Improved Schedule Analysis Considering Rework Impact and Optimum Delay Mitigation

by

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AUTHOR'S DECLARATION

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.

I understand that my thesis may be made electronically available to the public.

Mohamed Said

ABSTRACT

Rework has been a primary cause of cost and schedule overruns in the construction of heavy industrial projects such as those related to oil and gas. It has been reported that the direct cost of rework is about 5% of total construction costs. Several research studies have analyzed the causes and effects of rework in construction projects, but almost no research exists to support decisions with respect of an effective strategy for mitigating the effects of rework on the cost and schedule of the project. This research introduces a new schedule analysis mechanism that considers the impact of rework on project delays and then optimises corrective actions for mitigating those delays. The proposed mechanism considers rework from three perspectives: (1) a schedule representation of the magnitude of rework as a negative percentage completed with respect to the activities affected, as documented on a specific schedule date, (2) a day-by-day delay analysis for quantifying and apportioning project delays among the parties responsible, and (3) an optimization mechanism for determining the best mitigation strategy for recovering rework at a minimum additional cost. The proposed mechanism can represent and mitigate rework caused by both the Owner and the Contractor. The proposed schedule analysis mechanism has been applied to a case study in order to demonstrate its usefulness and applicability. The resulting mechanism offers a quantitative approach to the consideration of rework in delay analysis and the optimization of corrective action, which are important aspects of effective project control.

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Above all, praise is to God.

To My Parents

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CHAPTER 1
INTRODUCTION

1.1 Construction Rework

Construction projects all over the world involve many challenges, particularly for large industrial oil and gas projects. These challenges affect the delivery of projects within specified deadlines and the estimated budget. Most oil and gas projects involve multiple contractors, suppliers, and trades that interact with one another and can thus affect progress in other areas. In such a complex environment, in which hundreds of activities take place simultaneously, errors, omissions, and misunderstandings often cause undesirable outcomes that must be reworked. Several research studies, therefore, have focused on the major role that rework plays in cost and schedule overruns, particularly for large industrial projects. According to the Construction Industry Institute (CII), the cost of rework is estimated to be about 5 % of the total value of construction contracts (CII, 2005). Another study conducted by the Construction Industry Development Agency in Australia (CIDA) estimates the direct cost of rework to be 10 % or higher (Love and Li, 2000). In a study by Love (2002a), it was reported that rework is one of the significant factors contributing to construction delays. Burati et al. (1992) also showed that quality problems, including rework, are responsible for more than a 12 % deviation from the value of the contract. Hammarlund and Josephson (1991) also found such defects to be 6 % of the production cost.

In the literature, the term “rework” has been used interchangeably with other terms such as “quality deviations,” “non-conformance,” “defects,” and “quality failures.” All of these terms indicate that a specific activity or task must be redone or reworked. As well, several definitions of rework appear in the literature. Ashford (1992) defines rework as “the process by which an item is made to conform to the original requirement by completion or correction.” CIDA’s definition of rework is “doing something at least one extra time due to non-conformance to requirements” (CIDA 1995). Another realistic definition of rework was adopted by Love et al. (2000): “the unnecessary effort of redoing a process or activity that was incorrectly implemented the first time.” As distinguished from general rework, field rework has been defined as “activities in the field that have to be done more than once in the field or activities which remove work previously installed as part of the project” (Rogge et al 2001). A more detailed definition of field rework has been adopted by the Construction Owners Association of Alberta (COAA, 2001), which defines field rework as “the total direct cost of redoing work in the field regardless of initiating cause.” COAA also clarifies that field rework does not constitute change orders (for new work), off-site fabricator errors, or off-site modular fabrication errors (Fayek et al. 2004).

Since rework is the act of performing a task more than once, it can occur at different stages throughout the project life cycle. Rework can therefore occur during the design phase or the project execution phase. The Building Research Establishment in the UK (BRE, 1981) found that 50 % of the origin of errors in buildings occurred during the design stage and 40 % during the construction stage. Cnuddle (1991) reported the cost of non-conformance to be between 10 % and 20 % of the total project cost. It was also found that 46 % of total deviation costs were created during the design phase, compared with 22 % during construction. In a comprehensive study of field rework, Fayek et al. (2003) reported the major causes as “engineering and reviews,” (55.4 %), followed by “equipment and material” (23.5 %), while human error was found to contribute only 18.3 %.

As indicated by the above research, rework clearly has a huge impact whether projects can be completed within time and cost constraints. Rework also has a large general impact on the industry as a whole. In addition to recognizing the impact of rework and its causes, which have been extensively reported in the literature, it is important that project managers have adequate tools not only to analyze the time and cost implications of rework but also to generate practical plans for corrective action that is cost effective and that can mitigate the impact of rework on the time and cost of a project. The literature contains few studies that have proposed such tools for the construction industry, which is therefore the objective of this research.

1.2 Research Motivation

Rework has been a primary cause of cost and schedule overruns in construction, particularly for heavy industrial projects such as those needed to oil and gas. Because oil and gas represents a multi-billion dollar industry, a small percentage of rework means huge loss in investments and/or revenues. Even a minor reduction in the cost associated with rework can translate into substantial benefit for individual projects and for the industry as a whole. For this important topic, the research motivation can be summarized as follows:

- The Contribution of rework to major increase in project time and cost overruns.

  As mentioned previously, several studies such as CII (2004), have reported that the direct costs of rework is about 5 % of total construction costs. In most cases, the impact of rework extends beyond its direct costs. A delay in production, for example, means not only large losses in revenue but also apply penalties, and a detrimental effect on reputation.

- The absence of a dynamic method of measuring the effect of rework on the project schedule.

  No quantitative studies have been conducted with respect to analyzing the impact of rework on a schedule. The existing literature on the causes has emphasized the importance of such analysis (Hwang et al., 2009)

- The lack of detailed analysis and mitigation decision support

  Almost no research exists that analyzes the responsibility for rework-related delays and supports decisions with respect to an effective strategy for mitigating the effects of rework on the cost and schedule of the project.

1.3 Research Scope and Objectives

This research introduces a new schedule analysis mechanism that considers the impact of rework on project delays and optimises corrective actions for mitigating those delays. The detailed research objectives are as follows:

1. Introduce a new schedule representation of the magnitude of rework as a negative percentage completed with respect to the activities affected, as documented on a specific date in the schedule.

2. Develop a modified daily windows delay analysis in order to quantify and apportion among the responsible parties project delays that are caused by rework and other progress events.

3. Examine a variety of project acceleration strategies and use an optimization mechanism in order to determine the best acceleration strategy that recovers rework at a minimum additional cost.

The proposed mechanism can represent and mitigate the rework caused by both the Owner and the Contractor. The resulting mechanism can therefore be used as a tool for optimum project control and also as a delay analysis tool.

1.4 Research Methodology

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

- Conduct a comprehensive literature review of the causes and impact of rework.
- Study existing strategies for recovering project delays through acceleration.
- Study existing schedule analysis techniques that can quantify the time and cost implications of rework-associated delays.
- Introduce a new method of representing rework on the schedule.
- Develop an analysis procedure for calculating the impact of rework o time and cost, as well as the impact of the acceleration strategies needed in order to recover delays.
- Design and develop an optimization mechanism for determining the least costly acceleration strategy that recovers the impact of the rework.
- Design and implement a modified schedule analysis approach that reads the as-built data and apportion rework-related delays among the parties who caused the rework.
- Present a case study for a computer prototype in order to validate the results of the method developed.

1.5 Organization of the Thesis

The thesis consists of 5 additional chapters. Chapter 2 is a literature review of the studies related to rework and its cause and effects in the construction industry. Chapter

2 also includes a review of schedule analysis techniques, which are important for mitigating the effect of rework.

Chapter 3 begins with a brief description of the representation of a schedule in existing commercial software. The chapter then introduces a new representation of the amount and timing of rework and responsibility for it. Next, the application of the new representations to specific cases is described in order to illustrate the effects of rework.

In Chapter 4, the investigation of a number of acceleration and mitigation strategies in the construction industry is presented. These strategies are used later in the research as a method of overcoming the effects of rework. The chapter includes a description of the modified daily window analysis that has been developed in order to accommodate the new rework representation for single and multiple-activity occurrences. The development of a detailed schedule analysis procedure for considering rework events with respect to the project schedule is explained, and its application in a case study is described.

In Chapter 5, the implementation of the proposed analysis mechanism in a prototype computer program is introduced. The chapter includes a description of the demonstration of the prototype using a small industrial case study in order to determine the practicality of the new representation and the ability of the schedule optimization mechanism to determine the least costly acceleration strategy for mitigating the impact of rework on the project schedule.

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

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

Construction projects involve many challenges that jeopardize the cost, schedule and contractual obligations associated with the project. One main source of these challenges is rework. This chapter, therefore, provides a review of the available construction literature concerning rework and examines previous research regarding its root causes, its impact on project performance and indexes for categorizing it. The chapter then presents the available research with respect to progress recording and delay analysis techniques used in the construction industry, with the goal of helping to quantify the impact of rework.

2.2 Research on Construction Rework

Rework is a serious problem in large construction projects, particularly industrial projects that involve multiple contractors, suppliers, and trades. In such a complex environment in which many activities take place simultaneously, errors, omissions, and misunderstandings often cause undesirable outcomes that must be reworked. Rework has therefore been defined as the effort of redoing a process or activity that was incorrectly implemented the first time (Love, 2000). In the literature, the term “rework” has been related to other terms such as “quality deviations” (Burati et al., 1992), “non-conformance” (Ashford, 1992; Abdul-Rahman, 1995), “defects” (Josephson and Hammarlund, 1999), and “quality failures” (Barber et al., 2000). Since rework can occur at different stages throughout the project life cycle, the term “field rework” has been defined by the Construction Owners Association of Alberta (COAA, 2001) as not incorporating change orders or off-site fabrication errors.

A number of researchers have studied rework from different perspectives: its root causes, its impact on project performance, and its categorization using a verity of indexes. Details of each of these three research areas are highlighted in the following subsections.

2.2.1 Root Causes of Rework

Several researchers have extensively studied the causes and effects of rework (Love and Smith, 2003; O’Conner and Tucker, 1986; CII, 1989; Davis et al., 1989; Burati et al., 1992; Love et al., 1999a, b; Love, 2002b; Fayek et al., 2003; Love and Sohale, 2003; Love and Edwards, 2004; Ruwanpura et al., 2003; Hwang et al., 2009). Almost all studies have reported that rework plays a major role in cost and schedule overruns. They have, therefore, identified the main root causes of rework as errors, omissions, failures, damage, poor leadership, poor communication, and ineffective decision-making.

Almost all studies have emphasized the fact that more rework originates in the design stage than in the construction stage. The Building Research Establishment in the UK (BRE, 1981), for example, found that 50 % of the origin of errors in buildings occurred in the design stage and 40 % during the construction stage. Burroughs (1993) reported that a major Australian Contractor had experienced rework costs amounting to 5 % of the contract value in one of its major projects and that these costs were attributable to poor documentation by design consultants. Since many causes of rework originate during the design phase, effective design management has been reported as a key factor in reducing rework (Love and Smith, 2003).

Since rework has been defined as a form of quality deviation, research with respect to quality problems, such as the survey conducted by the National Economic Development Office (NEDO, 1987), has reported that the main factors affecting the quality of building projects are related to design. These design factors (affecting 46 % of total deviation costs) include lack of coordination of the design as well as unclear and missing documentation. In addition to design-related factors, quality is also affected by poor workmanship (contributing to about 22 % of construction deviations). This research confirms the findings of earlier studies on quality, such as Cusack (1992) who suggested that projects without a quality system typically require rework that results in a 10 % increase in the cost.

One interesting study by Burati et al. (1992) involving nine industrial construction projects, identified the causes of rework in the form of a list of deviation categories that are result in rework, as summarized in Table 2.1.

Table 2.1: Categorise of Deviation that Causes Rework (based Burati et al., 1992)

Deviation Category	Description
Construction Change	Change in the method of construction
Construction Error	Results of erroneous construction methods
Construction Omissions	Omission of some construction activity or task
Design Error	Error during design
Design Omission	Omission made during design
Design Change/Construction	Changes in design at the request of field/construction personnel
Design Change/ Field	Changes by the designer due to unforeseen field conditions
Design change/Owner	Design change initiated by Owner (Scope definition)
Design Change/Process	Design change in the process, initiated by Owner/designer
Design Change/Fabrication	Design change initiated or requested by fabricator or supplier
Design change/Improvement	Design revisions, modifications, and improvements
Design Change/ Unknown	Redesign due to an error
Operability Change	Change to improve operability
Fabrication Change	Change during fabrication
Fabrication Error	Error during fabrication
Fabrication Omission	Omission during fabrication
Transportation Change	Change to the method of transportation
Transportation Error	Error in the method of transportation
Transportation Omission	Omission in the transportation

In other research (e.g., Ruwanpura et al., 2003; COAA, 2001; Fayek et al., 2003) the root causes of rework have been represented in a fishbone diagram, showing all the potential or actual causes of rework. The fishbone diagram (Fig. 2.1) consists of five basic sources of rework, with four possible sub-sources in each of the basic sources.

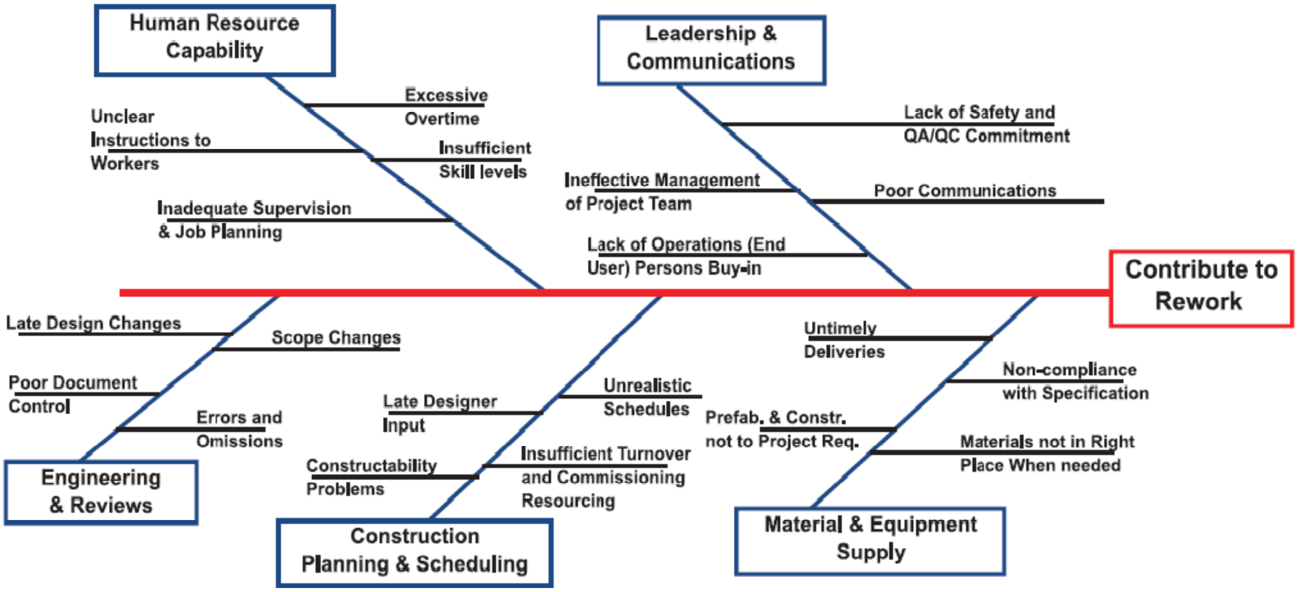


Fig. 2.1: Fishbone Classification Model of the Causes Of Rework (Fayek et al., 2003)

Based on the outcome of a pilot study of rework in a mega industrial project in Alberta (Fayek et al., 2004), the major causes of field rework were identified, as shown in Table 2.2. The study used two criteria to compare the contribution of a variety of causes of rework: the frequency of the occurrence and the monetary value of rework-related cost increase. Fig. 2.2 shows that the classification of the root causes based on frequency of occurrence is very similar to that based on monetary value.

Table 2.2: Causes of Rework (based on Fayek et al., 2004)

	Classification based on:	
Root Cause	**Freq. of Occurrence (%)**	**Monetary Value (%)**
Engineering and Reviews	55.4	61.7
Human Resources Capability	18.3	20.7
Material and Equipment Supply	23.5	14.8
Planning and Scheduling	2.5	2.1
Leadership & communication	0.4	0.5

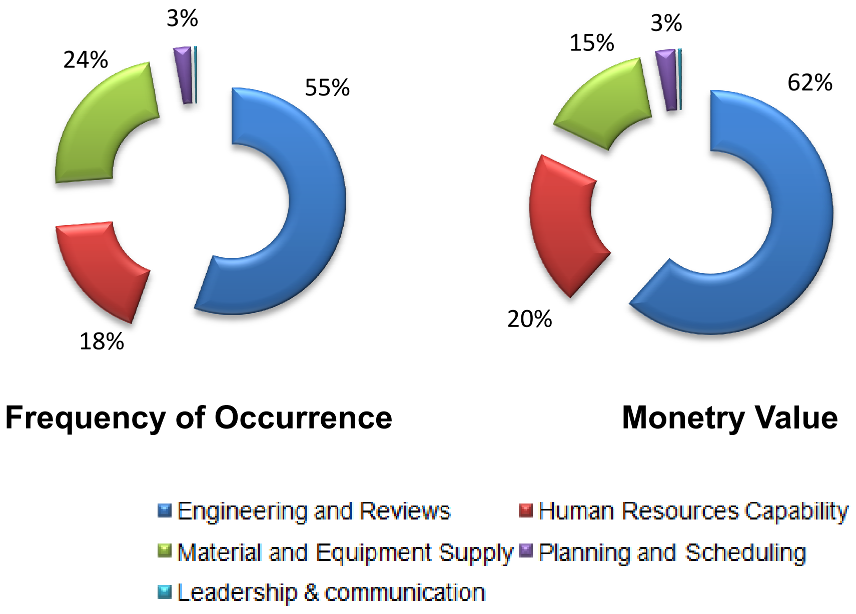


Fig. 2.2: Classification of rework causes (based on Fayek et al. 2004)

An interesting study by Love et al. (1999) compared the causes and effects of rework experienced in many countries around the world. The study concluded that the variability in the cost of rework in different countries "… should not be considered to be authoritative, but merely indicative, as levels and interpretations of quality will differ …… Local practices, industry culture, and contractual agreements may also have a significant influence on the incidence and cost of rework in any situation and locality." Another interesting study by Love et al. (2003) grouped the causes of rework into categories based on the initiator of the cause. The ranked causes within each category are shown in Table 2.3

Table 2.3: Rework Cost Categories Causes (based on Love et al. 2003)

Category	Rank	Cause
Design Causes	1	Changes made at the request of client
	2	Errors made in contract documentation
	3	Omission of items from contract documentation
	4	Changes initiated by end-user/regulatory bodies
	5	Changes made at the request of the contractor during construction
	6	Modifications of the design initiated by the contractor or subcontractor
Construction Causes	1	Changes initiated by client after some work had been undertaken on site
	2	Changes initiated by client or occupier after some work had been completed
	3	Changes in construction methods due to site conditions
	4	Changes in method of construction to improve constructability
	5	Errors due to inappropriate construction methods
	6	Damage caused by subcontractor
	7	Omissions of some activity or task
	8	Changes initiated by contractor to improve quality
	9	Changes made during manufacture of product
Client Cause	1	Lack of experience and knowledge of design and construction process
	2	Payment of low fees for preparing contract documentation
	3	Poor communication with design consultants
	4	Inadequate time and money spent on briefing process
	5	Lack of funding allocated for site investigations
	6	Lack of client involvement
Design Team Cause	1	Ineffective use of information technologies
	2	Staff turnover/allocation to other projects
	3	Incomplete design at time of tender
	4	Insufficient time to prepare contract documentation
	5	Poor coordination between design team members
	6	Poor planning of workload
	7	Ineffective use of quality management practices
	8	Time boxing
	9	Lack of manpower to complete required tasks
	10	Inadequate client brief to prepare detailed contract documentation
Site Management Cause	1	Poor planning and coordination of resources
	2	Ineffective use of quality management practices
	3	Setting-out errors
	4	Ineffective use of information technologies
	5	Staff turnover/allocation to other projects
	6	Failure to provide protection for constructed work
Subcontractor Cause	1	Ineffective use of quality management practices
	2	Inadequate managerial and supervisory skills
	3	Damage to other trades due to carelessness
	4	Low labour skill level
	5	Use of poor quality materials

In Australia, Love et al. (2004) found that the primary factors that contribute to construction rework were as shown in Fig. 2.3. Based on several studies of rework, Love et al. (2004), also, concluded that to reduce rework in projects, attention should be given to a number of design and production management strategies, as shown in Fig. 2.4. According to that study, these strategies are perceived to be relatively straightforward and do not require significant changes in current practices.

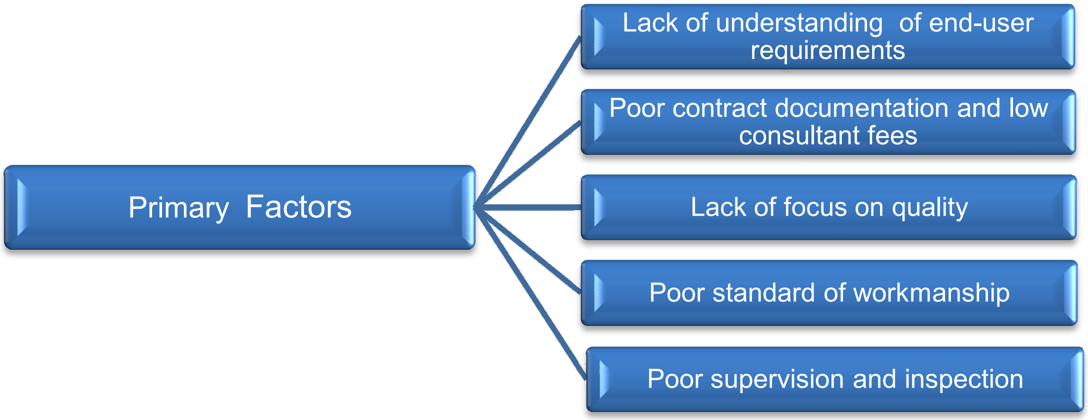


Fig. 2.3: Primary Rework Factors (based on Love et al. 2004)

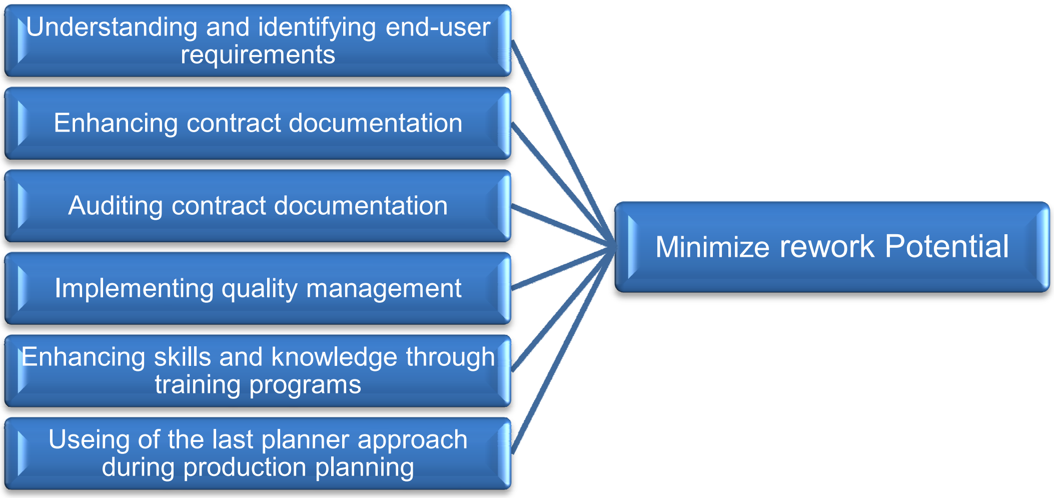


Fig. 2.4: Rework control criteria (based on Love et al. 2004)

2.2.2 Impact of Rework on Project Performance

Several studies in literature have focused on analysing the impact of rework on construction projects and on the whole construction industry. Josephson and Hammarlund (1999) reported that the cost of rework in residential, industrial, and commercial building projects ranged from 2 % to 6 % of their contract values. Similarly, Love and Li (2000), in their study of rework costs for a residential and an industrial building, found the cost of rework to be 3.15 % and 2.40 % of the contract value, respectively. In addition, Love and Li (2000) found that when a Contractor implemented a quality assurance system in conjunction with an effective continuous improvement strategy, rework costs were found to be less than 1 % of the contract value.

Two key research studies have indicated the cost of quality deviations in civil and heavy industrial engineering projects. First, the study by Burati et al. (1992) of nine major engineering projects indicated that, for all nine projects, quality deviations accounted for an average of 12.4 % of the contract value. A significantly lower figure was reported by Abdul-Rahman (1995), who found the non-conformance costs (excluding material wastage and head office overheads) of a highway project to be 5 % of the contract value. Abdul-Rahman (1995) pointed out that non-conformance costs may be significantly higher for projects characterized by poor quality management.

In a recent study undertaken with the goal of identifying the influence of the type of project and procurement methods on the cost of rework for building construction projects, Love (2002) obtained direct and indirect rework costs from 161 Australian construction projects via a questionnaire. He found that rework contributed to 52 % of the cost growth of a project, and that 26 % of the variance in cost growth was attributable to changes due to direct rework. A summary of the rework costs reported in the literature is shown in Fig. 2.5.

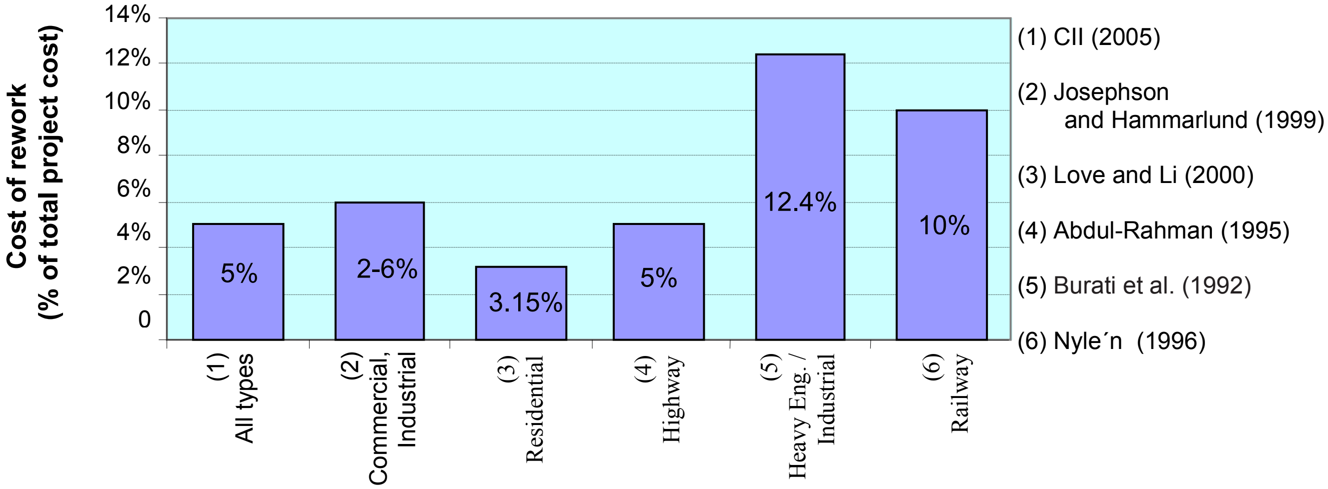


Fig. 2.5: Cost Impacts of Rework Reported In the Literature

Studies were conducted in different parts of the world to show the effect of rework on project cost as well as the causes that led to the rework. Examples of such studies are summarised by regional classification in Table 2.4.

With many studies analysing rework-related cost performance, Hwang (2009) recommended conducting further studies on rework impact on schedule performance. Among the various project types, they found that industrial projects exercise most cost increase due to rework.

Table 2.4: Research Related to Rework (based on Love and Edwards 2004)

Region	Study	cause of Rework	cost of Rework
Australia	Cusack (1992)	Documentation errors	10 % cost increase
	Burroughs (1993)	Poor documentation produced by design consultants	5 % of contract value
	Gardiner (1994)	Design consultant errors	20 % of consultant fee
	CIDA (1995)	Poor communication Traditional lump sum procurement Lack of a formal quality management	15 % of a project's contract value
Singapore	CIDB (1989)	Rectifying errors	5 % and 10% of the project costs
Sweden	Hammarlund et al. (1990)	Quality failures	20 % of the quality failures registered
	Josephson and hammarlund (1999)	Defects	2.3 % to 9.3 % of the production cost
	Nylén (1996)	Quality failures due to the client and consultants during the design process	10 % of project's production cost
UK	Abdul-rahman (1993)	Non-conformances	2.5 % of contract value
	Barber et al. (2000)	Quality failure	6 % and 23 % of contract value
USA	Bowersox et al. (1985)	A poor quality product	Eight times original cost
	Farrington (1987)	Cost of rework (including re-designs)	12.4 % of total project cost
	Willis and willis (1996)	Cost of failure and deviation correction	12 % of labour expenses for design & const.

2.2.3 Rework Indexes

To help provide early warning of field rework, four rework indexes shown in Table 2.5 are currently used to provide general suggestions to help reduce rework. While these indexes are useful, no mechanism exists for incorporating rework in current scheduling and project control tools to enable the assessment of the impact of rework, the allocation of responsibility for delays, or the devising of cost-effective mitigation action.

Table 2.5: Summary of Rework Indexes

Index	Developer	Use
Field Rework Index (FRI) (Rogge et al., 2001)	Construction Industry Institute (CII)	• Provides early warning against high levels of field rework.
Project Definition Rating Index (PDRI) (Gibson and Dumont 1996)	Construction Industry Institute (CII)	• Measures the degree of scope development. • Analyzes the scope definition package and predicts factors that may impact project risk. • Monitors progress at various stages during the pre-project planning phase. • Aids in communication between the owner and the designers/contractors by highlighting poorly defined areas.
Project Rework Reduction Tool (PRRT) (East 2002).	Construction Owners Association of Alberta (COAA)	• Software that rates project performance against known rework-causes. • Carries out project “health checks” by making evaluations, rating key field rework-causing factors, and suggesting solutions for improve the rating as the project proceeds. • The questions and responses to a questionnaire are weighted to calculate a periodic rating and to further allow analysis by overall project or by principal cause of rework.
Quality Performance Management System (QPMS) (Rogge et al. 2001).	Construction Industry Institute (CII)	• Identifies quality improvement opportunities and tracks rework. • Tracks the cost of quality and provides a cost breakdown identifying the cost of rework by its primary cause.

2.3 Recording and Analysis of Construction Progress

Various progress events, including rework, can have a significant impact on the project schedule in the form of stoppages and delays. Therefore, precise recording of site events and accurate analysis of delays are vital for enabling the project management team to solve any conflicts and to enhance project performance. In the next subsections, research related to progress recording and schedule analysis is discussed in order to account for rework and its impact and to provide a basis for the discussion of improvements in this area in subsequent chapters.

2.3.1 Recording Site Events

Daily recording of the actions performed by all parties on a construction site is necessary for effective delay analysis. Site events involve a large amount of data related to weather, staffing, use of resource, work accomplished, work stoppage, accidents, delivery of materials, and change orders. This information is recorded using a variety of media such as daily site diaries, notes from progress meetings, daily weather records, photographs, and weekly progress reports. When analysis is required a search through all of these records is therefore very time consuming. In practice, this process usually takes place after construction and only in the case of a conflict or a dispute.

An important schedule analysis tool is delay analyses, which requires progress-related data, such as start and finish times, work completed, resources used, idle times, and work disruption periods. For a 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 that planned. Acceleration, on the other hand, means that more work is produced than was planned, and it should be defined as either 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 of progress reporting. In his bar chart (Fig. 2.6), 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

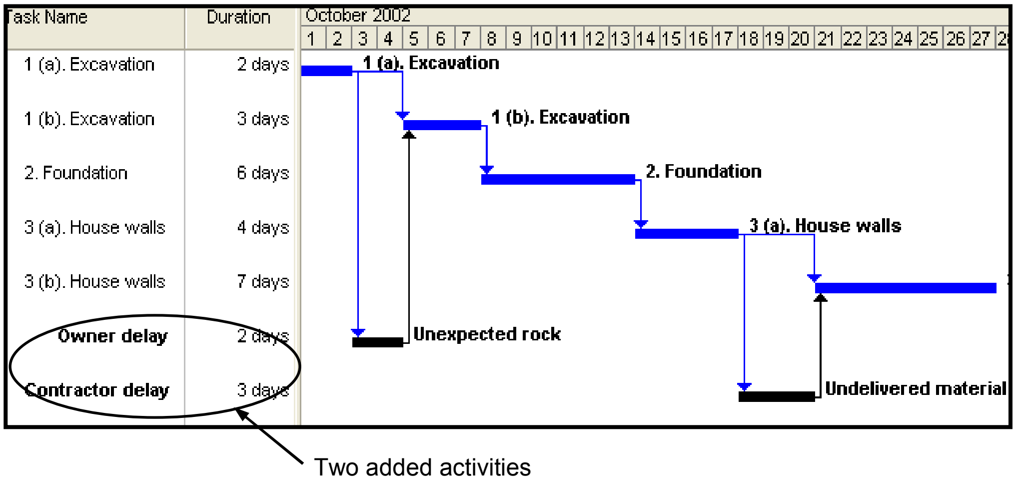
R - Activity not working half day due to weather

Code	Activity Description	June 90														
			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. 2.6: Recording Site Data in a Bar Chart (based on Scott 1990)

Stumpf (2000) presented an approach that manipulates existing software in order to facilitate the analysis. His approach simulates each delay by adding a separate activity with duration equal to the delay period, as shown in Fig. 2.7. For example, the activity "Excavation" in Fig. 2.7 involved 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 by 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.



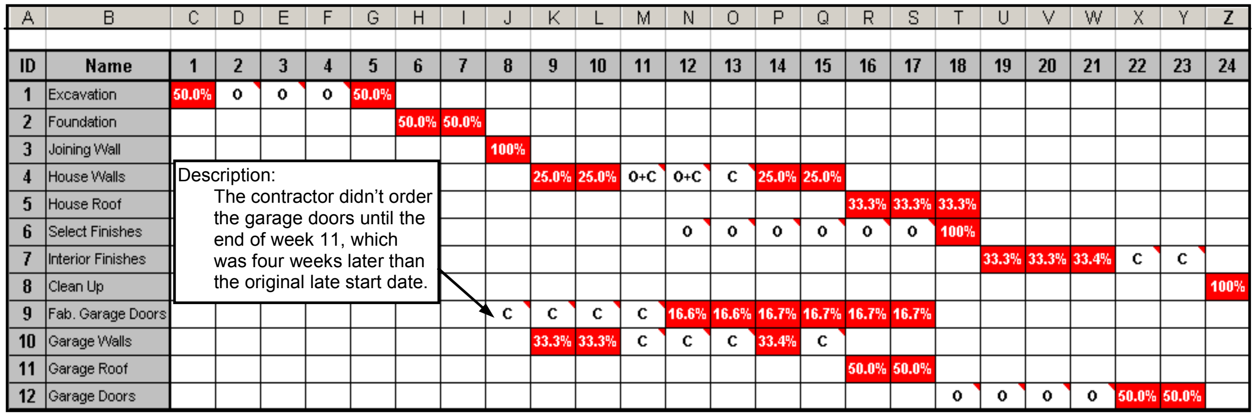
Task Name	Duration
1 (a). Excavation	2 days
1 (b). Excavation	3 days
2. Foundation	6 days
3 (a). House walls	4 days
3 (b). House walls	7 days
Owner delay	2 days
Contractor delay	3 days

Two added activities
for the delays

Fig. 2.7: Representing Delays on 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 for each activity, which can be calculated from the start and finish dates, and then comparing it to the planned percentage. Slow progress can then be identified when actual progress results in lower productivity than planned; acceleration, when work results in higher productivity than planned; and suspension, when work is completely stopped. They then presented a bar chart made of spreadsheet cells, each representing one day or one week, or any unit of time. 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 for each activity, the delays, the party responsible for each delay, and any other related data.

Delays are recorded on the bar chart on the day they occur. As shown in Fig. 2.8, 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 the Contractor, e.g., the weather, an “N” is shown. If concurrent delays occur, 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%	

Description:
The contractor didn’t order the garage doors until the end of week 11, which was four weeks later than the original late start date.

Fig. 2.8: Recording Site Data Using an Intelligent Bar Chart
(based on Hegazy et al., 2005)

One of key benefits of this representation is the clear manner in which the complete evolution of the schedule and all the actions of all parties are shown. This system facilitates accurate calculation of responsibility for project delays with less disagreement among the parties involved in the project. This representation can therefore be a good basis for improvements that can enhance the representation of rework on the schedule.

2.3.2 Schedule Analysis Techniques

Delay analysis, or more generally, schedule 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 apportion project delays among the parties responsible (Holloway, 2002). Several delay analysis methods are available; the selection of the proper method depends on a variety of factors, including the value of the dispute, the records available, and the time available for the analysis. The four traditional methods often mentioned in the literature are described briefly below, and the latest developments in the Daily Windows Analysis, which is used in this research, are discussed in a separate subsection.

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 researchers do not recommend this method because it simply determines the net impact of all delay events as a whole rather than examining each individual delay event separately.

The Impacted As-Planned Method (what-if approach): The impacted as-planned method adopts the as-planned schedule as a 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 be 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.

The Collapsed As-Built Method (but-for method): The collapsed as-built method is used by 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 (i.e., delays because of the Owner) is the difference between the as-built schedule and the but-for schedule. The collapsed as-built method is a very practical approach that 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 effort than detailed event-by-event 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.
- The dynamic nature of the project’s critical paths is not considered.
- It is highly subjective, and the results are different when the analysis is conducted from the Owner’s versus Contractor’s point-of-view.

Based on these points, using the collapsed as-built analysis is resonable when the time and resources available for detailed analysis are limited, but it should be used with an awareness of its limitations and weaknesses.

The Contemporaneous Period Analysis Method (window analysis): This method breaks the construction period into discrete time increments and examines the effects of 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 updated at the end of each planned time period. Ideally, the windows method can be followed during the course of construction and is distinguishable from the but-for method because it incorporates delays attributable to both parties into the analysis and because the dynamic nature of the project's critical paths is taken into consideration. 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 researchers agree that windows analysis yields the most reliable results. Despite its advantages, windows analysis requires significant time and effort. Since it is based on a large amount of information, and the schedule needs to be updated periodically, this method may not be appropriate for projects that lack strict administrative procedures and schedules updates. Arditi and Pattanakitchamroon (2006) presented the views of some of the researchers and practitioners who wrote about delay analysis methods from 1990 to 2004. The comments of a sample of these researchers and practitioners with respect to windows analysis are summarized in Table 2.6.

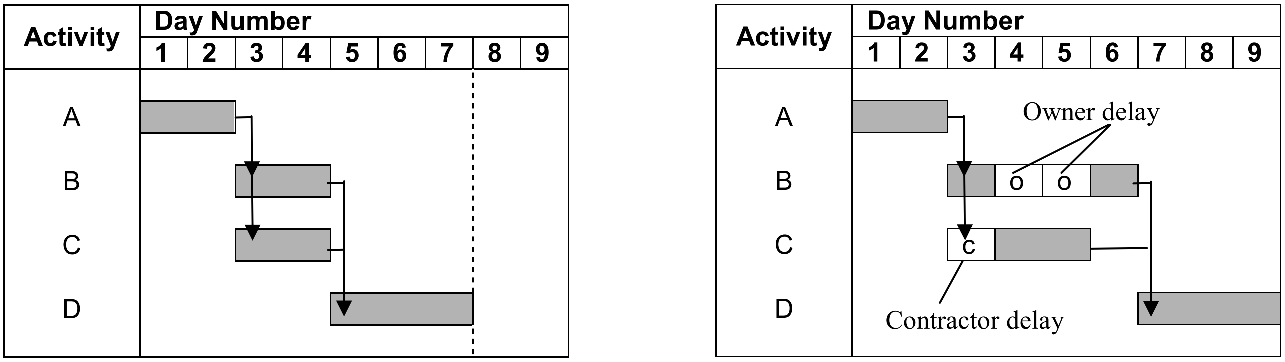
Table 2.6: Comments on the Windows Delay Analysis
(Based on Arditi and Pattanakitchamroon 2006)

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

2.3.3 Latest Development: Daily Windows Analysis

Zhang (2003) introduced changes to the traditional windows analysis method in order to address some of its drawbacks. A window size of one day was used to precisely analyze and capture any changes that might affect the critical path(s). The simple example reported in Hegazy and Zhang (2005), shown in Fig. 2.9, was used to demonstrate this daily windows analysis. The relationships show that activities B and C both follow activity A. Activities B and C are then followed by activity D. The as-planned duration is 7 days, while the as-built duration is 9 days, which indicates 2 days of project delay. As shown on the as-built schedule, activity B was stopped for 2 days due to

Owner caused events, while activity C experienced one day of work stoppage due to the Contractor. The key question now is how to apportion the project delay between the 2 parties.



(a) As-Planned Bar Chart **(b) As-Built Bar Chart**

Fig. 2.9: Bar Charts for a Small Example of Windows Analysis

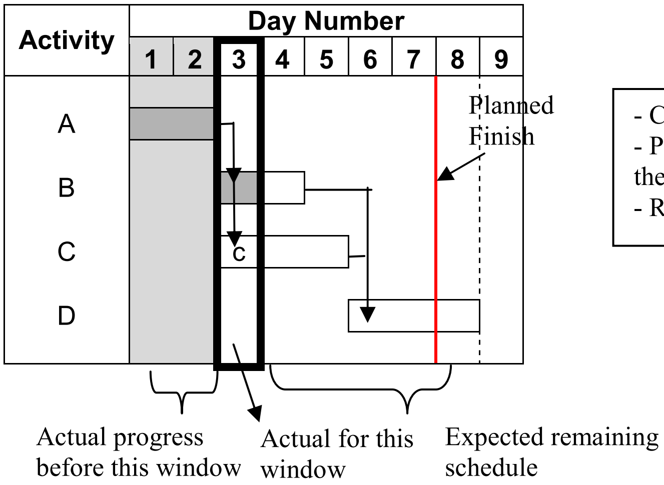
Using the traditional windows analysis with a traditional window size equal to the full duration of the project (9 days), the final critical path is A-B-D, and the project delay would therefore be attributed to the Owner alone since the 2 Owner delays (o) occurred on the final critical path.

Applying daily window method can provide a more accurate result. First, all progress events are removed from the as-built schedule shown in Fig 2.9, so that the process begins with the as-planned schedule. The events of each day are then entered and their impact analysed. 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 that progress is stopped in each case.

Following the daily windows process in this example yields 9 daily windows which can be analyzed as follows:

Days 1 and 2: The project did not experience any delays, so the project duration remains 7 days.

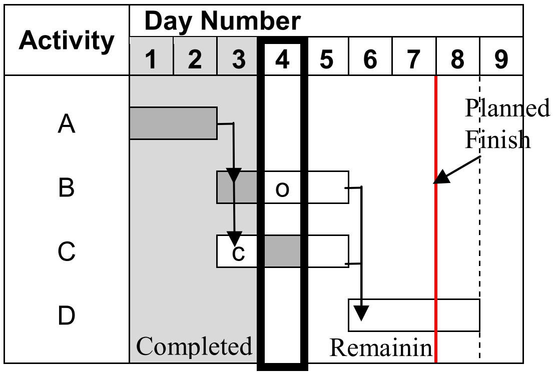
Day 3 (Fig. 2.10): The critical path A-C-D exhibits a one-day Contractor delay (c), which extends the project duration to 8 days. an Examination of the critical path A-C-D reveals that this one-day project delay was caused by the Contractor's (c) event, so, a one-day delay is apportioned to the Contractor.



- Critical path: A-C-D
- Project delay as compared to the previous window = 1 day
- Responsibility = 1 Contractor

Fig. 2.10: Daily Windows Analysis Showing the Window for Day 3

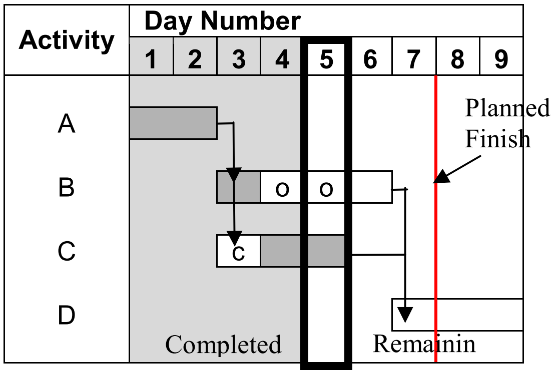
Day 4 (Fig. 2.11): The window for the fourth day shows a one-day Owner delay on path A-B-D, but the project duration remains 8 days because no changes affected the critical path shown for the previous day.



- Critical paths: A-C-D & A-B-D
- Project delay as compared to previous window = 0
- Responsibility = none

Fig. 2.11: Daily Windows Analysis Showing the Window for Day 4

Day 5 (Fig. 2.12): The project is delayed by one day due to the Owner's delay on critical path A-B-D, thus extending the project duration to 9 days and apportioning a one-day delay to the Owner.



- Critical path: A-B-D
- Project delay as compared to the previous window = 1 day
- Responsibility = 1 Owner

Fig. 2.12: Daily Windows Analysis Showing the Window for Day 5

Days 6 to End: Progress continues as planned, and no additional delays occur. The final result of the daily window analysis is that 2 days of project delays are attributed 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), which could be overlooked using the traditional windows analysis. However, the daily windows analysis still needs improvement because it does not take into consideration other factors such as rework events.

2.4 Conclusion

As demonstrated in many studies, rework clearly has a huge impact on the completion of projects on time and within cost constraints. Rework has been reported as a main contributor to cost and schedule overruns and is the cause of more than 10 % of the contract price, which represents a very large amount in heavy construction areas such as oil and gas projects. A number of researchers have studied rework from a variety of perspectives: root causes, the impact on project performance, and the categorization of rework using several indexes. While these studies are useful, no mechanism yet exists for incorporating rework into current scheduling and project control tools to enable the assessment of the impact of rework, the allocation of responsibility for the delays, and the determination of cost-effective mitigation actions.

In addition to recognizing the causes and impacts of rework, which have been reported extensively in the literature, it is also important that project managers have adequate tools not only for analyzing the time and cost implications of rework but also for generating practical and cost-effective corrective action plans. The literature reported little or no effort devoted to proposing such tools for the construction industry, which is the objective of this research.

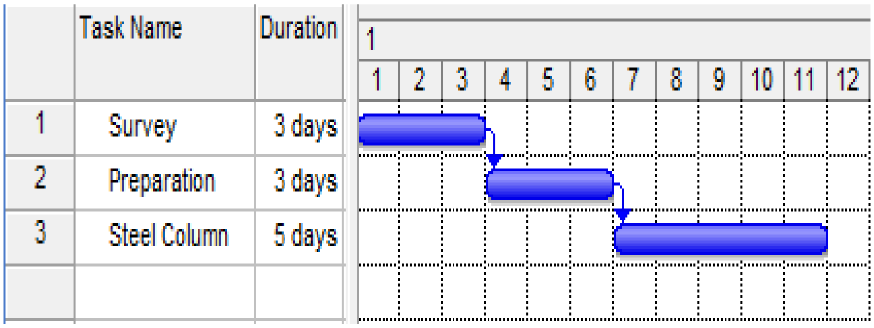
CHAPTER 3
PROPOSED REWORK REPRESENTATION

3.1 Introduction

Available project management tools have standardized schedule representations of a project in the form of a set of activities and milestones. During the actual progress of a project, when rework can happen, it’s important to document the rework events within the standard schedule representation. Since existing tools do not facilitate the documentation of rework within the schedule, a new representation of rework has been developed and is described in this chapter. The new technique includes an analysis mechanism for automatically quantifying the impact of rework on the schedule. A schedule analysis mechanism has also been created for optimizing rework-related corrective actions and apportioning the associated project delays. This mechanism is presented in chapter 4.

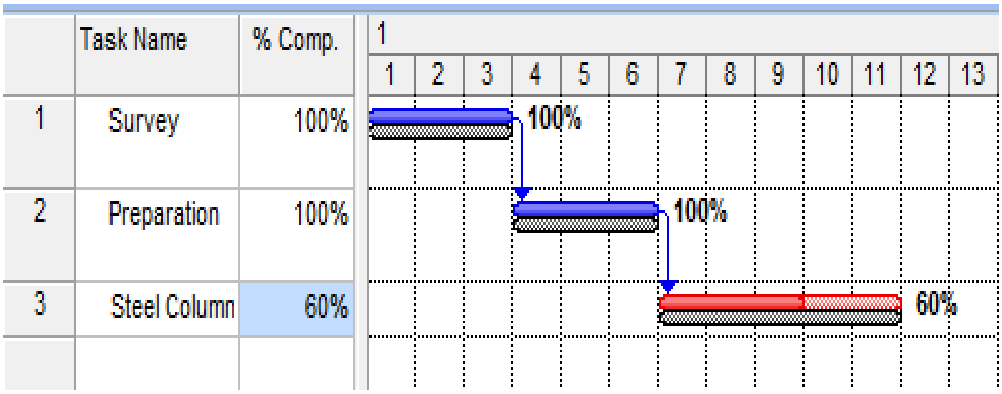
3.2 Typical Schedule Representation

Existing project management tools allow the representation of some information about the baseline schedule and the updated schedule. In none of these tools, however, is it possible to incorporate a structured representation of rework or a calculation procedure for considering rework events and apportioning delays and accelerations. In most of them, a rework event is typically represented by the introduction of a new activity, and then an attempt is made to tie the new activity into the rest of the schedule. In heavy construction projects such as an oil and gas project, this task is not simple. Because schedules that have thousands of activities and relations, it is extremely difficult to update or change the schedule in order to introduce a rework activity. Fig. 3.1 shows an example of the representation of activities in MS Project, a commonly used software tool, in which that a rework event has occurred on a specific date is very difficult. The solution is to split the activity into pieces so that the rework portion can be added in the correct place and then linked with the rest of the schedule. This process is lengthy and tedious, especially for large projects.



	Task Name	Duration
1	Survey	3 days
2	Preparation	3 days
3	Steel Column	5 days

a) Planned



	Task Name	% Comp.
1	Survey	100%
2	Preparation	100%
3	Steel Column	60%

b) Updated

Fig. 3.1: Planned and Updated Schedules in Microsoft Project

Primavera P6 (2007), which is industry-standard software, also has numerous options for entering the progress of an activity, as shown in fig 3.2. However, even in its latest version, P6 does not offer an effective way to represent a rework event in the project schedule. While P6 does have a new option for uploading a daily profile for an activity, as shown in fig. 3.3, but although this is an important function, it does not include a mechanism that allows documentation of the reasons. Furthermore, all analysis mechanisms must be programmed in the Primavera language, which is not simple.

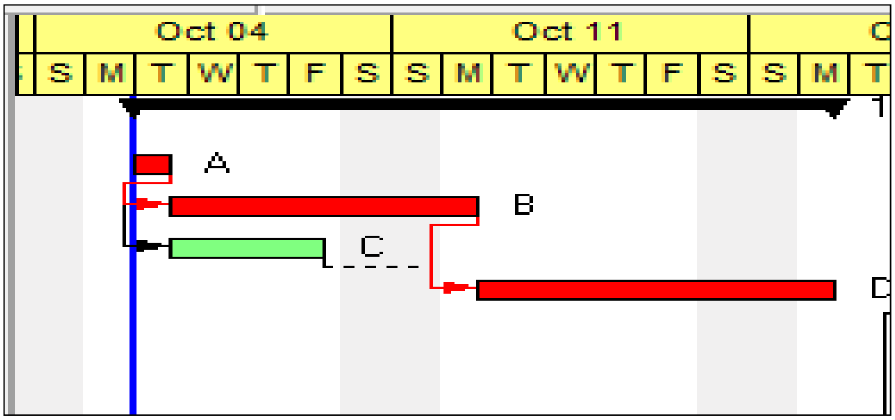
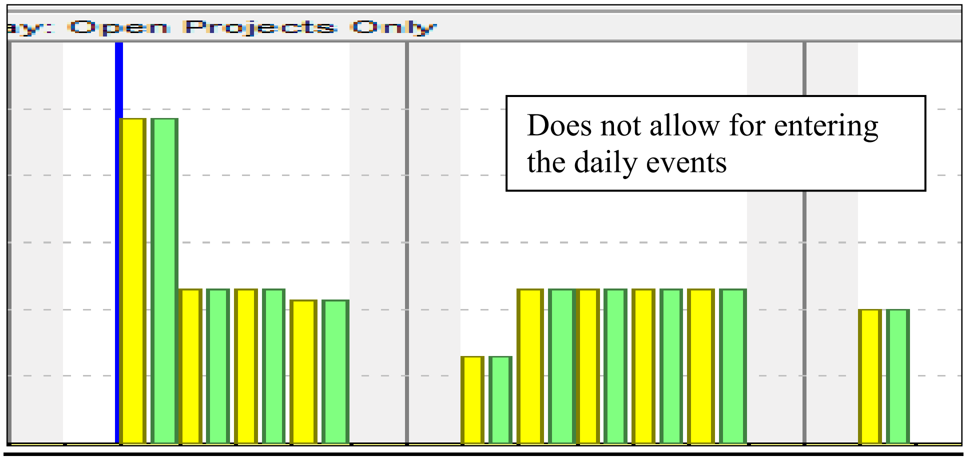


Fig. 3.2: Primavera P6 Project Schedule

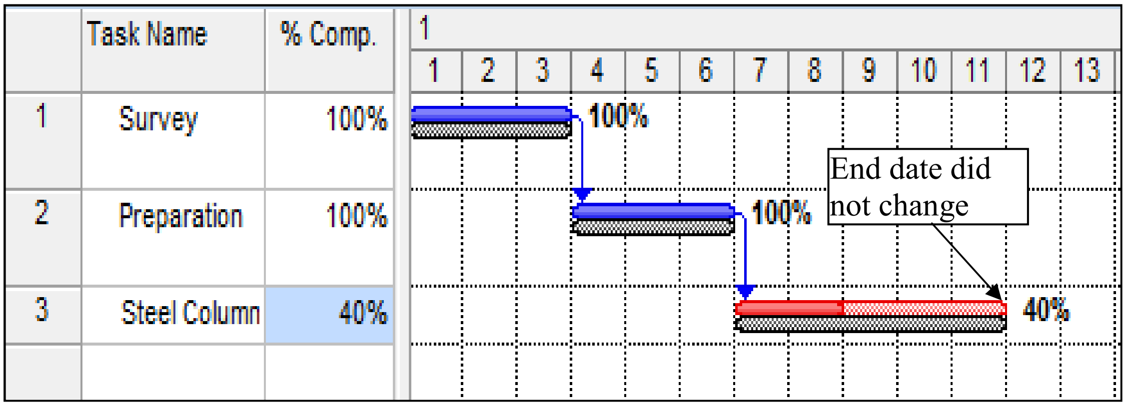


Does not allow for entering the daily events

Fig. 3.3: Activity Profile Primavera 6

3.3 New Representation of Rework

For better progress documentation and project control, this research has developed a new method of representing rework events on the project schedule. Improving the schedule representation to include rework can be accomplished in several ways. One simple approach is to consider rework as a negative percentage complete for the related activities, as shown in Fig. 3.4. The value of the negative percent complete is equal to the amount of work that needed to be redone for the specific activity. Fig. 3.4 illustrates an example in which the activity involves 10 steel columns which are planned to be constructed in 5 days. After 60 % of the job is completed (6 columns in 3 days), the site supervisors discover that they have 2 columns not properly aligned and decide that they need to be realigned. Since the amount of rework is 20 %, as shown in Fig. 3.4, 20 % is subtracted from the earlier 60 % complete so that the cumulative progress (shown on the right side of Fig.3.4) is only 40 % complete. While this representation is simple and can be implemented in existing software, the project end date did not reflect the change, and it is difficult to keep track of the individual history of all project events, since the latest value replaces the previous one.



	Task Name	% Comp.
1	Survey	100%
2	Preparation	100%
3	Steel Column	40%

End date did not change

Fig. 3.4: Changing the Percentage Complete as a Result of Rework

As developed in this research a more practical approach, is to use a daily representation of the actual progress so that rework can be specified in terms of exact times and quantities, as shown in Fig. 3.5. The new representation includes colour coding on the schedule to indicate that rework has been recorded for an individual activity, with the specific information about the rework shown as, for example “C-20” indicating Contractor responsibility and the amount of rework. the rework percentage amount could be calculated in 2 ways:

1- As a percentage of the work performed or the current progress i.e., 2 columns out of the 6 completed, or 33 %
2- As a percentage of the total activity quantity i.e., 2 columns of the total 10, or 20 %

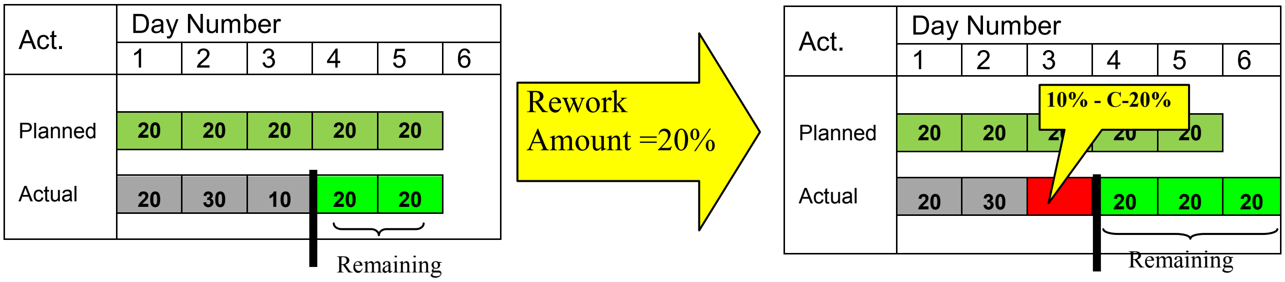


Fig. 3.5: Representing Rework as Negative Progress

For ease of calculation, this research adopted the second approach. The letter before the value of the rework represents the party responsible. For example, O-20 for a specific activity means that 20 % of the total activity has to be redone and that the rework is the result of Owner’s action. This new rework representation has been demonstrated for a number of activity cases, as presented in the following section.

3.4 The Effect of Rework on Construction Schedules

Depending on the construction schedule, there are several cases in which a rework event can have an impact on other activities, the project completion, and resource allocation. The cases described in the following subsections are presented in order of complexity, from simple to more involved.

3.4.1 Case Involving Rework for a Non-Critical Activity

In the case of a rework event occurring for a non-critical activity, which is the simplest case, the activity float can be used to absorb the delay caused by rework. This method will be only if the time required for rework is shorter than the total activity float. This case can be demonstrated by the example shown in Fig. 3.6. The schedule consists of 6 activities and activities B and C begin after activity A. Activity D then follows activity C and is followed by activity E. Activity F follows both activity B and activity E. Based on these relationships and duration of the activities, the critical path is A-C-D-E-F, and the planned schedule shows that activity B has a total float of 3 days, as shown in Fig. 3.6.

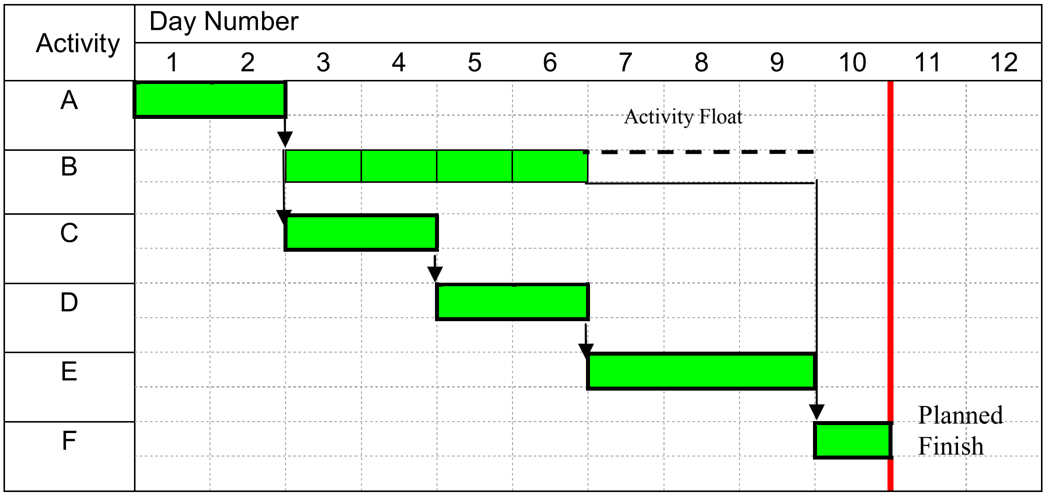


Fig. 3.6: Simple As-Planned Construction Schedule

Fig. 3.7 shows a rework event during the execution of activity B, which is a non-critical activity. The rework event is shown on day 4 as C-25, indicating a rework amount of 25 % is needed for the activity. Based on this rework amount, the duration of activity B is extended to 5 days [4 days planned + 25% * 4 for rework = 5 days]. Since the activity is non-critical and has a total float of 3 days, the project duration will not be extended. The duration of the activity after the inclusion of rework can thus be calculated using the following equation:

New Activity Duration = Planned Duration + Rework% * Planned Duration (1)

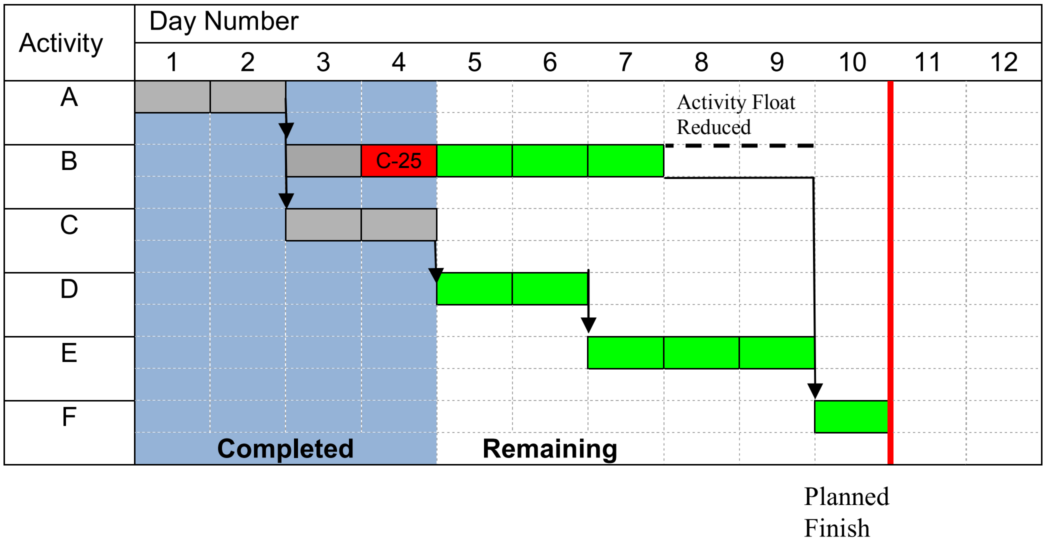


Fig. 3.7: Effect of Rework on a Non-Critical Activity

3.4.2 Case Involving Rework for a Critical Activity

Undesired effects may occur when a critical activity requires rework. This situation can be demonstrated for the same as-planned schedule shown in Fig. 3.6. The progress schedule is shown in Fig. 3.8, with rework occurring for activity C, which is a critical activity. If the amount of rework is 50 %, using equation 1 the activity is extended by one day. A general expression of the extension of the total project can thus be calculated as follows:

Project Extension (>0, or 0 if negative) =

(New Activity Duration (Eq.1) – Original Activity Duration) – Activity Total Float (2)

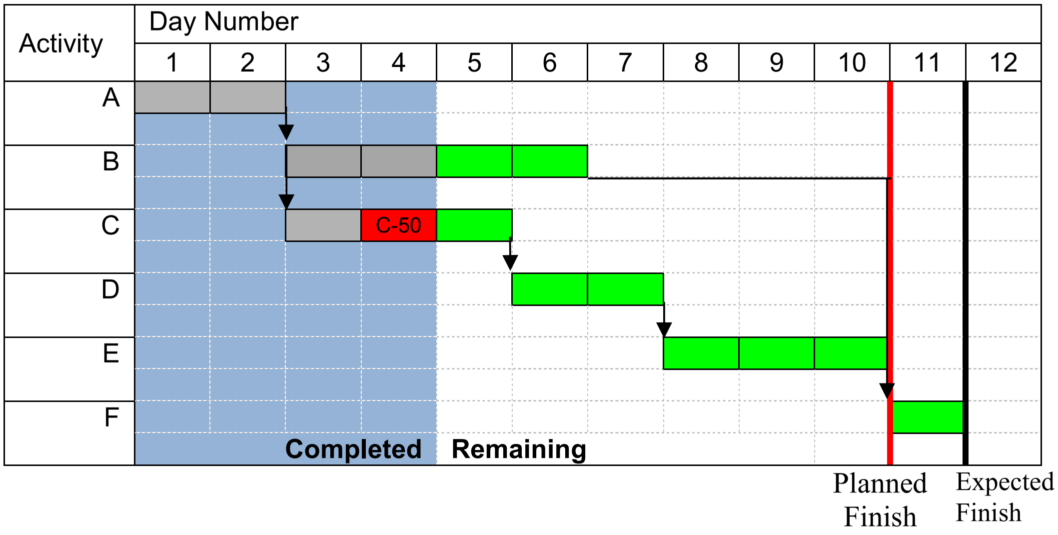


Fig. 3.8: Effect of rework on the Critical Path

As shown in Fig 3.8, rework events that affect the project schedule as a whole can lead to undesired results, including project delay and cost overruns. It should be noted that the new rework representation and related calculations can show clearly the impact of rework on the overall project duration, which was not possible with existing tools.

3.4.3 Case Involving Rework and Resource Limits

Another more practical case that demonstrates the impact of rework on a schedule involves project that has limited resources. To illustrate this case for the planned schedule shown in Fig. 3.6, the specific labour resource required for each activity are indicated by 🧍, as shown in Fig. 3.9. Assuming that the resource limit for the project is 2 workers per day, the planned schedule meets this constraint.

In this case, a rework event is introduced for activity B, which is non-critical as in the case described in 3.3.1. However, due to the resource limits, the impact of the rework event is different because it creates an over-allocation of the project resources, as shown in Fig. 3.10. While in the first case, described in section 3.3.1, the rework does not affect the completion date, in this case, when limited resources are involved, the rework causes a one-day project extension because the resource over-allocation must be resolved, as shown in Fig. 3.11.

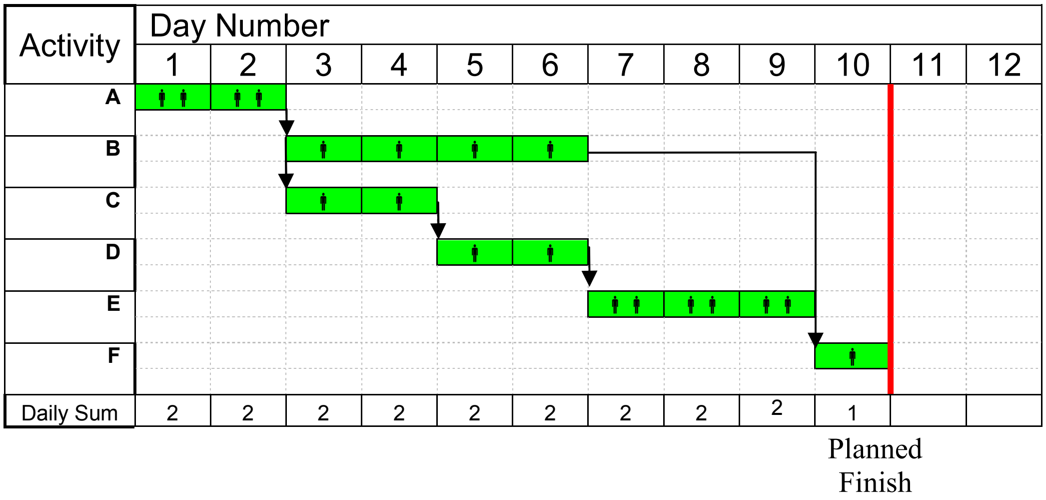


Fig. 3.9: Resource Loading Over the Planned Schedule

Therefore, in the case of a Rework event involving a schedule with resource limits, even when the rework occurs with respect to a non-critical activity, it might also delay the overall project schedule because of resource over-allocation.

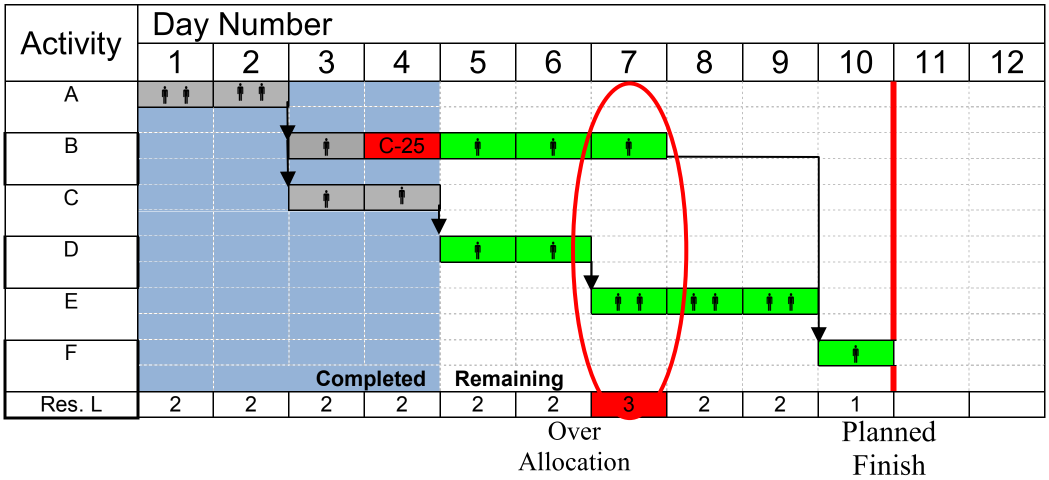


Fig. 3.10: Resource Over-Allocation Due to Rework

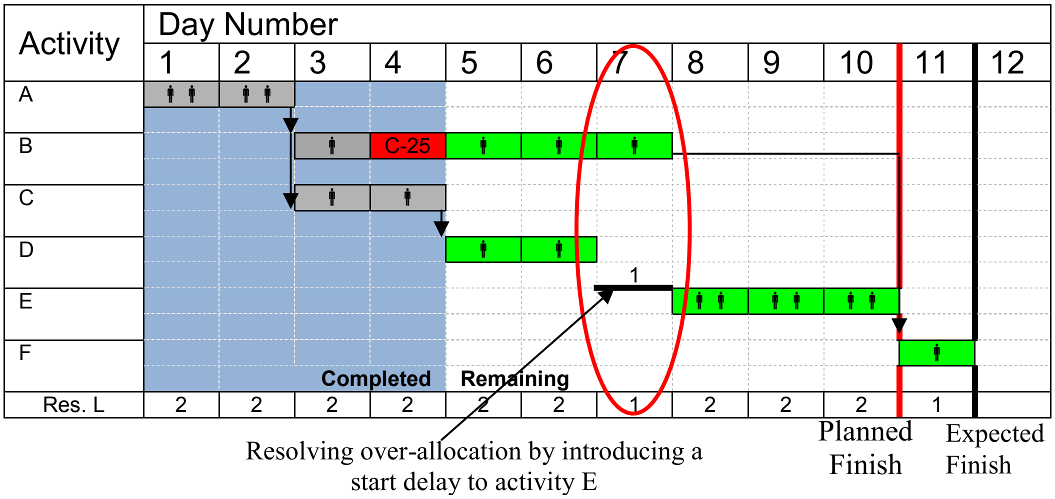


FIG. 3.11: Extension of the Project Caused By Resolving The Resource Over-Allocation

3.4.4 General Case Involving Rework

At any stage of the project, rework can affect one activity or multiple activities. A more realistic example is therefore a case in which a rework for one activity can have an impact on a group of activities. For example, when a completed column must be redone because of misalignment or disorientation, it is then important to add not only the new activity of removing the column but also a set of additional activities that are prerequisites for the rework, such as formwork, steel, and concrete. Other tasks, such as surveying, quality control, and other administrative activities, also have to be added to represent the impact of the rework. Fig. 3.12 shows a schematic illustration of the impact of reworking a concrete column on the activities and the schedule.

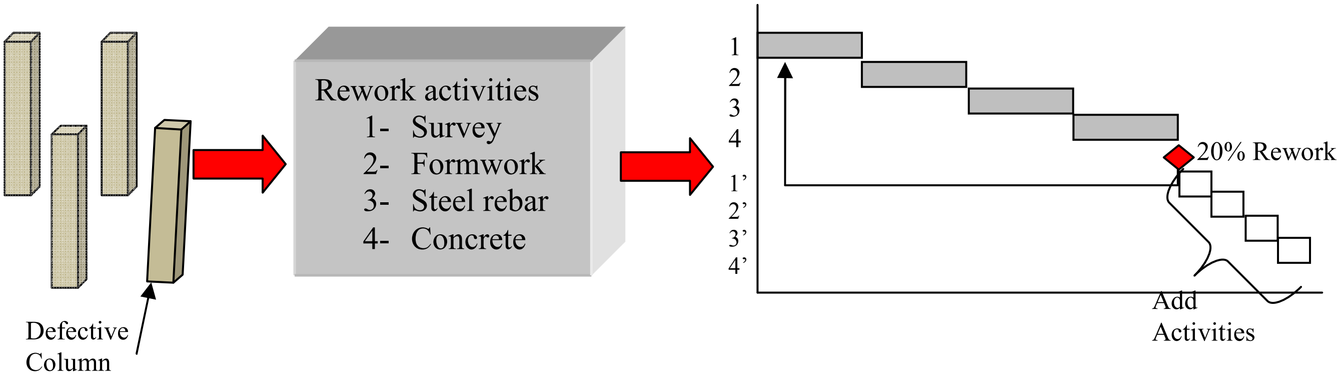


Fig. 3.12: Effect of Rework on the Schedule

For the purpose of this research, while additional activities must be added, it is possible to utilize activities that already appear on the existing schedule without the need to add or split the current schedule. Using the new representation, the project schedule and cost can be updated with respect to the magnitude of the rework. The following case illustrates the effect of a general case of rework on the construction schedule.

The planned schedule used is the one shown in Fig. 3.9, with the activities' resources loaded. For the general case, additional schedule events were introduced into the schedule, as shown in Fig. 3.13. In this case, the schedule is affected not only by delays from rework events , but also by delays resulting from the actions of the Owner and the Contractor, which are indicated on the schedule as "o" for work stops due to Owner, and "c" for work stops caused by Contractor. Example of Owner-related work stoppage are delaying the approvals of documents or changing the conditions they contain. Contractor delays include late procurement or supply of materials or equipment. Recording such events on the project schedule affects the resource allocation, as shown in Fig. 3.13. As a result of the resource over-allocation, delays are introduced for some activities. A start delay equal to 3 days is thus introduced into activity E, which was to start on day 8. The resulting updated schedule is as shown in Fig. 3.14, with an overall project delay of 4 days.

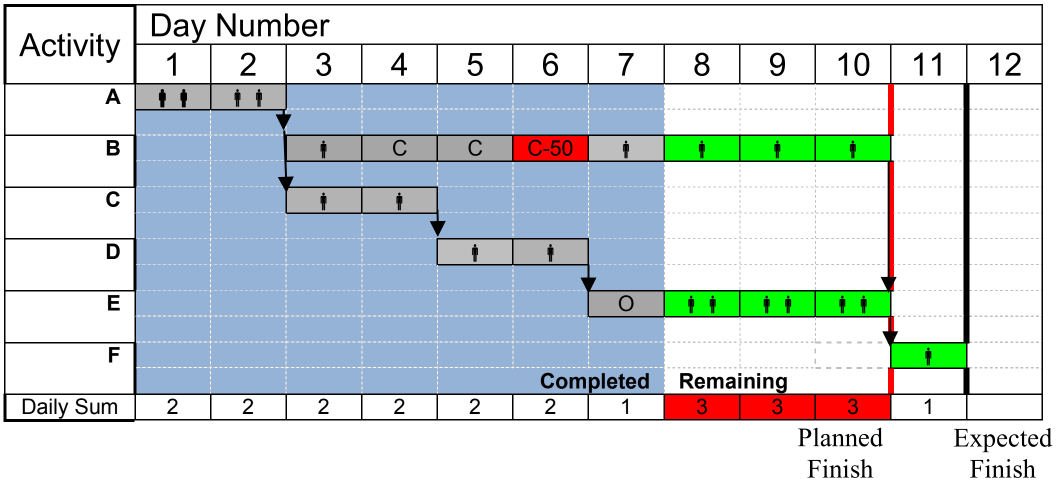


Fig. 3.13: Schedule with a Varity of Events, Showing Resource Over-Allocation

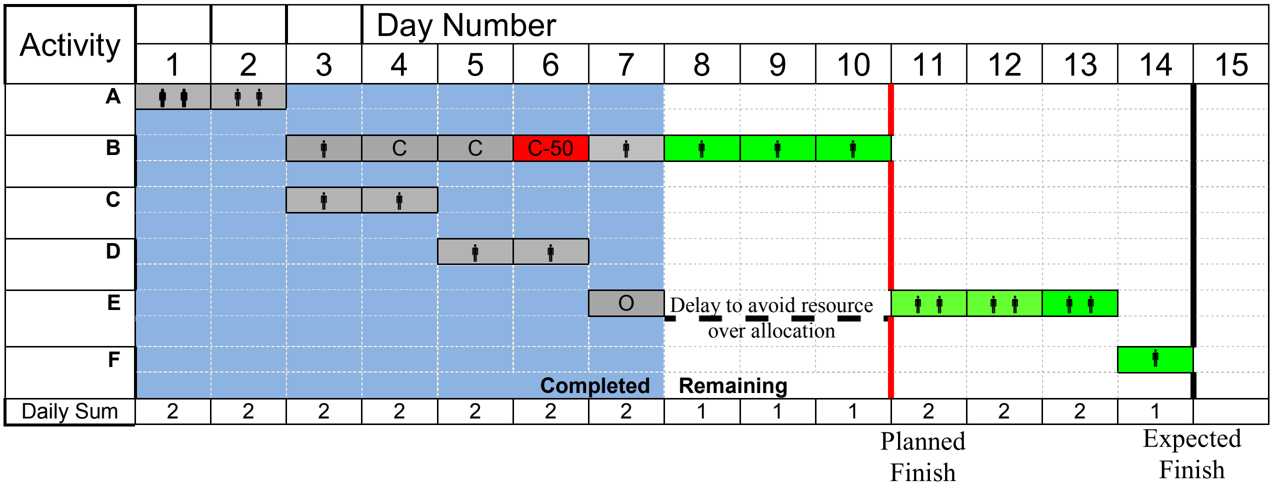


Fig. 3.14: Updated Schedule with Delays to Resolve the Resource Over-Allocation

This case then becomes more complex when a rework event occurs with respect to any of the remaining activities, as shown in Fig. 3.15. This general case, then, becomes challenging not only because the impact of the rework on the project completion date must be understood, but also because the responsibility of each party for the net delay must be analyzed so that accurate mitigation action can be taken. A mechanism for conducting this detailed analysis is presented in Chapter 4.

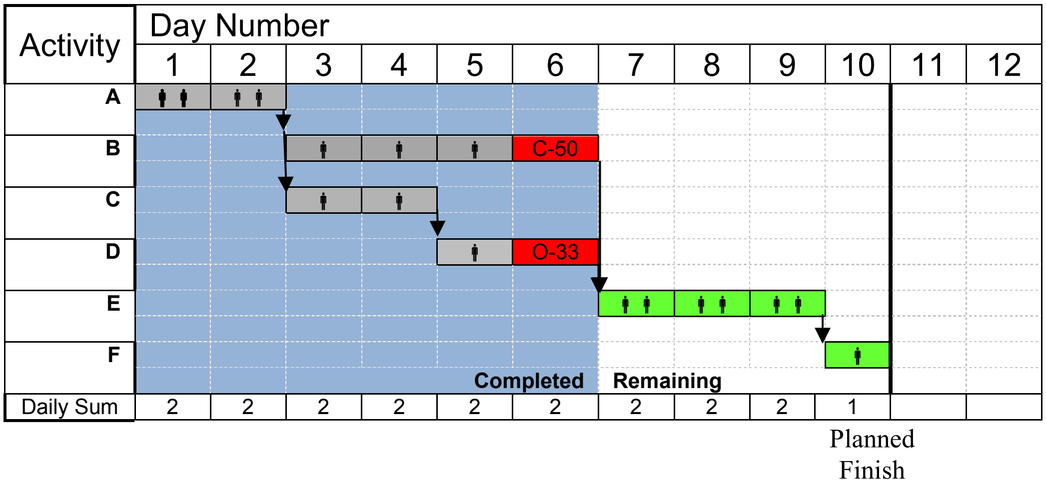


Fig. 3.15: General Case of Progress Events Including, Multi-Party Rework

3.5 Conclusion

This chapter has presented a simplified approach for representing rework as a negative percentage complete as recorded on a specific date on the schedule. Several rework cases have been presented, and a general case involving rework and other progress events is highlighted. This general case is considered in subsequent chapters along with the development of a schedule analysis mechanism for quantifying the impact of rework on the duration of the project and to apportion project delays among the parties responsible, in order to optimize corrective actions.

CHAPTER 4
SCHEDULE ANALYSIS CONSIDERING REWORK, DELAY, AND ACCELERATION

4.1 Introduction

As mentioned in Chapter 3, the basis for the new rework representation is the daily recording of events, including rework, on the schedule. Based on this daily representation, schedule analysis should be applied in order to determine the amount of the project extension and the responsibility for the delays. In the literature, two specific studies (Hegazy and Menesi, 2008; Hegazy and Zhang, 2005) have proposed schedule analysis mechanisms that use a daily representation but that does not include rework. It is thus important to extend previous schedule analysis mechanisms by incorporating rework into the formulation. This chapter therefore begins with a description of the previous analysis mechanism and then introduces the suggested modifications for incorporating rework.

4.2 Rework Mitigation Strategies

Rework mitigation mandates the acceleration of the project in order to recover the resulting delays. According to the American Association of Cost Engineers International (AACE 2004), acceleration, which sometimes referred to as schedule compression or schedule crashing, is formally defined as “A method of schedule analysis used to shorten the critical path of the schedule.”

Generally, however, Construction literature mentions three main acceleration strategies, which depend on the type of project and its duration and on the type of delay to be recovered. The three common types of acceleration strategies are shown in Fig. 4.1 and briefly discussed below:

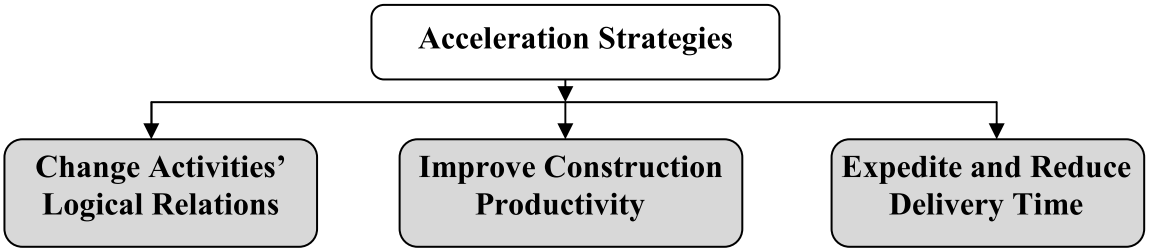


Fig. 4.1: Acceleration Strategies

Change the Activities' Logical Relations: One of the easiest ways for a Contractor to accelerate a project is to re-sequence the activities. Most construction schedules have logical links that are driven by either physical constraints (hard logic) or resource constraints. Some of the logical links may also be driven by the Contractor, which means that the logical links can be flexible (soft logic) and can be changed to save project time.

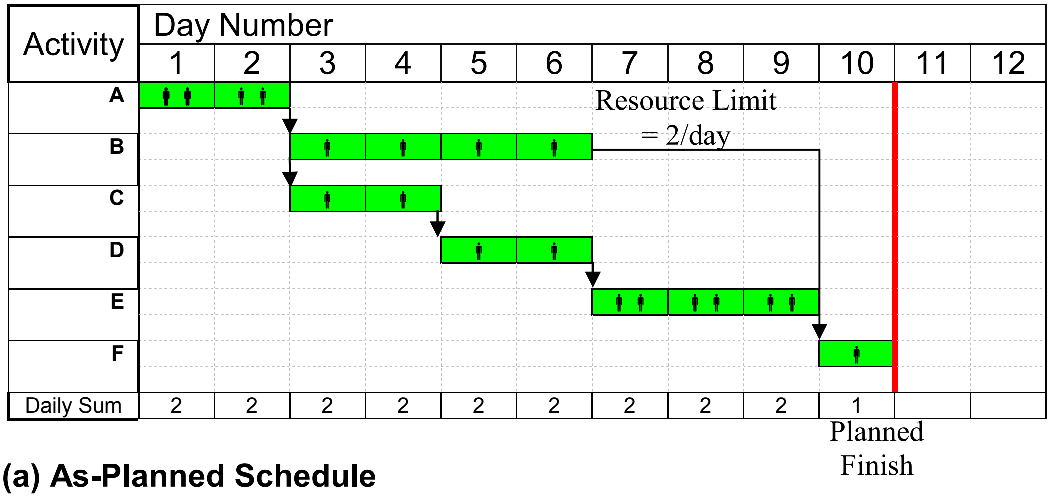
Improve Construction Productivity: The addition of extra resources to improve productivity is often the first response to a direction to accelerate, although this step may not be the most economical. The added resources could either be equipment or labour. Another approach for increasing productivity is to schedule overtime work. However, may lead to reduced productivity over an extended period, and involves the payment of an overtime premium, which must also be included in the cost of the acceleration.

Expedite and Reduce Material Delivery Lead-Time: If the critical path of a project includes procurement activities, shortening the material lead-time results in an accelerated schedule. The lead-time could be shortened by paying for the reduced lead-time or by adopting a partial delivery approach, in which the material delivery is divided into smaller delivery packages that are sequenced according to the site need dates. Another approach to controlling the delivery of the material is through close expediting and follow-up with vendors in order to resolve any obstacles or delays that might arise in the production or supply of materials and equipment.

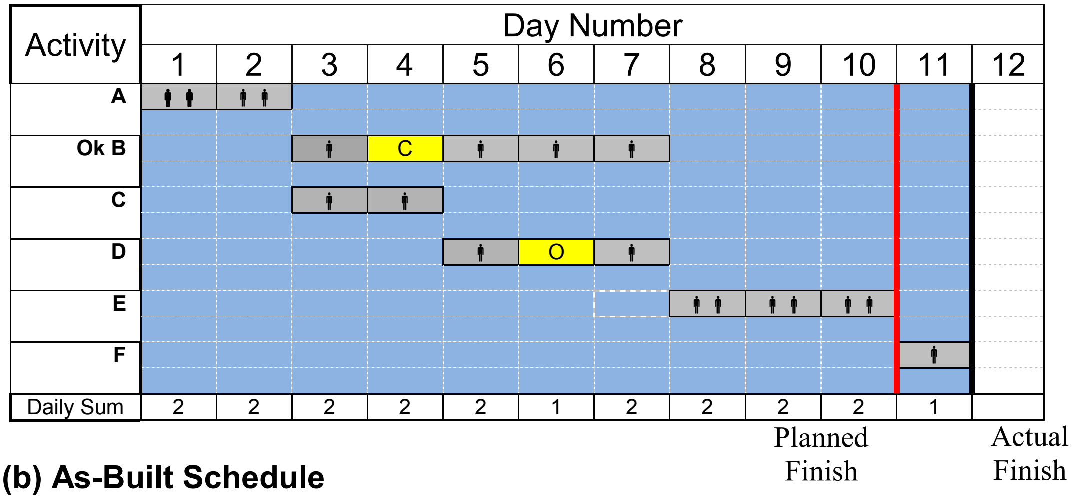
The above strategies could be used to accelerate the project after the amount that must be accelerated or mitigated is quantified. This amount depends on a thorough analysis of the schedule.

4.3 Utilizing Existing Schedule Analysis Tools

The latest schedule analysis mechanism developed by Hegazy and Menesi (2008) uses the daily windows analysis that was first introduced by Hegazy and Zhang (2005), but with two important extensions: (1) consideration of the impact of multiple baseline updates and (2) consideration of the impact of resource over-allocation on delay analysis. To capture and consider all the fluctuations in the critical path(s), the window size used is one day. The simple example in Fig. 4.2 demonstrates this daily windows analysis. The project has an as-planned duration of 10 days. The Contractor has a limit of 2 resources per day. The daily resource needs for each activity are shown on the activity bars.



(a) As-Planned Schedule



(b) As-Built Schedule

Fig. 4.2: As-Planned and As-Built Schedules for a Simple Case Study

The as-planned schedule shows that the Contractor planned the project so as to maintain the 2 workers per day resource limit. During the course of the actual work, the Contractor caused a delay of one day for activity B, while the Owner caused a delay of one day for activity E. The total project was delayed one day and was expected to finish on day 11, as opposed to day 10 in the as-planned schedule. Analyze which party is responsible for the project delay is important.

4.2.1 Analysis Using the Traditional Daily Windows Analysis

With the traditional daily windows analysis, a total of 11 windows are analyzed. The windows for days 4, 5 and 6 are shown in Fig. 4.3, 4.4 and 4.5, respectively. The windows for the first to the third day the project is advancing according to the baseline schedule, and the project duration remains at 10 days. The analysis of the windows for days 4, 5 and 6 is explained below:

Window for day 4 (Fig. 4.3): Activity B has a one-day Contractor delay, which is accommodated in the total float for the activity, and the project duration remains 10 days, the effect of resource allocation is not considered. As shown in Fig. 4.3, the traditional window analysis does not consider the resource over-allocation resulting from the delay of activity B, which affects the resources for day 7.

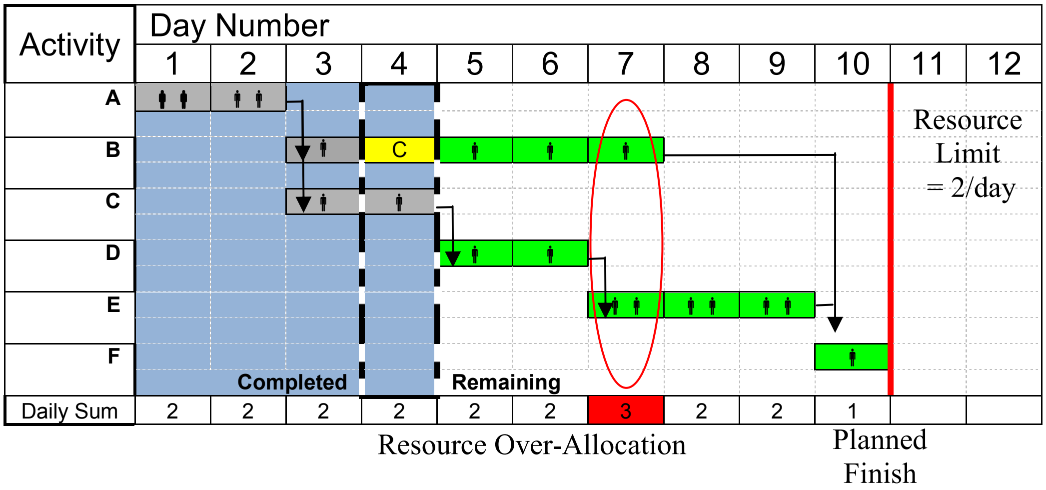


Fig. 4.3: Traditional Daily Windows Analysis (Window for Day 4)

Window for Day 5 (Fig. 4.4): No changes or delays occurred, so the project duration remains 10 days.

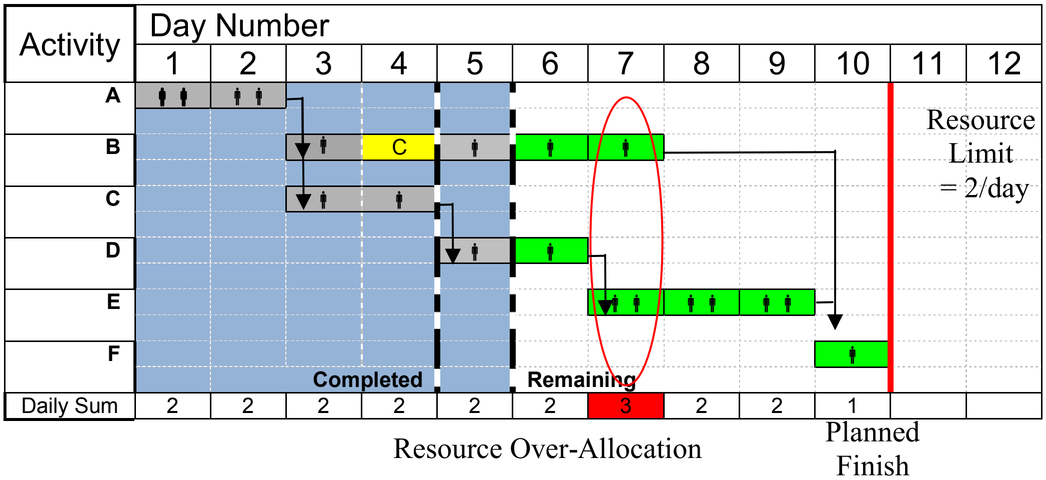


Fig. 4.4: Traditional Daily Windows Analysis (Window for Day 5)

Window for Day 6 (Fig. 4.5): After the events of day 6 are added, the project has a one-day Owner delay in activity D (critical activity), leading to the extension of the project duration to 11 days. The results of the daily windows analysis therefore show a one-day Owner delay. It should also be noticed that the resource over-allocation resulting from the Contractor delay no longer exists.

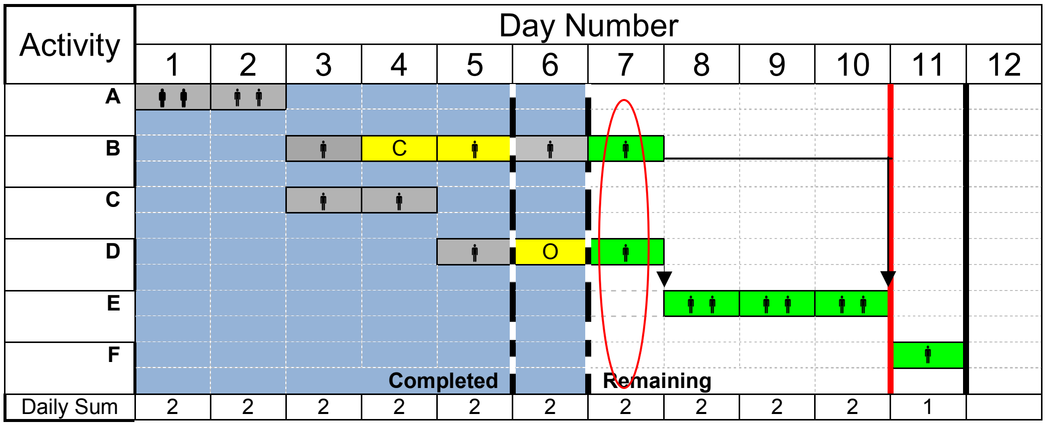


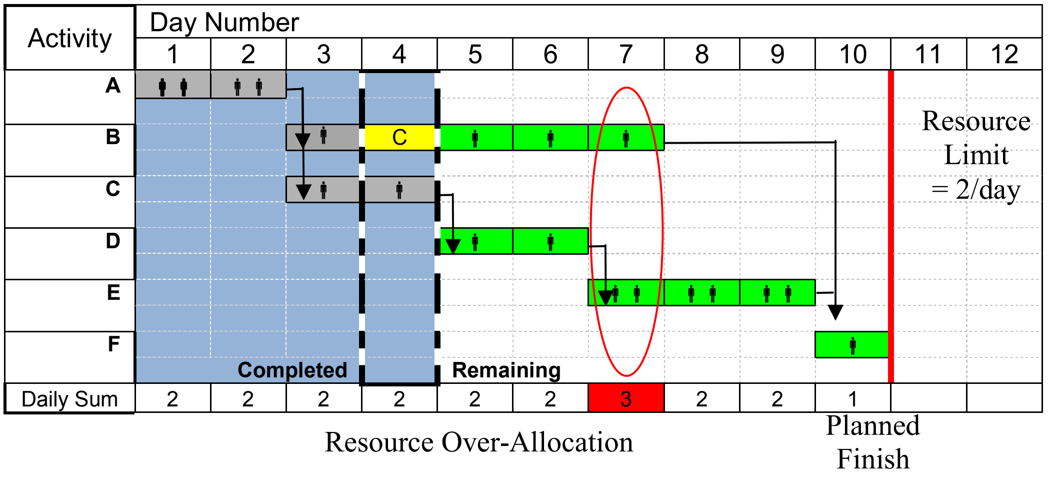
Fig. 4.5: Traditional Daily Windows Analysis (Window for day 6)

4.3.2 Analysis Considering Resource Over-Allocation

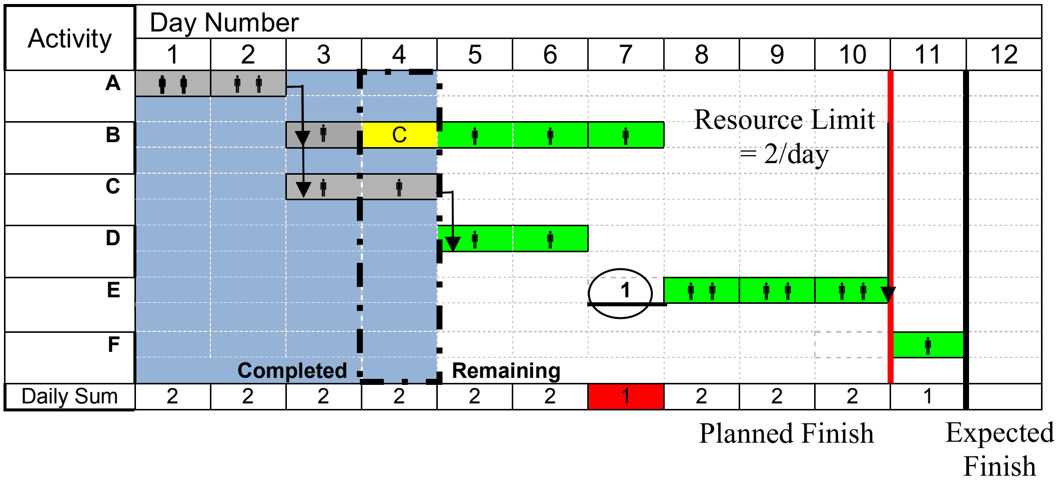
When the modified daily windows analysis is applied, a total of 11 windows are analyzed. For the purposes of this research the focus is on the windows for days 4 and 6, when the Contractor and Owner events occurred, as shown in Fig. 4.6 and 4.7, respectively. The project advances according to the baseline schedule until day 4, when the first event occurs. The analysis of this event using the modified window analysis of Hegazy and Menasi (2008) is discussed below:

Window for Day 4 (Fig. 4.6): The Contractor delay in activity B (a non-critical activity), as shown in the planned schedule presented in Fig. 4.6 a, caused a resource over allocation in day 7. Resolving this resource problem required that a start delay be introduced to push activity E forward one day (Fig. 4.6 b). The new project duration thus becomes 11.

Window for Day 6 (Fig. 4.7): The Owner delayed activity D by one day, but because this delay can be absorbed by the planned start-delay for activity E (Fig 4.7), the Owner event does not affect the project duration or the resource allocation.



a) **Schedule Before Resolving the Resource Over-Allocation**



b) **Schedule After Resolving the Resource Over-Allocation**

Fig. 4.6: Modified Daily Windows Analysis (window of day 4)

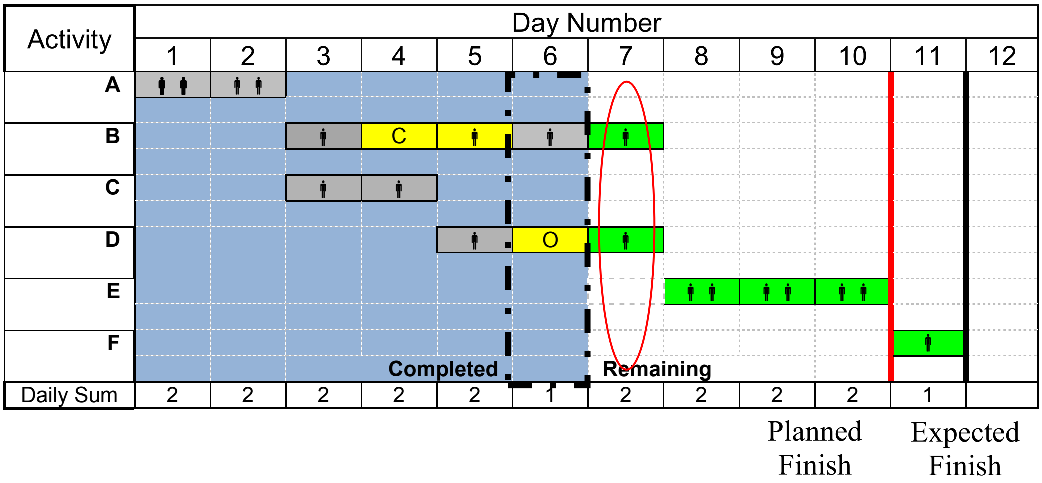


Fig. 4.7: Modified Daily Windows Analysis (Window of day 6)

When the process is continued for the remaining windows (from day 7 to day 11), the project duration remains at 11 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 if 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. This example thus demonstrated the importance of considering resource over-allocation to produce accurate schedule analysis.

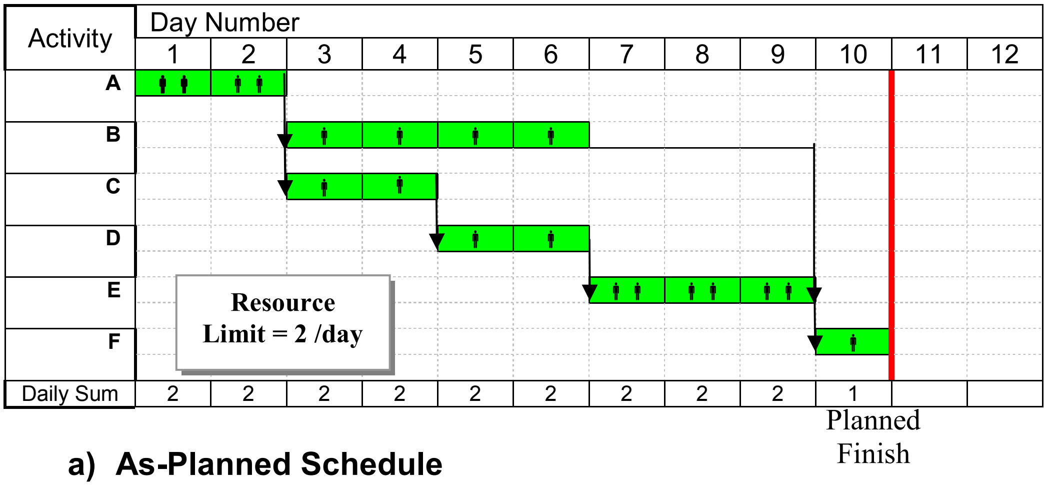
Table 4.1: Results of the Traditional and Modified Daily Windows Analyses

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

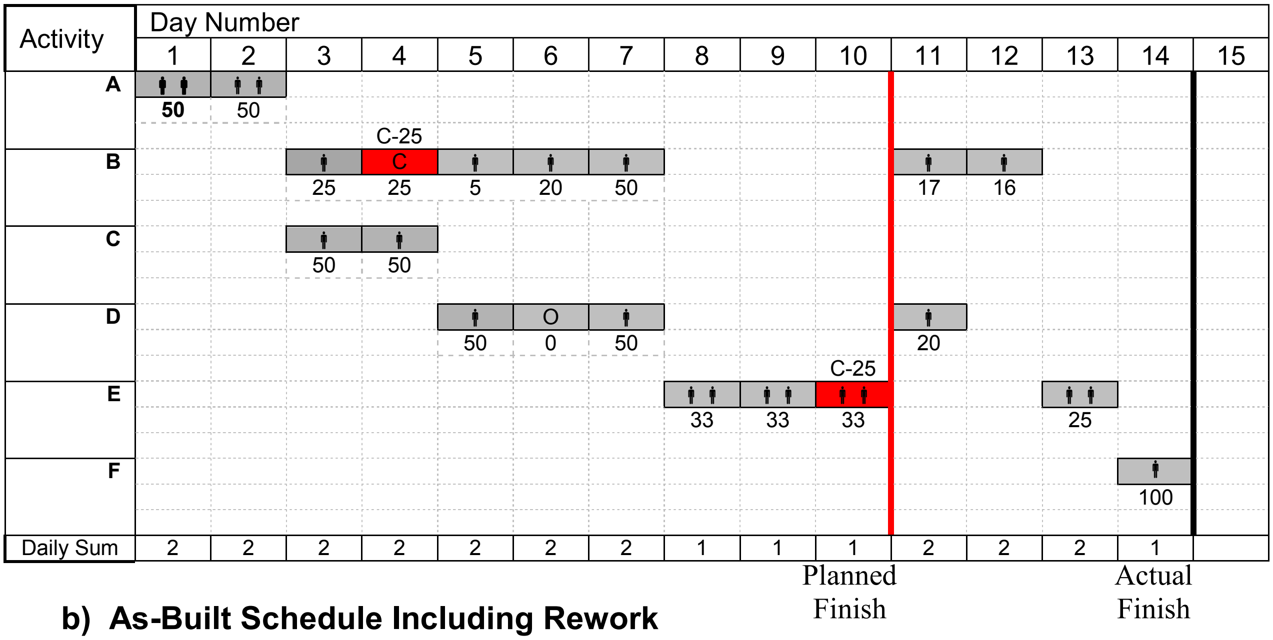
4.3 Schedule Analysis Considering Rework and Acceleratio

In this section, the approach of Hegazy and Menasi (2008) has been extended to include consideration of rework events caused by any of the project parties, that is, the Owner or The Contractor. The extended analysis technique is also beneficial for detailed project documentation and record keeping. Using the same as-planned schedules presented in the previous section, rework events are recorded on the schedule along with other schedule events, such as accelerations and delays. The as-planned and as-built schedules are shown in Fig. 4.8a, and Fig 4.8b, respectively. When the modified daily windows analysis is applied to the schedule, a total of 14 windows are analyzed. The current research focused on the windows for days 4, 5, 6, 7, 10, 11, 12, 13, and 14, explained below:

Window for Day 4 (Fig. 4.8): On day 4, as shown in Fig. 4.8b, a rework event was reported for activity B with a magnitude of 25 %, so the cumulative progress percentage is 25 % (day 3) + 25 % (day 4) – 25 % (rework) = 25%. Because of this event, the schedule was updated to accommodate the reported rework delay while also taking into consideration the resource limits.



a) **As-Planned Schedule**



b) **As-Built Schedule Including Rework**

Fig. 4.8: Schedules for a Simple Case Study that Considers Rework

The updated schedule is shown in Fig. 4.9. It should be noted that due to the resource limits, a start delay equal to one day must be introduced before activity E in order to resolve the over-allocation resulting on day 7. As a result, one day of project delay is attributed to the Contractor.

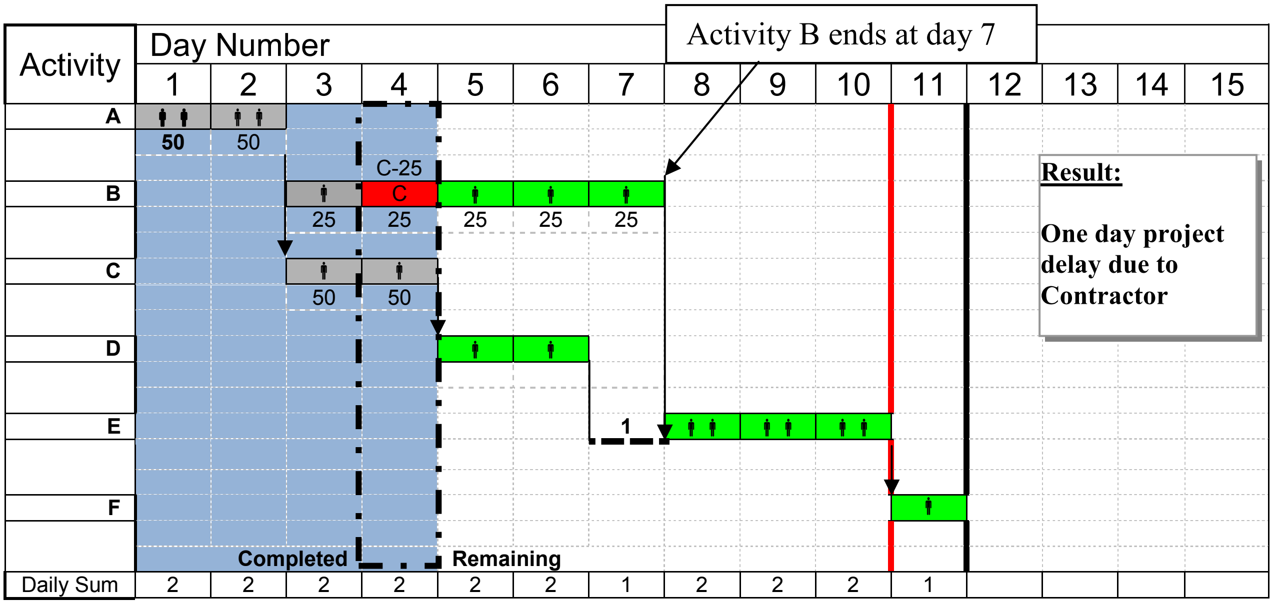


Fig. 4.9: Updated Schedule (Window of Day 4)

Window for Day 5 (Fig. 4.10): As the schedule progress continues, a slowdown is recorded on day 5 for activity B. This slowdown results in an increase in the duration of activity B, and another start-delay is added to activity E in order to remain within the resources constraints. As shown in Fig. 4.11 the result of the analysis is another project delay due to the Contractor. The Contractor thus has accumulative responsibility for 2 days of delay.

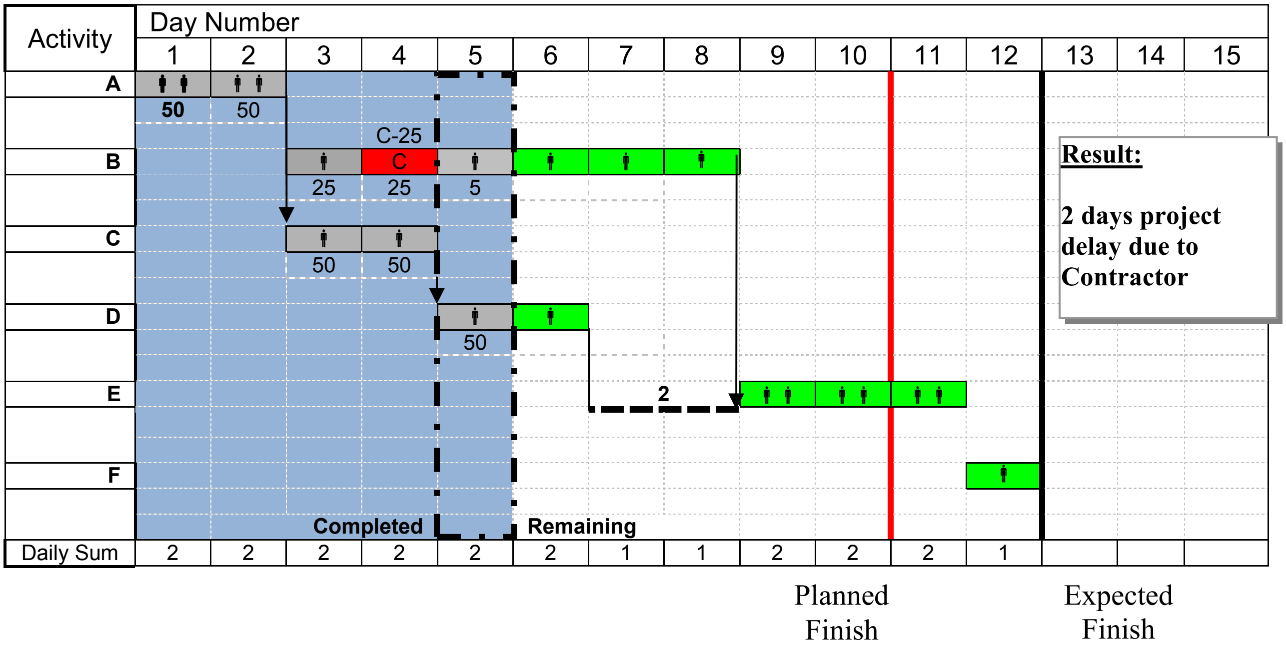


Fig. 4.10: Extended Daily Windows Analysis (Window for Day 5)

Window for Day 6 (Fig. 4.11): When the progress for day 6 is recorded, another slowdown is documented for activity B, and an Owner event has stopped the work on activity D. When the schedule is updated with the progress data and the remaining duration is calculated for activities B and D, the project duration remains at 12 days, as shown in Fig. 4.11. At this stage, the Contractor decided to accelerate activity B by using a different method of execution that doubles productivity, and the remaining duration of activity B was therefore decreased by one day, as shown in Fig. 4.12. Accordingly, the duration of the project is shortened by one day so that the end date is day 11 rather than day 12.

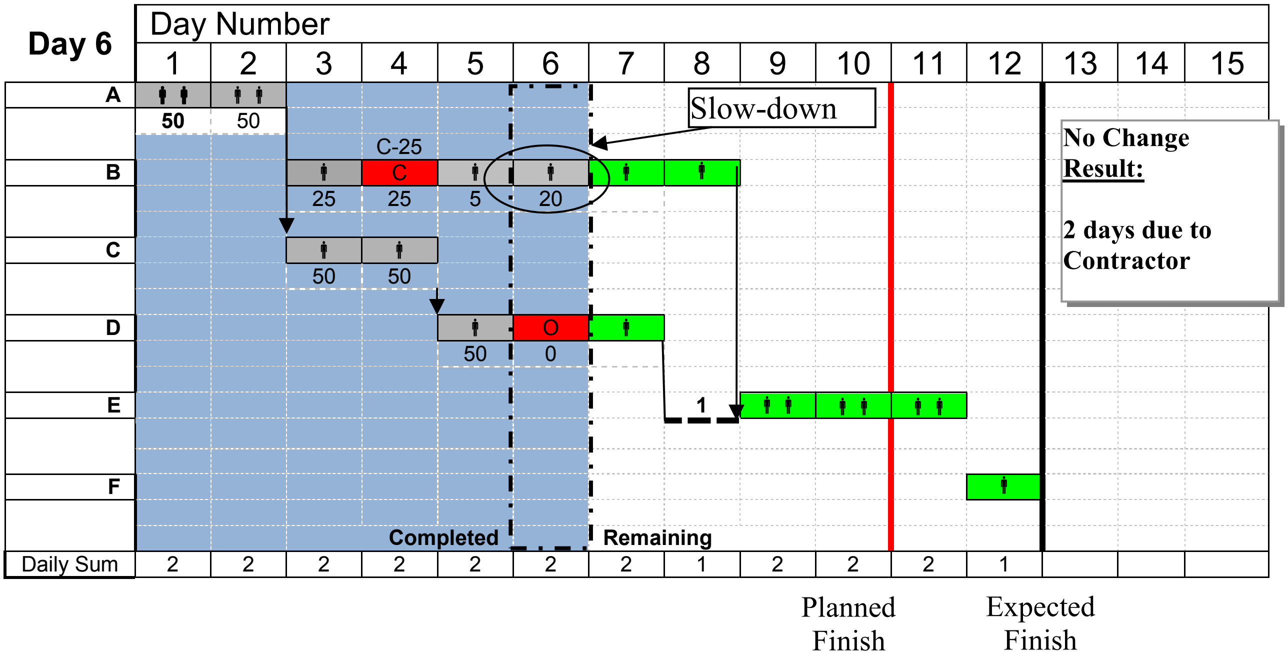


Fig. 4.11: Modified Daily Windows Analysis (Window for Day 6)

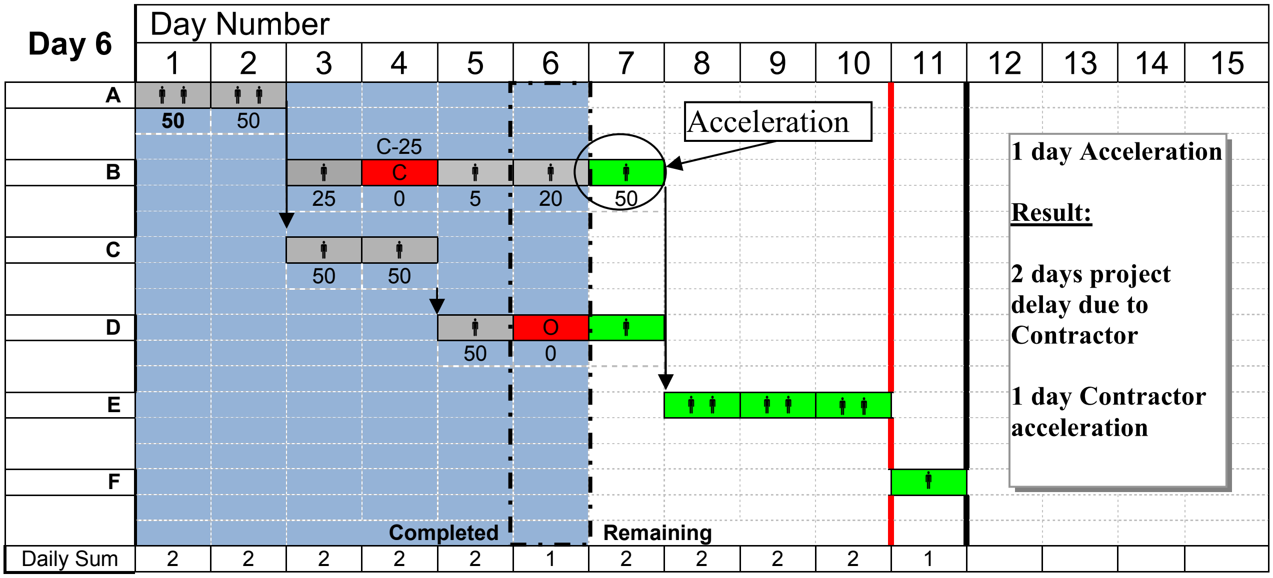


Fig. 4.12: Accelerated Schedule (Window for Day 6)

Window for Day 10 (Fig. 4.13): AS the daily updates continues, a rework event is recorded on day 10 for activity E with a value of 25 %, as shown in Fig. 4.13. The rework required for activity E affects not only that activity but also other activities which have already been completed. Activities B and D will therefore need to include rework with amounts equal to 33 % and 20 %, respectively (Fig. 4.14). Since the rework in activity E cannot start until the rework for the preceding activity is completed, the calculation of remaining schedule must take into consideration the relations of the activities and the resource limits, as shown in Fig.4.15. The schedule indicates a project delay until day 14. Since all events are the Contractor's responsibility, the analysis results in 4 days allocated to the Contractor delay. This example thus shows the micro level required for a consideration of the effect of schedule variables on project time, and accordingly, cost.

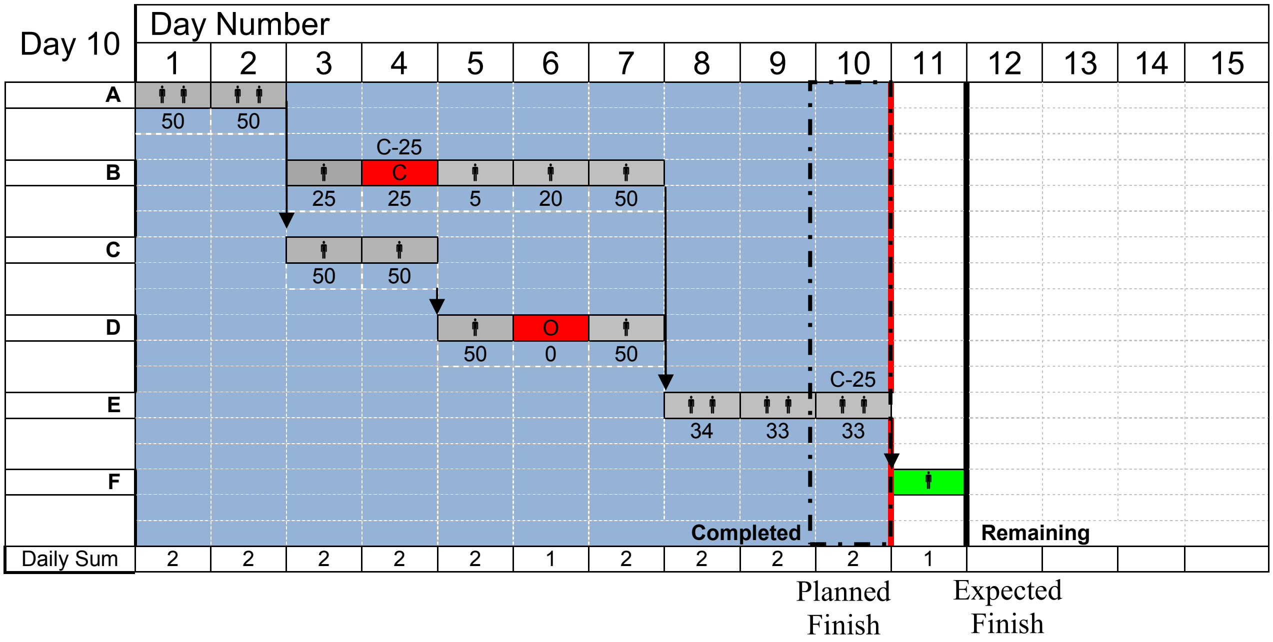


Fig. 4.13: Extended Daily Windows Analysis (Window for Day 10)

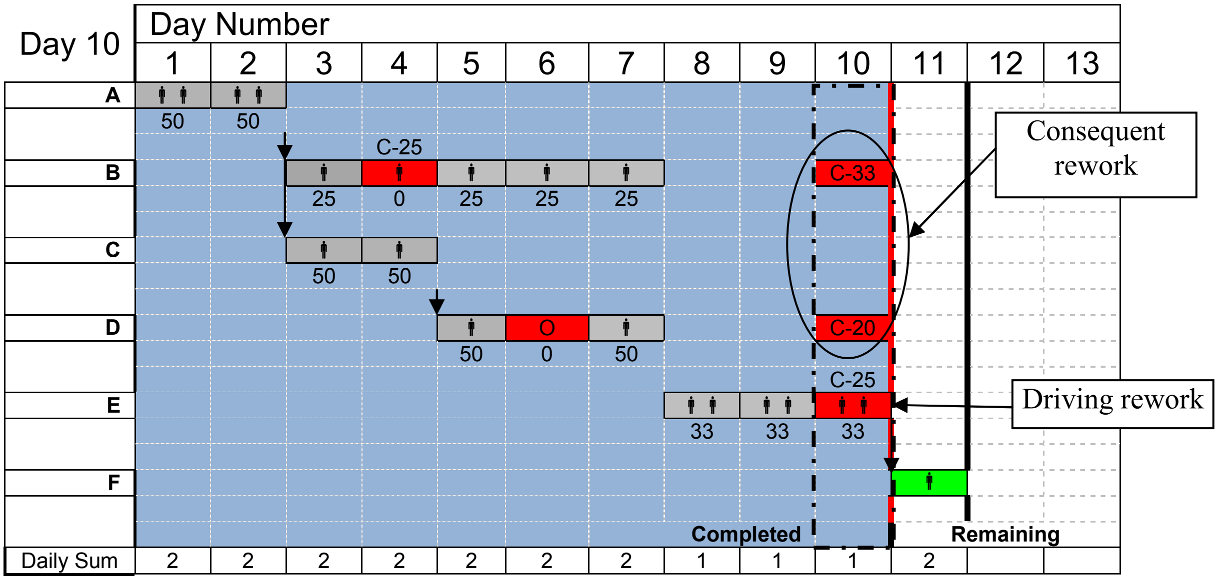


Fig. 4.14: Effect of Rework on Multiple Activities (Window for Day 10)

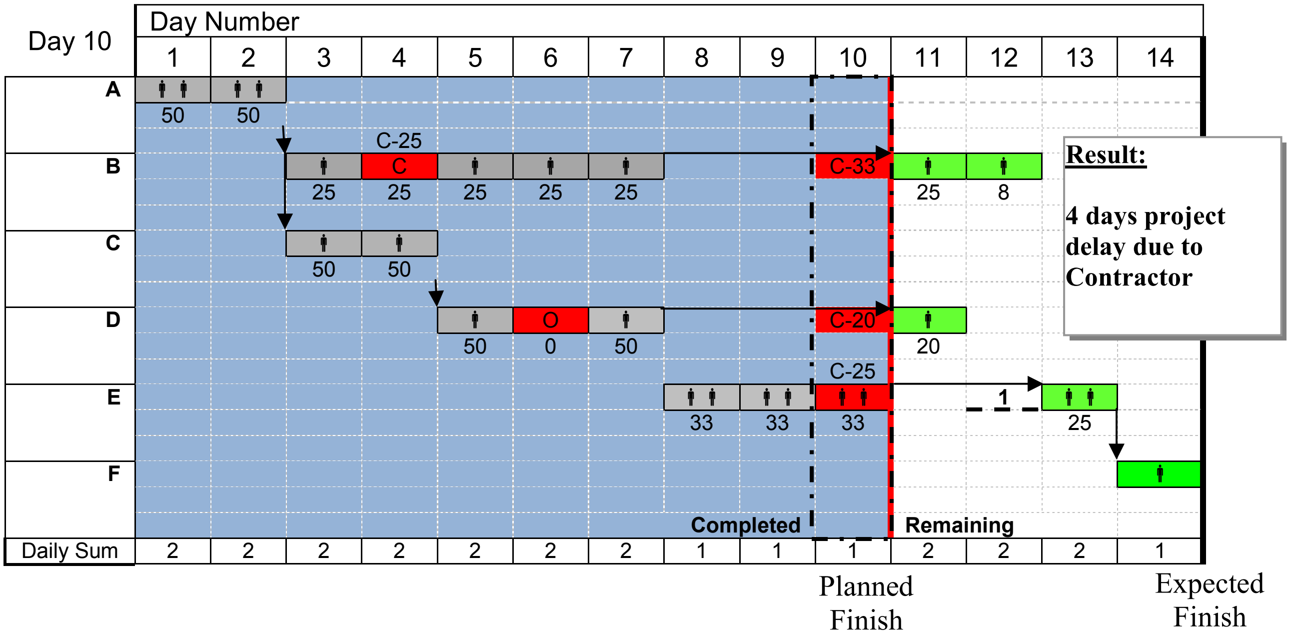
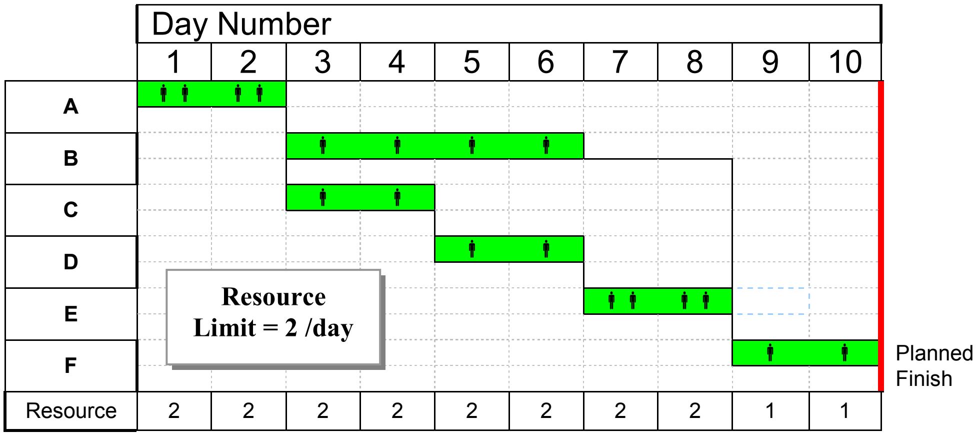


Fig. 4.15: Updated Schedule Showing Rework (Window of Day 10)

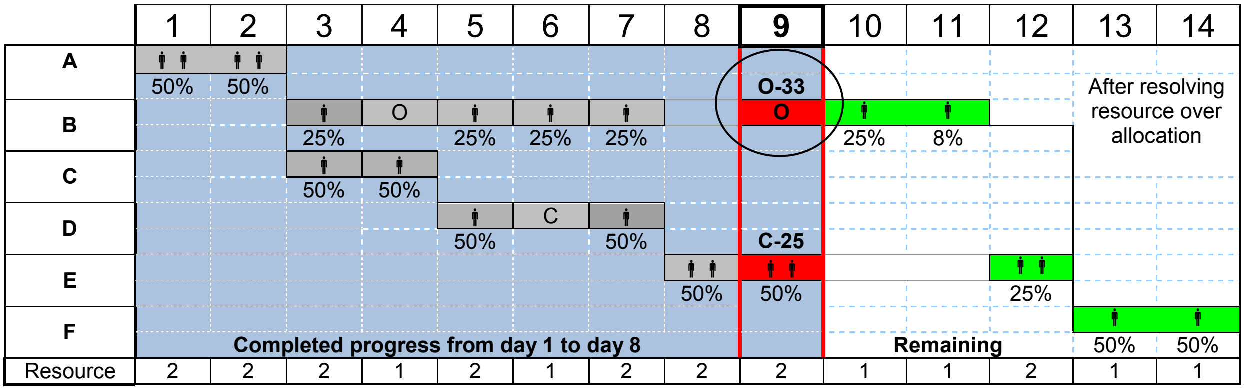
4.4 Analysis of Rework Due to Multiple Parties

For an even more complex situation involving rework due to multiple parties can be examined through consideration of the simple case study shown in fig. 4.16, which is a modified version of the previous case study. Fig. 4.16 shows a 10-day plan in which all resources are within the specified limit of 2 per day. Several progress events are shown for the first 8 days, including work stops by the Owner and the Contractor. On the current progress date (day 9) shown in Fig. 4.16b, rework caused by the Contractor affects activity E (C-25%), and rework for activity B is the responsibility of the Owner, and “O-33%” is therefore indicated. This rework thus extends the project to day 13 before the resource over-allocation is resolved and to day 14 after the resource over-allocation is resolved (Fig. 4.16b). It should be noted that due to the rework, activity B must be extended 2 days since the planned progress is 25 % daily, and the rework amount is 33 %. At this point, the Contractor must consider all the daily events, the rework, and the resource limit in order to calculate his share of the project delay.

Because the first 3 days of progress followed the planned schedule, the daily windows analysis begins with day 4. As shown in Fig. 4.17, the Owner’s work stop (o) for activity B caused an extension to the duration of the activity duration, thus causing a resource over-allocation on day 7. When the Contractor resolves the resource allocation by delaying activity E one day, as shown, a project delay of one day is then anticipated.



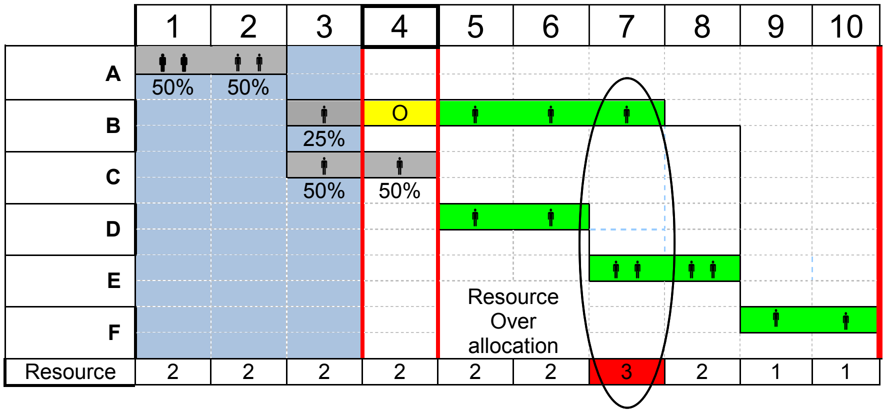
(a) Planned Schedule



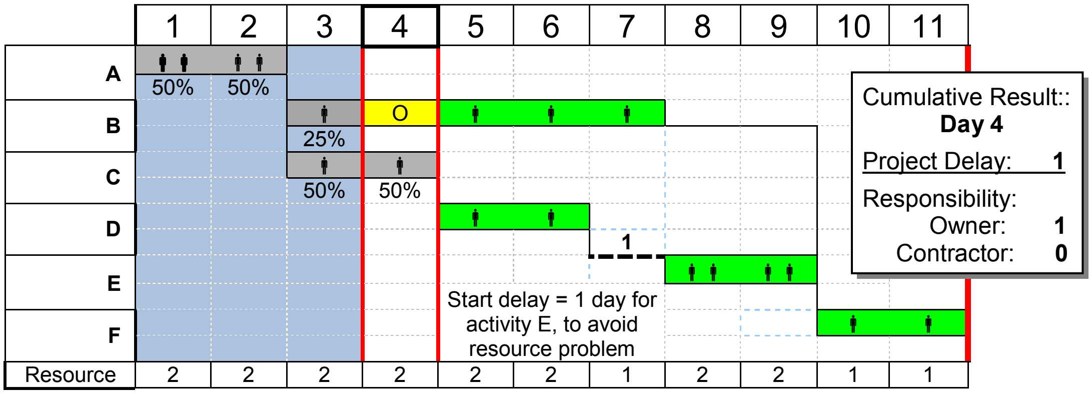
(b) Actual Progress with Owner and Contractor Rework on Day 9

Fig. 4.16: Case Study with Rework Due to Multiple Parties

Thus, according to the events of day 4, the project will be delayed by one day due to Owner's action. Following this process, the events of each day are analyzed, and the responsibility is accumulated, as shown in Fig. 4.17. Some days are omitted because they exhibit no change.



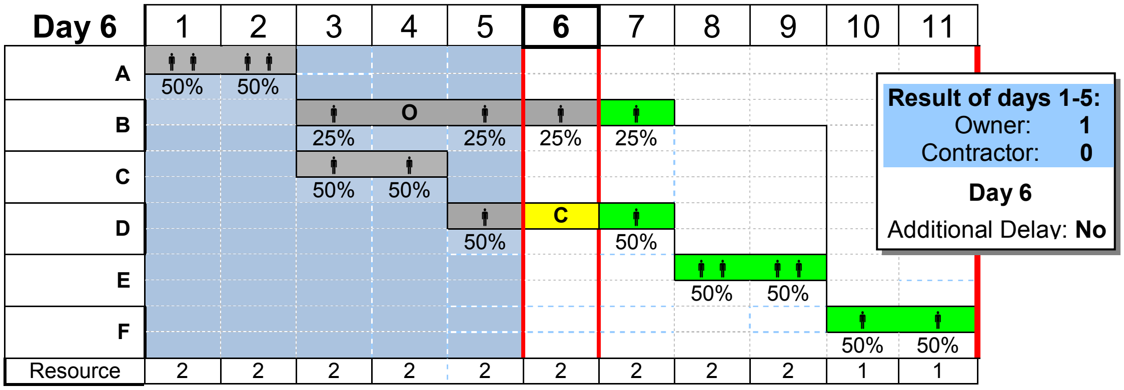
a) Before Resource Allocation



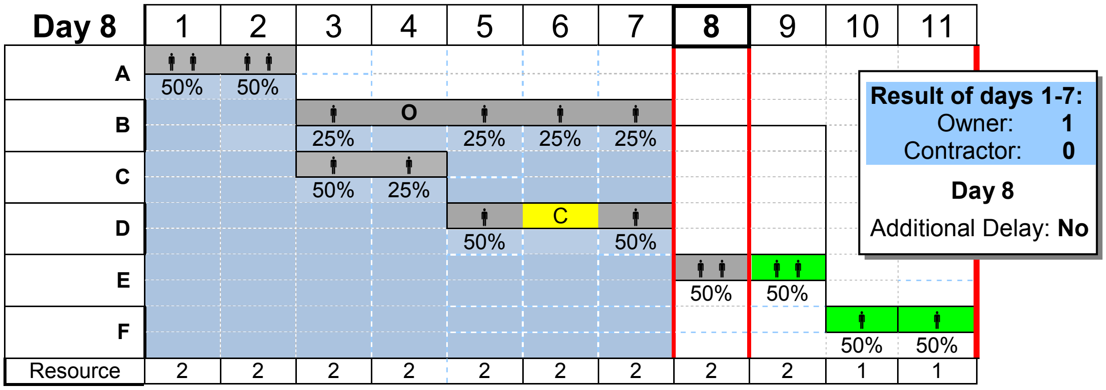
b) After Resource Allocation

Fig. 4.17: Daily Windows Analysis for Day 4

In each analysis window, which represents a day, actual progress is entered on the left side, and the remaining schedule is then recalculated on the right side taking into consideration the resolution of resource over-allocations. Any resulting project delay is thus attributed to the party who caused the delay on the date currently being analyzed. It should be noted that the Contractor's work stop for activity D in window 6 does not cause a project delay (Fig. 4.18a). Progress for day 6 to day 8 also does not lead to any changes in the results (Fig. 4.18b).



a) **Window for Day 6**



b) **Window for Day 8**

Fig. 4.18: Daily Windows Analysis for Days 6 to 8

The analysis for day 9, which included both Owner and Contractor rework (Fig. 4.16), requires a detailed assessment of the actions of each party, and of both combined, as shown in Fig. 4.19. The analysis for window 9 is as follows:

- The cumulative result from the previous window (8) is as follows: Owner (1), Contractors (0), and Neither (0).
- The project extension in window 9 changes from day 11 (window 8) to day 14.
- The day 14 delay appears only when both actions are combined (right side of the schedule in Fig. 4.19). Day 14 is therefore attributed to Owner + Contractor.

- Day 13 appears only in the case of the Owner actions alone (middle of the schedule in Fig. 4.19). Day 13 is therefore attributed to the Owner alone.
- Day 12 appears in all the parties' actions for all cases of Fig. 4.19. therefore day 12 is attributed to Owner + Contractor.
- When all the above results are added the following cumulative delay analysis results:

  Owner (2), "Owner + Contractor" (2), and Neither (0),

  Or more simply, Owner (3), and Contractor (1).

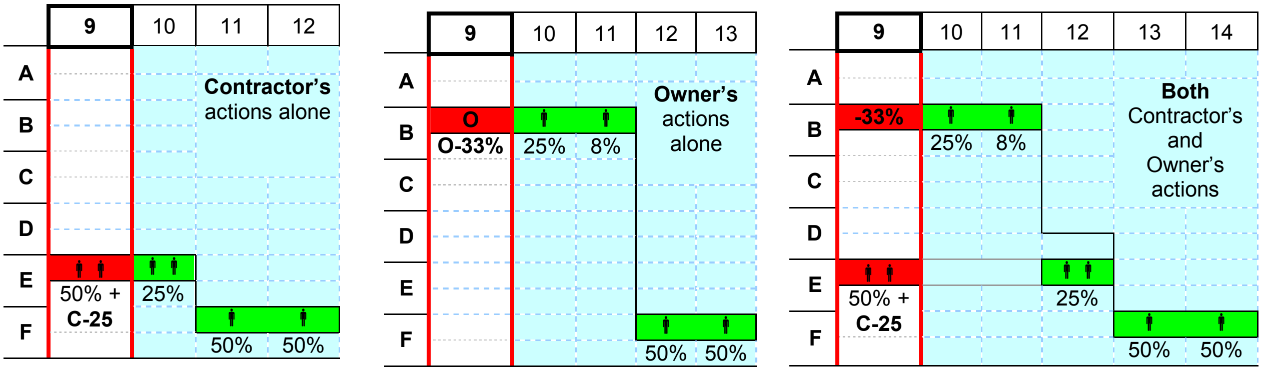


Fig. 4.19: Day 9 Analysis with both Owner and Contractor Rework

4.4 Detailed Schedule Analysis Procedure

The simple example above shows that a systematic analysis procedure is needed. The last case study involving multiple parties shows that the analysis for any day that involves rework requires specific steps as follows:

1. After all site events are recorded, check for any rework required for the performed activities.

2. Check whether the rework affects multiple activities and calculate the magnitude of the work needed for each activity.
3. Confirm whether the rework will be performed or postponed, or not performed.
    a. If the decision is postponed or not performed repeat step one.
    b. If the rework will be performed go to step 4.
4. Calculate the modified activity percentage complete (MPC %), as follows:

    MPC % = Actual Progress to Date (%) – Rework Amount (%) (4.1)

    Calculate the modified activity duration accordingly,

    Modified Activity Duration

    = Actual Duration to Date + Remaining Duration (4.2)

    Where Remaining Duration = Planned Duration * (1 – MPC) (4.3)
5. Update the schedule to accommodate the required duration needed to perform the reworked activities.
6. Check for resource allocation and use start delays to resolve any resource over-allocation.
7. Update the schedule and check for baseline changes; if any exist, check the new project duration (NPD).
8. Calculate delay = NPD – current project duration (CPD) (4.4)
9. If acceleration is required, check the strategies available and select the least costly strategy that restores the CPD.
10. End and advance to the next day.

This detailed rework analysis procedure is shown in Fig. 4.20, and Fig. 4.21 also shows the incorporation of the rework procedure into the extended daily window analysis developed in this research.

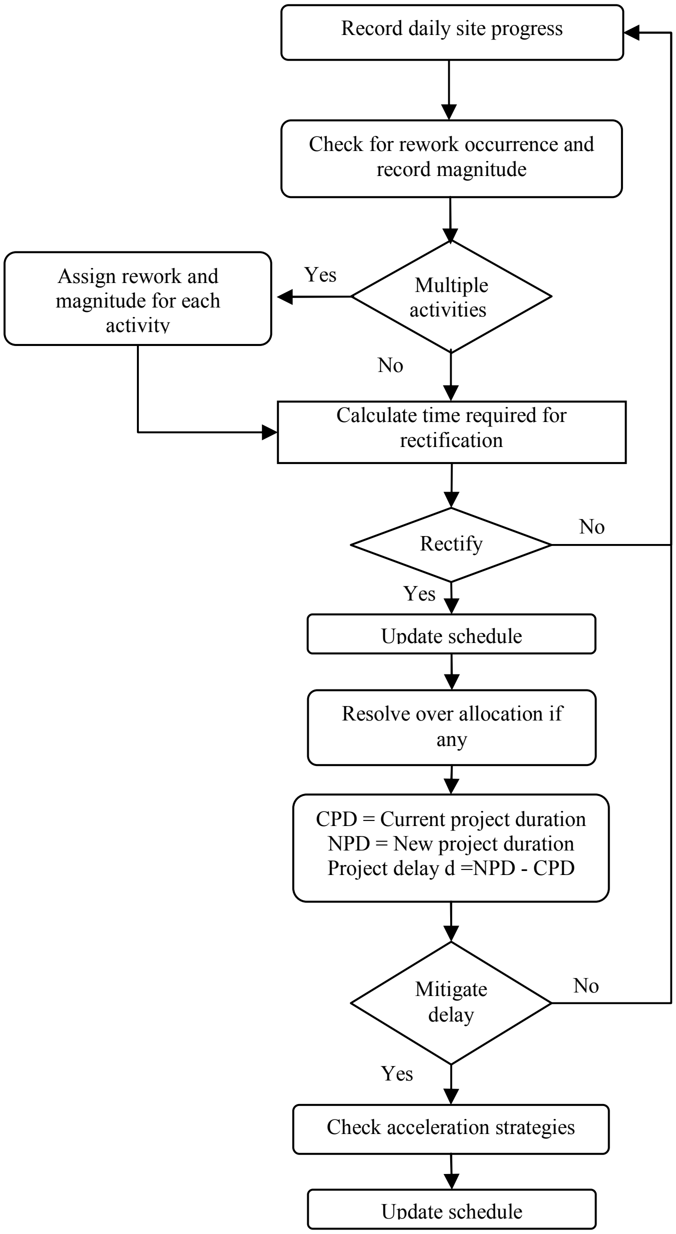


Fig. 4.20: Flowchart of the Rework Analysis Process

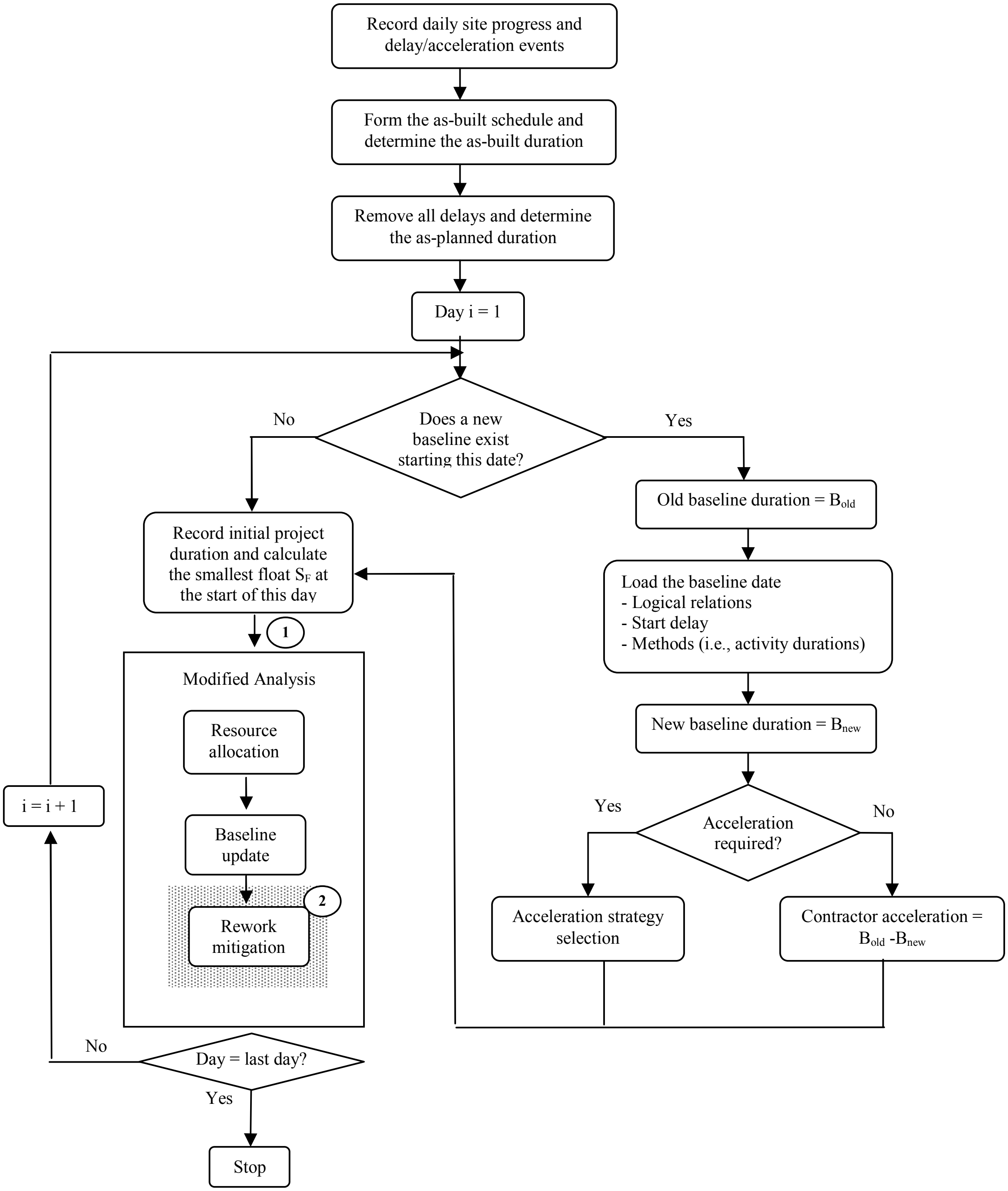


Fig. 4.21: Flowchart of the Schedule Analysis that Takes Rework Mitigations into Consideration

4.5 Conclusion

This chapter has described a generic schedule analysis mechanism for quantifying the impact of rework on a project schedule. Using simple case studies, the new approach has proven beneficial in apportioning responsibility for delays along with an accurate calculation of the impact of the rework on the project schedule and the activities affected. The last step in mitigating the delays is to use an optimization technique to determine the least costly corrective action. Chapter 5 includes a description of this step along with the presentation of the prototype and a case study application.

CHAPTER 5
PROTOTYPE AND CASE STUDY

5.1 Introduction

This chapter describes the implementation of the new analysis mechanism in a prototype computer program. The implementation facilitates the application for a case study and the use of optimization features in order to determine the least costly acceleration strategy for mitigating the impact of rework on the project schedule. The schedule optimization mechanism takes into account all daily events, including rework.

5.2 Case Study Implementation

In line with the representation of daily progress used in this research, a computer prototype, EasyPlan (Hegazy 2006) has been extended to include consideration of rework. The prototype has a number of integrated functions for: managing a simple depository of resources, allowing optional execution methods to be specified, applying optimization in order to test different combinations of decisions, recording actual progress and work interruptions, performing delay analysis, and producing a variety of reports. The three main changes were made to EasyPlan so that rework could be considered: rework representation, modified resource levelling, and modified delay analysis. The built-in schedule optimization feature then optimizes the choice of corrective action and rework mitigation by selecting the optimum combination of decisions (execution methods and start delays) for the remaining activities, as explained in subsequent sections. To demonstrate the prototype, a simple case study was analyzed using the prototype.

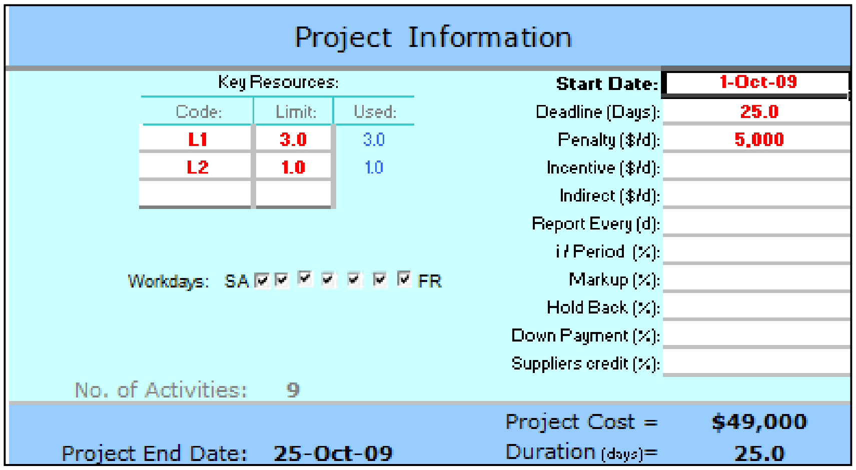
The case study is a segment of a real offshore oil and gas project. The selected activities relate to the off-site preparation of the pipeline (sandblasting and coating), transportation, and installation. Because the durations of the real activities were long, it is not possible to demonstrate them clearly in this chapter. Therefore, for demonstration purposes, the durations of the activities have been reduced, but the relationships remained unchanged. The sample activities are thus shown in Table 5.1.

Table 5.1: Activities and Their Logical Relationships

Activity Number and Name	Sequence
1. Material delivery	None (first activity)
2. Sand blasting	Starts after end of activity1
3. Fusion Bond Epoxy (FBE) coating for type 1pipes	Starts after end of activity 2
4. Concrete coating for type 2 pipes	Starts after end of activity 2
5. Concrete curing for type 2 pipes	Starts one day after start of activity 4
6. Transportation for FBE pipes (type 1)	Starts three days after start of activity 3
7. Transportation for concrete coated pipes (type 2)	Starts after end of activity 6 and six days after start of activity 5
8. Loading to the transportation vessel and	Starts after end of both activities 6 and 7
9. Pipe installation	Starts after end of activity 8

5.2.1 Baseline Schedule

Using the prototype, the project information is first entered into the project information window shown in Fig. 5.1: project start date, deadline duration, and the delay penalty for each day beyond the deadline. In this window, the resource availability limits are also specified, as follows: resource L1 (limit = 3 per day) and resource L2 (limit = 1 per day).



Key Resources:

Code:	Limit:	Used:
L1	3.0	3.0
L2	1.0	1.0

Workdays: SA ☑ ☑ ☑ ☑ ☑ ☑ ☑ FR

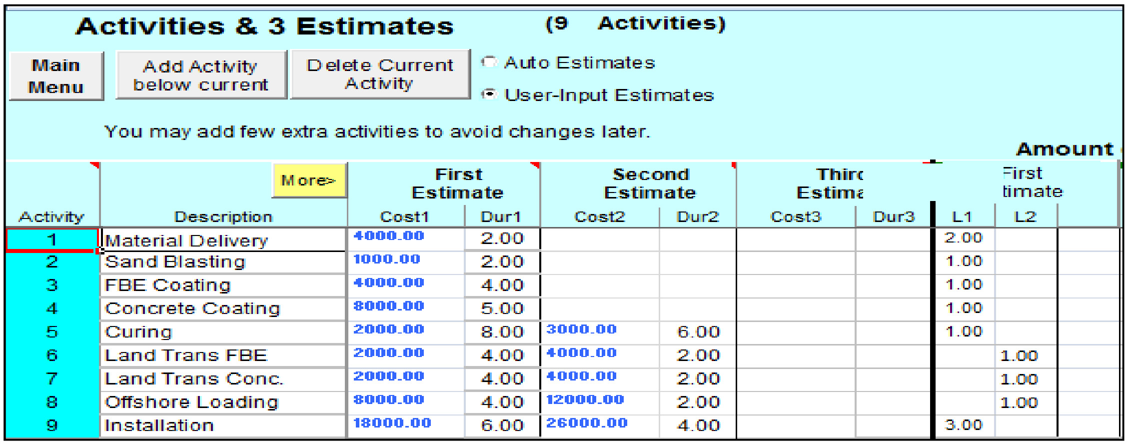
Start Date: 1-Oct-09
Deadline (Days): 25.0
Penalty ($/d): 5,000
Incentive ($/d):
Indirect ($/d):
Report Every (d):
i / Period (%):
Markup (%):
Hold Back (%):
Down Payment (%):
Suppliers credit (%):

No. of Activities: 9

Project Cost = $49,000
Project End Date: 25-Oct-09
Duration (days)= 25.0

Fig. 5.1: General Project Information

After the project general information is entered, the project activities and their optional methods of construction, along with their durations, costs, and resource needs, are defined in the system (Fig. 5.2). Initially, the cheapest construction option is used for the activities and the more expensive alternatives, which have a shorter duration, are saved as optional execution methods that can be used by the schedule optimization feature in case the project needs to be accelerated for any reason, as discussed earlier. The information about the activities is shown in Fig. 5.2.



○ Auto Estimates
● User-Input Estimates

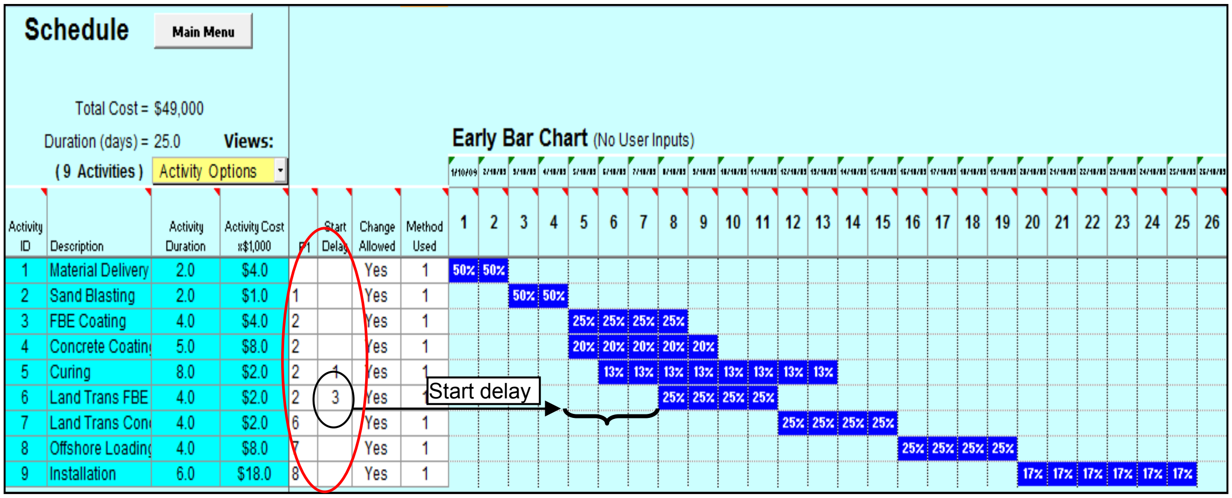
You may add few extra activities to avoid changes later.

		First Estimate		Second Estimate		Thirc Estima		Amount First timate	
Activity	Description	Cost1	Dur1	Cost2	Dur2	Cost3	Dur3	L1	L2
1	Material Delivery	4000.00	2.00					2.00	
2	Sand Blasting	1000.00	2.00					1.00	
3	FBE Coating	4000.00	4.00					1.00	
4	Concrete Coating	8000.00	5.00					1.00	
5	Curing	2000.00	8.00	3000.00	6.00			1.00	
6	Land Trans FBE	2000.00	4.00	4000.00	2.00				1.00
7	Land Trans Conc.	2000.00	4.00	4000.00	2.00				1.00
8	Offshore Loading	8000.00	4.00	12000.00	2.00				1.00
9	Installation	18000.00	6.00	26000.00	4.00			3.00	

Cheap & Slow Option
Expensive & Fast Option

Fig. 5.2: Activities and Their Construction Methods

After the project activities and their construction methods are defined, the logical relationships between the activities (Table 1) are entered, as shown in Fig. 5.3. It should be noted that activity 4 has a start delay of 3 days in order to satisfy the sequence requirements listed in Table 5.1.



Schedule

Total Cost = $49,000

Duration (days) = 25.0

(9 Activities)

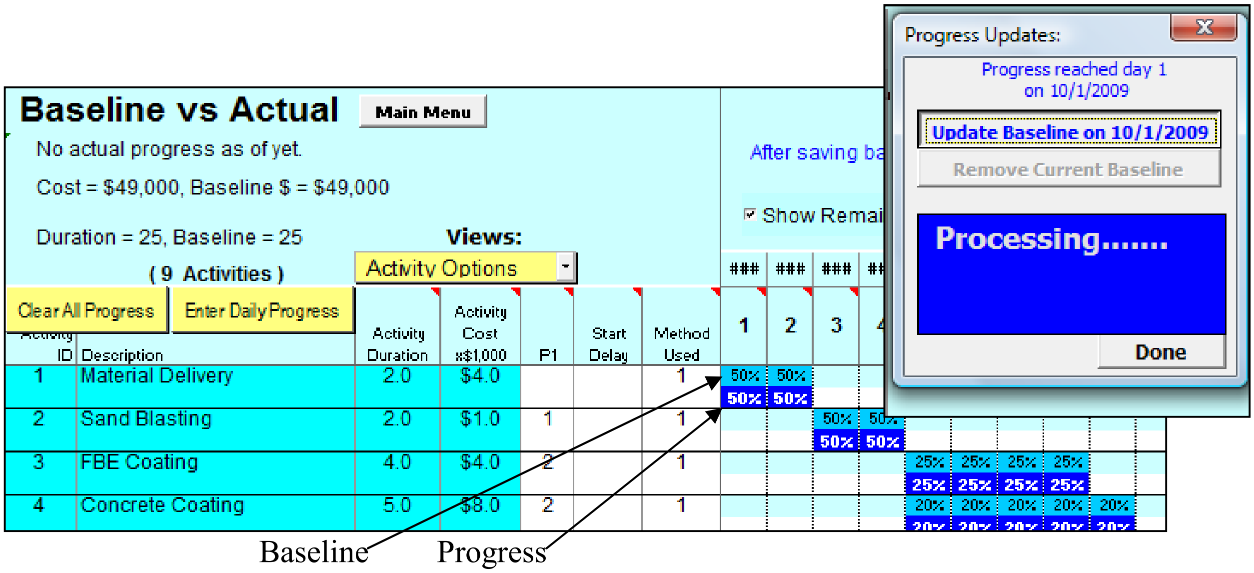
Views:

Early Bar Chart (No User Inputs)

Activity ID	Description	Activity Duration	Activity Cost x$1,000	P1	Start Delay	Change Allowed	Method Used	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1	Material Delivery	2.0	$4.0			Yes	1	50%	50%																								
2	Sand Blasting	2.0	$1.0	1		Yes	1			50%	50%																						
3	FBE Coating	4.0	$4.0	2		Yes	1					25%	25%	25%	25%																		
4	Concrete Coatin	5.0	$8.0	2		Yes	1					20%	20%	20%	20%	20%																	
5	Curing	8.0	$2.0	2	1	Yes	1						13%	13%	13%	13%	13%	13%	13%	13%													
6	Land Trans FBE	4.0	$2.0	2	3	Yes	1								25%	25%	25%	25%															
7	Land Trans Con	4.0	$2.0	6		Yes	1												25%	25%	25%	25%											
8	Offshore Loadin	4.0	$8.0	7		Yes	1																25%	25%	25%	25%							
9	Installation	6.0	$18.0	8		Yes	1																				17%	17%	17%	17%	17%	17%	

Fig. 5.3: Relationships among the Activities and Resulting Schedule

The schedule shows no resource over-allocation, and the overall project duration is 25 days. The critical path for the project flows through activities 1-2-4-5-7-8-9. Since this plan is satisfactory for the Contractor, a baseline is approved by the Owner, and accordingly the project baseline is saved as shown in Fig. 5.4. The Fig. shows the schedule before the start of actual progress with 2 bars for each activity. The top bar represents the baseline while the bottom bar represents the actual, which is assumed to follow the baseline. The user then can enter the actual progress events, as explained in the next subsection.



No actual progress as of yet.

Cost = $49,000, Baseline $ = $49,000

Duration = 25, Baseline = 25

(9 Activities)

After saving ba

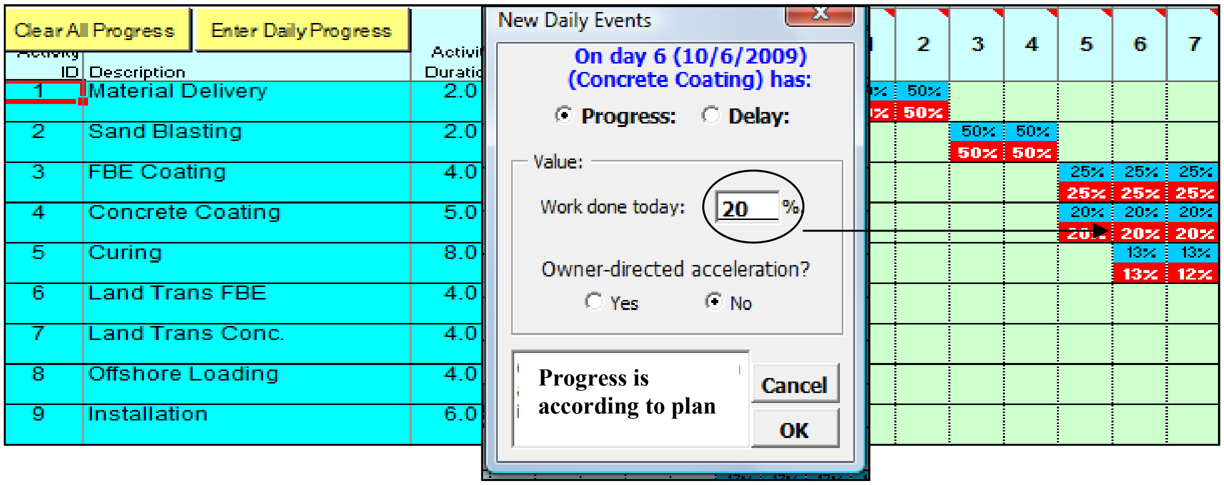
Progress reached day 1 on 10/1/2009

Activity ID	Description	Activity Duration	Activity Cost x$1,000	P1	Start Delay	Method Used	1	2	3
1	Material Delivery	2.0	$4.0			1	50% 50%	50% 50%	
2	Sand Blasting	2.0	$1.0	1		1			50% 50%
3	FBE Coating	4.0	$4.0	2		1			
4	Concrete Coating	5.0	$8.0	2		1			

Fig. 5.4: Saving the Project Baseline Schedule

5.2.2 Actual Progress Events

From day one through day 7, the actual progress followed the as-planned schedule without deviation. This data was entered into the prototype using the activity progress form, an example of which for day 6 is shown in Fig. 5.5. The as-built schedule followed the as-planned schedule for the first 7 days, as shown in Fig. 5.6, with the project duration still expected to be 25 days.



On day 6 (10/6/2009) (Concrete Coating) has:

● Progress: ○ Delay:

Value:

Work done today: 20 %

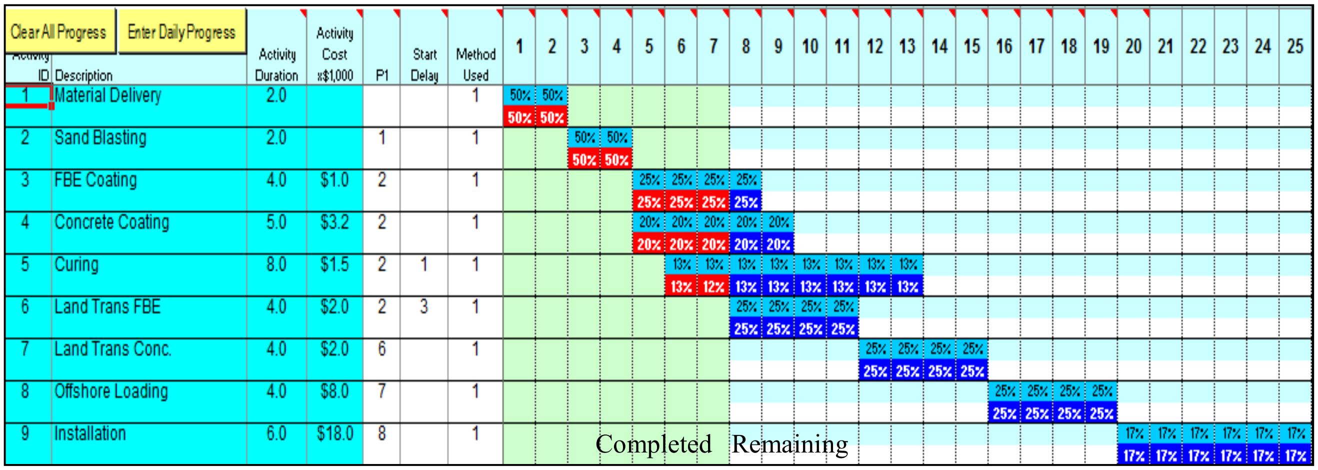
Owner-directed acceleration?

○ Yes ● No

Progress is according to plan

Activity ID	Description	Activity Duration
1	Material Delivery	2.0
2	Sand Blasting	2.0
3	FBE Coating	4.0
4	Concrete Coating	5.0
5	Curing	8.0
6	Land Trans FBE	4.0
7	Land Trans Conc.	4.0
8	Offshore Loading	4.0
9	Installation	6.0

Fig. 5.5: Form for Entering Activity Progress Information on Day 6

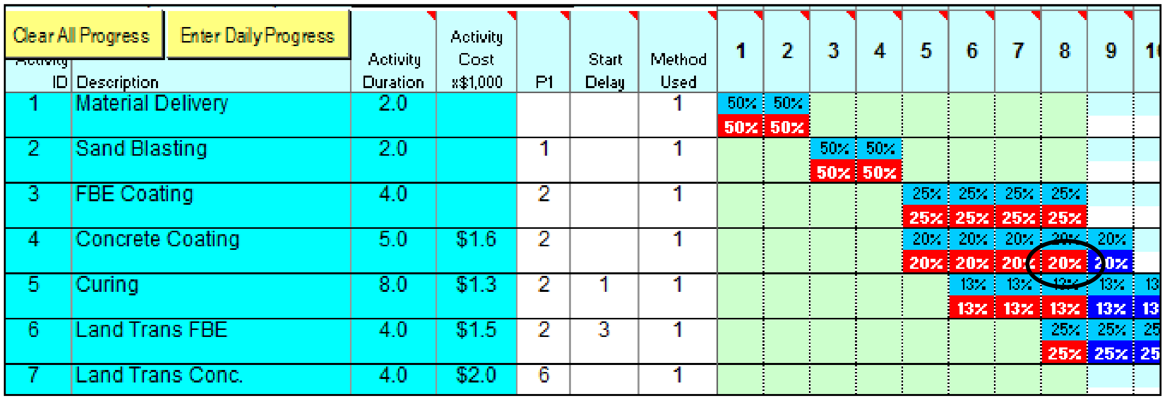


ID	Description	Activity Duration	Activity Cost x$1,000	P1	Start Delay	Method Used	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	Material Delivery	2.0				1	50% 50%	50% 50%																							
2	Sand Blasting	2.0		1		1			50% 50%	50% 50%																					
3	FBE Coating	4.0	$1.0	2		1					25% 25%	25% 25%	25% 25%	25% 25%																	
4	Concrete Coating	5.0	$3.2	2		1					20% 20%	20% 20%	20% 20%	20% 20%	20% 20%																
5	Curing	8.0	$1.5	2	1	1						13% 13%	13% 12%	13% 13%	13% 13%	13% 13%	13% 13%	13% 13%	13% 13%												
6	Land Trans FBE	4.0	$2.0	2	3	1								25% 25%	25% 25%	25% 25%	25% 25%														
7	Land Trans Conc.	4.0	$2.0	6		1												25% 25%	25% 25%	25% 25%	25% 25%										
8	Offshore Loading	4.0	$8.0	7		1																25% 25%	25% 25%	25% 25%	25% 25%						
9	Installation	6.0	$18.0	8		1																				17% 17%	17% 17%	17% 17%	17% 17%	17% 17%	17% 17%

Fig. 5.6: Schedule at the End of Day 7 with the Project Duration Still 25 Days

5.2.3 The Challenge of Representing Rework

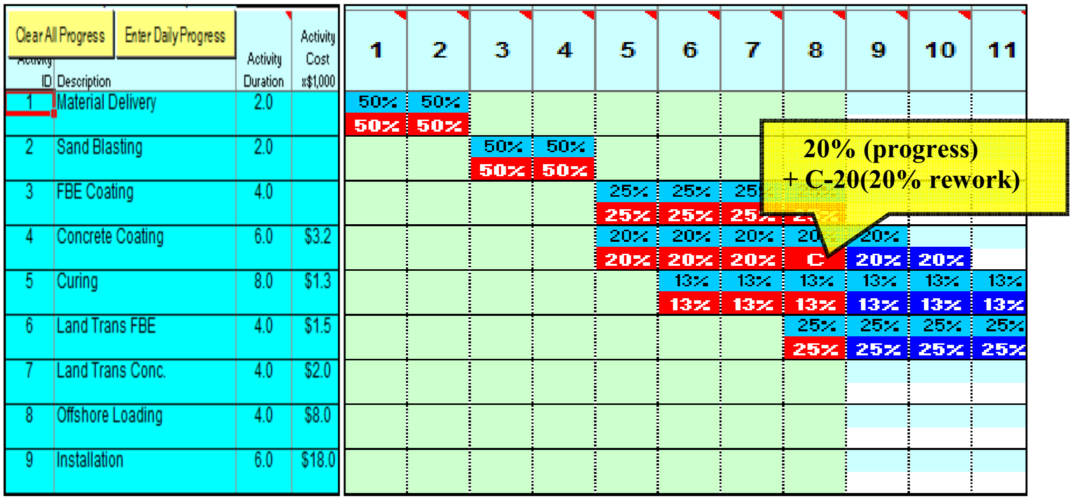
On day 8, activity 4 (concrete coating) was progressed another 20 % but then defects were observed in the pipe coating that had been completed earlier and that was estimated to be about 20 % of the activity. Accordingly, a decision was made to redo the defective pipes. To represent this situation, on day 8, 20 % progress is first entered for the activity on that day, as shown in Fig 5.7.



ID	Description	Activity Duration	Activity Cost x$1,000	P1	Start Delay	Method Used	1	2	3	4	5	6	7	8	9	1
1	Material Delivery	2.0				1	50% 50%	50% 50%								
2	Sand Blasting	2.0		1		1			50% 50%	50% 50%						
3	FBE Coating	4.0		2		1					25% 25%	25% 25%	25% 25%	25% 25%		
4	Concrete Coating	5.0	$1.6	2		1					20% 20%	20% 20%	20% 20%	20% 20%	20% 20%	
5	Curing	8.0	$1.3	2	1	1						13% 13%	13% 13%	13% 13%	13% 13%	13 13
6	Land Trans FBE	4.0	$1.5	2	3	1								25% 25%	25% 25%	25 25
7	Land Trans Conc.	4.0	$2.0	6		1										

Fig. 5.7: Recording the Progress for Day 6, Before Rework

Then, since the magnitude of the rework is calculated as 20 %, a rework event is then entered as a negative percentage complete. Thus, the total amount of progress for the activity on that day is zero, as shown in Fig 5.8.



Activity ID	Description	Activity Duration	Activity Cost x$1,000	1	2	3	4	5	6	7	8	9	10	11
1	Material Delivery	2.0		50% 50%	50% 50%									
2	Sand Blasting	2.0				50% 50%	50% 50%							
3	FBE Coating	4.0						25% 25%	25% 25%	25 25				
4	Concrete Coating	6.0	$3.2					20% 20%	20% 20%	20% 20%	20 C	20% 20%	20%	
5	Curing	8.0	$1.3						13% 13%	13% 13%	13% 13%	13% 13%	13% 13%	13% 13%
6	Land Trans FBE	4.0	$1.5								25% 25%	25% 25%	25% 25%	25% 25%
7	Land Trans Conc.	4.0	$2.0											
8	Offshore Loading	4.0	$8.0											
9	Installation	6.0	$18.0											

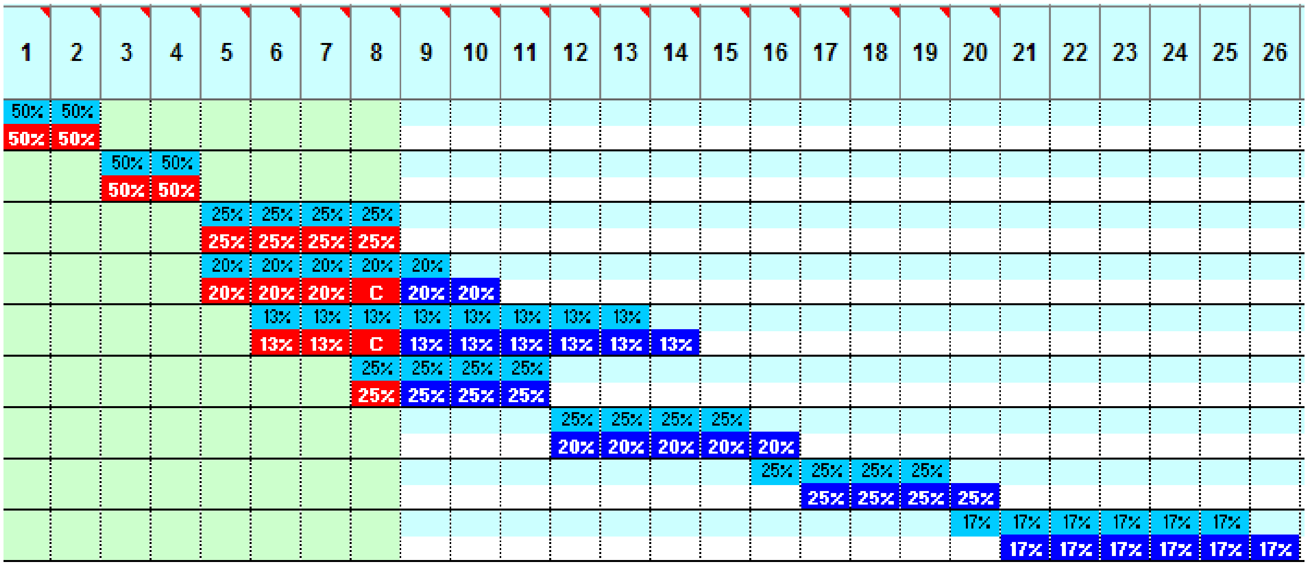
20% (progress)
+ C-20(20% rework)

Fig. 5.8: Updating Activity 4 on Day 6 Based on the Observed Rework

As a result of the rework, the duration of the activity is extended by the amount of time needed to perform the rework, in this case, from 5 days in Fig. 5.7 to 6 days in Fig. 5.8. It should be noted that the remaining part of the activity duration is calculated using Eq. 4.1. Therefore, activity 4 is scheduled to finish on day 10 rather than day 9. Moreover, the extended duration of activity 4 was assessed and found to affect other activities as follows:

- Successor activity 5 (curing) must be performed for the reworked pipes, and a curing rework of 13 % must therefore be added, which will extend the total duration for curing to 9 days (ending on day 14)
- Transportation activity 7 must be rearranged, and transportation will thus take 5 days rather than 4.

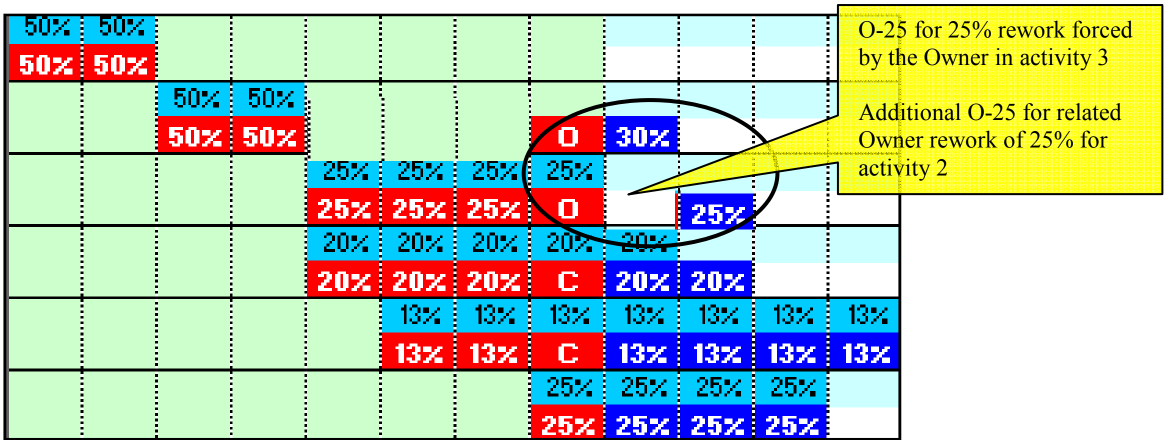
Once these changes are made to the schedule, the project duration is extended to 26 days rather than 25, as shown in Fig. 5.9.



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
50%	50%																								
50%	50%																								
		50%	50%																						
		50%	50%																						
				25%	25%	25%	25%																		
				25%	25%	25%	25%																		
				20%	20%	20%	20%	20%																	
				20%	20%	20%	C	20%	20%																
					13%	13%	13%	13%	13%	13%	13%	13%													
					13%	13%	C	13%	13%	13%	13%	13%	13%												
							25%	25%	25%	25%															
							25%	25%	25%	25%															
											25%	25%	25%	25%											
											20%	20%	20%	20%	20%										
															25%	25%	25%	25%							
																25%	25%	25%	25%						
																			17%	17%	17%	17%	17%	17%	
																				17%	17%	17%	17%	17%	17%

Fig. 5.9: Revised Schedule Showing the Rework in Activity 4 and Its Consequences

Concurrently with the Contractor events on day 8 described above, the Owner was contemplating another rework on the same day, due to a design change for activity 3 (FBE coating), which represented 25 % of the total work for the activity. This rework caused by the Owner is expected to impact other activities, mainly sandblasting (activity 2) in order to remove the old FBE coating (also 30 % of the work executed in activity 2). The updated schedule resulting from these events is shown in Fig 5.10.

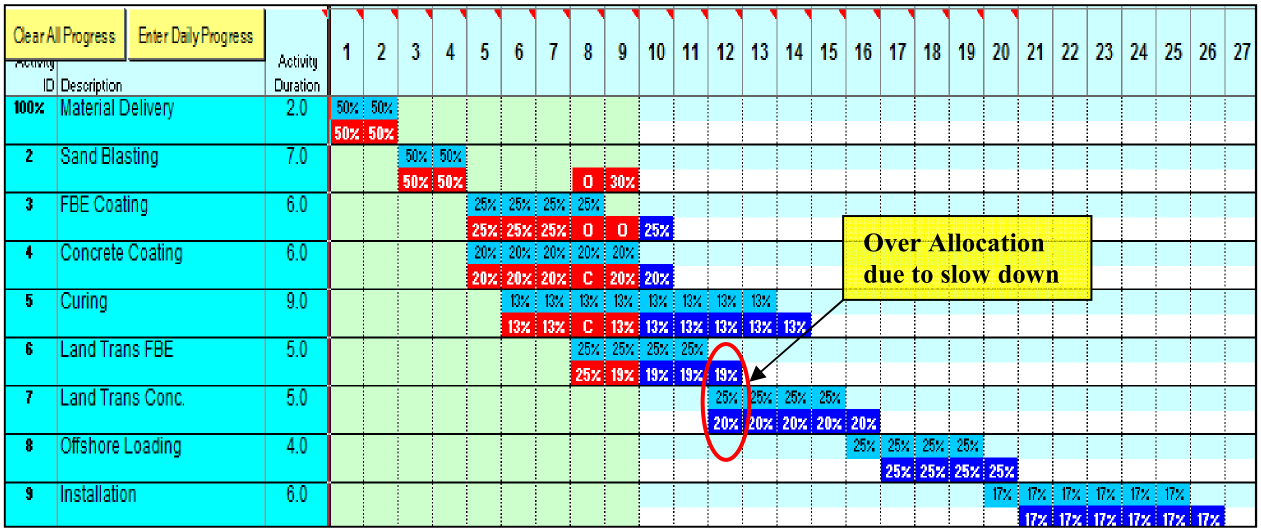


O-25 for 25% rework forced by the Owner in activity 3

Additional O-25 for related Owner rework of 25% for activity 2

Fig. 5.10: Effect of Rework on Multiple Activities

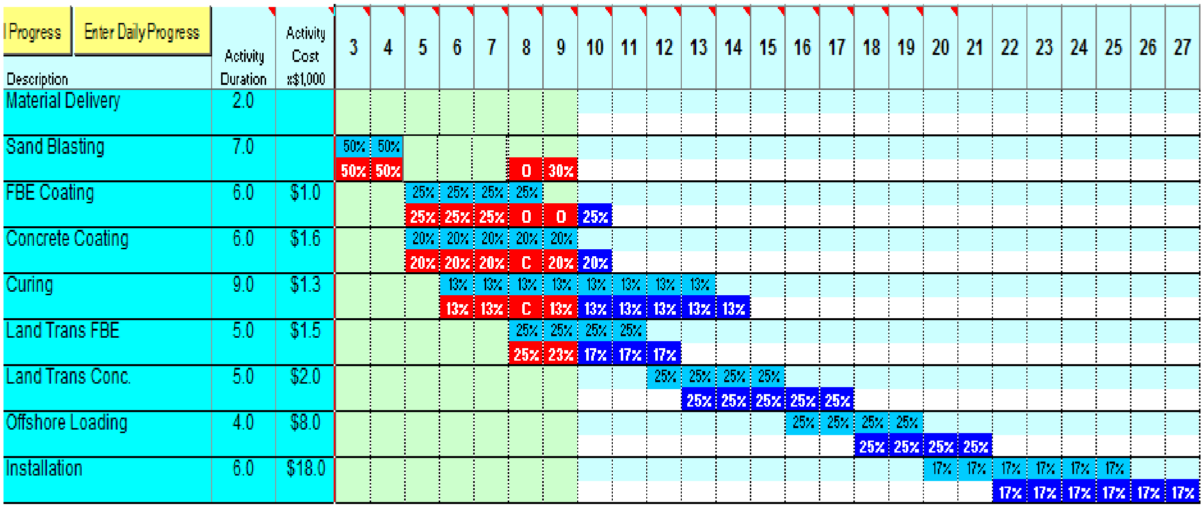
As a result of these schedule events, the Contractor is not in a rush to complete the transportation activity with the as-planned speed. To ensure the continued flow of transportation activity and to save money, the Contractor decided to slow down the remaining transportation activity, perceiving that it will not have a negative effect on the schedule. However, the schedule in this case as shown in Fig. 5.11, also included a resource over-allocation for day 12 due to the extension of activity 5 (FBE pipes transportation). It is noted that the Contractor's action of slowing down some activities is common in practice and has been referred to in the literature as a pacing delay, which changes the pace of some activities to match the pace of others (Zack, 1999).



ID	Description	Activity Duration	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
100%	Material Delivery	2.0	50%	50%																									
			50%	50%																									
2	Sand Blasting	7.0			50%	50%																							
					50%	50%				0	30%																		
3	FBE Coating	6.0					25%	25%	25%	25%																			
							25%	25%	25%	0	0	25%																	
4	Concrete Coating	6.0					20%	20%	20%	20%	20%																		
							20%	20%	20%	C	20%	20%																	
5	Curing	9.0						13%	13%	13%	13%	13%	13%	13%	13%														
								13%	13%	C	13%	13%	13%	13%	13%	13%													
6	Land Trans FBE	5.0								25%	25%	25%	25%																
										25%	19%	19%	19%	19%															
7	Land Trans Conc.	5.0												25%	25%	25%	25%												
														20%	20%	20%	20%	20%											
8	Offshore Loading	4.0																25%	25%	25%	25%								
																	25%	25%	25%	25%							
9	Installation	6.0																				17%	17%	17%	17%	17%	17%		
																					17%	17%	17%	17%	17%	17%	

Fig. 5.11: Updated Schedule Showing the Resource Over-Allocation

To resolve the resource over-allocation, the Contractor was forced to introduce a start delay of one day to activity 7 (concrete coated pipes transportation). This start delay affects the project duration by one day, so, the final updated schedule for the project has 27-day duration, with a total delay of 2 days compared to the baseline. After all the rework events and their effects on the project schedule are taken into consideration, and after all the resource over-allocations are resolved, the schedule is updated as shown in Fig. 5.12.



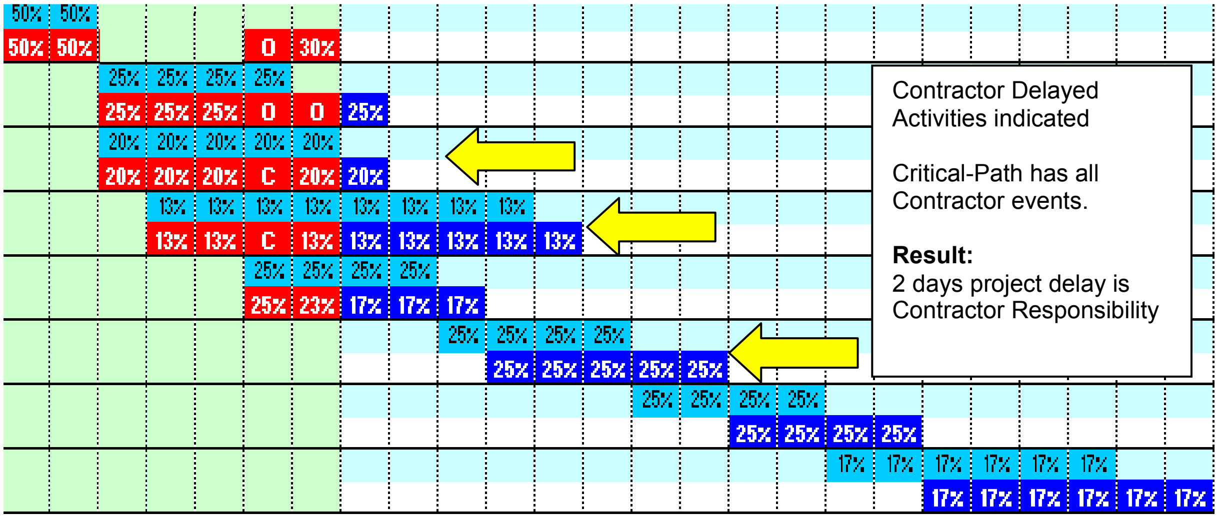
Description	Activity Duration	Activity Cost x$1,000	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Material Delivery	2.0																										
Sand Blasting	7.0		50%	50%																							
			50%	50%				0	30%																
FBE Coating	6.0	$1.0			25%	25%	25%	25%																			
					25%	25%	25%	0	0	25%																	
Concrete Coating	6.0	$1.6			20%	20%	20%	20%	20%																		
					20%	20%	20%	C	20%	20%																	
Curing	9.0	$1.3				13%	13%	13%	13%	13%	13%	13%	13%														
						13%	13%	C	13%	13%	13%	13%	13%	13%													
Land Trans FBE	5.0	$1.5						25%	25%	25%	25%																
								25%	23%	17%	17%	17%															
Land Trans Conc.	5.0	$2.0										25%	25%	25%	25%												
													25%	25%	25%	25%	25%										
Offshore Loading	4.0	$8.0														25%	25%	25%	25%								
																		25%	25%	25%	25%						
Installation	6.0	$18.0																		17%	17%	17%	17%	17%	17%		
																						17%	17%	17%	17%	17%	17%

Fig. 5.12: Updated Schedule That considers Rework and Pacing Delays

Based on the delay penalty amount mentioned in the project information (delay penalty = $5,000 per day), the project team decided to investigate the mitigation strategies available to enable them to meet the original project deadline.

Accelerating the project schedule involves changing some of the execution methods by selecting faster (although more costly) ones. First, the responsibility for the delays should be apportioned among the project parties. Both the traditional and the extended daily window analysis were used to compare the results.

The traditional window analysis was used first when the project was analyzed as one window of 27 days without considering the effect of resource over-allocation as shown in Fig. 5.13, the 2 days of project delay were apportioned to the Contractor.



Contractor Delayed Activities indicated

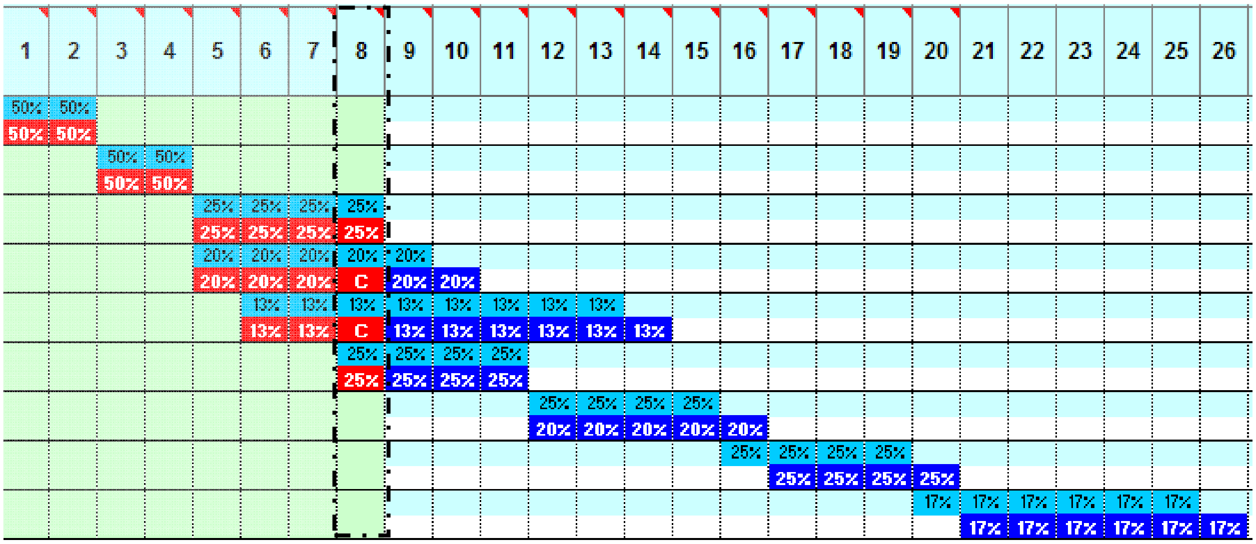
Critical-Path has all Contractor events.

Result:
2 days project delay is Contractor Responsibility

Fig. 5.13: Traditional Window Analysis Using One Window of 27 Days

When the extended window analysis is used, on the other hand, the analysis focused on days 8 and 9, as follows:

Window for Day 8 (Fig. 5.14): The Contractor experiences a rework event that delays activity 4 by one day and extends the preceding activities (5 and 7) by one day so that the project duration is extended to 26 days. Adding the Owner's rework does not change the project duration. One day delay is therefore attributed to the Contractor.

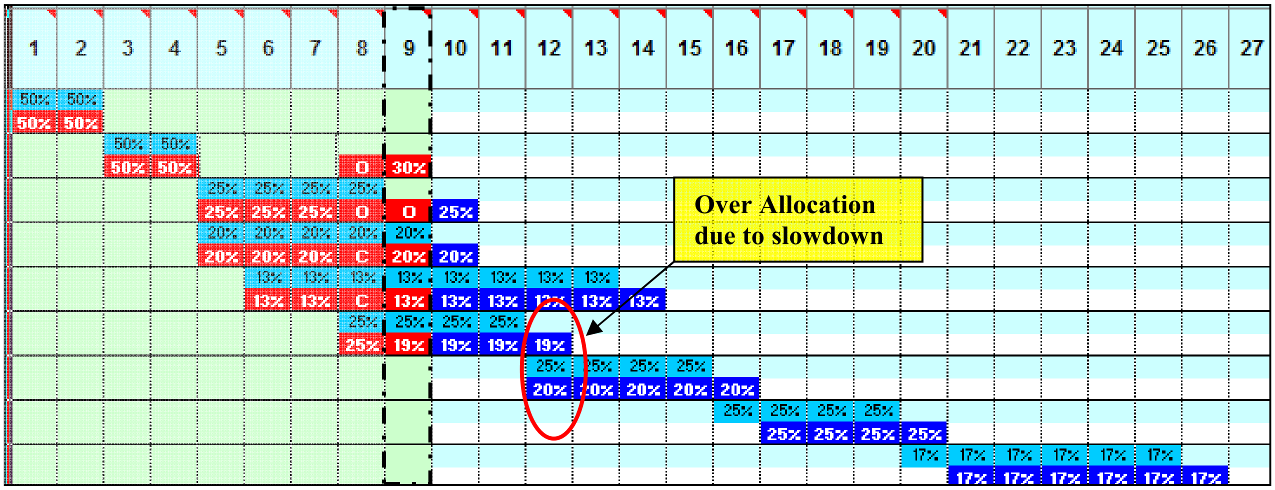


1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
50%	50%																								
50%	50%																								
		50%	50%																						
		50%	50%																						
				25%	25%	25%	25%																		
				25%	25%	25%	25%																		
				20%	20%	20%	20%	20%																	
				20%	20%	20%	C	20%	20%																
					13%	13%	13%	13%	13%	13%	13%	13%													
					13%	13%	C	13%	13%	13%	13%	13%	13%												
							25%	25%	25%	25%															
							25%	25%	25%	25%															
											25%	25%	25%	25%											
											20%	20%	20%	20%	20%										
															25%	25%	25%	25%							
																25%	25%	25%	25%						
																			17%	17%	17%	17%	17%	17%	
																				17%	17%	17%	17%	17%	17%

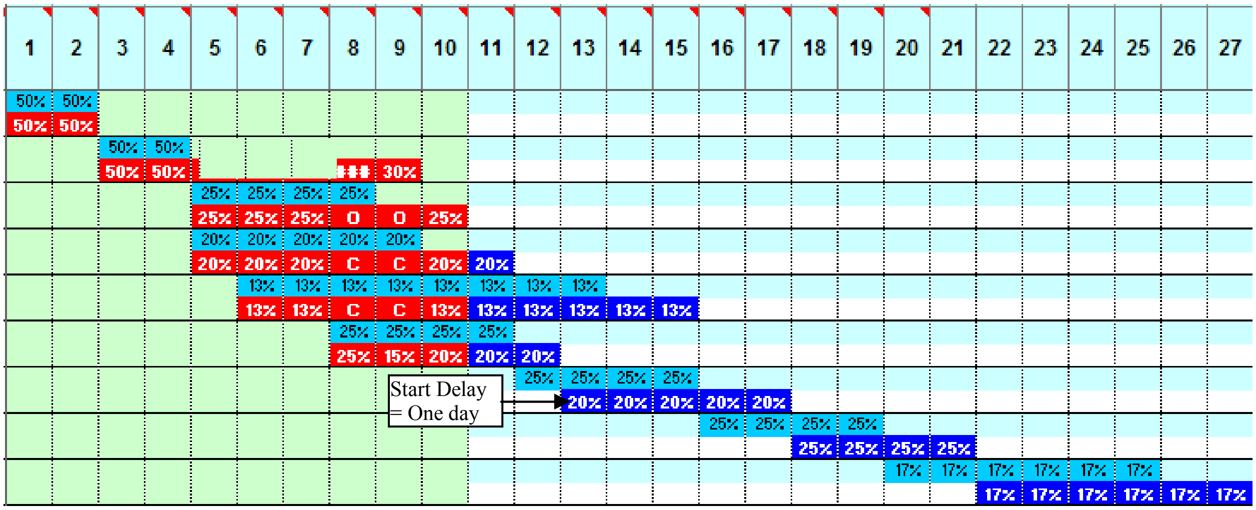
Fig. 5.14: Extended Windows Analysis - Window for Day 8 Before Owner Rework

Window for Day 9 (Fig. 5.15): The Owner forced a rework of activity 3 on day 8, which results in an additional Owner delay for activity 3, which is caused by the rework for activity 2 that is necessary for the proper execution of the work. This delay causes an extension to activity 6 of one day, leading to a resource over-allocation on day 12, as shown in Fig 5.15.

To resolve this over-allocation, a start delay was introduced to activity 7, which leads to the extension of the project from 26 days to 27. The cause of this delay was therefore attributed to the Owner.



a) With Resource Over-Allocation



b) After Resolving Resource Over-Allocation

Fig. 5.15: Window for Day 9 After Owner Rework

The results of the analysis the project delays are as follows;

- One day of Contractor rework delay on day 8
- One day of Owner resource over-allocation delay on day 12

Based on this analysis, the project team then investigates the options for mitigating the rework delay, as explained in the following subsection.

5.2.4 Optimizing the Mitigation Decision

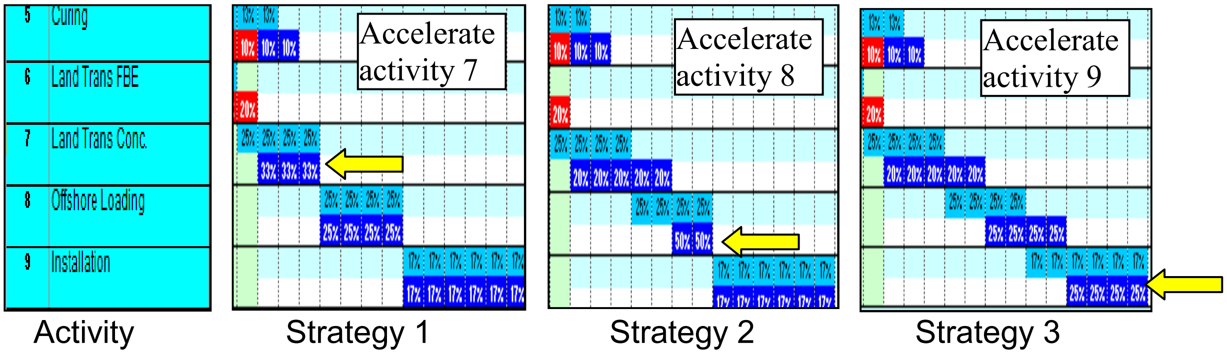
Once the results of the delay analysis are known (Owner (1) and Contractor (1)), the Contractor can present these results to the Owner so that the Contractor can choose between 2 options: (1) request a one-day extension due to the Owner delay and attempt to mitigate his own one-day delay; (2) mitigate all delays by considering a one-day Owner-directed acceleration. In general, however, the ability of the Contractor to mitigate delays depends on when the rework is discovered and scheduled. The earlier the rework occurs in the project, the less impact it will have and more options will also be available for mitigating the impact. In the present case study, the rework was introduced nearly in the middle of the project. The Contractor therefore seek to mitigate all delay days and so that the 25-day duration deadline can be met without violating the resource limit.

To facilitate the planning of corrective action, this research uses optimization to help the Contractor select the best mitigation strategy. The mechanism basically involves total cost minimization under time and resource constraints, which also takes into consideration any penalty, incentive, or indirect costs. To enable the optimization, optional execution methods (e.g., larger crew formations, better equipment, and/or overtime hours) need to be identified for the activities remaining in the schedule. In essence, two basic decisions are needed for each of the remaining activities: (1) the execution method that will enable the deadline to be met with at minimum cost (e.g., normal versus a speedier and more costly option), and (2) any start time delay that can be applied to any activity (as in Fig. 5.12 on day 12) to avoid resource over-allocation. The combination of these activity decisions represents a corrective action plan. Because of the number of possibilities for speeding up one activity versus another and for delaying one activity versus another, any real-life project requires some automation so that different combinations can be tested until a satisfactory or near optimum, solution is determined.

Exploring the options available for the remaining duration of the project reveal 3 possible options. The Contractor has the option to crash one of 3 activities:

1- Activity 7, Concrete land transportation: an increase in cost of $ 2000
2- Activity 8, Offshore loading: an increase in cost of $ 4000
3- Activity 9, Installation: an increase in cost of $ 8000

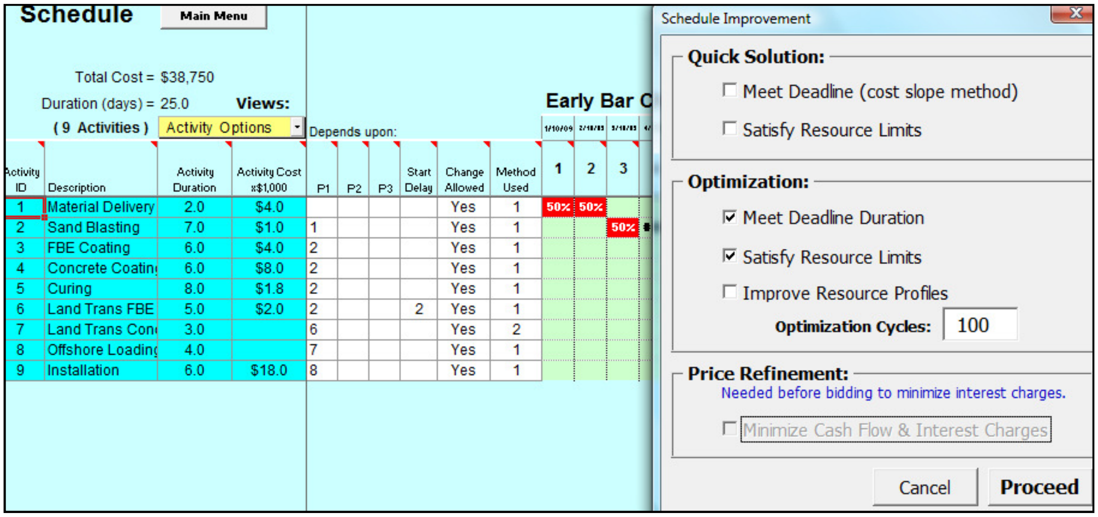
Fig. 5.16 shows these crashed schedule options.



Activity Strategy 1 Strategy 2 Strategy 3

Fig. 5.16: Three Acceleration Options

The most cost-effective mitigation strategy will be to use an alternative of construction for the land transportation (Activity 7), which will save 2 days of execution, which means that the overall project duration of 25 days can be met. This prototype feature can thus be used to optimize the project schedule without the need for manual calculation or a trial-and-error process. Fig. 5.17 shows the schedule optimization feature in EasyPlan, indicating both options: meeting the deadline or satisfying the resource limits. The updated schedule after acceleration is shown in Fig. 5.18. The mathematical formulation of the optimization feature in EasyPlan is outside the scope of this research.



Total Cost = $38,750
Duration (days) = 25.0
(9 Activities)
Depends upon:

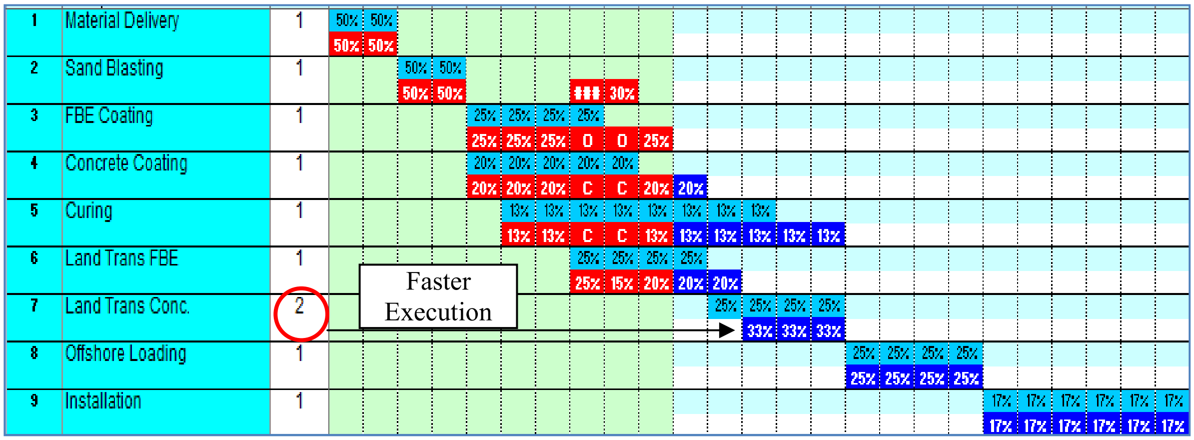
Activity ID	Description	Activity Duration	Activity Cost x$1,000	P1	P2	P3	Start Delay	Change Allowed	Method Used	1	2	3
1	Material Delivery	2.0	$4.0					Yes	1	50%	50%	
2	Sand Blasting	7.0	$1.0	1				Yes	1			50%
3	FBE Coating	6.0	$4.0	2				Yes	1			
4	Concrete Coatin	6.0	$8.0	2				Yes	1			
5	Curing	8.0	$1.8	2				Yes	1			
6	Land Trans FBE	5.0	$2.0	2			2	Yes	1			
7	Land Trans Con	3.0		6				Yes	2			
8	Offshore Loadin	4.0		7				Yes	1			
9	Installation	6.0	$18.0	8				Yes	1			

Quick Solution:
☐ Meet Deadline (cost slope method)
☐ Satisfy Resource Limits

Optimization:
☑ Meet Deadline Duration
☑ Satisfy Resource Limits
☐ Improve Resource Profiles
Optimization Cycles: 100

Price Refinement:
Needed before bidding to minimize interest charges.
☐ Minimize Cash Flow & Interest Charges

Fig. 5.17: Schedule Optimization Options



1	Material Delivery	1	50%	50%																							
			50%	50%																							
2	Sand Blasting	1			50%	50%																					
					50%	50%				###	30%																
3	FBE Coating	1					25%	25%	25%	25%																	
							25%	25%	25%	O	O	25%															
4	Concrete Coating	1					20%	20%	20%	20%	20%																
							20%	20%	20%	C	C	20%	20%														
5	Curing	1						13%	13%	13%	13%	13%	13%	13%	13%												
								13%	13%	C	C	13%	13%	13%	13%	13%	13%										
6	Land Trans FBE	1								25%	25%	25%	25%														
										25%	15%	20%	20%	20%													
7	Land Trans Conc.	2												25%	25%	25%	25%										
														33%	33%	33%											
8	Offshore Loading	1																25%	25%	25%	25%						
																		25%	25%	25%	25%						
9	Installation	1																				17%	17%	17%	17%	17%	17%
																						17%	17%	17%	17%	17%	17%

Fig. 5.18: Updated Schedule after Acceleration (Activity 7)

5.2.5 Discussion of Results

The case study demonstrated the implementation of the proposed schedule analysis mechanism on a portion of a simulated real project. The new rework representation appears to provide an easier, more practical way to represent rework events in the project schedule, without the need to introduce new activities or to split existing ones. The project schedule is thus kept clear and visually informative in order to facilitate progress updates and record keeping. The case study also shows the effects of rework events on the project schedule.

The case study included examples of rework due to different causes. The first rework was associated with a critical activity (activity 4) and was due to an error by the Contractor on day 8, which is a common cause of rework. The rework therefore had a direct effect on the schedule because it delayed the activities affected and their successors. The second rework event occurred for a different reason. It was part of a non-critical activity (activity 3) and occurred due a design change or omission that was forced by the Owner. This rework event affected another (already completed) activity (activity 2). In this case, the modeling included the realistic situation that involved the Contractor slowing down an activity to balance the pace of construction. The rework time also caused a resource over-allocation for activity 7, which led to the extension of the project by an additional day.

The case study illustrates the effectiveness and practicality of the schedule analysis procedure and the optimization mechanism. The system demonstrated its ability to evaluate a number of acceleration methods, to compare their consequences with the reported delay, and to propose a cost effective mitigation strategy and schedule optimization procedure.

5.3 Conclusion

This chapter has discussed a simple implementation of the proposed rework analysis mechanism on a computer program. Applying the prototype to a case study has demonstrated its ability to consider a variety of causes of rework and to analyze their consequences with respect to delay. To mitigate these delays, optional execution methods have been examined in order to determine the least costly corrective active plan. While the prototype allows a reasonably accurate representation of site events and related analysis, several areas could be improved, as discussed in the following chapter.

CHAPTER 6
CONCLUSION

6.1 Conclusion

Rework is a serious problem in the construction industry and has been identified as one of the main causes of schedule delays and cost overruns. It has been reported that the direct costs of rework exceed about 5 % of the total construction costs. Despite this significant impact, traditionally no quantitative methods of schedule analysis have been developed that consider the impact of rework on the project schedule.

The research has addressed this problem by introducing a new technique for quantifying rework over the project schedule, through day-by-day segmentation of the duration of activities. This method has proven to be beneficial for representing all progress events, including rework. Scheduling in this case is more practical when it reacts to the specific timing of progress events rather than relying on the cumulative percentage complete.

The developed technique for analysing rework has been designed as a project control tool with a core cost optimization feature. The technique has been demonstrated to have several interesting features, including the following:

- It represents project rework events for activities affected on the same bar chart used to display progress updates.

- It considers the magnitude of the rework and recalculates the remaining duration of the activity.
- The responsibility for and magnitude and effects of the rework are apportioned over the project schedule to the party responsible.
- The update of project schedule for each day includes all rework events, delays, and accelerations.
- The prototype dynamically checks the project resources and provides prompt resource over-allocation alerts.
- The baseline is updated whenever any changes occur in the logical relationships between the activities and/or the duration of any of the activities is changed.
- The schedule can be optimized so that it adheres to deadlines and resource limits.

6.2 Future Research and Development

More research is still needed so that practical situations can be considered within a computational framework in order to support decisions about corrective action. This research could be used as an initial point for further study that would enhance the proposed technique and the prototype. Areas of potential improvement are as follows:

- Introduce a rework performance index that can be calculated during the execution of a project in order to measure project performance with respect to rework.
- One possible improvement to the representation presented in this research is to consider the delay time before the commencement of the rework, as shown in

Fig. 6.1. In this case, it is possible to adjust the remaining duration based on Eq. 6.1, as follows:

$$\text{Remaining Duration} = \text{Delay Time} + \text{Planned Duration} * (1 - \text{MPC}) \qquad (6.1)$$

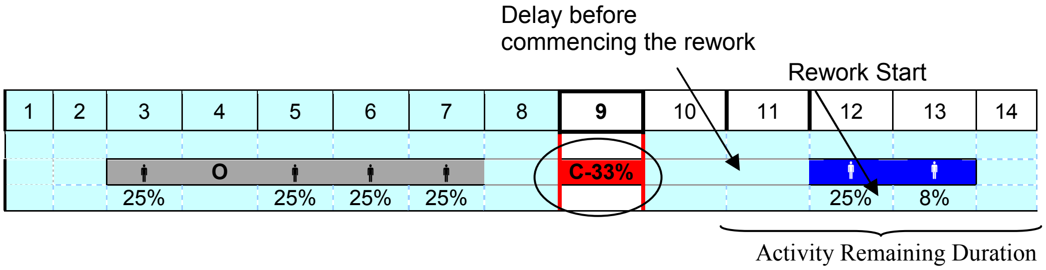


Fig. 6.1: Effect of the Timing of rework mitigation

- Allow an option for external resources to be used for the rework, and manage the schedule resources accordingly between new progress and rework.
- Incorporate other features related to project control, such as cash flow analysis, earned value, cost and schedule performance indices, and productivity analysis, considering the impact of the rework on time and cost.
- Rewrite the prototype in a more powerful programming language in order to improve speed and usability so that the number of activities it can handle can be increased.
- Examine the new technique using a large real case study, with more multi-discipline interfaces, including an examination of the additional planning needed to carry out a detailed schedule analysis.
- Examine the ability of the technique to handle EPC contracts that have extensive engineering and procurement activities.

- Experiment with different evolutionary optimization techniques in order to speed up the optimization process.
- Add an early warning mechanism that can recognise rework events and benchmark the areas that have a high frequency of occurrence so that the project team can focus on these areas in future projects.

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