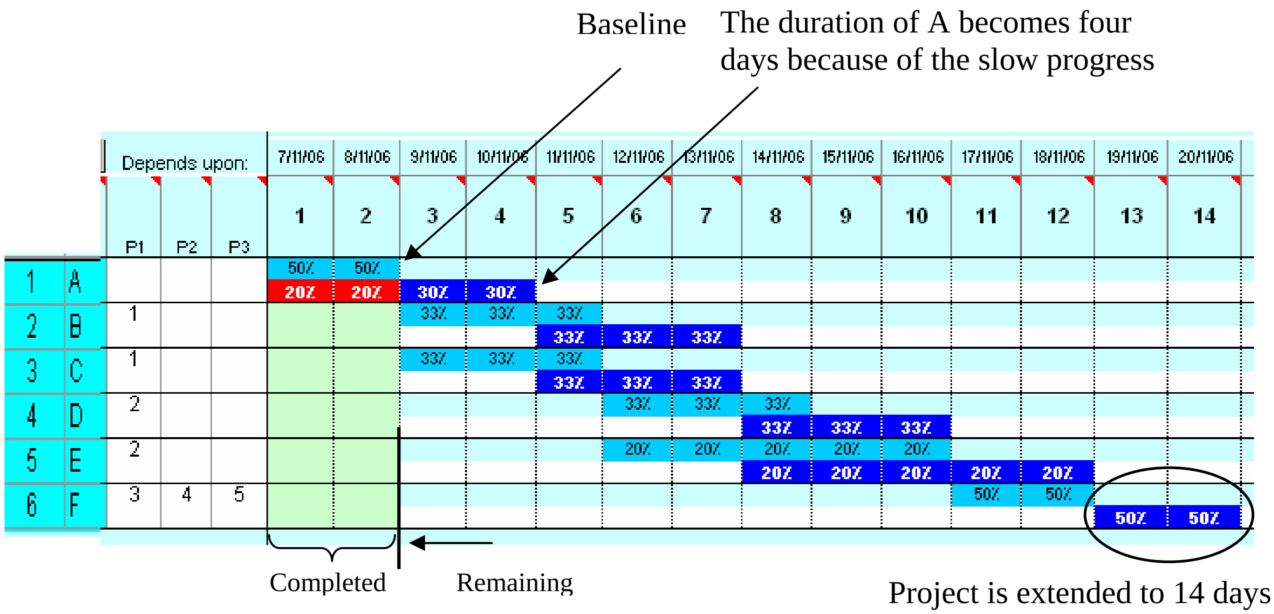


Fig 5.9: Actual Progress of the First Two Days

To avoid paying the high penalty for the two-day delay, the contractor decided to make a change in the work sequence by rescheduling activity F to start parallel with, rather than after, activity E. Fortunately for the contractor, this change does not cause any resource over-allocation. This change mandated an adjustment to the logical relationship in the schedule, as shown in Fig. 5.10, and also required the owner's approval.

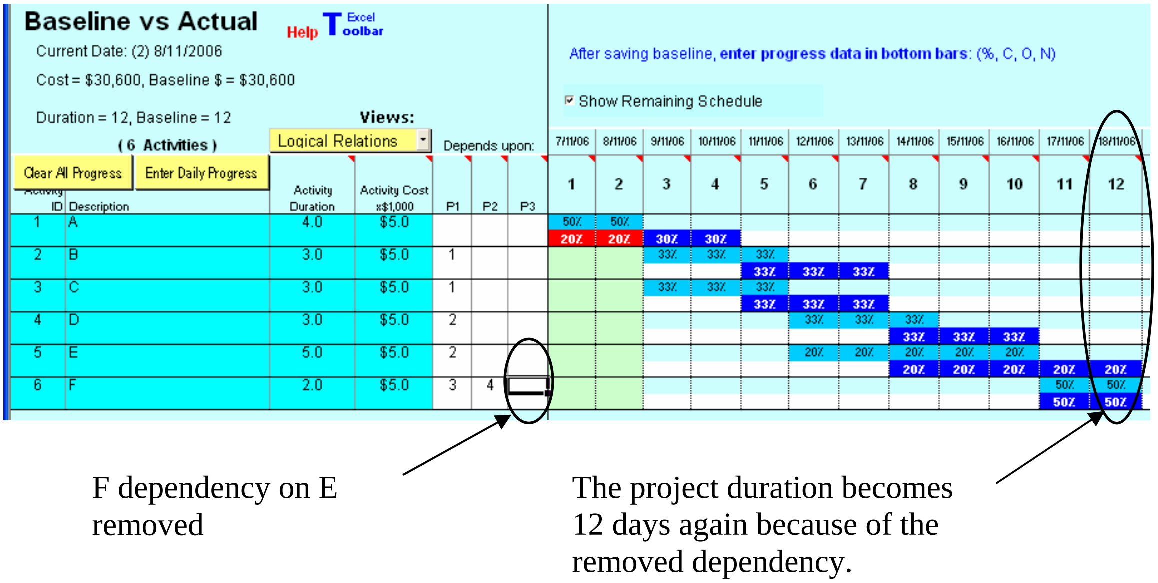


Fig. 5.10: Project Schedule after a Change in the Logical Relations

5.3.3 Multiple Baselines and Resource Challenge

When the as-planned schedule is updated during the execution of a project due to changes either in logical relationships between the activities or in the activities' durations, a new baseline that includes all the changes should be used to analyze the events that take place after the updates. In the present case study, the owner and the contractor agreed to use a new baseline after the logical relationship between activities F and E was changed. A new baseline was then saved in EasyPlan, as shown in Fig. 5.11. Accordingly, the progress sheet shows the new baseline. Fig. 5.11 shows the progress sheet after entering the progress of days 3 and 4 in which the contractor exactly followed the new baseline.

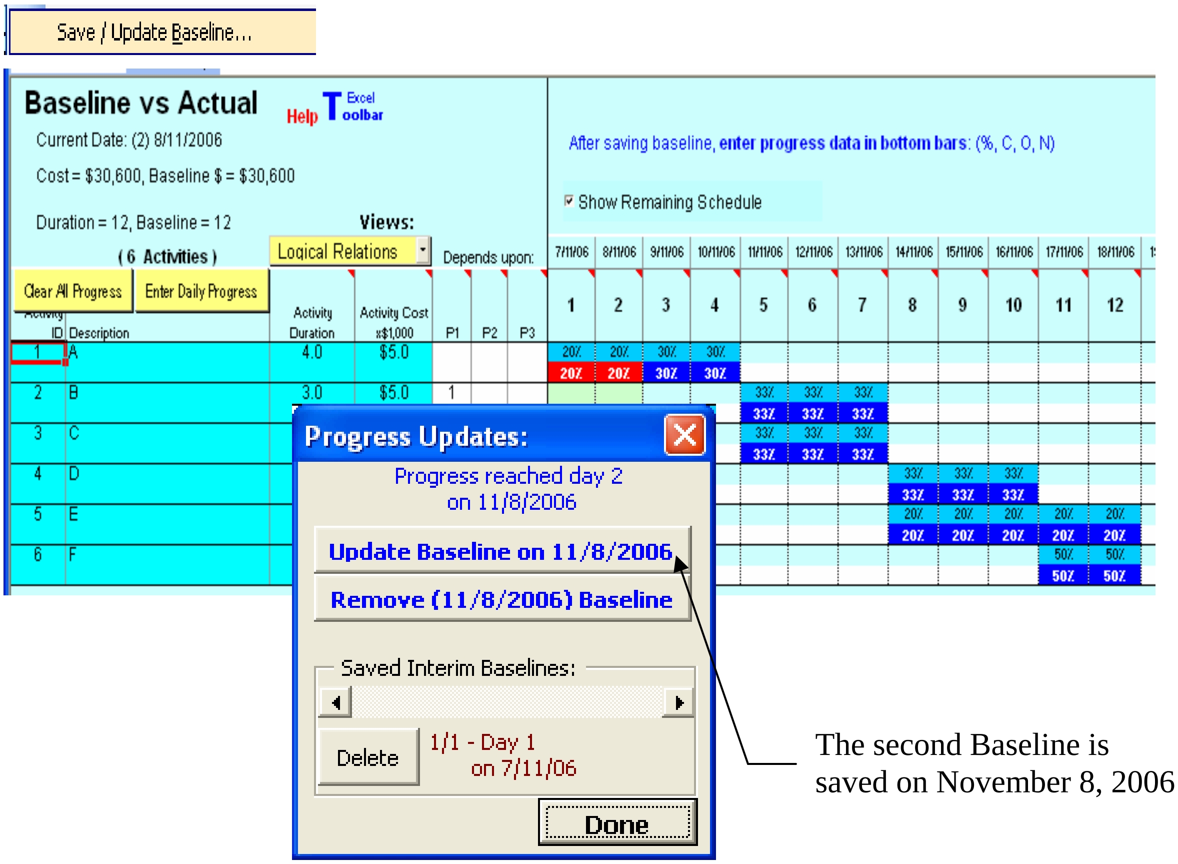


Fig. 5.11: Saving the Second Baseline

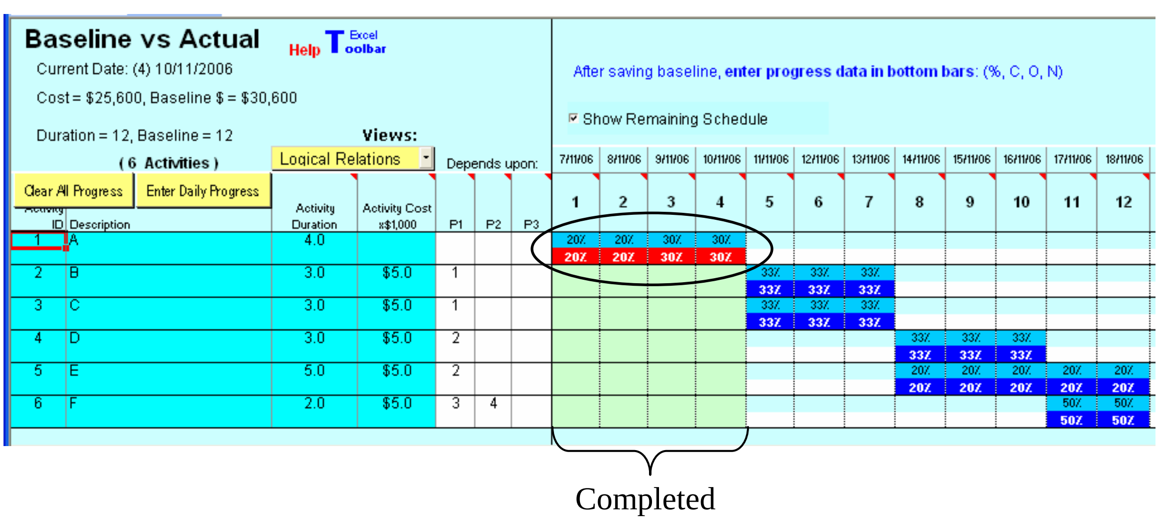


Fig. 5.12: Actual Progress at the End of Day 4

On day 5, the owner delayed activity C by one day. Although the delay did not affect the overall project duration, it caused a resource over-allocation at day 8, as shown in Fig. 5.13. This implies that the owner's delay will later force the contractor to change the schedule or even delay some activities to avoid exceeding the resource limit.

On days 6 and 7, the project progressed according to the baseline and did not experience any delays or accelerations (Fig. 5.14).

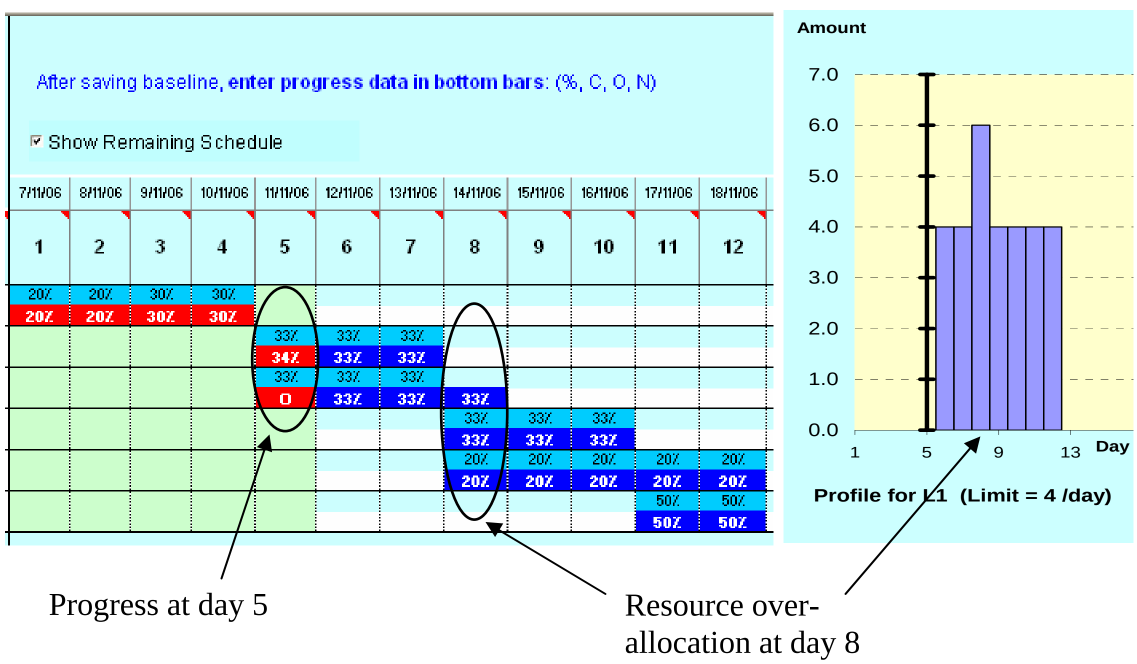


Fig. 5.13: Actual Progress at the End of Day 5

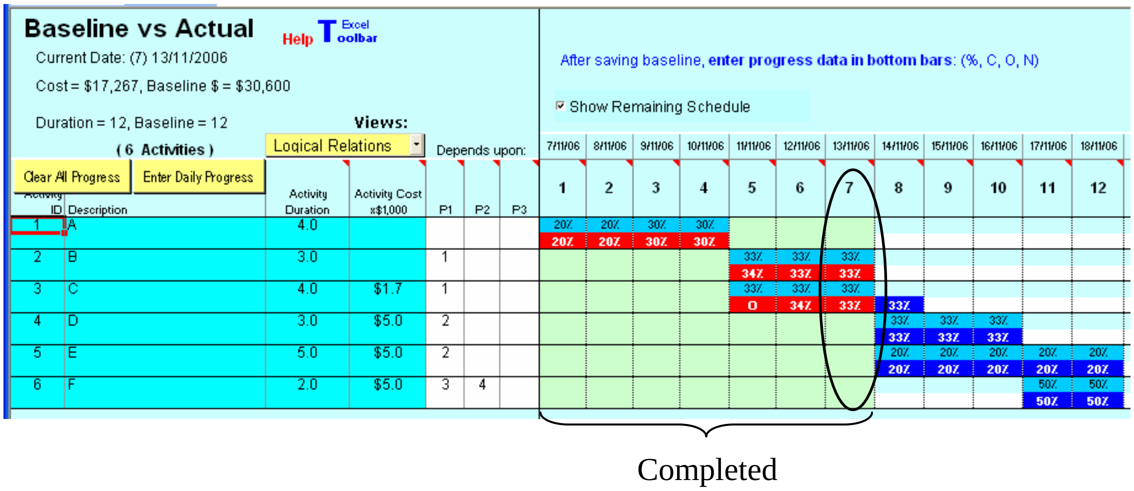


Fig. 5.14: Actual Progress at the End of Day 7

On day 8, the contractor did not start activity E due to his inability to proceed with the three activities C, D, E in parallel, because of the resource limit. Thus, activity E and the project duration would be extended to day 13, as shown in Fig. 5.15. To compensate for this one-day delay, the contractor decided to accelerate activity E, and accordingly accelerate the overall project by one day, by changing the method of executing activity E. The faster and more expensive second method reduces the duration of activity E to four days instead of five. Consequently, the project duration becomes 12 days again (Fig 5.16). This change also mandates another adjustment and the approval of a new baseline after day 8. Fig. 5.17 shows the saving of a third baseline after the construction method of activity E is changed. After day 8, the project progressed according to the new baseline, and the project duration remains 12 days, as shown in Fig. 5.18.

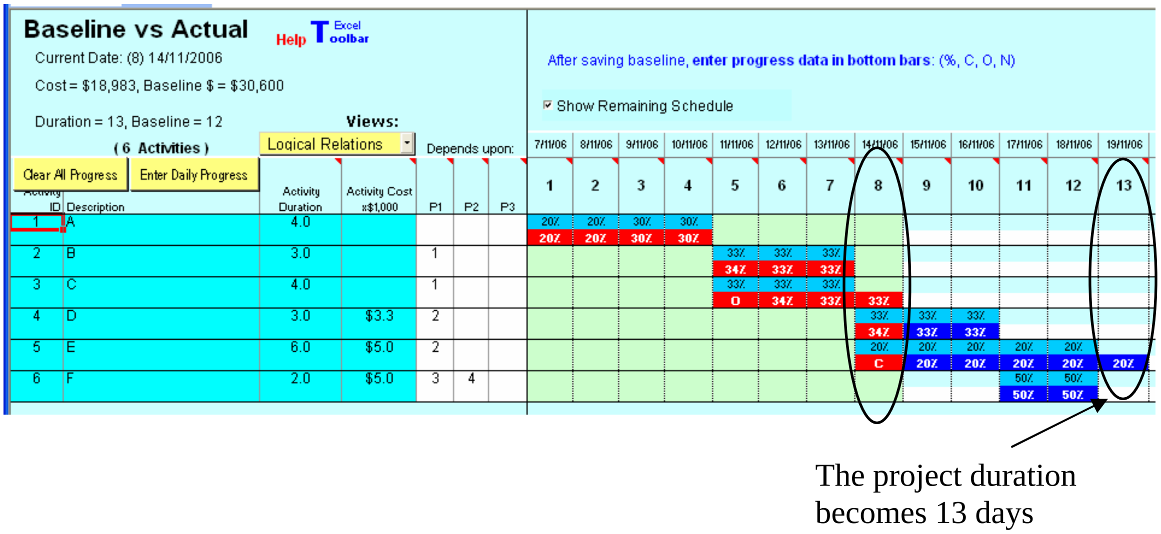


Fig. 5.15: Actual Progress at the End of Day 8

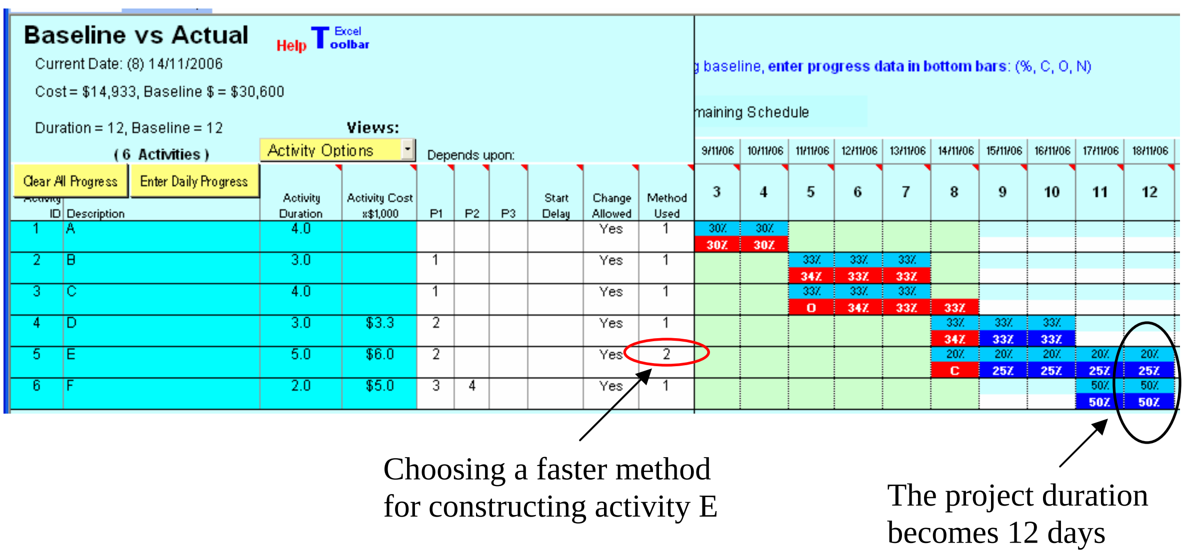


Fig. 5.16: Changing the Method of Executing Activity E

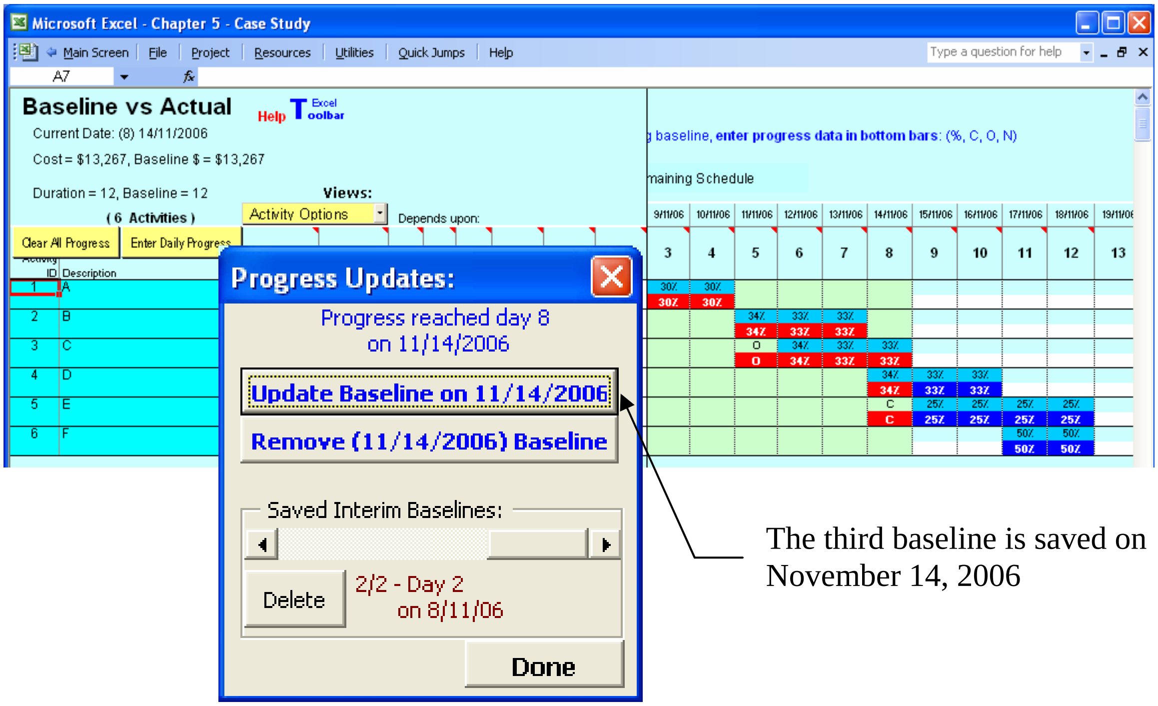


Fig. 5.17: Saving the Third Baseline

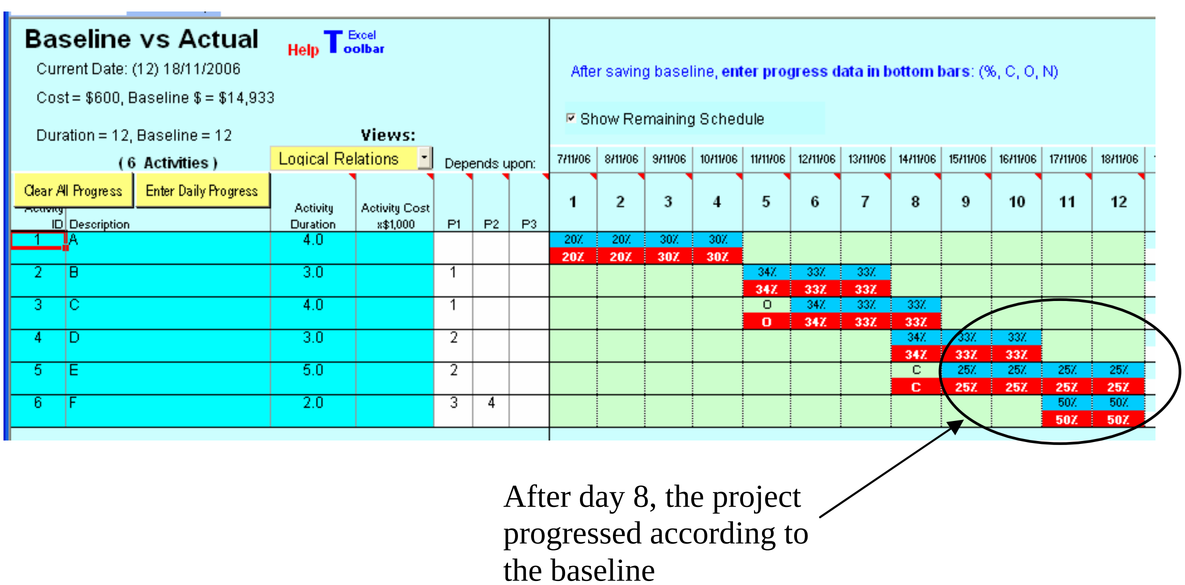


Fig. 5.18: The Actual Progress at End of Day 12 (completed as-built)

5.3.4 Delay Analysis

Once all the progress events are entered, including delays caused by all parties, the proposed prototype can be used for delay analysis. When the user clicks on the "Windows Analysis" button, as illustrated in Fig. 5.19, the MDWA is conducted, and a small window containing a summary of the delay analysis results is presented (Fig 5.20).

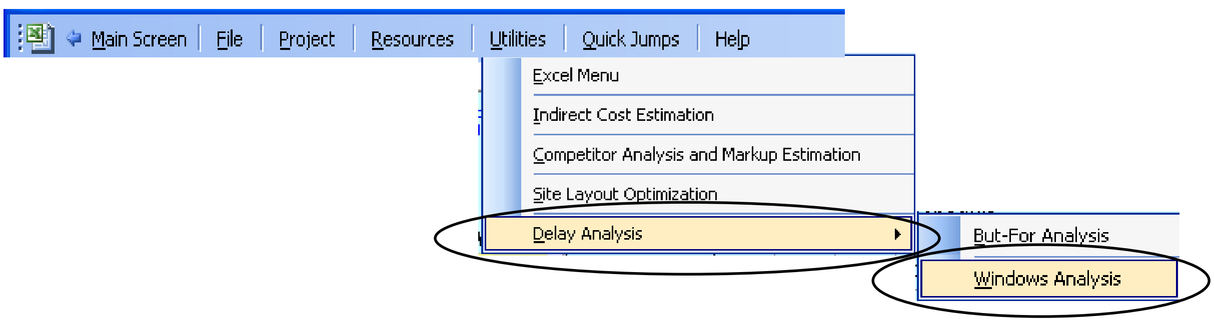


Fig. 5.19: Using Delay Analysis in EasyPlan

The results summary indicates that the contractor was responsible for two days of non-excusable delays, which were compensated by his three days of acceleration. The project duration, however, remained 12 days due to an excusable (N) delay of one day.

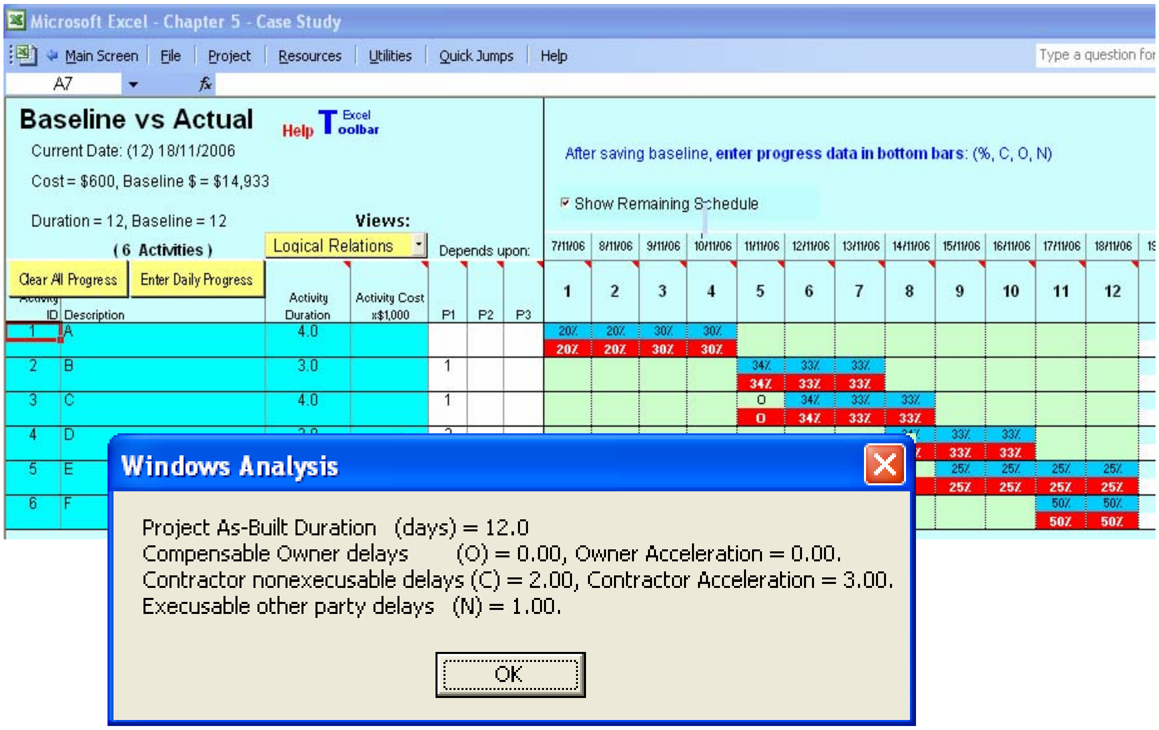


Fig. 5.20: Summary of Delay Analysis Results

5.3.5 Discussion of Results

Detailed results of the delay analysis are presented in an automated report, providing MDWA results on a day-by-day basis. Fig. 5.21 shows the portion of the report that relates to the first baseline, compared to the associated events.

The report shows the steps followed in applying the analysis. The results of day 1 show one contractor delay (C = 1.0), increased to two contractor delays (C = 2.0) at the end of day 2, which corresponds to the progress shown in the first two days.

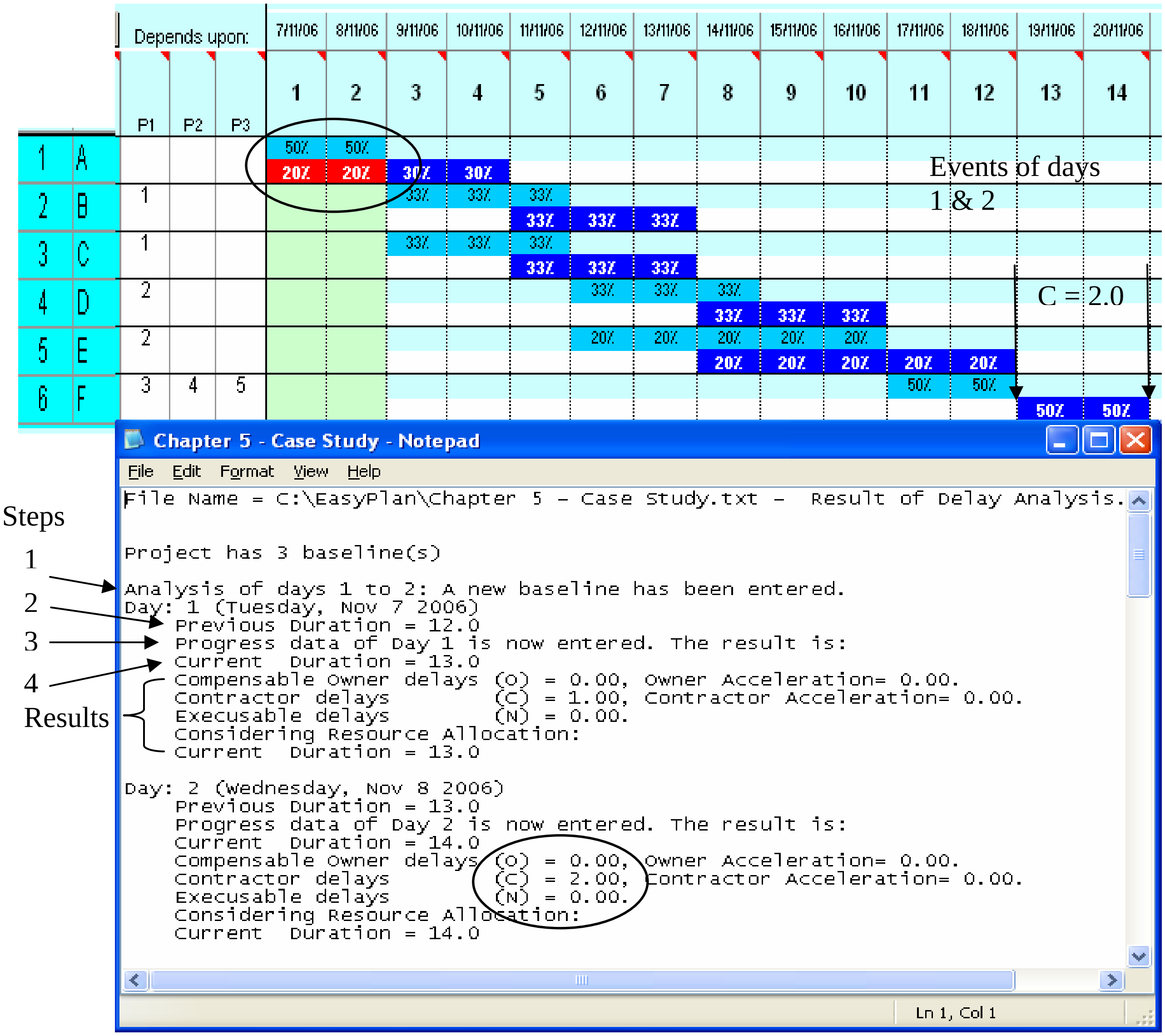
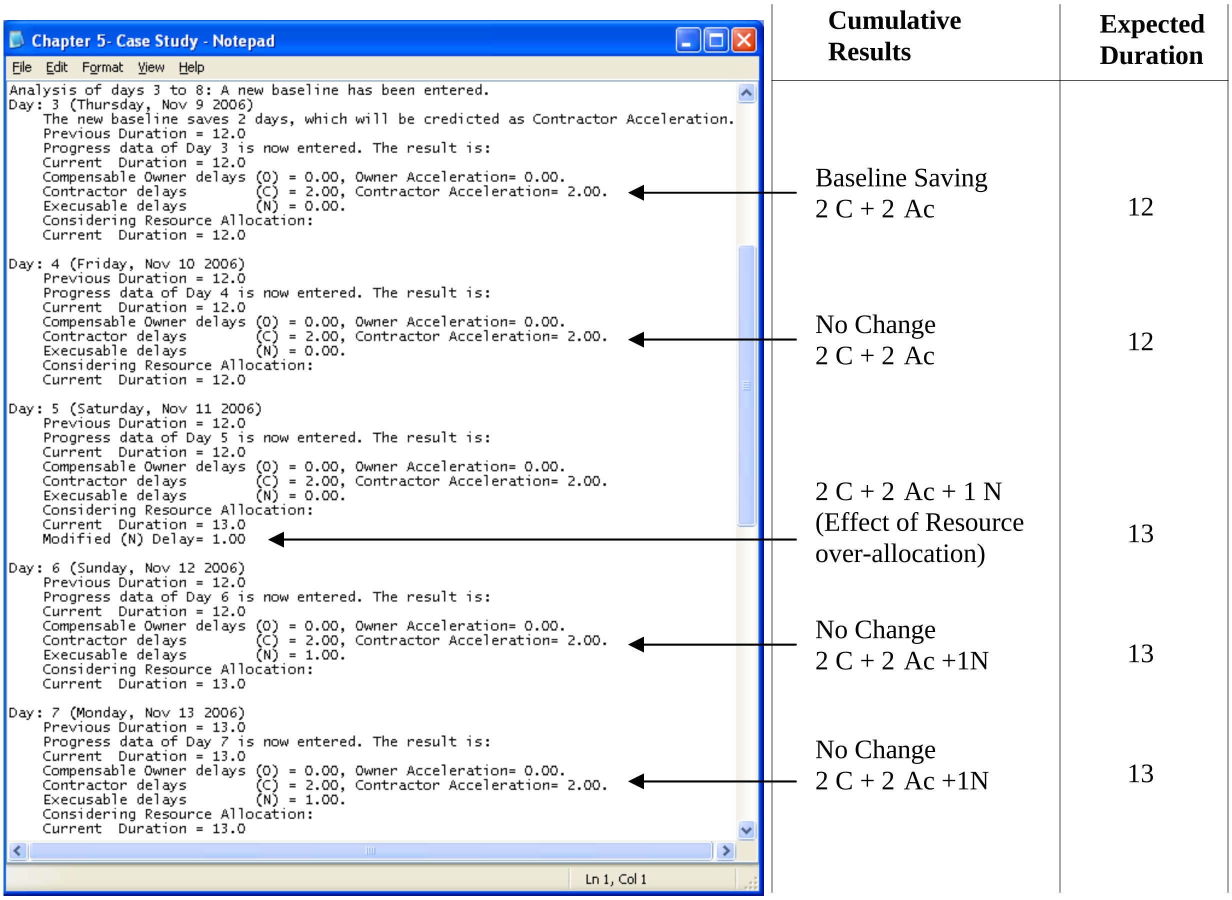


Fig. 5.21: The MDWA Results of the First Baseline (days 1 and 2)

Fig. 5.22 shows the portion of the MDWA report from days 3 to 7, indicating the cumulative results on a day-by-day basis. At the beginning of day 3, a new baseline was entered because of the contractor's corrective action. Since the new baseline duration is 12 days and the previous duration was 14, a two-day contractor acceleration is accumulated (A_c).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Chapter 5- Case Study - Notepad
File Edit Format View Help
Analysis of days 3 to 8: A new baseline has been entered.
Day: 3 (Thursday, Nov 9 2006)
    The new baseline saves 2 days, which will be credicted as Contractor Acceleration.
    Previous Duration = 12.0
    Progress data of Day 3 is now entered. The result is:
    Current  Duration = 12.0
    Compensable Owner delays (O) = 0.00, Owner Acceleration= 0.00.
    Contractor delays        (C) = 2.00, Contractor Acceleration= 2.00.
    Execusable delays        (N) = 0.00.
    Considering Resource Allocation:
    Current  Duration = 12.0

Day: 4 (Friday, Nov 10 2006)
    Previous Duration = 12.0
    Progress data of Day 4 is now entered. The result is:
    Current  Duration = 12.0
    Compensable Owner delays (O) = 0.00, Owner Acceleration= 0.00.
    Contractor delays        (C) = 2.00, Contractor Acceleration= 2.00.
    Execusable delays        (N) = 0.00.
    Considering Resource Allocation:
    Current  Duration = 12.0

Day: 5 (Saturday, Nov 11 2006)
    Previous Duration = 12.0
    Progress data of Day 5 is now entered. The result is:
    Current  Duration = 12.0
    Compensable Owner delays (O) = 0.00, Owner Acceleration= 0.00.
    Contractor delays        (C) = 2.00, Contractor Acceleration= 2.00.
    Execusable delays        (N) = 0.00.
    Considering Resource Allocation:
    Current  Duration = 13.0
    Modified (N) Delay= 1.00

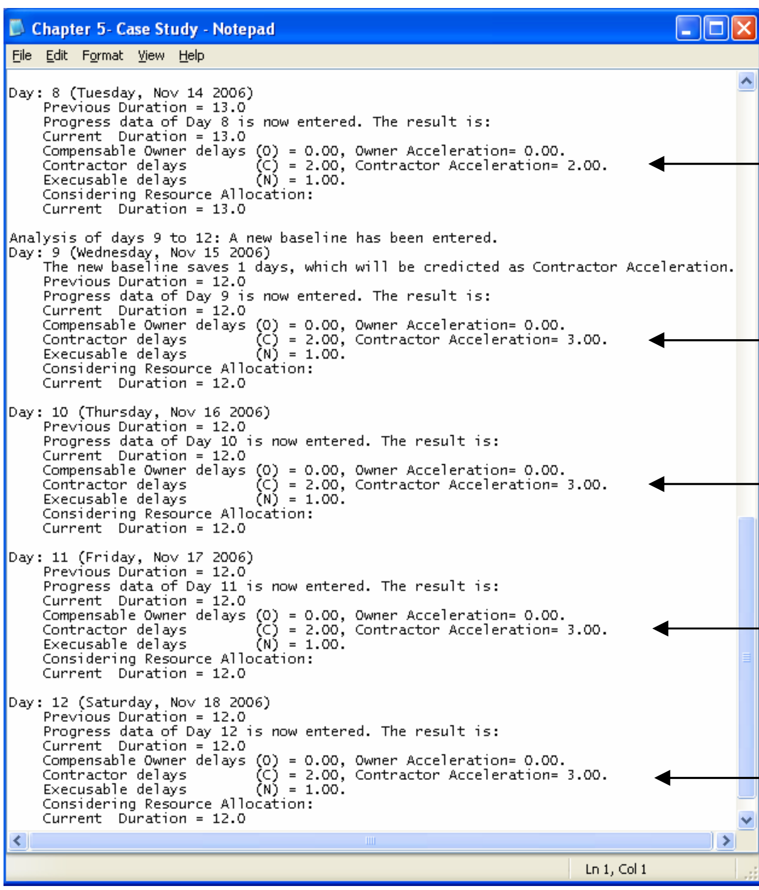
Day: 6 (Sunday, Nov 12 2006)
    Previous Duration = 12.0
    Progress data of Day 6 is now entered. The result is:
    Current  Duration = 12.0
    Compensable Owner delays (O) = 0.00, Owner Acceleration= 0.00.
    Contractor delays        (C) = 2.00, Contractor Acceleration= 2.00.
    Execusable delays        (N) = 1.00.
    Considering Resource Allocation:
    Current  Duration = 13.0

Day: 7 (Monday, Nov 13 2006)
    Previous Duration = 13.0
    Progress data of Day 7 is now entered. The result is:
    Current  Duration = 13.0
    Compensable Owner delays (O) = 0.00, Owner Acceleration= 0.00.
    Contractor delays        (C) = 2.00, Contractor Acceleration= 2.00.
    Execusable delays        (N) = 1.00.
    Considering Resource Allocation:
    Current  Duration = 13.0
Ln 1, Col 1
```


Fig. 5.22: The MDWA Results of the Second Baseline

At day 5, the owner caused a delay in the path A-C-F, which is not the critical path. Therefore, no (O) is shown in the cumulative results of day 5 (Fig. 5.22). However, the owner's event on this day will lead to future resource over-allocation as indicated in the extra day of expected project delay (13 days instead of 12 days), as shown in the third column in Fig. 5.22. Accordingly, one (N) delay is accumulated in this case since it is not purely caused by the contractor (i.e., the owner is the reason).

The result of the report for day 8 validates the correct performance of the proposed model (Fig. 5.23). On this day, although the contractor delayed the start of activity E, which was a critical activity, no additional contractor delay was accumulated on this day because one day of delay was already accumulated at day 5 after the resource allocation was considered in the analysis.


Chapter 5- Case Study - Notepad
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```
Day: 8 (Tuesday, Nov 14 2006)
     Previous Duration = 13.0
     Progress data of Day 8 is now entered. The result is:
     Current  Duration = 13.0
     Compensable Owner delays (O) = 0.00, Owner Acceleration= 0.00.
     Contractor delays        (C) = 2.00, Contractor Acceleration= 2.00.
     Execusable delays        (N) = 1.00.
     Considering Resource Allocation:
     Current  Duration = 13.0

Analysis of days 9 to 12: A new baseline has been entered.
Day: 9 (Wednesday, Nov 15 2006)
     The new baseline saves 1 days, which will be credicted as Contractor Acceleration.
     Previous Duration = 12.0
     Progress data of Day 9 is now entered. The result is:
     Current  Duration = 12.0
     Compensable Owner delays (O) = 0.00, Owner Acceleration= 0.00.
     Contractor delays        (C) = 2.00, Contractor Acceleration= 3.00.
     Execusable delays        (N) = 1.00.
     Considering Resource Allocation:
     Current  Duration = 12.0

Day: 10 (Thursday, Nov 16 2006)
     Previous Duration = 12.0
     Progress data of Day 10 is now entered. The result is:
     Current  Duration = 12.0
     Compensable Owner delays (O) = 0.00, Owner Acceleration= 0.00.
     Contractor delays        (C) = 2.00, Contractor Acceleration= 3.00.
     Execusable delays        (N) = 1.00.
     Considering Resource Allocation:
     Current  Duration = 12.0

Day: 11 (Friday, Nov 17 2006)
     Previous Duration = 12.0
     Progress data of Day 11 is now entered. The result is:
     Current  Duration = 12.0
     Compensable Owner delays (O) = 0.00, Owner Acceleration= 0.00.
     Contractor delays        (C) = 2.00, Contractor Acceleration= 3.00.
     Execusable delays        (N) = 1.00.
     Considering Resource Allocation:
     Current  Duration = 12.0

Day: 12 (Saturday, Nov 18 2006)
     Previous Duration = 12.0
     Progress data of Day 12 is now entered. The result is:
     Current  Duration = 12.0
     Compensable Owner delays (O) = 0.00, Owner Acceleration= 0.00.
     Contractor delays        (C) = 2.00, Contractor Acceleration= 3.00.
     Execusable delays        (N) = 1.00.
     Considering Resource Allocation:
     Current  Duration = 12.0
```

Ln 1, Col 1

Cumulative Results	Expected Duration
No Change 2 C + 2 Ac +1N	13
Baseline Saving 2 C + 3 Ac + 1N	12
No Change 2 C + 3 Ac +1N	12
No Change 2 C + 3 Ac +1N	12
No Change 2 C + 3 Ac +1N	12

Fig. 5.23: The MDWA Results of the Third Baseline

A third baseline is entered for this day due to a change in the construction method of activity E. Since the new baseline duration is 12 days and the previous duration was 13 days, a one-day contractor acceleration is accumulated. The final result of the analysis becomes 2C + 1N + $3A_c$, i.e., 2 days of contractor-caused delays, 1 day of (N) delay, and 3 days of contractor acceleration.

As shown in this case study, the model is practical and sensitive to the various types of site events and the parties who caused them. For example, the results would be different if the acceleration after day 8 was requested by the owner and therefore considered as “owner directed acceleration”. When this modification of the case is implemented on EasyPlan, as shown in Fig. 5.24, the analysis results becomes 2C + 1N + $1A_o$ + $2A_c$, i.e., 2 days of contractor-caused delay, 1 day of (N) delay, 1 day of owner acceleration, and 2 days of contractor acceleration (Fig. 5.25). This validates the model’s ability to distinguish the parties causing the delay and acceleration. As such, it is suitable for decisions related to cost and time compensation.

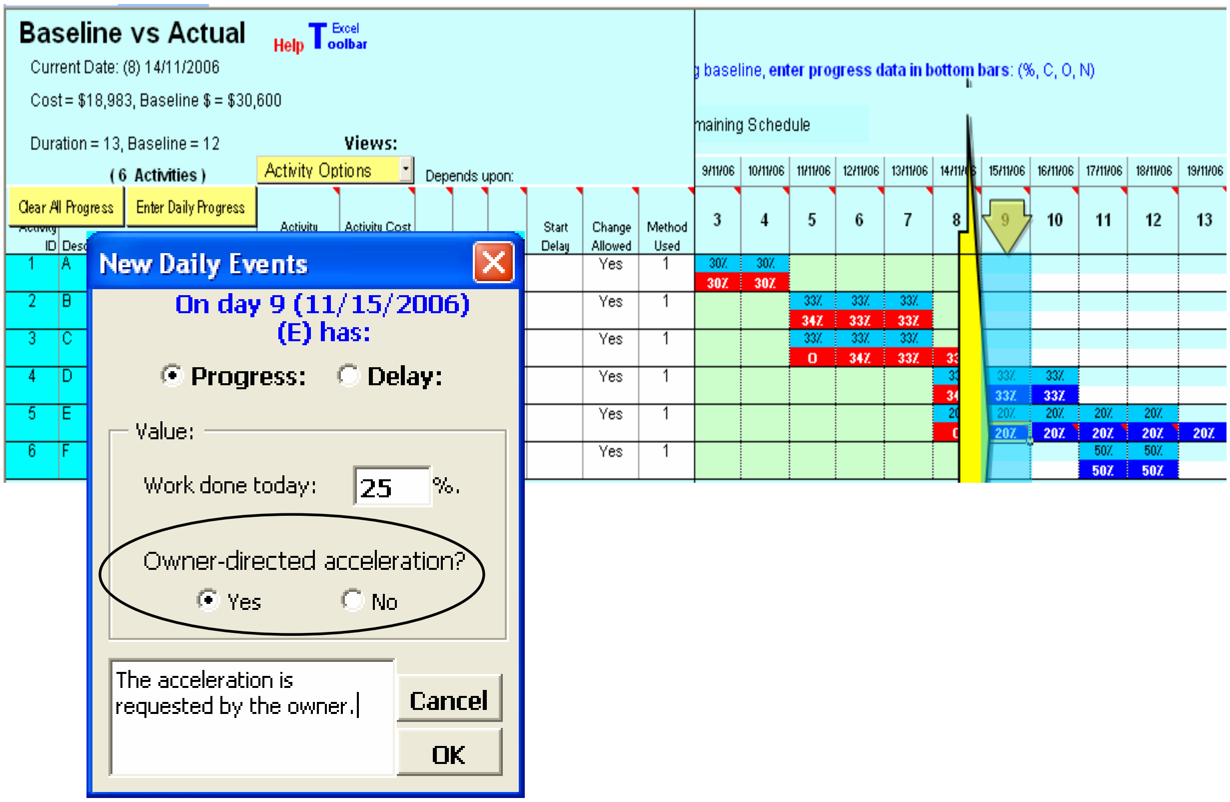

Fig. 5.24: Considering the Owner-Directed Acceleration in EasyPlan

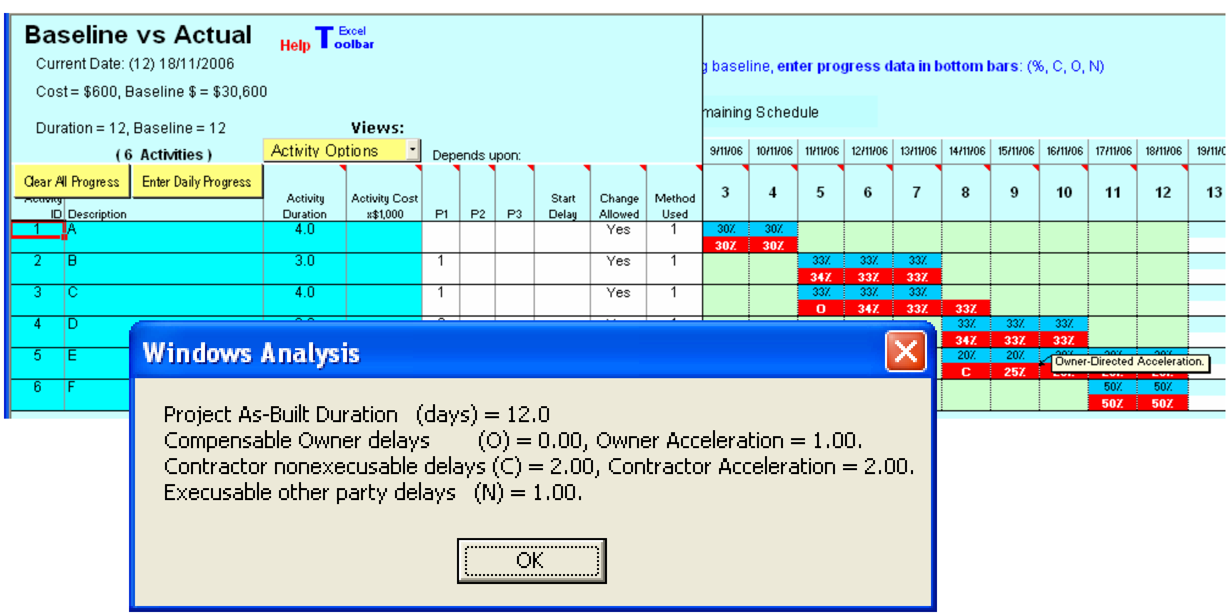

Fig. 5.25: MDWA Results in Case of Owner-Directed Acceleration

5.4 Conclusion

In this chapter, a simple case study of a six-activity project has been implemented on the proposed schedule analysis model MDWA. The model considers multiple baseline updates and the effect of resource allocation in delay analysis. In addition, the daily percentage representation of the planned and actual progress facilitates the recording and viewing of all site events as well as the calculation of the project status and responsibility for delays.

CHAPTER 6

CONCLUSIONS

6.1 Conclusions

Construction projects are, by nature, difficult to control because of their dynamic and complex environment, resulting in frequent changes, delays, and cost overruns. The ability to assess the impact of site events on construction projects is vital in the preparation and settlement of claims. None of the commonly recognized methods of delay analysis, including windows delay analysis and but-for method, is able to assess the impact of resource allocation on delay analysis. In addition, the effects of actions taken by the contractor to accelerate the project and minimize potential delays are usually ignored in delay analysis. Since it is approved by professionals and courts, traditional windows analysis is used as the theoretical basis of this approach, which introduces improvements to the daily windows analysis method. The resulting modified daily windows analysis takes into consideration the effects on delay analysis of multiple baselines and resource allocation. It recognizes any resource over-allocation due to delays and apportions the responsibility for associated delays that result from resource rescheduling.

Using a window size of one day and a legible representation of the progress information, a computerized schedule analysis model has been introduced. This model takes into consideration multiple baseline updates and accurately apportions delays and accelerations among the project parties. The modified daily windows approach has been validated on a small case study.

The proposed delay analysis technique is unique in its consideration of the following aspects of construction projects:

- The project schedule is updated each day, including all the delays and changes in total floats until the as-built schedule is reached.
- The baseline is updated whenever the logical relationships between the activities and/or the activities' durations are changed.
- When a new baseline is entered, the new baseline duration is calculated and compared with the previous duration. The difference is credited to the party responsible for delay or acceleration.
- The type of delay and the corresponding responsibility, including concurrent delays, are identified.
- The responsibility for delays, slowdowns, and accelerations is identified and assigned.
- Any changes in the resource allocation because of delays or slowdowns are identified.
- The project is rescheduled to meet the resource limits, and the duration of the new schedule is compared with the previous one. Any additional delays are allocated to the party responsible.
- While the model becomes most accurate if progress data is entered daily, the model is still usable even at the end of the project. It is possible to

create the as-built schedule simply using the activities' start and finish dates and the dates of the unusual site events. In this case, daily percentages can be easily calculated and any delays recorded in their dates.

6.2 Future Research and Developments

This research could be used as an avenue for other researchers to conduct additional studies of construction delay analysis. Several aspects of the proposed delay analysis model could be improved, including the following:

1. The resource allocation algorithm applied in this model reschedules the project using the best five rules available for resource allocation, which are the earliest latest-start, shortest duration, longest duration, smallest ID, and Longest ID rules. It then selects the best schedule from the resulting five schedules. However, in some cases, using these rules may not produce the optimum schedule. This algorithm could be improved so that it produces the optimum schedule that meets the project deadline and satisfies the resource limits with the least cost.
2. The resource allocation algorithm moves only the activities that did not start before or at the day of rescheduling and it deals with the activity duration as one block of activity, so it delays only the start of the activity. Splitting each activity into a number of blocks that equal the activity's total duration (i.e., an activity with a duration of three days can be split into three blocks) may produce better schedules since the algorithm will be

able to move each part of the activity while it is searching for the optimum schedule.

3. The resource allocation process implemented within the proposed model is based on a maximum of three key resources. This limitation could be improved through the consideration of all the resources required for the project.
4. The scheduling process used in the proposed model is based only on FS (Finish to Start) relationships. Although SS (Start to Start), FF (Finish to Finish), and SF (Start to Finish) relationships can be indirectly represented by the FS (Finish to Start) relationship, it could be possible to allow the user to directly specify all the relationships in the model in order to improve efficiency and usability.
5. The application of the proposed model to real life projects is necessary in order to examine whether courts and boards would accept the use of this model and to validate the approaches developed in this research.
6. The proposed model has been incorporated into EasyPlan, which has been developed using the VBA language of Microsoft Excel software. It could be possible to develop some of the suggested approaches on commercial scheduling software such as Microsoft Project software, in order to facilitate construction delay analysis. More advanced programming languages could also be used to develop the proposed model.

7. The proposed model was developed to identify schedule delays and accelerations and to apportion them among the parties responsible. It could be possible to link the proposed model to commercial estimating software in order to determine the relevant cost of these delays and accelerations.

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