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Development of a New Delay Analysis Method that Considering Schedule Updates and Resource Over Allocation

(تطوير طريقه جديدة لتحليل التأخير تراعي تحديثات الجدول الزمني و التخصيص الزائد للمصادر)

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بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

{ يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنْكُمْ وَالَّذِينَ
أُوتُوا الْعِلْمَ دَرَجَاتٍ وَاللَّهُ بِمَا تَعْمَلُونَ خَبِير }

صدق الله العظيم

سورة المجادلة (11)

DEDICATION

To my loving parents who supported me all the way; to my wife for her unlimited encouragement ; to all of my friends and colleagues who stood beside me with great commitment; I dedicate this work, hoping that I made all of them proud.

Ihab R. Jendeya

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Finally I would also like to express my sincerest gratitude to my parents and my wife, whose love and support made this work possible.

ABSTRACT

Due to the inherent risks and increasing complexity of modern construction projects, delays and cost overruns have become common facts in the industry.

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

This study proposes a new schedule analysis model that considers multiple schedule updates and resource over-allocation. The model uses a daily window size in order to consider all fluctuations in the critical path(s) and uses a legible representation of progress information to accurately apportion delays and accelerations among project parties.

A simple case study has been demonstrated on the proposed delay analysis model in order to validate its accuracy and usefulness.

To facilitate its use, the study has been introduced detailed procedures to make the control process on the scheduling and resource management through the project period is easy process.

ABSTRACT (ARABIC) ملخص البحث

بسبب الأخطارِ المتأصّلةِ والتعقيدِ المتزايدِ في مشاريعِ البناءِ الحديثةِ، تجاوزات التكلفةَ والتأخيراتَ أَصْبَحا حقائقَ مشتركةَ في الصناعةِ.

استخدم الباحثونُ والممارسونُ العديد مِنْ التقنياتِ لتَقييم تأخيراتِ المشروعِ وتقسيم مسؤوليةَ التأخيرِ بين الأطراف المعنية. طريقة النوافذ لتحليل التأخير عُرِفَت كأحد التقنياتَ الأكثر ثقة لتَحليل تأخيراتِ البناءِ. على الرغم مِنْ منافعِها، فإن التحليل بطريقة النوافذِ يُمْكِنُ أَنْ يَعطي نَتائِجَ مختلفةَ تَعتمدُ على حجمِ النافذةَ، لا تأخذ في الحسبان تعجيلَ المقاولَ والمالكَ، ولا تأثيرَ تحديثات الجدول الزمني بشكل منظّم طبقا للتغيير في المدّةِ الزمنية والعِلاقاتِ المنطقيّةِ للنشاطاتِ، وكذلك لا تأخذ في الحسبان تبعاتَ تقدم الأحداث على تخصيصِ المصادرِ وتبعات التأخير.

هذه الدراسةِ تَقترحُ نموذجَ جديد لتحليلِ الجدولِ الزمني يأخذ في الحسبان التحديثات المتعدّدِة للجدول الزمني وكذلك تخصيص المصادر. النموذج يستخدم نافذةِ بحجم يوميِ لكي يَعتبرَ كُلّ التقلّبات في المسار الحرجِ و يستخدم تمثيل واضح مِنْ معلوماتِ التقدّمِ لتَقسيم التأخير والتعجيل بدقّة بين أطرافِ المشروعِ.

حالة دراسية مبسطة طُبّقتْ على نموذجِ تحليلِ التأخيرِ المُقتَرَحِ لكي يَعْرضَ دقتَه وفائدتَه.

لتَسهيل استعماله، الدراسة قدّمتْ إجراءات مُفصّله لجعل عملية التحكم في الجدولة و إدارةِ المصادرَ خلال فترةِ المشروعَ عملية سهلة.

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CHAPTER 1

INTRODUCTION

1.1. Construction Delays

Delays are one of the biggest problems construction firms face. Delays can lead to many negative effects such as lawsuits between owners and contractors, increased costs, loss of productivity and revenue, and contract termination. According to Bordoli and Baldwin (1998) and the World Bank (1990), for 1627 projects completed worldwide between 1974 and 1988, the overrun varied between 50% and 80%. Al-Khalil and Al-Ghafly (1999) confirmed in a study carried out by them in 1995 that contractors agreed that 37% of all their projects were subject to delay while consultants admitted that delayed projects accounted for 84% of projects under their supervision. They further reported another study, which concluded that 70% of public projects in the same country experienced time overrun. Odusami and Olusanya (2000) concluded that projects executed in the Lagos metropolis experienced an average delay of 51% of planned duration for most projects. According to Pincock, Allen & Holt (2007), projects are probably fewer than 10% that are completed within budget and schedule. The other 90% run the spectrum from close to the projected values to an outside limit of about double the budget and double the schedule.

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

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

1.2. Research Motivation

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

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

1.2.1. Problem with Window Size

When windows analysis is performed, attention is paid to the critical path(s) that exist(s) at the end of each window, and the fluctuations in the critical path(s) within the window are overlooked. Therefore, the selection of a window size can have a significant impact on the results of the analysis, especially when concurrent delays are involved. Hegazy and Zhang (2005) discussed this problem and proposed a daily windows approach in an attempt to overcome it. The approach uses a window size of one day to account for all fluctuations that occur in the project's critical path(s). However, this approach still does not consider other factors such as the effect of resource over-allocation and schedule updates.

1.2.2. Inadequate Consideration of Acceleration

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

1.2.3. Inadequate Consideration of Baseline Changes Along the Project

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

1.2.4. No Consideration of Resource Over-Allocation in Delay Analysis

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

1.3. Research Objectives and Scope

The main objective of this research is to Modify the Daily Windows Analysis Method "**MDWAM**" for construction delay. The specific objectives are as follows:

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

1.4. Research Methodology

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

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

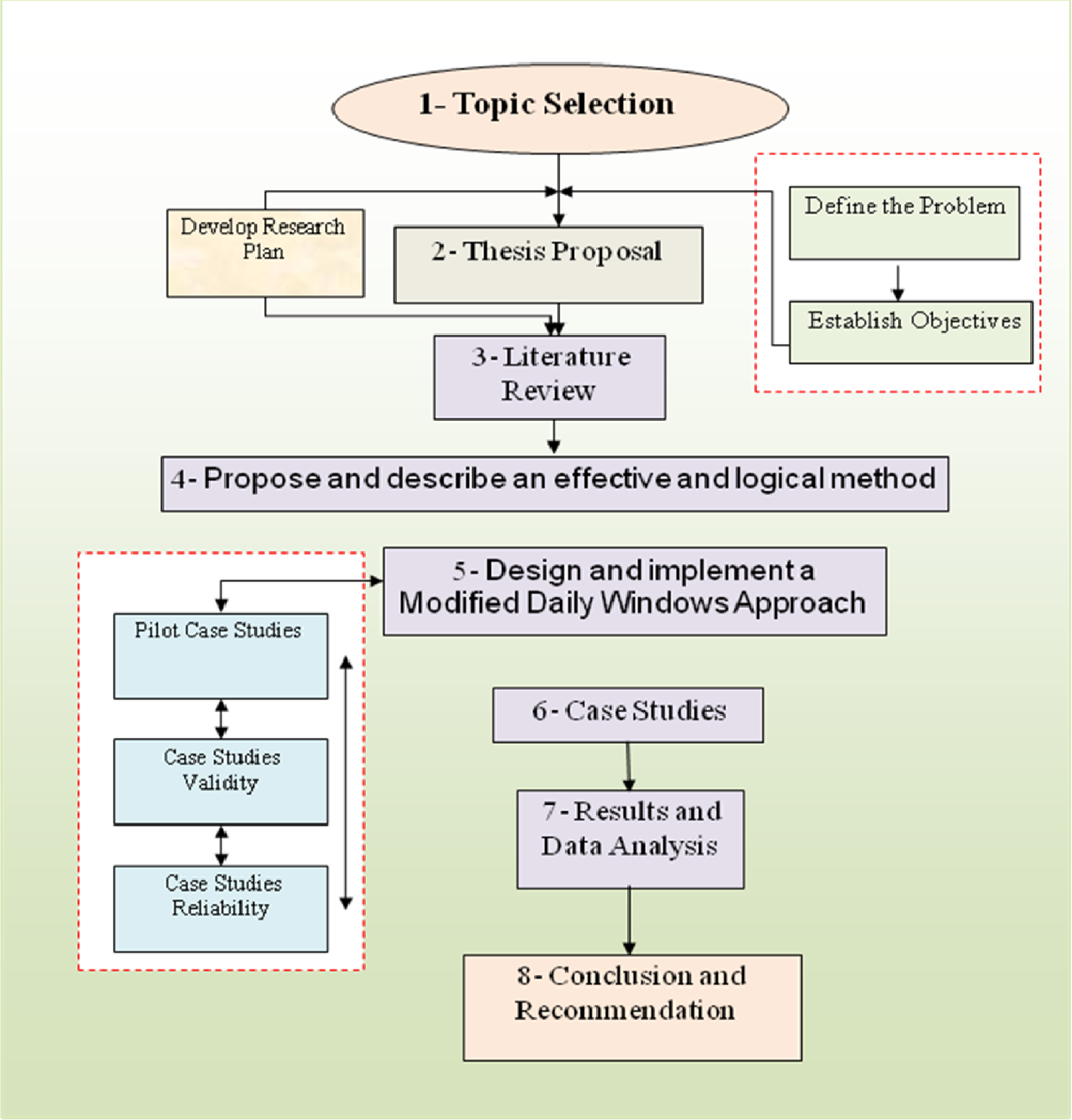


Fig. 1.1: Research Methodology Flow Chart

1.5. Thesis Organization

The thesis consists of 4 additional chapters. Chapter 2 is a literature review of the causes of delays and the traditional techniques for delay analysis in construction. The history of the development of delay analysis techniques is reviewed, including the modified techniques and recent approaches mentioned in the literature.

Chapter 3 presents the Traditional Windows Analysis Method "**TWAM**" through a simple case study then presents the Daily Windows Analysis Method "**DWAM**" by using the same case study and showing the difference between the results of two analyses. Also, introduces developments to the Daily Windows Analysis Method by using rather example that illustrates what will happen when the as-planned and the as-built schedules have the same duration. This development depends on the schedule updates and named as the Modified Daily Windows Analysis Method "**MDWAM**". In this approach, the contractor’s corrective actions (i.e., changes in the logical relations between the activities and the changes in the activities’ durations) are considered in the analysis as contractor’s acceleration. A systematic procedure for a daily windows analysis with a schedule updates is established.

Chapter 4 shows the methods of solving resource over allocation problems and how the parallel method is selected for the delay analysis process to solve the resource over allocation problem. The Daily Windows Analysis Method "**DWAM**" is introduced for analyzing the delay without considering resource allocation. A Modified Daily Windows Analysis Method "**MDWAM**" is introduced along with its algorithm. A systematic procedure for a Modified Daily Windows Analysis Method considering resource allocation is established.

In chapter 5, a summary of the study and some of the areas for possible future research are presented.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

Delays happen in most construction projects, whether simple or complex. In construction, delay could be defined as the time overrun either beyond the contract date or beyond the date that the parties agreed upon for delivery of a project (Assaf and Al-Hejji, 2006).

A project consists of a collection of activities. Delays can occur in any or all of these activities, and these delays can concurrently cause delays in the completion of the project. A project delay is the accumulated effect of the delays in the individual activities. Delay analysis is used to determine the cause(s) of the delay in order to ascertain whether an extension of time should be awarded. An extension of time relieves the contractor from the liability for damages (Lowsley and Linnett, 2006).

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

The proposed bar chart guides the user through progress reporting by observing any conflict with the planned logic of the work. It automatically recognizes the occurrence of delays and asks the user to record the responsible party and the reasons. Based on percent completes and recorded delays, the bar chart recognizes the progress status of activities as being slow, suspended, or accelerated (Hegazy, Elbeltagi and Zhang, 2005).

2.2. Causes of Delays

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

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

Researchers	Country	Major causes of delay
Baldwin et al. (1971)	United States	- inclement weather - shortages of labor supply - subcontracting system
Arditi et al. (1985)	Turkey	- shortages of resources - financial difficulties faced by public agencies and contractors - organizational deficiencies - delays in design work - frequent changes in orders/design - considerable additional work
Okpala and Aniekwu (1988)	Nigeria	- shortages of materials - failure to pay for completed work - poor contract management
Dlakwa and Culpin (1990)	Nigeria	- delays in payment by agencies to contractors - fluctuations in materials, labor and plant costs
Mansfield et al. (1994)	Nigeria	- improper financial and payment arrangements - poor contract management - shortages of materials - inaccurate cost estimates - fluctuations in cost
Semple et al. (1994)	Canada	- increases in the scope of the work - inclement weather - restricted access
Assaf et al. (1995)	Saudi Arabia	- slow preparation and approval of shop drawings - delays in payments to contractors - changes in design/design error - shortages of labor supply - poor workmanship
Ogunlana et al. (1996)	Thailand	- shortages of materials - changes of design - liaison problems among the contracting parties
Chan and Kumaraswamy (1996)	Hong Kong	- unforeseen ground conditions - poor site management and supervision - slow decision making by project teams - client-initiated variations

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

Al-Khal and Al-Ghafly (1999)	Saudi Arabia	- cash flow problems/financial difficulties - difficulties in obtaining permits -"lowest bid wins" system
Al-Momani et al. (2000)	Jordan	- poor design - changes in orders/design - inclement weather - unforeseen site conditions - late deliveries
Lo et al. (2006)	Hong Kong	- inadequate resources - unforeseen ground conditions - exceptionally low bids - inexperienced contractor - work in conflict with existing utilities - poor site management and supervision -unrealistic contract duration
Faridi and El-Sayegh (2006)	UAE	- slow preparation and approval of drawings - inadequate early planning of the project - slowness of owner's decision making - shortage of manpower - poor site management and supervision - low productivity of manpower
Assaf and Al-Hejji (2006)	Saudi Arabia	- change in orders by the owner during construction - delay in progress payment - ineffective planning and scheduling - shortage of labor - difficulties in financing on the part of the contractor
Ibbs and Nguyen (2007)	United States	- fault of, or is due to the negligence of the owner/contractor - language of the contract itself
Studies in Gaza Strip (2008)	Palestine	-Poor material handling on site -Inadequate construction planning -Skilled labor shortage -Mistake during construction -Inadequate contractor experience

2.3. Types of Delays

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

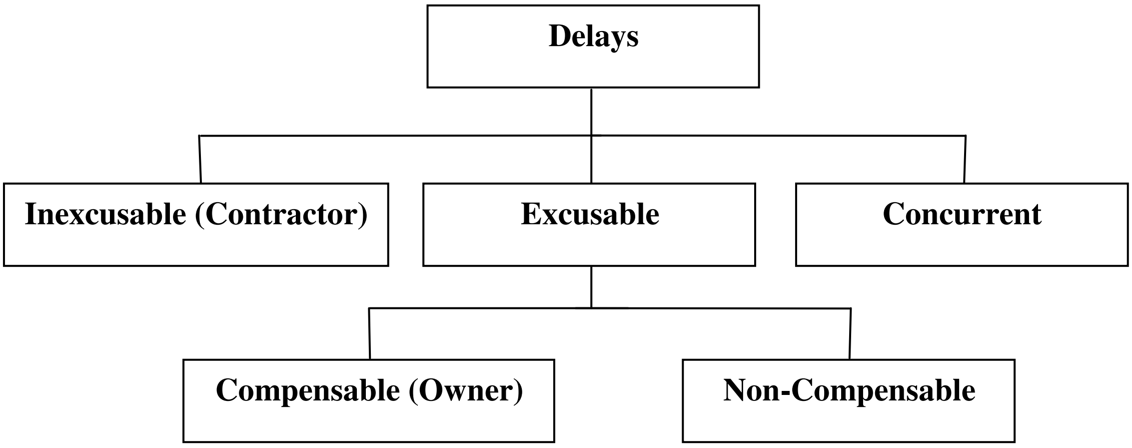


Fig. 2.1: Types of Delays (Based on Vidalis 2002)

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

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

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

2.4. Types of Schedules Used in Delay Analysis

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

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

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

2.5. Recording Site Events for Delay Analysis

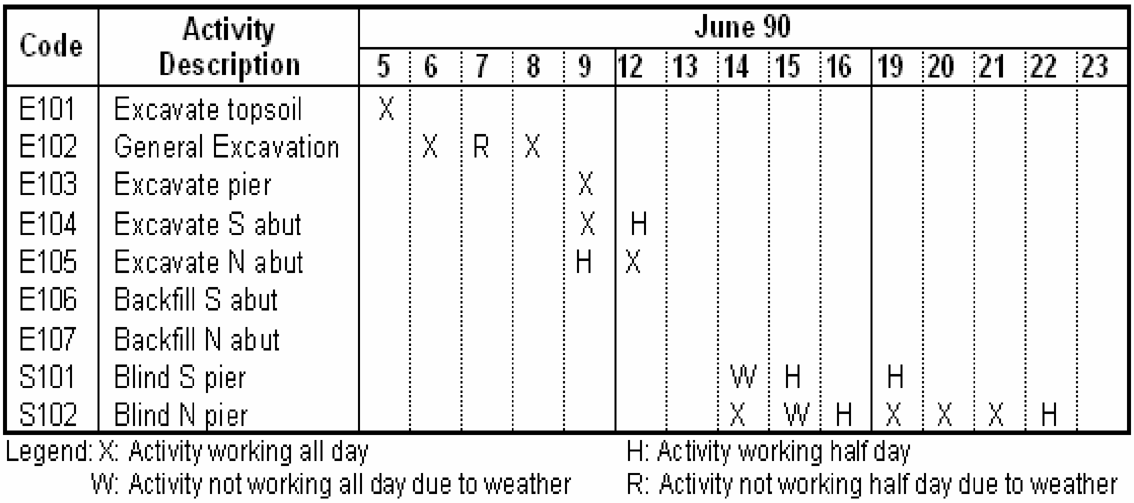
Daily recording of the actions performed by all parties on a construction site is necessary for delay analysis. Site events involve a large amount of data related to weather, staffing, resource use, work accomplished, inspections, accidents, delivery of materials, and changes in orders.

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

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

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

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

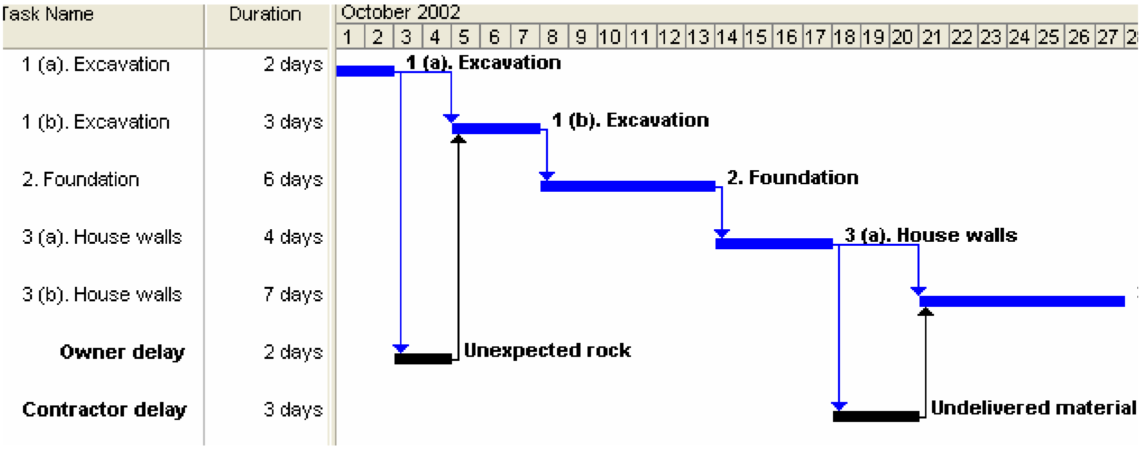


Code	Activity Description	June 90														
		5	6	7	8	9	12	13	14	15	16	19	20	21	22	23
E101	Excavate topsoil	X														
E102	General Excavation		X	R	X											
E103	Excavate pier					X										
E104	Excavate S abut					X	H									
E105	Excavate N abut					H	X									
E106	Backfill S abut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

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

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

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

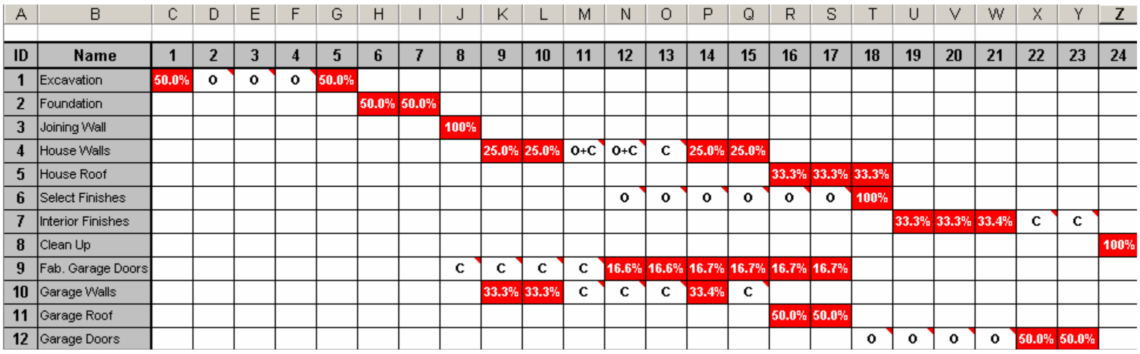


Task Name	Duration
1 (a). Excavation	2 days
1 (b). Excavation	3 days
2. Foundation	6 days
3 (a). House walls	4 days
3 (b). House walls	7 days
Owner delay	2 days
Contractor delay	3 days

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

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

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



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

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

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

2.6. Delay Analysis Techniques

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

2.6.1. The As-Planned Versus As-Built Comparison

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

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

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

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

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

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

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

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

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

2.6.4. The Contemporaneous Period Analysis Method (window analysis)

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

The majority of the viewpoints reviewed in the literature agree that windows analysis yields the most reliable results. Despite these advantages windows analysis requires significant time and effort. Since it requires a large amount of information and the schedule needs to be periodically updated, this method may not be appropriate for projects that lack strict administrative procedures and updated schedules.

Arditi and Pattanakitchamroon (2006) presented the views of some of the researchers and practitioners who wrote about standard delay analysis methods from years 1987 to 2004. The comments of these researchers and practitioners on windows analysis are summarized in Table 2.2.

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

References	**Comments**
Lovejoy (2004)	Very good
Sagarlata and Brasco (2004)	Useful for prospective analyses, but minimal utility supporting claims
Sandlin et al. (2004)	Overcomes some disadvantages of others
Gothand (2003)	Reliable
SCL (2002)	Most reliable when available

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

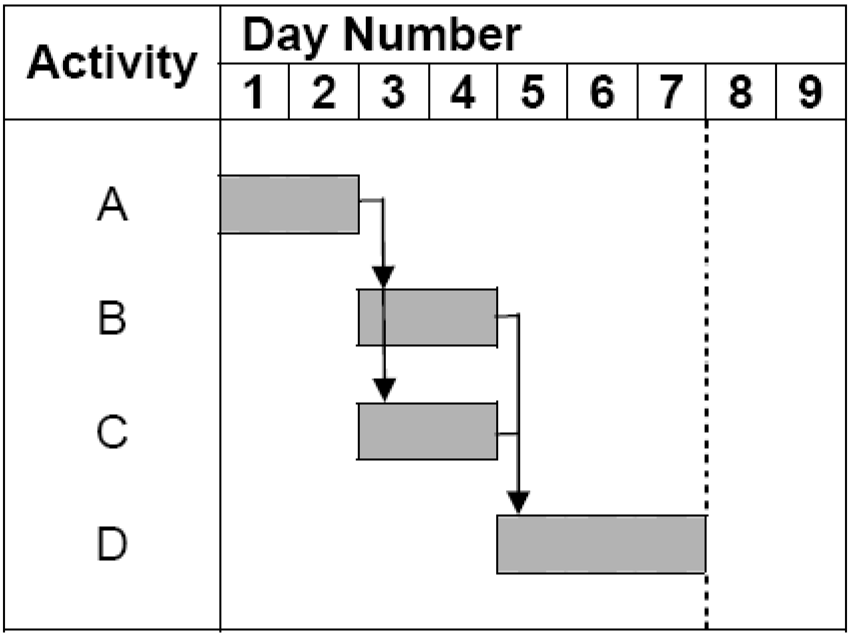
Harris and Scott (2001)	Make some use by claims consultants
Zack (2001)	Accurate but expensive
Fruchtman (2000)	Contemporaneous basis, but not future changes considered
Stumpf (2000)	Reliable, but time consuming
Finke (1999, 1997)	Most reasonable and accurate
McCullullough (1999)	Dependent on baseline schedule, accurate
Zack (1999)	Suitable
Bubshait and Cunningham (1998)	Acceptable, dependent on availability of data
Levin (1998)	Dependent on how the method is applied
Alkass et al. (1996)	Some drawbacks/propose modified method
Schumacher (1995)	Effective method
Baram (1994)	Most desirable approach
Wickwire et al. (1991)	Recommended

The windows analysis method can be demonstrated by an example reported in Hegazy and Zhang (2005). Fig. 2.5 shows the as-planned and the as-built schedules of a simple 4-activity case study.

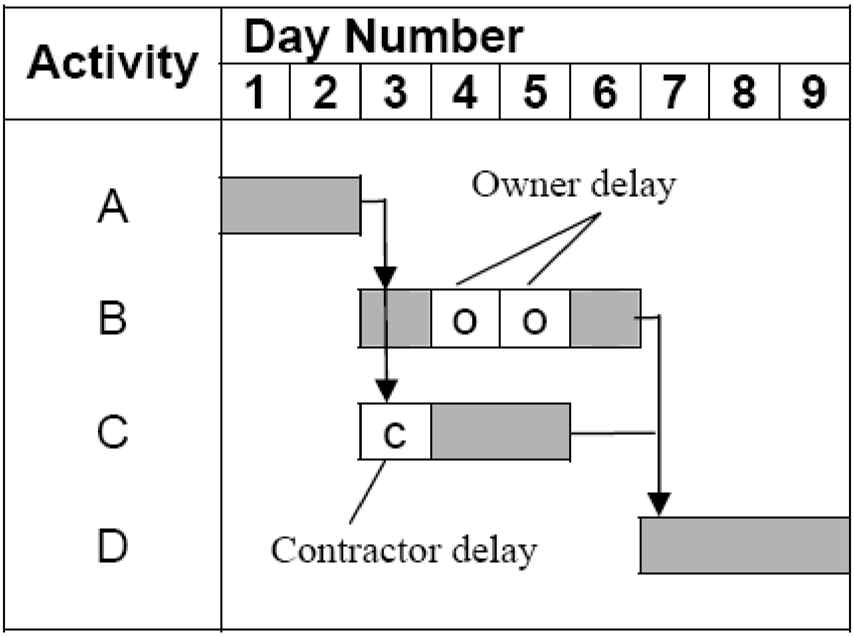
According to the relationships shown, activities B and C both follow activity A and are then followed by activity D. The as-planned duration is seven days, while the as-built duration is nine days; thus, the project delay is two days.

a- Windows Analysis Using One Window of Nine Days

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



(a) As-Planned Bar Chart

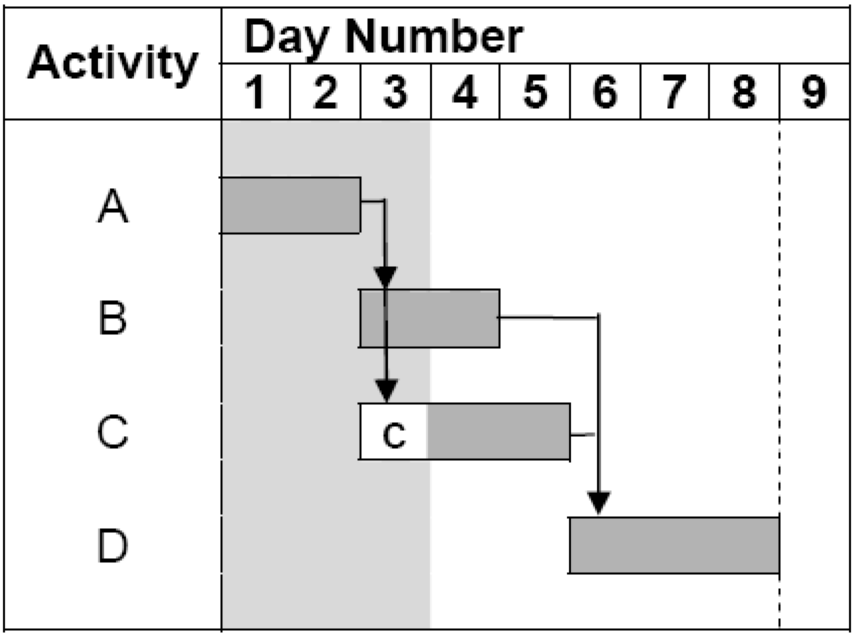


(b) As-Built Bar Chart

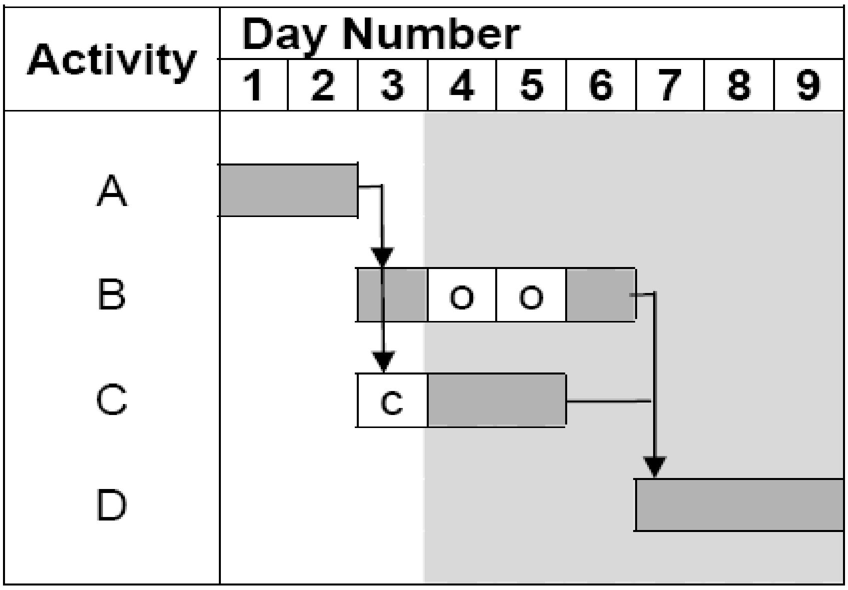
Fig. 2.5: Bar Charts for a Small Example of Windows Analysis (Based on Hegazy and Zhang, 2005.)

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

In the first window (Fig. 2.6a), the shaded part to the left of day 4 represents the actual progress of the project. Looking at the window's critical path A-C-D, one day of contractor delay (C) occurred, leading to a one-day project delay. This window becomes the basis for the next window. In the second window (Fig. 2.6b), the critical path becomes A-B-D which exhibits two days of owner delay, causing the project duration to become nine days. One day of the two-day owner delays at current critical path did not affect project duration since there was a one-day project delay from the previous window. Therefore, only one-day owner delay is decided at the second window. Thus the analysis concludes that the two-day project delay should be allocated as one day of contractor delay and one day of owner delay.



(a) Window Ending at Day 3



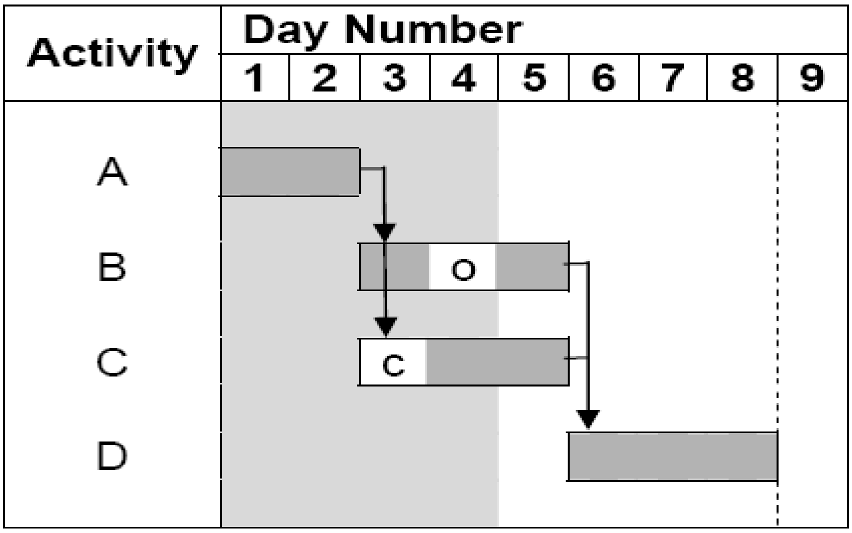
(b) Window Ending at Day 9

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

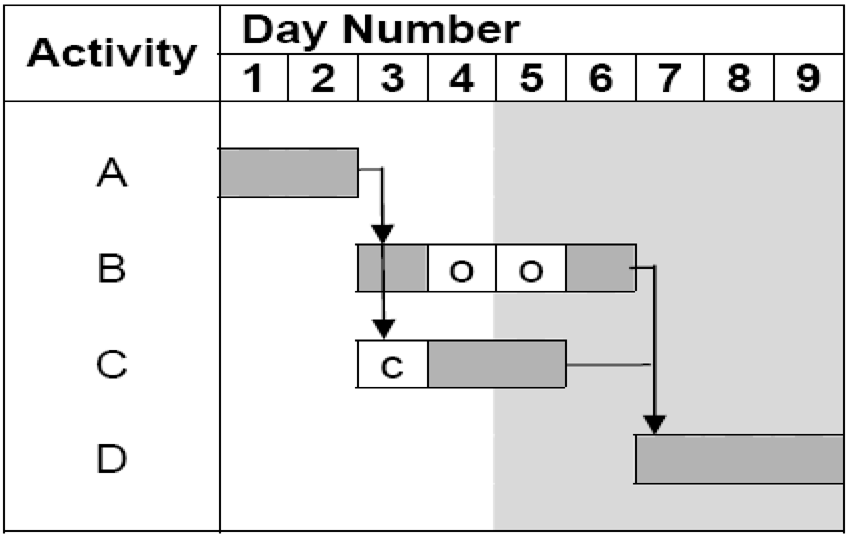
b- Windows Analysis Using Two Windows (Ending at Days 4 and 9):

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

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



(a) Window Ending at Day 4



(b) Window Ending at Day 9

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

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

Table (2.3): Comparison of the Results of Different Window Sizes

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

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

2.7. New Developments

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

2.7.1. Improved But-for Analysis

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

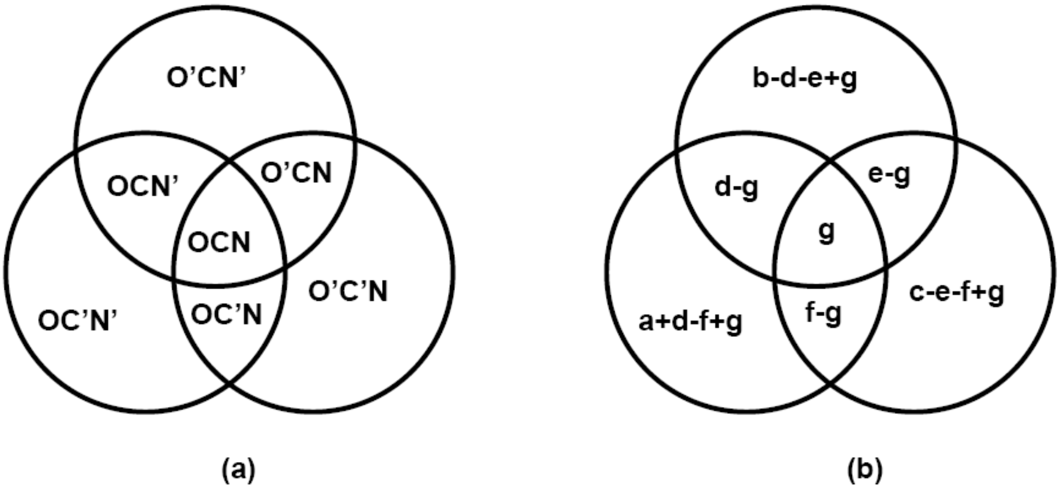


Fig. 2.8: Concurrent Delay Representation Using a Venn Diagram

2.7.2. Improved Windows Analysis

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

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

2.7.3. Other Approaches

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

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

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

2.8. Conclusions

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

CHAPTER 3

MODIFIED DAILY WINDOWS ANALYSIS METHOD CONSIDERING SCHEDULE UPDATES

3.1. Introduction

Project schedules are invariably dynamic and uncertain. Various controllable and uncontrollable factors can adversely affect the project schedule and cause delays. As a result, the identification and analysis of delays become essential (Finke 1999). They are however, onerous tasks. Contractors are prone to view most delays as the responsibility of the owner while owners frequently attempt to tag delays as contractor caused, third party caused, or concurrent (Zack 2001). Consequently, delays may lead to some form of dispute resolution alternatives, from negotiation to litigation, which may be expensive and a crapshoot. Responding to such challenge, the industry has created and employed many schedule analysis techniques. The level of acceptability of each technique depends on its credibility and the court or board ruling the corresponding delay claims (Ibbs and Nguyen 2007).

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

Effective delay analysis must include provision for these updates (schedule updates).

In this chapter, the Traditional Windows Analysis Method **"TWAM"** is illustrated through an example, and then the same example will be used to illustrate the Daily Windows Analysis Method **"DWAM"**, and finally further sample case will be used to illustrate the Modified Daily Windows Analysis Method **"MDWAM"** proposed by the researcher for analyzing the project delays considering the schedule updates and comparing the results among the three approaches. A systematic procedure for the proposed approach is also developed in order to facilitate its computer implementation.

3.2. Traditional Windows Analysis Method "TWAM"

The Traditional Windows Analysis Method "**TWAM**" can be illustrates by a simple case Figure 3.1 shows the as-planned and the as-built schedules of a simple 5-activities case study. According to the relationships shown, activities B and C both follow activity A and activity D follows activity B and finally activity E follows both activities C and D. The as-planned duration is ten days, while the as-built duration is twelve days; thus, the project delay is two days.

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

- Small letters (o), (c), (n), or combinations of them (e.g., o + c) on an activity bar chart represent work stops for a given day on a specific activity, as caused by the party indicated (o = owner, c = contractor, n = neither).
- A percentage (e.g., 50%) on an activity bar chart represents the amount of work done by the contractor on a given day for this specific activity. The absence of a percentage on the activity as-built bar indicates that the planned and as-built percentages are the same.

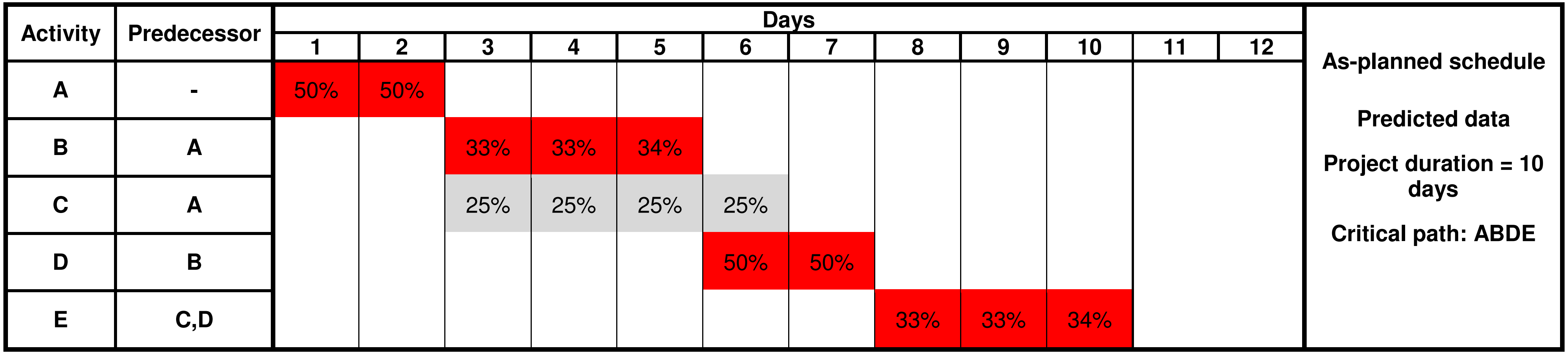
In addition, capital letters (O, C, and N) indicate the delay analysis results apportioned to the indicated party. The values are calculated as a result of the analysis and are not shown on the as-built bar chart.

a. Case no.1: TWAM Using One Window of Twelve Days.

Since two owner delays (O) occurred on the final critical path A-B-D-E, the two days of project delay are attributed to the owner as shown in Fig. 3.1.

b. Case no.2: TWAM Using Two Windows, Ending at Days 3 and 12.

In the first window (Fig. 3.2a), the shaded part to the left of day 3 represents the actual progress of the project. Looking at the window’s critical paths A-B-D-E and A-C-E, one day of contractor delay (C) occurred, but no delay was occurred for whole project where the project duration remains 10 days. This window becomes the basis for the next window. In the second window (Fig. 3.2b), the critical path becomes A-B-D-E which exhibits two days of owner delay, causing the project duration to become twelve days.



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

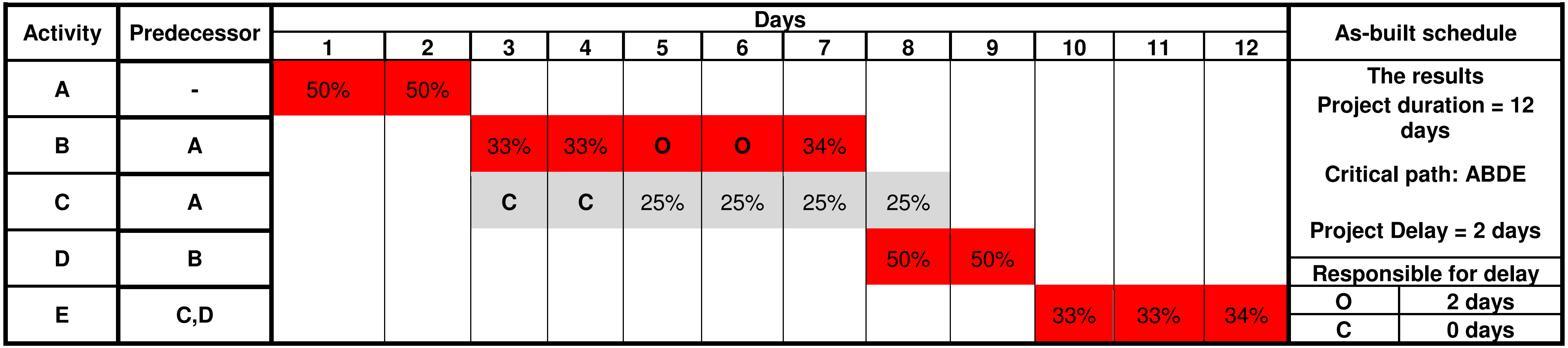
As-planned schedule

Predicted data

Project duration = 10 days

Critical path: ABDE

(a) As-Planned Bar Chart



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

As-built schedule

The results
Project duration = 12 days

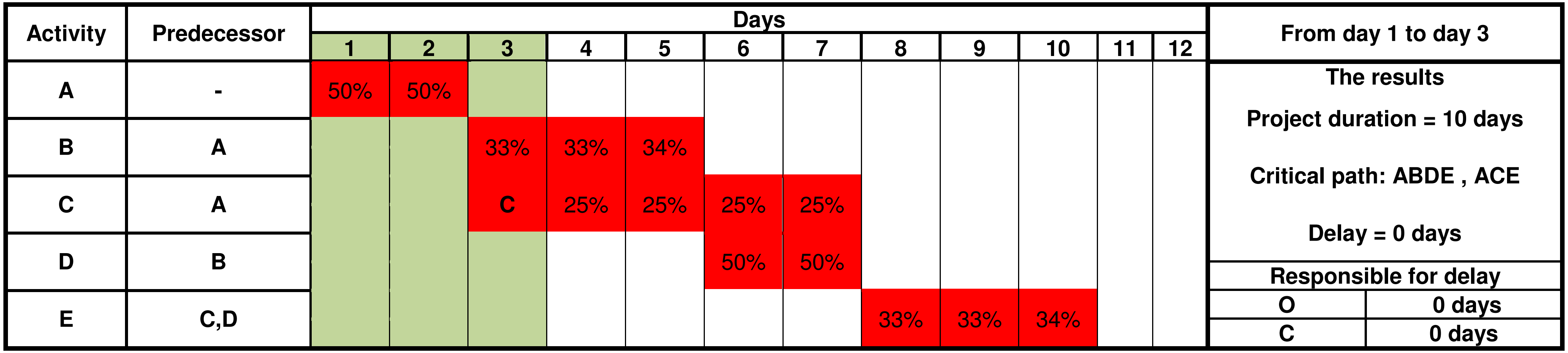
Critical path: ABDE

Project Delay = 2 days

Responsible for delay	
O	2 days
C	0 days

(b) As-Built Bar Chart

Fig. 3.1: Bar Charts for a Simple Case using Traditional Windows Analysis Method (Case no. 1)



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

From day 1 to day 3

The results

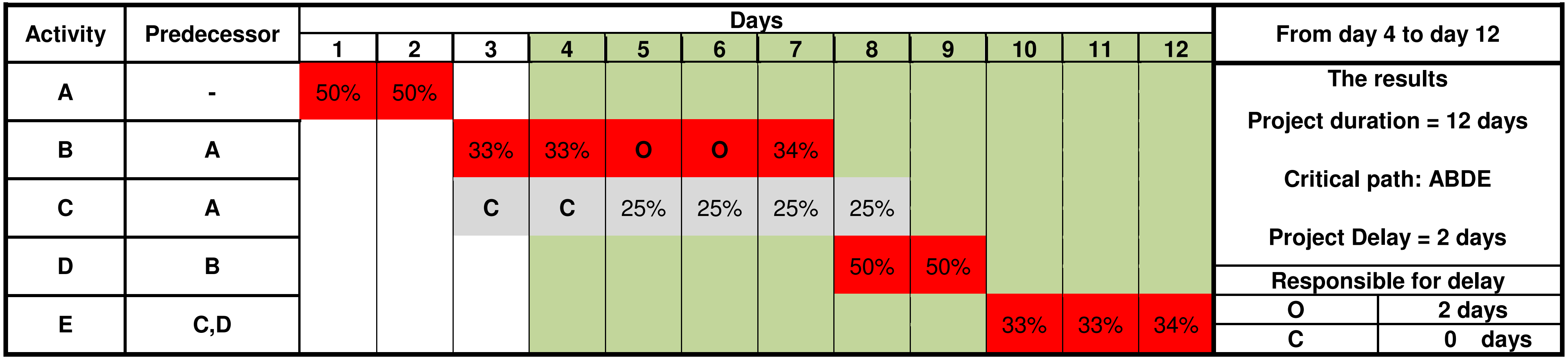
Project duration = 10 days

Critical path: ABDE , ACE

Delay = 0 days

Responsible for delay	
O	0 days
C	0 days

(a) Windows Ending at Day 3



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

From day 4 to day 12

The results

Project duration = 12 days

Critical path: ABDE

Project Delay = 2 days

Responsible for delay	
O	2 days
C	0 days

(b) Windows Ending at Day 12

Fig. 3.2: Bar Charts for a Simple Case using Traditional Windows Analysis Method (Case no. 2)

c. Case no.3: TWAM Using Two Windows, Ending at Days 4 and 12.

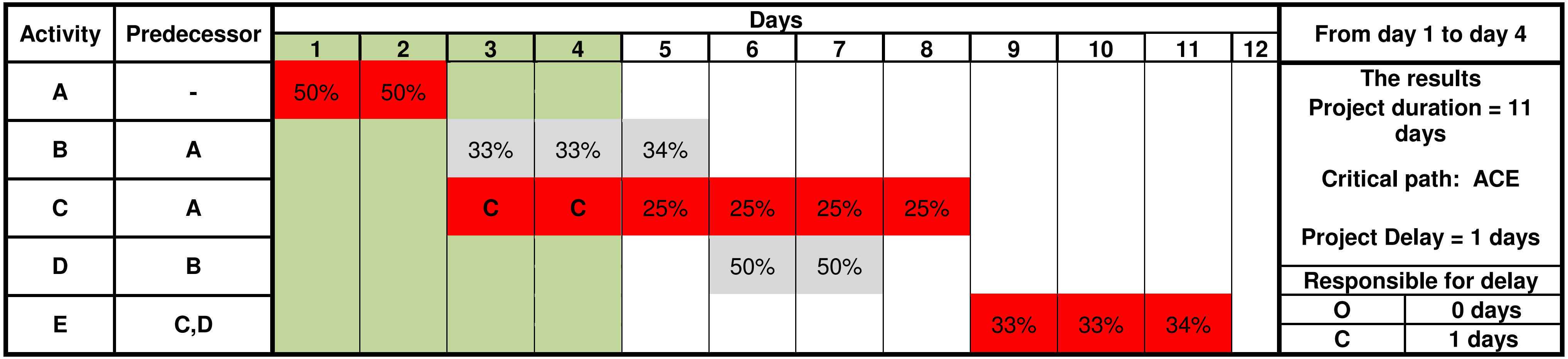
In the first window (Fig. 3.3a), the shaded part to the left of day 4 represents the actual progress of the project. Looking at the window's critical path A-C-E, two days of contractor delay (C) occurred, but project duration delayed one day only, and the project duration becomes 11 days. Thus the contractor was responsible for that one day. In the second window (Fig. 3.2b), the critical path becomes A-B-D-E which exhibits two days of owner delay, causing the project duration to become twelve days. One day of the two-day owner delays at current critical path did not affect project duration since there was a one-day project delay from the previous window. Therefore, only one-day owner delay is decided at the second window. Thus the analysis concludes that the two-day project delay should be allocated as one day of contractor delay and one day of owner delay.

d. Case no.4: TWAM Using Two Windows, Ending at Days 5 and 12.

In the first window shown in (Fig. 3.4a), the shaded part to the left of day 5 represents the actual progress of the project. Looking at the window's critical paths, the two paths A-B-D-E and A-C-E are critical, with one day of owner delay on the path A-B-D-E and one day of contractor delay on the path A-C-E resulting in an 11 days project duration. Although the delays occurred at different dates, the one-day delay is equally attributed to both. In the second window (Fig. 3.4b), the project duration becomes 12 days and the one-day delay is attributed to the owner because his delay on the critical path. Thus, the final conclusion of the analysis is a one-day delay shared by the owner and the contractor from the previous window and a one day owner delay from the second window.

e. Case no.5: TWAM Using Two Windows, Ending at Days 6 and 12.

In the first window (Fig. 3.5a), the shaded part to the left of day 6 represents the actual progress of the project. Looking at the window's critical paths A-B-D-E with two days of owner delay because his delayed on the critical path, and the project duration becomes 12 days. Thus the owner was responsible for the project delay. In the second window (Fig. 3.5b), the critical path remains A-B-D-E which exhibits two days of owner delay, causing the project duration to become twelve days.



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

From day 1 to day 4

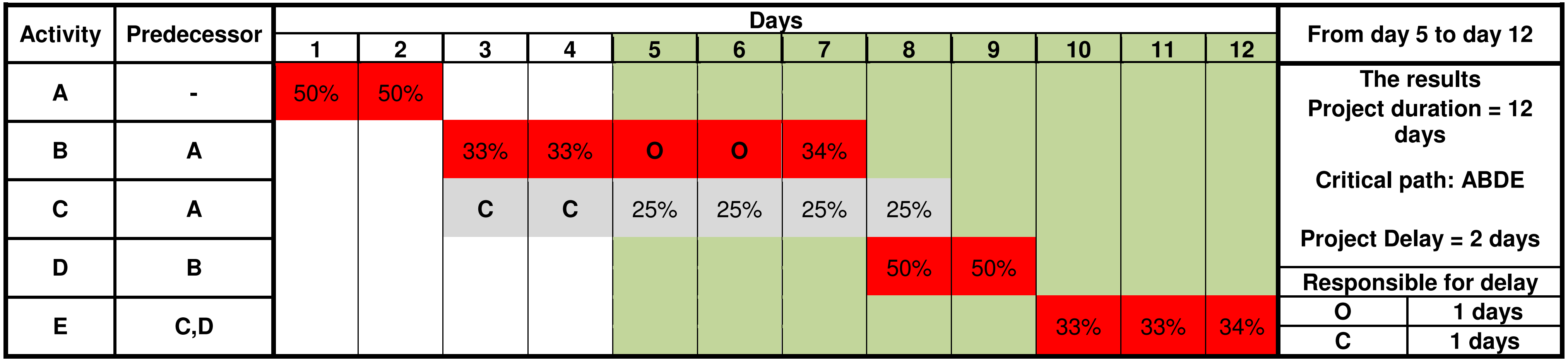
The results
Project duration = 11 days

Critical path: ACE

Project Delay = 1 days

Responsible for delay	
O	0 days
C	1 days

(a) Windows Ending at Day 4



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

From day 5 to day 12

The results
Project duration = 12 days

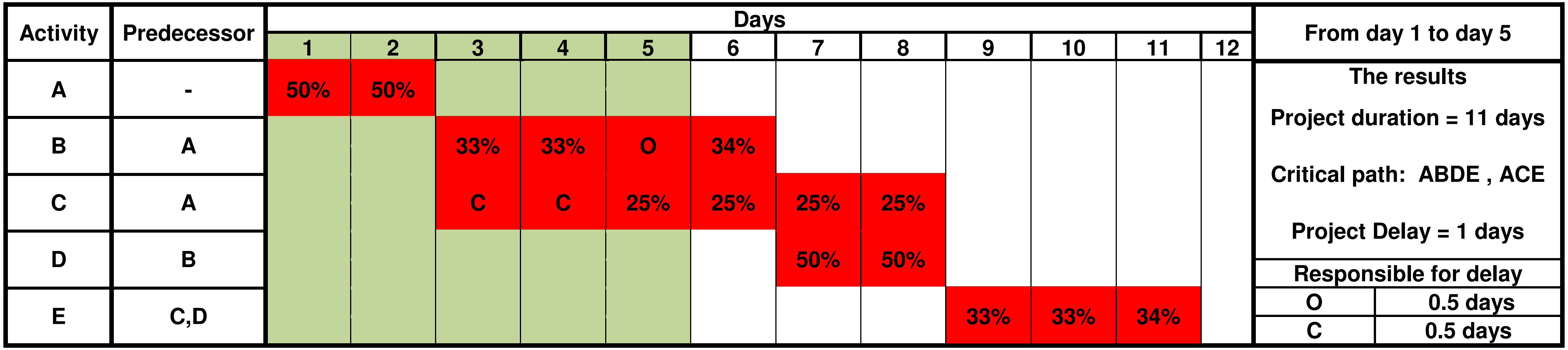
Critical path: ABDE

Project Delay = 2 days

Responsible for delay	
O	1 days
C	1 days

(b) Windows Ending at Day 12

Fig. 3.3: Bar Charts for a Simple Case using Traditional Windows Analysis Method (Case no. 3)



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

From day 1 to day 5

The results

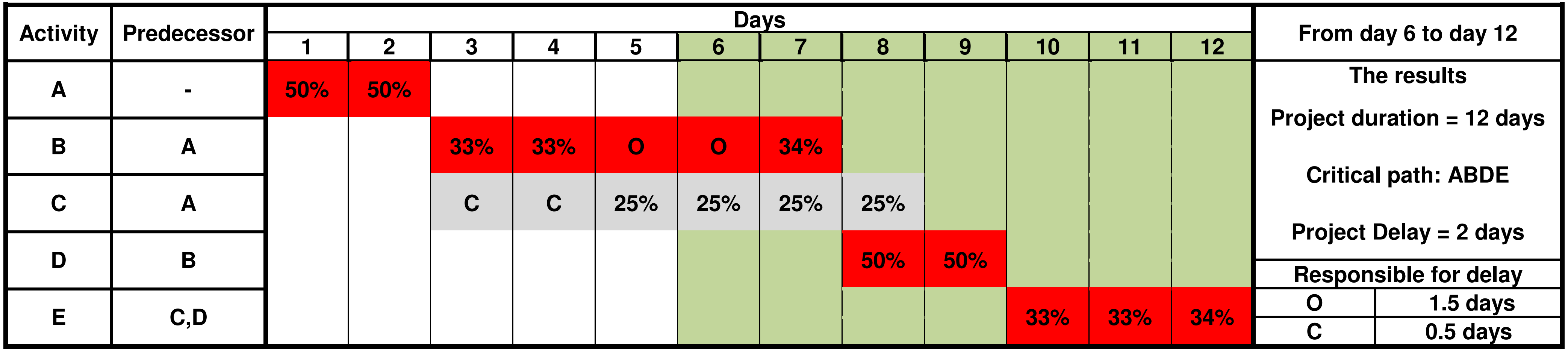
Project duration = 11 days

Critical path: ABDE , ACE

Project Delay = 1 days

Responsible for delay	
O	0.5 days
C	0.5 days

(a) Windows Ending at Day 5



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

From day 6 to day 12

The results

Project duration = 12 days

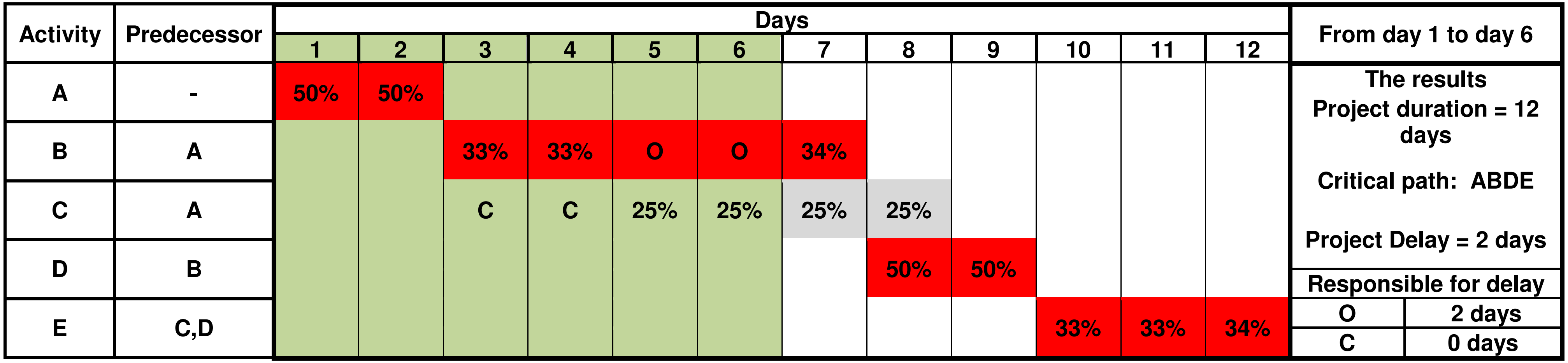
Critical path: ABDE

Project Delay = 2 days

Responsible for delay	
O	1.5 days
C	0.5 days

(b) Windows Ending at Day 12

Fig. 3.4: Bar Charts for a Simple Case using Traditional Windows Analysis Method (Case no. 4)



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

From day 1 to day 6

The results
Project duration = 12 days

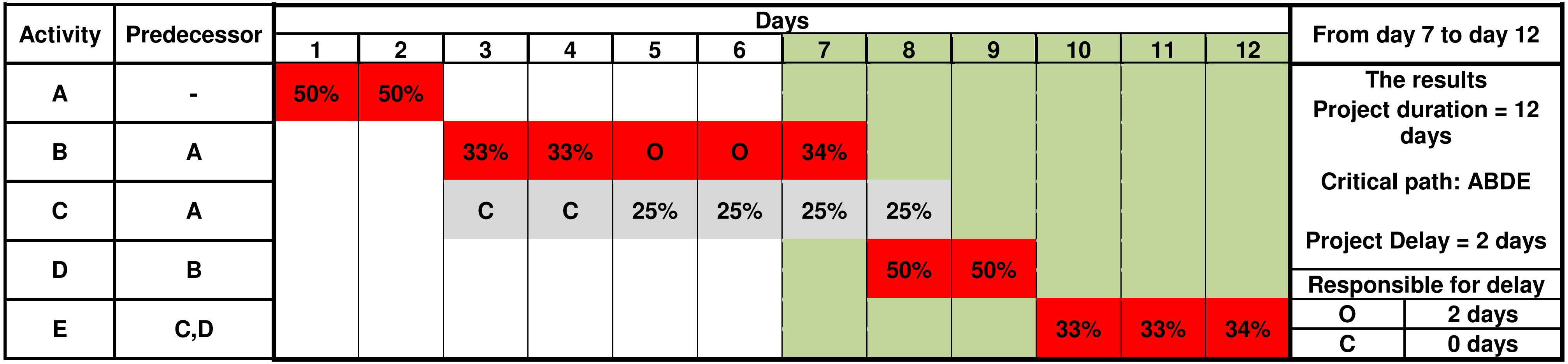
Critical path: ABDE

Project Delay = 2 days

Responsible for delay

O	2 days
C	0 days

(a) Windows Ending at Day 6



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

From day 7 to day 12

The results
Project duration = 12 days

Critical path: ABDE

Project Delay = 2 days

Responsible for delay

O	2 days
C	0 days

(b) Windows Ending at Day 12

Fig. 3.5: Bar Charts for a Simple Case using Traditional Windows Analysis Method (Case no. 5)

The previous sample cases show that windows analysis may overlook critical path fluctuations, and using different window sizes to analyze the same case may result in different conclusions, as shown in Table 3.1.

Table 3.1: Comparison of the Results of TWAM

Case no.	Windows size	Delay responsibility	
		Contractor	Owner
1	From day 1 to day 12	0	2
2	From day 1 to day 3 and from day 4 to day 12	0	2
3	From day 1 to day 4 and from day 5 to day 12	1	1
4	From day 1 to day 5 and from day 6 to day 12	0.5	1.5
5	From day 1 to day 6 and from day 7 to day 12	0	2

f. Conclusion

This simple example shows that windows analysis may overlook critical path fluctuations, and using different window sizes to analyze the same case may result in different conclusions as shown in Table 3.1.

When we suppose that the previous example was a project, and both parties (contractor and owner) go to the court to solve the dispute by litigation, the last step of resolving disputes, here we can imagine what will happen?, the contractor will defend himself using case no. 1,2,5 or at least case no.4 for analyzing the delay. Thus, he will be compensable for delay in the project because the owner is responsible for that delay.

On the other hand, the owner has no way to defend himself except case no.3 to minimize the cost of delay that will pay it to the contractor and to get the equilibrium state between him and the contractor. To that, the courts' decision may be very difficult to determine which party is responsible for delay, to facilitate this case and same cases the project delay will be analyzed by using the Daily Window Analysis Method "**DWAM**" to determine with better accuracy which party is responsible for the delay.

3.3. Daily Windows Analysis Method "DWAM"

Zhang (2003) introduced changes to the traditional windows analysis method "**TWAM**" in order to resolve some of its drawbacks. To capture and consider all the fluctuations in the critical path(s), he used a window size of one day.

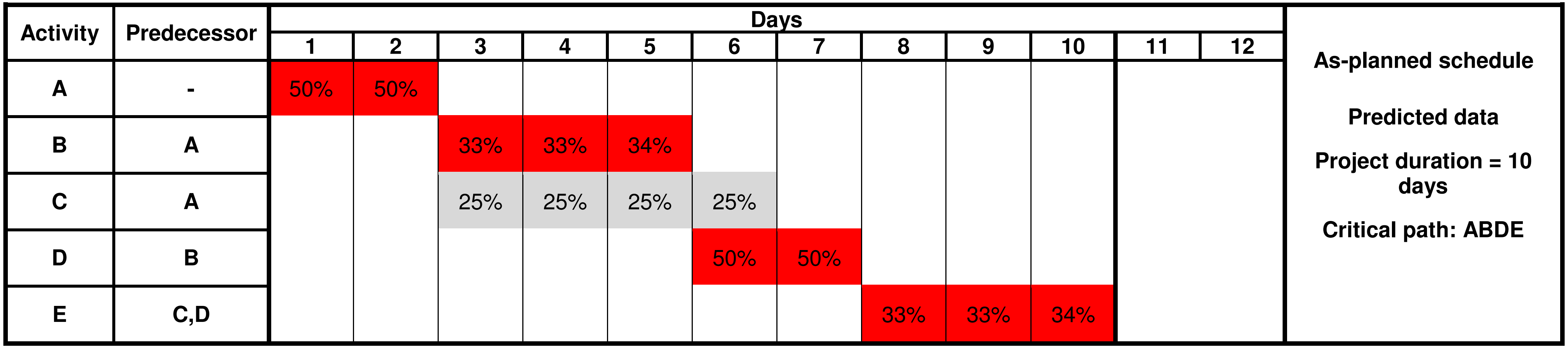
The simple example shown in Fig. 3.6 can be used to demonstrate this new daily windows analysis method "**DWAM**". The relationships shown, activities B and C both follow activity A, activity D follows activity B and finally activity E follows both activities C and D. The as-planned duration is ten days, while the as-built duration is twelve days thus exercising a two-day project delay. It is important to apportion the two-day delay properly among the parties responsible.

The daily windows analysis method "**DWAM**" uses a window size of one day. In this process, all delays and work stops caused by the different parties are first removed from the as-built schedule so that the process will begin with the as-planned schedule. Then, the events of each day are entered as shown in Fig. 3.6b. It is assumed in this representation of daily progress that the work stop caused by each party (contractor or owner) is for a full-day and progress is stopped in this case. The case of partial progress and partial interruption of work by the parties is not considered.

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

a. **Days 1 and 2:** The project did not experience any delay, so the project duration remains ten days.

b. **Day 3 (Fig. 3.7):** The window of the third day shows a one-day contractor delay on the new critical path A-C-E in additional to the first critical path A-B-D-E. However the project duration remains ten days, so this one-day of delay is not considered as a reason in the project delay.



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

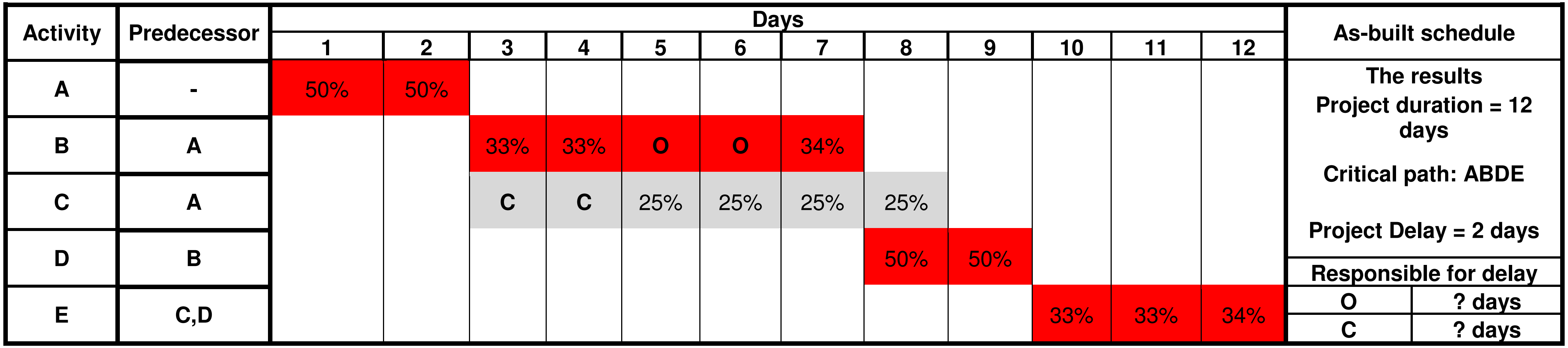
As-planned schedule

Predicted data

Project duration = 10 days

Critical path: ABDE

(a) As-Planned Bar Chart



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

As-built schedule

The results

Project duration = 12 days

Critical path: ABDE

Project Delay = 2 days

Responsible for delay	
O	? days
C	? days

(b) As-Built Bar Chart

Fig. 3.6: Bar Charts for a Sample Case of Daily Windows Analysis Method

c. **Day 4 (Fig. 3.8):** The only critical path A-C-E exhibits a one-day contractor delay (c), which extended the project duration to eleven days. Therefore, this window is one day longer than the previous window, indicating a project delay of one day. An examination of the critical path A-C-E reveals that this one-day project delay was caused by the contractor's (c) event. Accordingly, a contractor delay (C) is accumulated.

d. **Day 5 (Fig. 3.9):** The window of the fifth day shows a one-day owner delay on the new critical path A-B-D-E in additional to the previous critical path A-C-E, but the project duration remains eleven days, as in the previous window, so this one-day delay is not considered as a reason for the project delay.

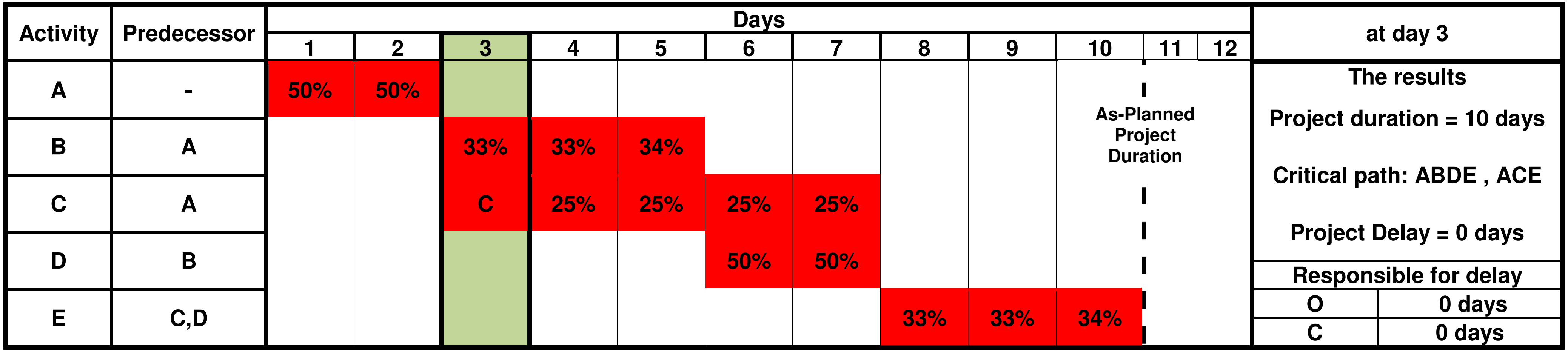
e. **Day 6 (Fig. 3.10):** The only critical path A-B-D-E experiences a one-day delay due to the owner's delay (o) leading to the project duration becoming twelve days.

f. **Days 7 to 12:** No additional delays occurred, so the project duration remains at twelve days.

Tables 3.2 and 3.3 show the result of "**DWAM**" using through window size of one day to analyze the project delay.

Table (3.2): Result of "DWAM"

Day no.	Delay responsibility		The effect of delay on the project	
	Contractor	Owner	Contractor caused	Owner caused
1 and 2	0	0	0	0
3	1	0	0	0
4	1	0	1	0
5	0	1	0	0
6	0	1	0	1
from 7 to 12	0	0	0	0



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

at day 3

The results

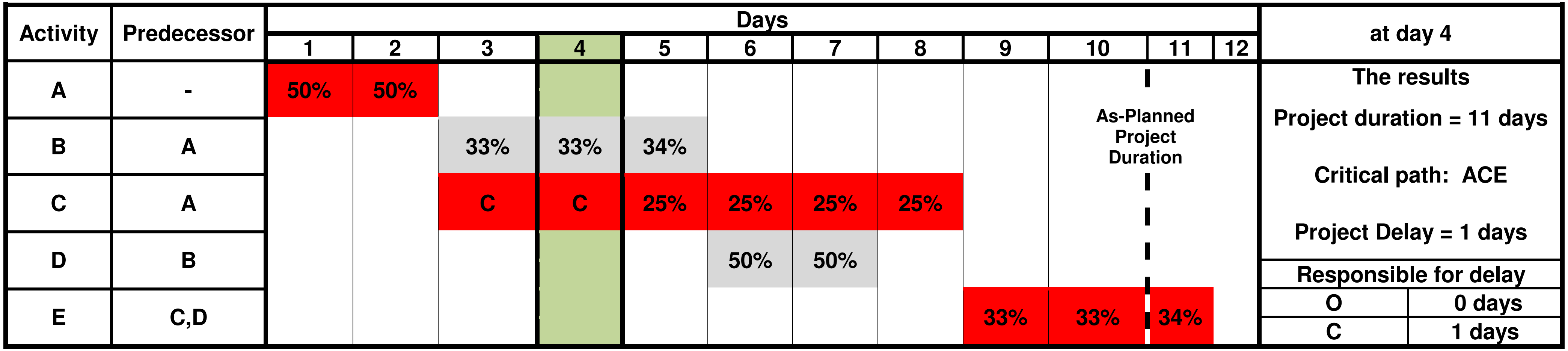
Project duration = 10 days

Critical path: ABDE , ACE

Project Delay = 0 days

Responsible for delay	
O	0 days
C	0 days

Fig. 3.7: Daily Windows Analysis Method at Day 3



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

at day 4

The results

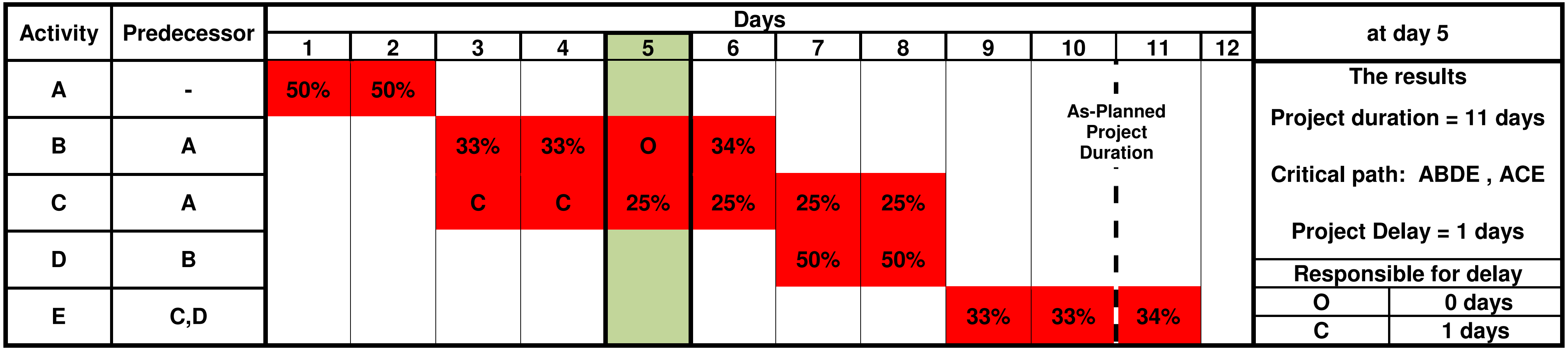
Project duration = 11 days

Critical path: ACE

Project Delay = 1 days

Responsible for delay	
O	0 days
C	1 days

Fig. 3.8: Daily Windows Analysis Method at Day 4



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

at day 5

The results

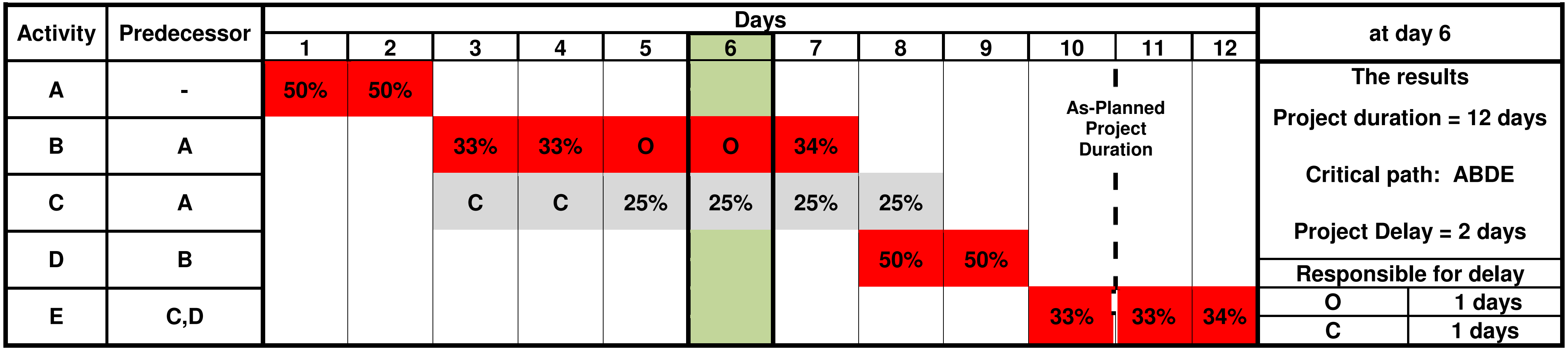
Project duration = 11 days

Critical path: ABDE , ACE

Project Delay = 1 days

Responsible for delay	
O	0 days
C	1 days

Fig. 3.9: Daily Windows Analysis Method at Day 5



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

at day 6

The results

Project duration = 12 days

Critical path: ABDE

Project Delay = 2 days

Responsible for delay	
O	1 days
C	1 days

Fig. 3.10: Daily Windows Analysis Method at Day 6

Table (3.3): Final Results of the Analysis by "DWAM"

	Delay events		Responsible for delay	
Project delays	**Contractor**	**Owner**	**Contractor**	**Owner**
2 days	**2 days**	**2 days**	**1 day**	**1 day**

g. Conclusion

As demonstrated by this simple example, the daily windows analysis method "**DWAM**" considers every change in the critical path(s). Some of these changes would be overlooked if the Traditional Windows Analysis Method "**TWAM**" is used to analyze the same case. However, the Daily Windows Analysis Method "**DWAM**" still needs improvement as it does not take into consideration other factors, such as schedule updates. Thus, this point will be tackled in the Modified Windows Analysis Method "**MDWAM**" in the next section.

3.4. Modified Daily Windows Analysis Method "MDWAM"

3.4.1. Schedule Updates

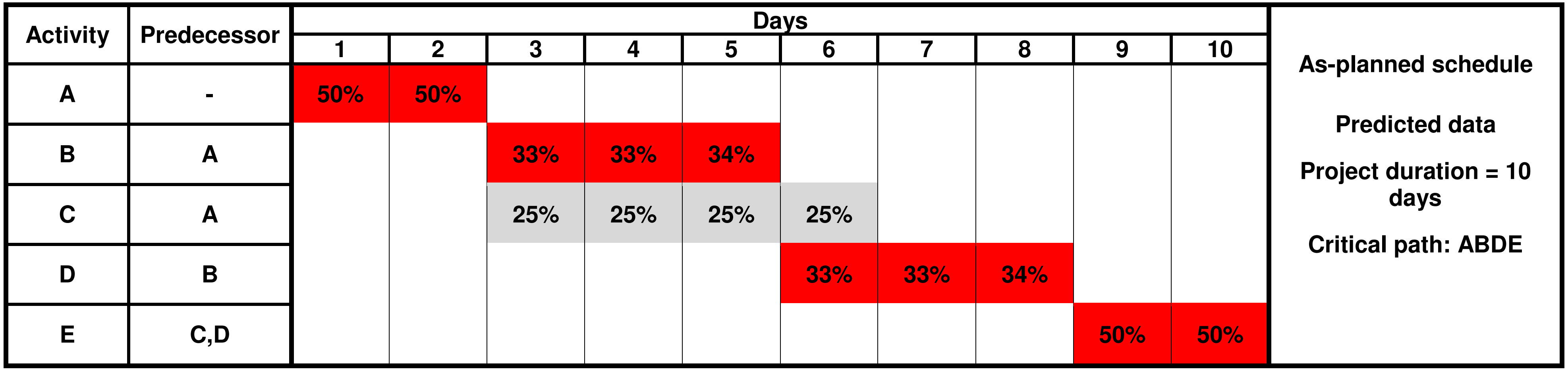
The as-planned schedule can be changed for many reasons: work delays, additional work requested by the owner, changes in the logical relationships between the activities, or changes in the duration of the activities. Delay analysis that does not consider such changes in the schedule may yield inaccurate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

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

3.4.2. Case Study Involving Schedule Updates

Figure 3.11 illustrates the as-planned schedule and the as-built schedule of a simple five-activity case study. Both the as-planned and the as-built durations are 10 days. Therefore, the project was completed as planned. However, the project experienced delays and accelerations during the course of the work. These delays and accelerations should be analyzed and apportioned among the parties in order to allocate any time-related costs.

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



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

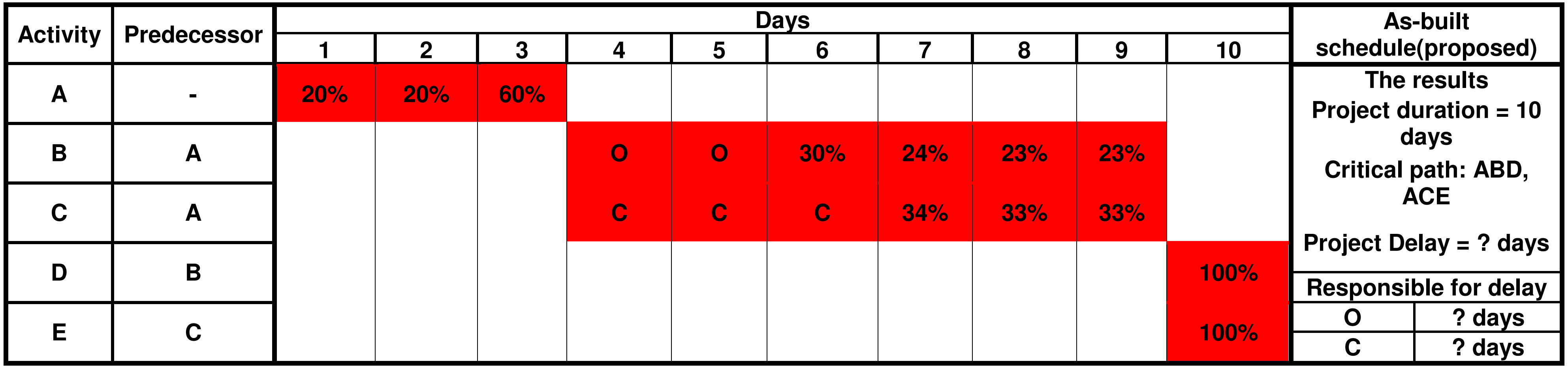
As-planned schedule

Predicted data

Project duration = 10 days

Critical path: ABDE

(a) As-Planned Bar Chart "1st Baseline"



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

As-built schedule(proposed)

The results

Project duration = 10 days

Critical path: ABD, ACE

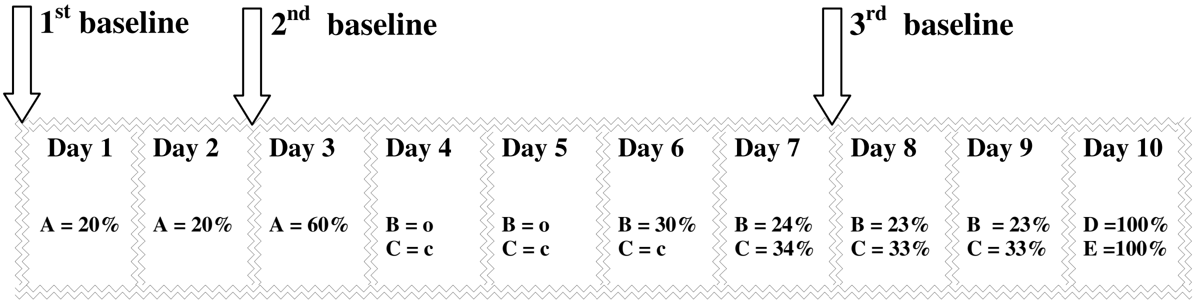
Project Delay = ? days

Responsible for delay	
O	? days
C	? days

(a) As-Built Bar Chart

Fig. 3.11: Planned and Actual Progress of the Sample Case

In the next few days, both the owner and the contractor caused delays to the project, and again the contractor had to take corrective actions and accelerate the project upon the owner's request. The contractor changed the method of construction of some activities to shorten the duration of these activities so the project would be finished in 10 days. As shown in Fig. 3.12, some of the events were caused by the owner, so an analysis is required to determine if the contractor is entitled to compensation by the owner.



c = contractor delay; o = owner delay

Fig. 3.12: Representation of Project Timeline as a Film Strip

3.4.3. Using "MDWAM" with Schedule Updates

Applying the Daily Windows Analysis Method "**DWAM**" for this case study, yielded a total of as-planned days as the same as the actual or as-built days, 10 days, so the difference between the two durations is zero days. Because the "**DWAM**" depends on the difference between the two charts then we can't apply this method. So the "**DWAM**" will be modify to adapt with the same cases of the previous case. The modified method is called Modified Daily Windows Analysis Method "**MDWAM**". Where the "**MDWAM**" depends on the project schedule updates, so the schedule updates consider as a very important element is to determine who is responsible for the delay in this case.

Fig. 3.11a represents the as-planned progress or the first baseline of the project and Fig. 3.11b illustrates the actual or as-built progress.

The "**MDWAM**" depends on schedule updates which mean that we need to re-schedule the remaining time of project duration after the current day is finished in order to know where and when to make a corrective action(s). This leads to updating the schedule and the new baseline will be obtained.

Re-scheduling of the remaining time of project duration may be happen only by three ways or equations as the following:

1. Remaining Duration equation
2. Earned Value equation
3. As-Planned Activity Duration equation

3.4.3.1. "MDWAM" Using Remaining Duration Equation:

The remaining duration equation is used to determine the anticipated activity or project duration depending on the percent planned production of the activity per day as shown in the following equation:

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

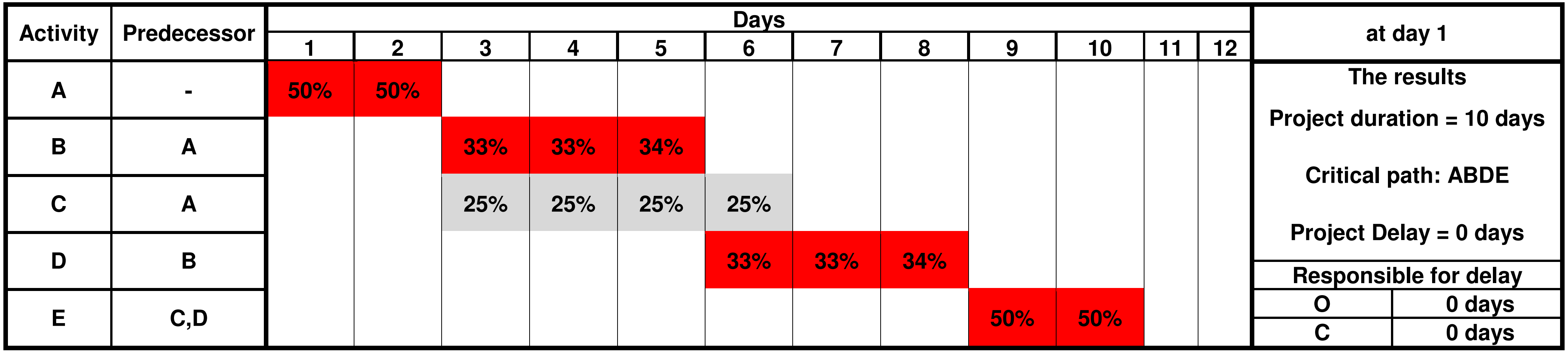
The "**MDWAM**" using remaining duration equation of the sample case is shown in the following procedure.

a. **Day 1 (Fig. 3.13) :** The contractor finished only 20% of activity A instead of the planned 50%. As such without accelerating this activity, the remaining 80% of the activity cannot be finished in one day, and activity A will not be completed within the planned two days. Rather, the remaining duration of activity A is calculated as:

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

Applying the previous equation we can get the new planned duration of activity A **= (100 – 20) / (50) = 80 / 50 = 1.6 days say 2 days**.

Therefore, the new planned duration of activity A becomes three days (one completed and two remaining), not the original planned duration of two days. Since this activity is critical at this window, the project duration will change from 10 days to 11 days. Accordingly, the analysis of day 1 shows that the contractor is responsible for one day of project delay (1 C) because of his slow progress, as shown in (Fig. 3.13b).



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

at day 1

The results

Project duration = 10 days

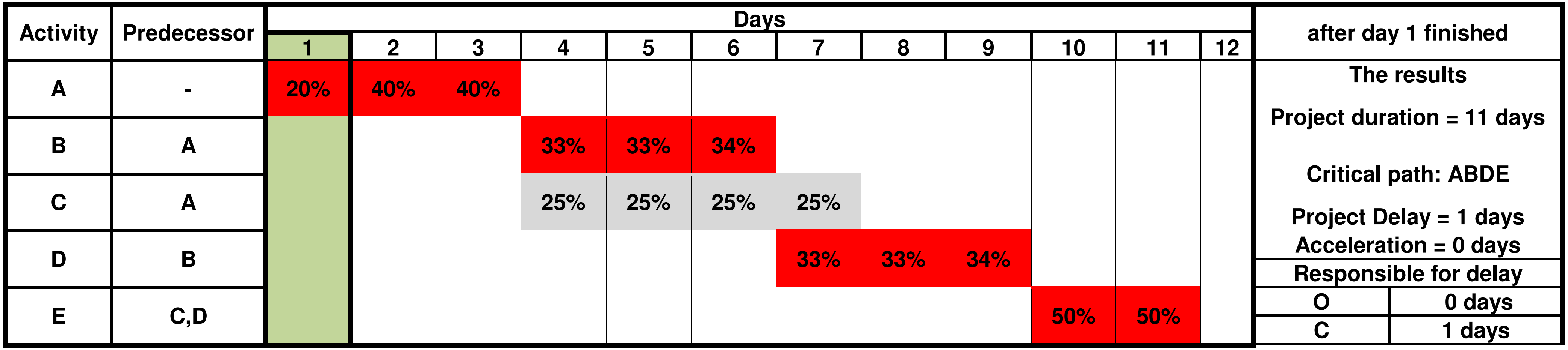
Critical path: ABDE

Project Delay = 0 days

Responsible for delay

O	0 days
C	0 days

(a) As-Planned Bar Chart "1st Baseline"



Activity	Predecessor	Days											
		1	2	3	4	5	6	7	8	9	10	11	12
A	-	20%	40%	40%									
B	A				33%	33%	34%						
C	A				25%	25%	25%	25%					
D	B							33%	33%	34%			
E	C,D										50%	50%	

after day 1 finished

The results

Project duration = 11 days

Critical path: ABDE

Project Delay = 1 days
Acceleration = 0 days

Responsible for delay

O	0 days
C	1 days

(b) Schedule of Remaining Project Duration Bar Chart "After Day 1 Was Finished"

Fig. 3.13: Delay Analysis with Schedule Updates Using "Remaining Duration Equation" (window of day 1)

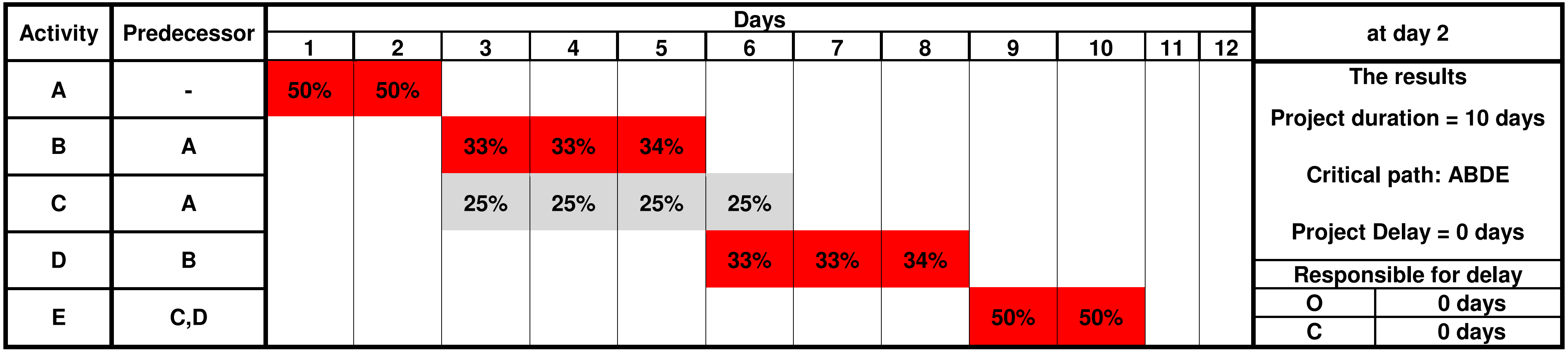
b. **Day 2 (Fig. 3.14) :** The progress of activity A was again slower than planned (20% instead of 40%), referring to the percentage of progress in the first two days and equation (3.1), the remaining 60% of the activity will be finished in two days (30% for each day). Thus, the project will be delayed another day to become 12 days (current window duration = 12, previous window = 11) because of the contractor's slowdown, as shown in (Fig3.14b).

c. **Corrective Action no.1 (Fig. 3.15) :** The contractor decided to run activity E in parallel with activity D and immediately after activity C as a corrective action in order to accelerate the project by two days and finish the work within the planned duration. Consequently, a two-day acceleration is accumulated, Where the acceleration is the opposite of delay (acceleration = - delay), so when the acceleration equals 2 days, it means that the delay equals -2 days. The baseline is updated on day 2. The new critical paths are A-B-D and A-C-E also the new baseline duration is again10 days as shown in (Fig.3.15b).

d. **Day 3 (Fig. 3.16) :** The contractor accelerates the work and finished the 60% remaining of activity A in one day instead of two days (30% for each day). The acceleration of one day in activity A, reduced the project duration to nine days. Accordingly, a one-day acceleration is accumulated (-1 C) as shown in (Fig. 3.16b).

e. **Day 4 (Fig. 3.17) :** The project experienced a concurrent delay (O+C), causing the project completion time to be 10 days rather than 9 days. But referring to the 2nd baseline schedule (the new as-planned) we find that the total project duration is 10 days, so this delay does not have any effect on the whole project. Consequently no party will be responsible for this delay as shown in (Fig. 3.17b).

f. **Day 5 (Fig. 3.18) :** Another concurrent delay (O+C) is experienced in activities B and C leading to the project duration becoming 11 days. Where the two activities B and C are on the critical path, so the owner and the contractor both are responsible for one day of project delay (0.5 O & 0.5 C) as shown in (Fig. 3.18b).



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

at day 2

The results

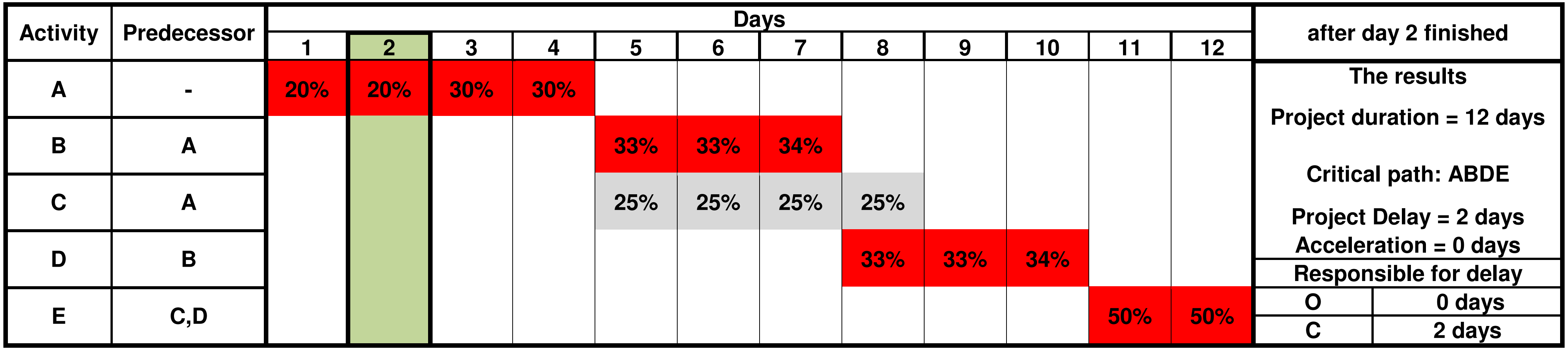
Project duration = 10 days

Critical path: ABDE

Project Delay = 0 days

Responsible for delay	
O	0 days
C	0 days

(a) As-Planned Bar Chart "1st Baseline"



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

after day 2 finished

The results

Project duration = 12 days

Critical path: ABDE

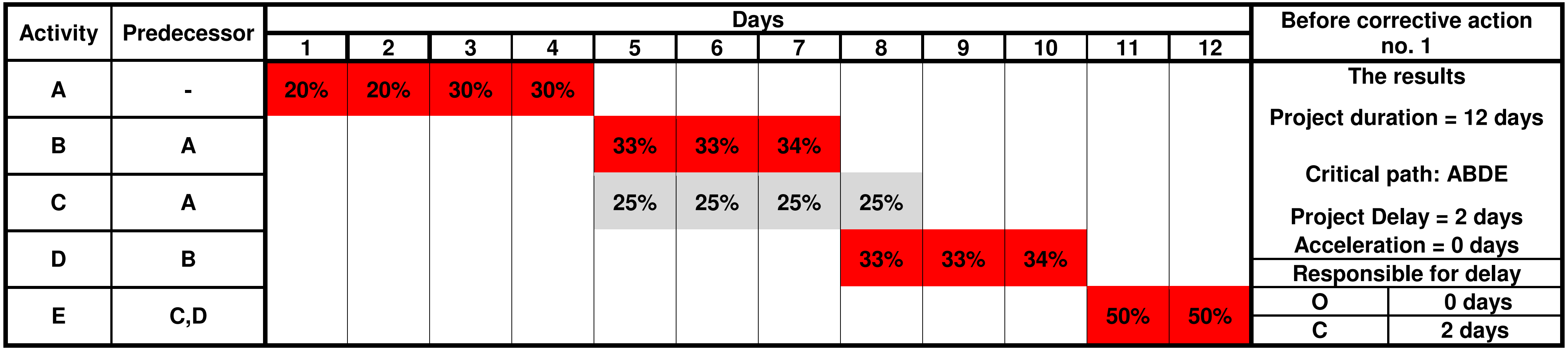
Project Delay = 2 days

Acceleration = 0 days

Responsible for delay	
O	0 days
C	2 days

(b) Schedule of Remaining Project Duration Bar Chart "After Day 2 Was Finished"

Fig. 3.14: Delay Analysis with Schedule Updates Using "Remaining Duration Equation" (window of day 2)



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

Before corrective action no. 1

The results

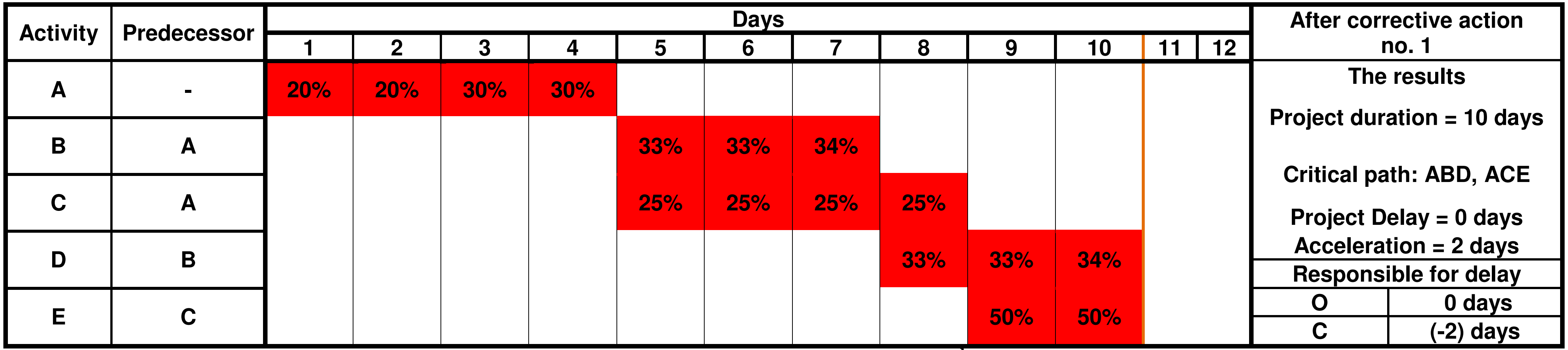
Project duration = 12 days

Critical path: ABDE

Project Delay = 2 days
Acceleration = 0 days

Responsible for delay	
O	0 days
C	2 days

(a) Bar Chart Before Schedule Update



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

After corrective action no. 1

The results

Project duration = 10 days

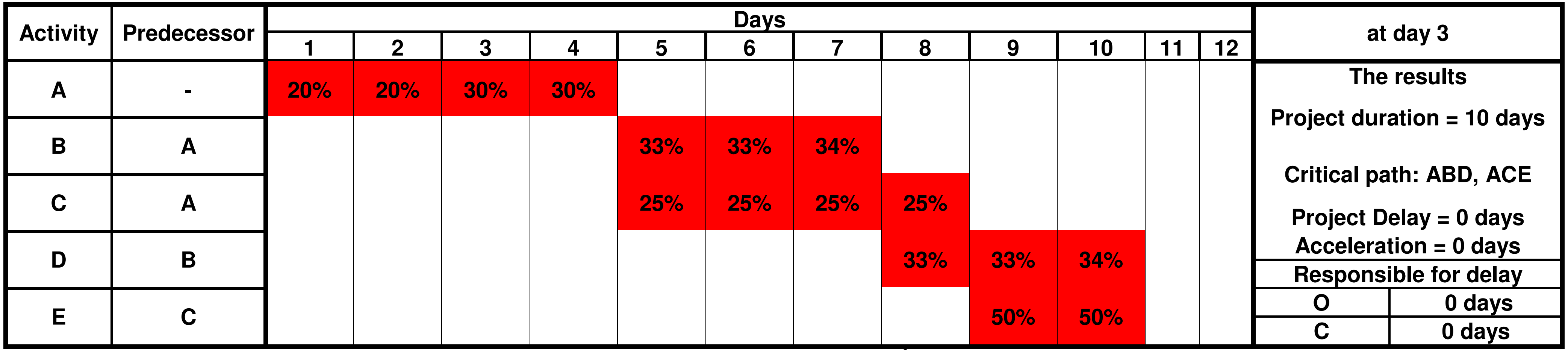
Critical path: ABD, ACE

Project Delay = 0 days
Acceleration = 2 days

Responsible for delay	
O	0 days
C	(-2) days

(b) Bar Chart After Schedule Update "2^{nd} Baseline"

Fig. 3.15: Delay Analysis with Schedule Updates Using "Remaining Duration Equation" (corrective action no.1)



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

at day 3

The results

Project duration = 10 days

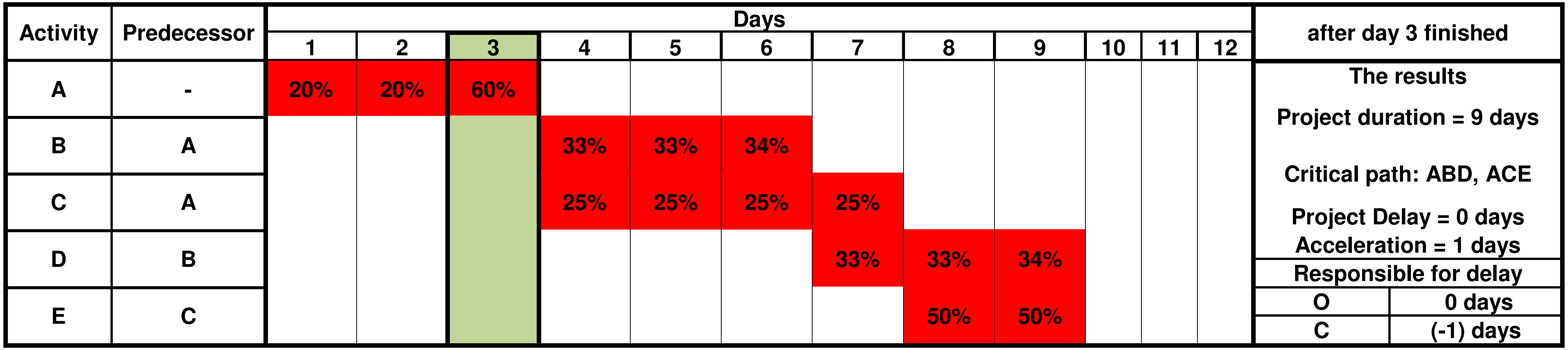
Critical path: ABD, ACE

Project Delay = 0 days
Acceleration = 0 days

Responsible for delay

O	0 days
C	0 days

(a) As-Planned Bar Chart "2^{nd} Baseline"



Activity	Predecessor	Days 1	2	3	4	5	6	7	8	9	10	11	12
A	-	20%	20%	60%									
B	A				33%	33%	34%						
C	A				25%	25%	25%	25%					
D	B							33%	33%	34%			
E	C								50%	50%			

after day 3 finished

The results

Project duration = 9 days

Critical path: ABD, ACE

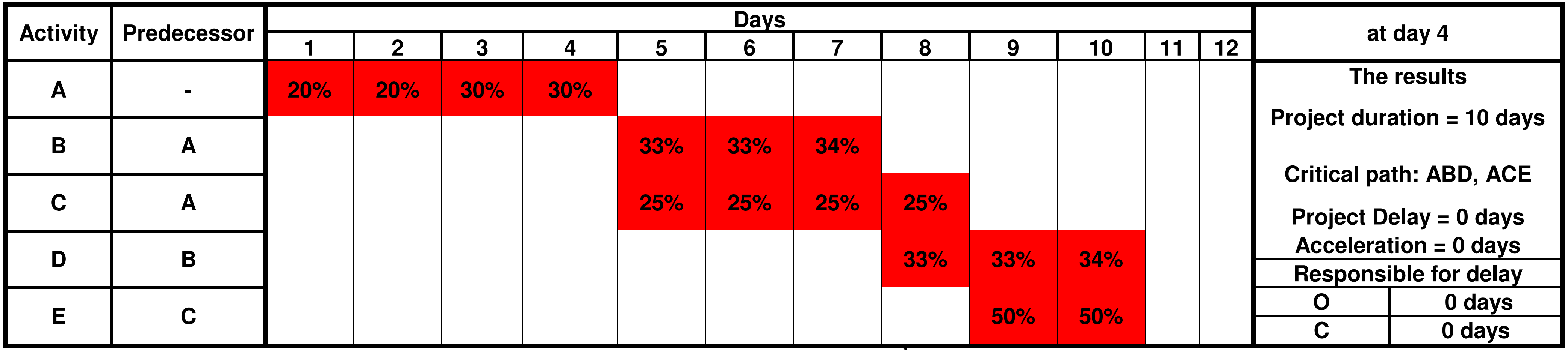
Project Delay = 0 days
Acceleration = 1 days

Responsible for delay

O	0 days
C	(-1) days

(b) Schedule of Remaining Project Duration Bar Chart "After Day 3 Was Finished"

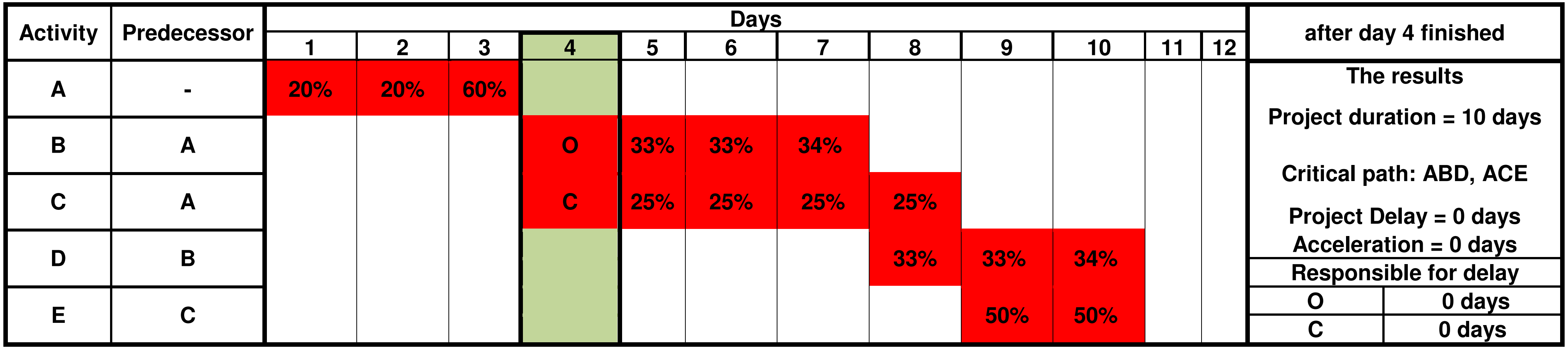
Fig. 3.16: Delay Analysis with Schedule Updates Using "Remaining Duration Equation" (window of day 3)



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

at day 4	
The results Project duration = 10 days Critical path: ABD, ACE Project Delay = 0 days Acceleration = 0 days	
Responsible for delay	
O	0 days
C	0 days

(a) As-Planned Bar Chart "2nd Baseline"

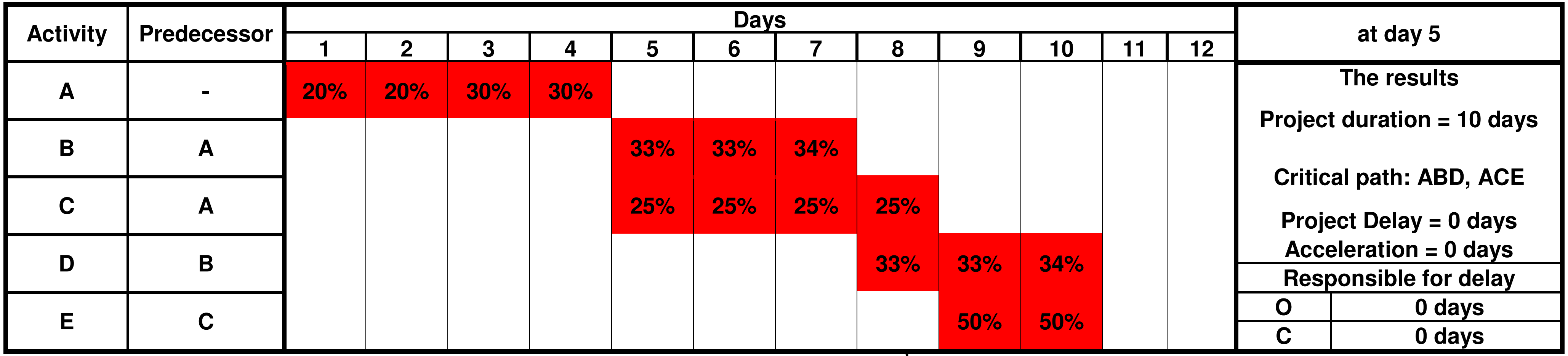


Activity	Predecessor	Days 1	2	3	4	5	6	7	8	9	10	11	12
A	-	20%	20%	60%	🟩								
B	A				O	33%	33%	34%					
C	A				C	25%	25%	25%	25%				
D	B				🟩				33%	33%	34%		
E	C				🟩					50%	50%		

after day 4 finished	
The results Project duration = 10 days Critical path: ABD, ACE Project Delay = 0 days Acceleration = 0 days	
Responsible for delay	
O	0 days
C	0 days

(b) Schedule of Remaining Project Duration Bar Chart "After Day 4 Was Finished"

Fig. 3.17: Delay Analysis with Schedule Updates Using "Remaining Duration Equation" (window of day 4)



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

at day 5

The results

Project duration = 10 days

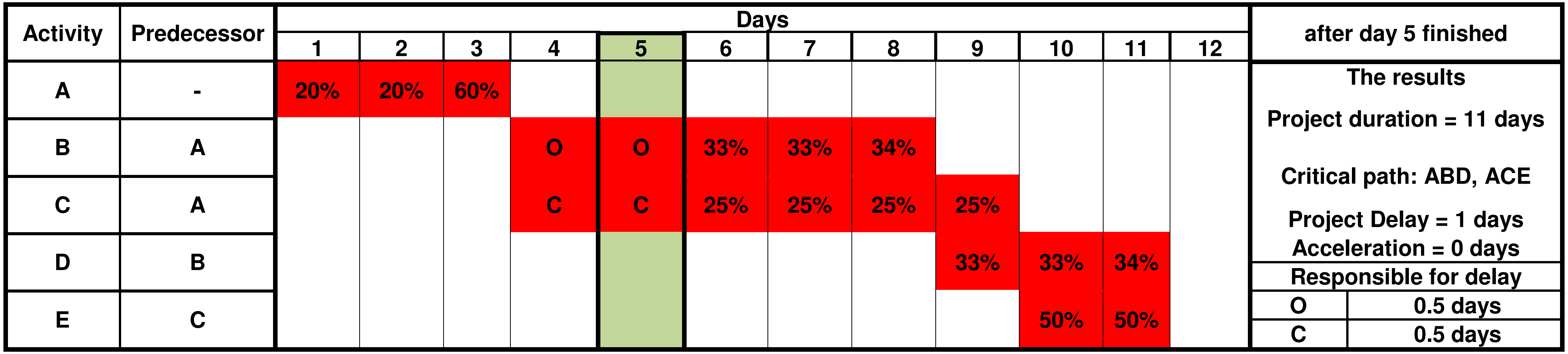
Critical path: ABD, ACE

Project Delay = 0 days
Acceleration = 0 days

Responsible for delay

O	0 days
C	0 days

(a) As-Planned Bar Chart "2nd Baseline"



Activity	Predecessor	Days											
		1	2	3	4	5	6	7	8	9	10	11	12
A	-	20%	20%	60%									
B	A				O	O	33%	33%	34%				
C	A				C	C	25%	25%	25%	25%			
D	B									33%	33%	34%	
E	C										50%	50%	

after day 5 finished

The results

Project duration = 11 days

Critical path: ABD, ACE

Project Delay = 1 days
Acceleration = 0 days

Responsible for delay

O	0.5 days
C	0.5 days

(b) Schedule of Remaining Project Duration Bar Chart "After Day 5 Was Finished"

Fig. 3.18: Delay Analysis with Schedule Updates Using "Remaining Duration Equation" (window of day 5)

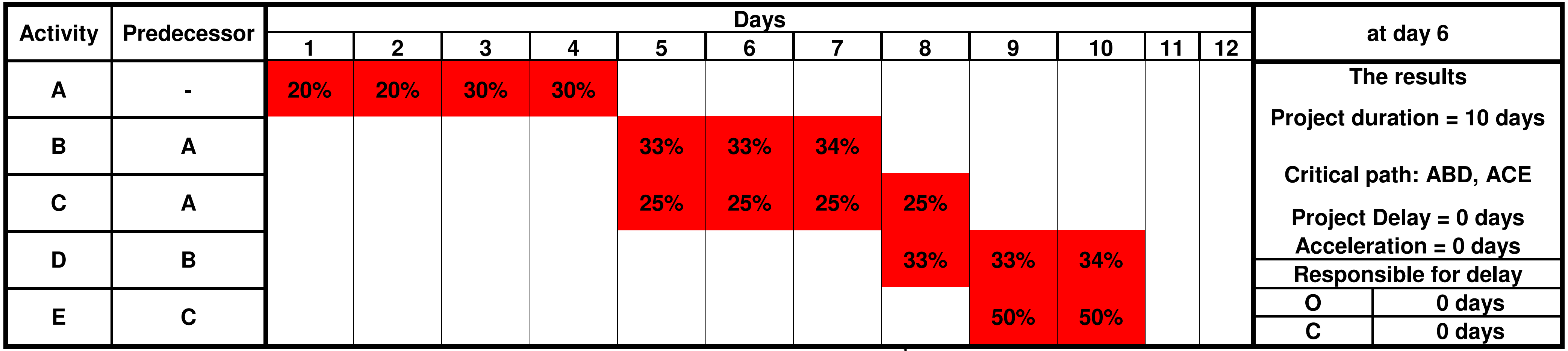
g. **Day 6 (Fig. 3.19) :** Continuing the analysis to the sixth day, the contractor delayed activity C and the critical paths were changed to becomes one critical path only is (A-C-E) and the project duration becomes 12 days. Therefore, the contractor is responsible for the additional one day of delay (1 C). Also he made a slowdown in activity B, where his progress in this activity was 30% instead of 33%, referring to equation (3.1) we get the remaining duration for activity B is two days (35% for each day) in additional to one day completed, so the total duration for this activity is 3 days equal the planned duration, as shown in (Fig. 3.19b).

h. **Day 7 (Fig. 3.20) :** The progress of activity B was again slower than planned (24% instead of 35%). Referring to the percentage of progress in this activity and equation (3.1), the remaining 46% of the activity will be finished in two days (23% for each day). On the other hand, he fast activity C (34% instead of 25%) and by using the same equation we will get two days remaining from activity C (33% for each day). Thus, the activity B will be delayed another one day and create a new critical path A-B-D in additional to the path A-C-E which becomes non critical, and the project will not be delayed another day (current window duration = 12, previous window = 12), as shown in (Fig3.20b).

i. **Corrective Action no.2 (Fig. 3.21) :** On the other hand, the contractor made another corrective action by speeding up activities D, and E to finish them in one day only and finish the project in just 10 days. Accordingly, two-day acceleration is decided. The baseline is updated on day 7, and the new critical paths are A-B-D and A-C-E with the new baseline duration again10 days as shown in (Fig.3.21b).

j. **Day 8 to Day 10 :** After the seventh day, the project progressed according to the new baseline and did not experience any further delays or accelerations (Fig. 3.21).

The previous case study shows that "**MDWAM**" considering schedule updates depends on Remaining Duration equations by using window size of one day to analyze the project delay, and the results of the analysis are shown in Tables (3.4 and 3.5).



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

at day 6

The results

Project duration = 10 days

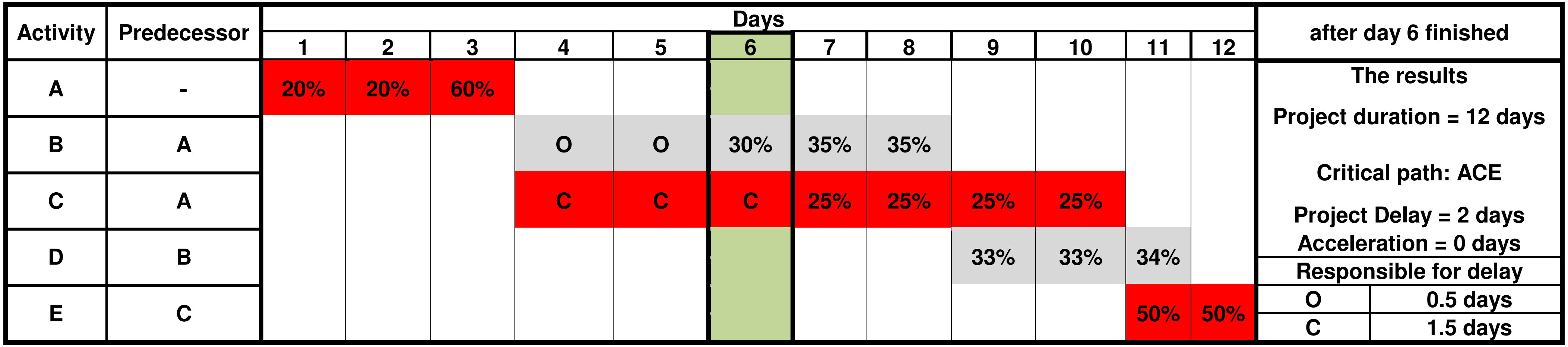
Critical path: ABD, ACE

Project Delay = 0 days
Acceleration = 0 days

Responsible for delay

O	0 days
C	0 days

(a) As-Planned Bar Chart "2nd Baseline"



Activity	Predecessor	1	2	3	4	5	6	7	8	9	10	11	12
A	-	20%	20%	60%									
B	A				O	O	30%	35%	35%				
C	A				C	C	C	25%	25%	25%	25%		
D	B									33%	33%	34%	
E	C											50%	50%

after day 6 finished

The results

Project duration = 12 days

Critical path: ACE

Project Delay = 2 days
Acceleration = 0 days

Responsible for delay

O	0.5 days
C	1.5 days

(b) Schedule of Remaining Project Duration Bar Chart "After Day 6 Was Finished"

Fig. 3.19: Delay Analysis with Schedule Updates Using "Remaining Duration Equation" (window of day 6)

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

at day 7

The results

Project duration = 10 days

Critical path: ABD, ACE

Project Delay = 0 days
Acceleration = 0 days

Responsible for delay	
O	0 days
C	0 days

(a) As-Planned Bar Chart "2nd Baseline"

Activity	Predecessor	Days 1	2	3	4	5	6	7	8	9	10	11	12
A	-	20%	20%	60%									
B	A				O	O	30%	24%	23%	23%			
C	A				C	C	C	34%	33%	33%			
D	B										33%	33%	34%
E	C										50%	50%	

after day 7 finished

The results

Project duration = 12 days

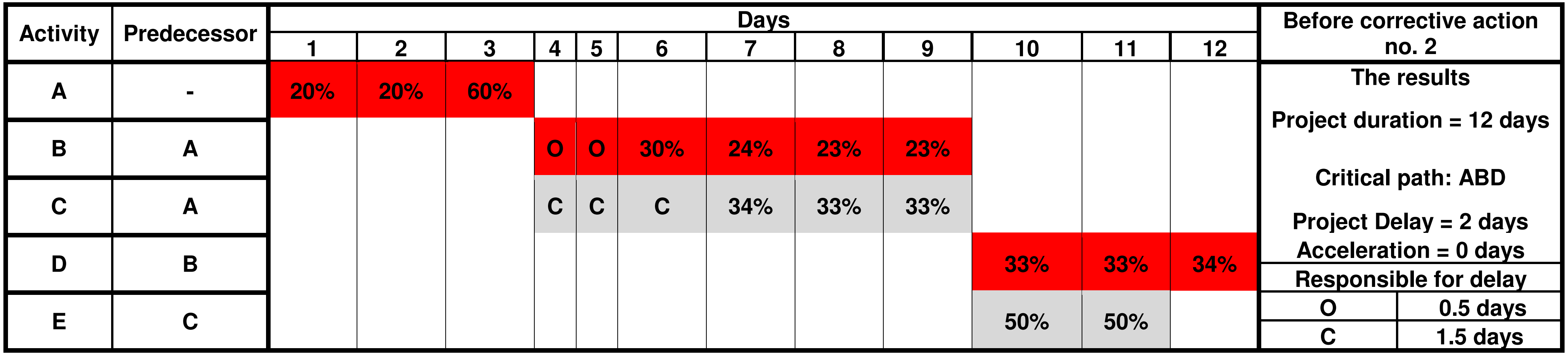
Critical path: ABD

Project Delay = 2 days
Acceleration = 0 days

Responsible for delay	
O	0.5 days
C	1.5 days

(b) Schedule of Remaining Project Duration Bar Chart "After Day 7 Was Finished"

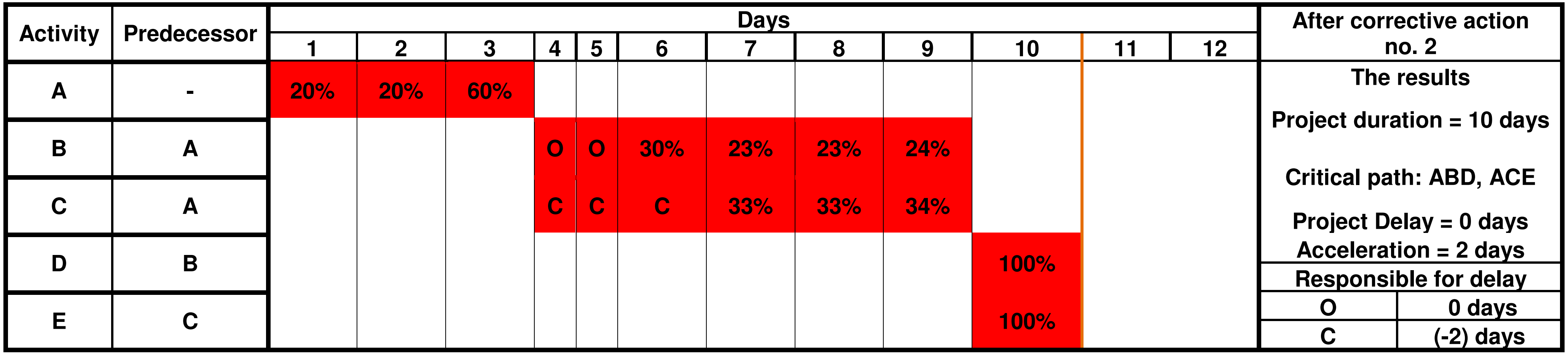
Fig. 3.20: Delay Analysis with Schedule Updates Using "Remaining Duration Equation" (window of day 7)



Activity	Predecessor	Days											
		1	2	3	4	5	6	7	8	9	10	11	12
A	-	20%	20%	60%									
B	A				O	O	30%	24%	23%	23%			
C	A				C	C	C	34%	33%	33%			
D	B										33%	33%	34%
E	C										50%	50%	

Before corrective action no. 2	
The results Project duration = 12 days Critical path: ABD Project Delay = 2 days Acceleration = 0 days	
Responsible for delay	
O	0.5 days
C	1.5 days

(a) Bar Chart Before Schedule Update



Activity	Predecessor	Days											
		1	2	3	4	5	6	7	8	9	10	11	12
A	-	20%	20%	60%									
B	A				O	O	30%	23%	23%	24%			
C	A				C	C	C	33%	33%	34%			
D	B										100%		
E	C										100%		

After corrective action no. 2	
The results Project duration = 10 days Critical path: ABD, ACE Project Delay = 0 days Acceleration = 2 days	
Responsible for delay	
O	0 days
C	(-2) days

(b) Bar Chart After Schedule Update "3rd Baseline"

Fig. 3.21: Delay Analysis with Schedule Updates Using "Remaining Duration Equation" (corrective action no.2)

Table (3.4): The Analysis of MDWAM Using Remaining Duration Equation

Baseline no.	Event.	Delay / Acceleration		Project Duration
		Contractor	Owner	
1st	Day 1	1	0	11
	Day 2	1	0	12
2nd	Corrective Action 1	(-2)	0	10
	Day 3	(-1)*	0	9
	Day 4	0.5	0.5	10
	Day 5	0.5	0.5	11
	Day 6	1	0	12
	Day 7	0	0	12
3rd	Corrective Action 2	(-2)	0	10
	from 8 to 12	0	0	10

* (-1) means the project was accelerated one day

Table (3.5): The Final Results of MDWAM Using Remaining Duration Equation

The party	Events		Responsibility
	Delay	acceleration	
Contractor	4	5	-1
Owner	1	0	1

The final results show that the contractor made four days delay and accelerated the project by five days and the owner made one day delay. Although, the as-built bar chart shows that the contractor and the owner made 3 days and 2 days delay respectively and the project not experience any delay because the difference between the as-built duration and the as-planned duration equal zero. By combining the events of delay and acceleration through the project we conclude that the contractor accelerate the project by one day (-1 day delay) and the owner delayed the project by one day and the combination results is zero (-1 day +1 day = zero day). Which means that the contractor accelerate that one day delayed by owner, **so the owner is responsible for one day delay**.

3.4.3.2. "MDWAM" Using Earned Value Equation:

The earned-value method is a project control technique that provides a quantitative measure of work performance. It is considered the most advanced technique for integration of schedule and cost (Kim and Ballard, 2000).

Earned value analysis usually integrates time and cost performance within the project scope. It helps the project manager to understand how to deal with project from two points of view. The first is to recognize current performance indexes and the second one is to provide a forecast to the future (Noori, Bagherpour and Zareei 2008).

The process of considering scope, schedule, and resources, measured against a project's actual performance. It compares the planned amount of work to the completed tasks, to the projects' cost, to determine if the cost, schedule, and work completed (thus far) are all in synch and in accordance with the plan. This analysis will show past performance and will estimate future efforts to complete the project (Carlos, 2007).

Modern or advanced project control uses an integrated cost/schedule concept called the earned value method (Kim and Ballard 2000). Kan 2005 Asserts that **EV** is the primary project management tool...that integrates the scope, schedule, and cost parameters of the contract.

Earned Value (**EV**) was formalized as a cost control tool in the US defense industry in the late 1960's, sponsored by government agencies looking for a solution to regular and serious overspending on defense projects. It really started to take off in the 1990's when the wider use of PC's made the processing of data easier and more available.

EV is often seen as a cost control tool, perhaps the best there is, but it can be much more than this. **EV** used in a proactive way to manage projects and suggest solutions to problems. Above all, **EV** brings realism and objectivity to projects (Kidston 2005).

From the above we can conclude that the **EV** provides a system for evaluating the performance of the project through integrating cost, schedule, and work, where the EV equation shown as the following:

Earned Value = (Percent Complete) x (Budgeted work hours or dollars)...(3.2)

Overall Project % Complete = (Earned work hours or dollars) / (Budgeted work hours or dollars) ……………………………………………………..(3.3)

The earned value system contain of three items 1- Actual cost or work, 2- Planned cost or work 3- Earned cost or work, these three items defined as the following:

1. Actual work hours or dollars to date that has been paid "**ACWP**"
2. Planned work hours or dollars to date planned "**BCWS**"
3. Earned work hours or dollars to date done "**BCWP**"

The previous three items called "**Cost and Schedule Performance Indicators**" they are considered the very important items in the earned value "**EV**" and leads to know the Schedule Variance "**SV**" and Schedule Performance Index "**SPI**", where "**SV**" is the difference between Earned works and Planned works, and "**SPI**" is an index between that Earned and Planned works as following equations:

Scheduled Variance (SV) = (Earned work hours or dollars) - (Planned work hours or dollars) or (SV) = BCWP - BCWS ……………..…………...……(3.4)

Schedule Performance Index (SPI) = (Earned work hours or dollars to date) / (Planned work hours or dollars to date) or (SPI) = BCWP / BCWS ……...(3.5)

That mean a positive Variance and an Index of 1.0 or greater is a favorable performance and we can illustrates the equation (3.4 and 3.5) as a graph shown in (Fig. 3.22).

From previous equations (3.4 and 3.5) we can conclude the Productivity Index "**PI**" according to the Earned Value "**EV**" to determine the productivity for each activity per day and that leads to determine the remaining duration for that activity after a part of that activity was finished as shown in the following equation:

Productivity Index "PI" = (Planned Unit Rate) / (Actual Unit Rate) ……...(3.6)

The productivity Index "**PI**" can be illustrates in the (Fig. 3.23), where (Fig. 3.23) shows the trend analyses and forecasting for each activity or project.

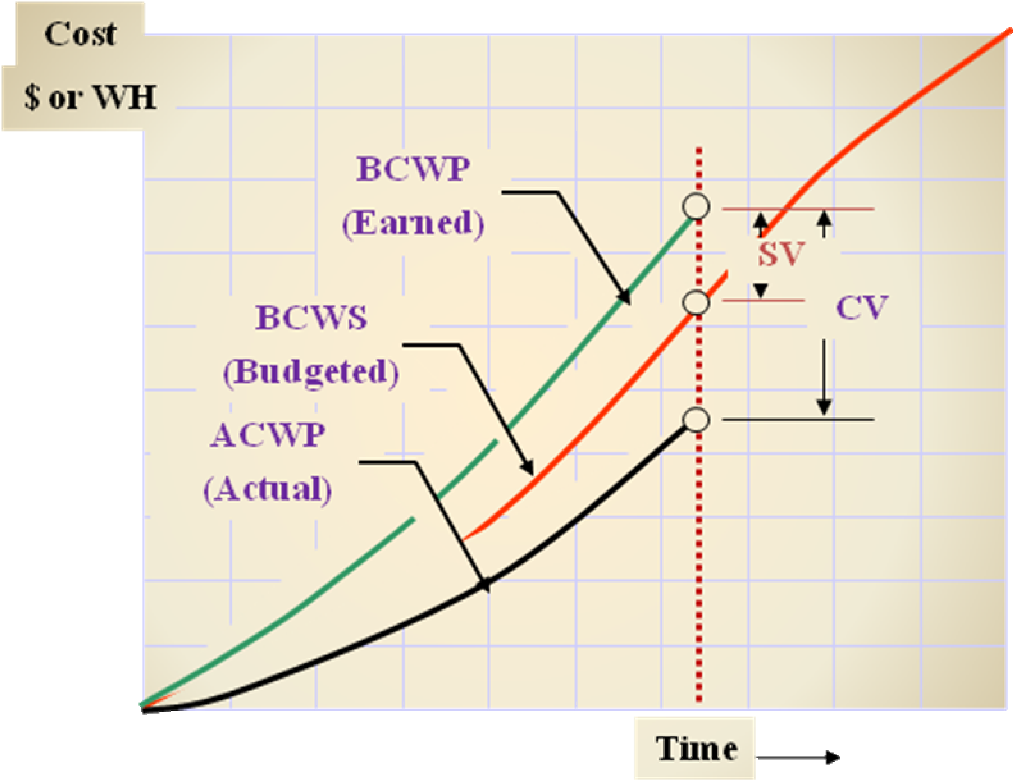


Fig. 3.22: Scheduled Variance and Schedule Performance Index

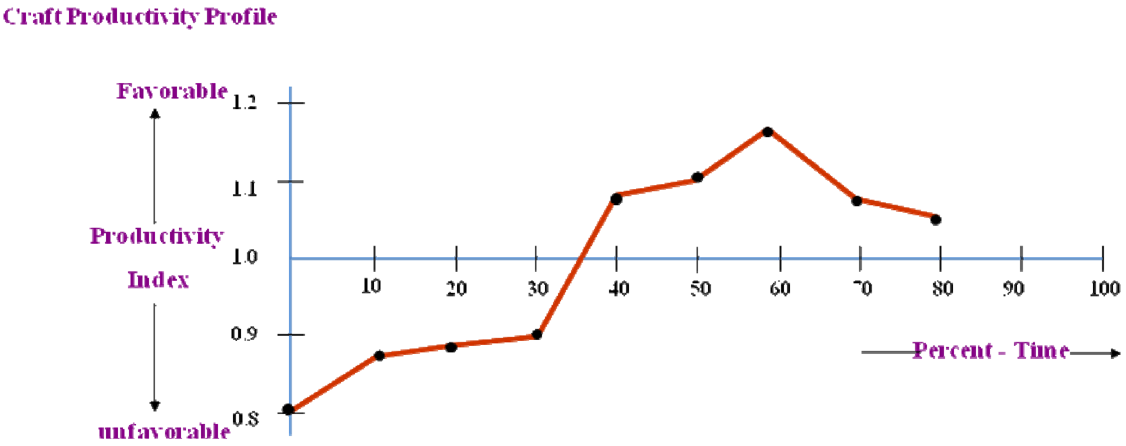


Fig. 3.23: Trend Analyses and Forecasting For any Activity

The productivity index equation considers the main equation for the analyses of delay using "MDWAM" considering schedule updates that depends on the Earned Value Equation as shown in the following analysis.

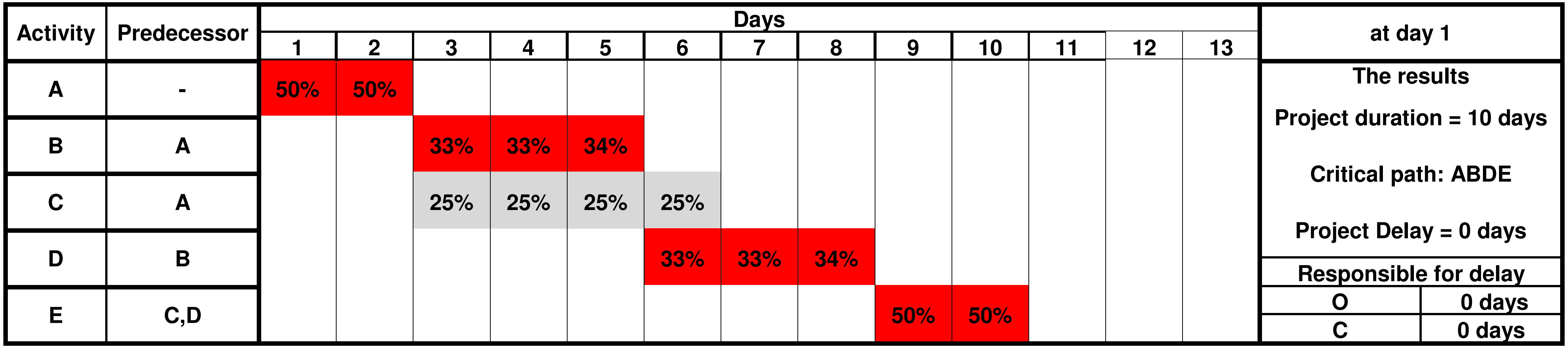
a. **Day 1 (Fig. 3.24) :** The contractor finished only 20% of activity A instead of the planned 50%. As such without accelerating this activity, the remaining 80% of the activity A according to the Earned Value **EV** when applying the Productivity Index equation "**PI**" cannot be finished in one day. Therefore, activity A will not be completed within the planned two days. Rather, the remaining duration of activity A is calculated as:

   Productivity Index "PI" = (Planned Unit Rate) / (Actual Unit Rate) ……...(3.6)

   Applying the previous equation we can get the new planned duration of activity A **= (100) / (20) = 5 days**.

   Therefore, the new planned duration of activity A becomes five days (one completed and four remaining), not the original planned duration of two days. Since this activity is critical at this window, the project duration will change from 10 days to 13 days. Accordingly, the analysis of day 1 shows that the contractor is responsible for three days of project delay (3 C) because of his slow progress, as shown in (Fig. 3.24b).

b. **Day 2 (Fig. 3.25) :** The progress of activity A was as planned according to Earned Value equation and Productivity Index equation (3.6), where the daily progress according to equation (3.6) is 20% per day. Thus, the project will not be delayed any extra days (current window duration = 13, previous window = 13) as shown in (Fig3.25b).



Activity	Predecessor	Days 1	2	3	4	5	6	7	8	9	10	11	12	13
A	-	50%	50%											
B	A			33%	33%	34%								
C	A			25%	25%	25%	25%							
D	B						33%	33%	34%					
E	C,D									50%	50%			

at day 1

The results

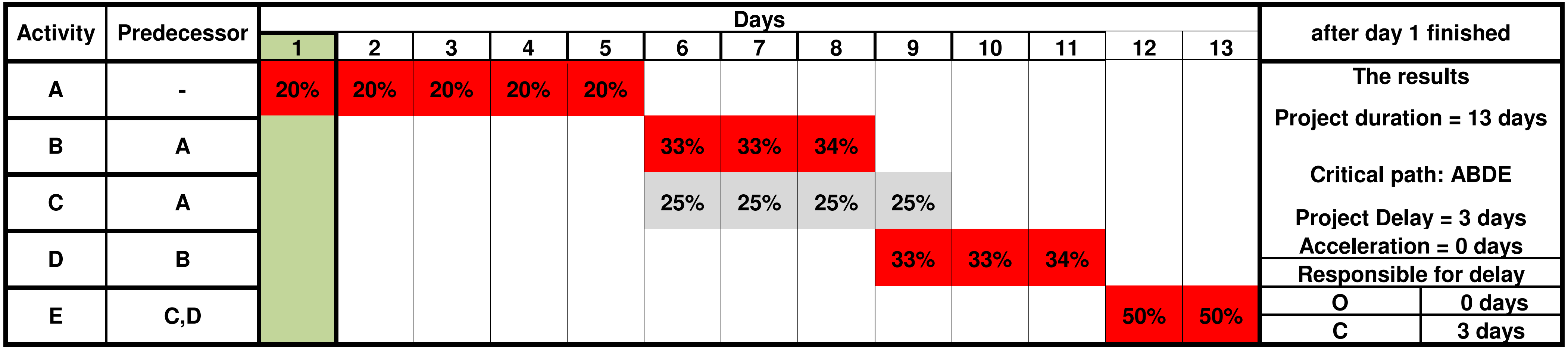
Project duration = 10 days

Critical path: ABDE

Project Delay = 0 days

Responsible for delay	
O	0 days
C	0 days

(a) As-Planned Bar Chart "1st Baseline"



Activity	Predecessor	Days 1	2	3	4	5	6	7	8	9	10	11	12	13
A	-	20%	20%	20%	20%	20%								
B	A						33%	33%	34%					
C	A						25%	25%	25%	25%				
D	B									33%	33%	34%		
E	C,D												50%	50%

after day 1 finished

The results

Project duration = 13 days

Critical path: ABDE

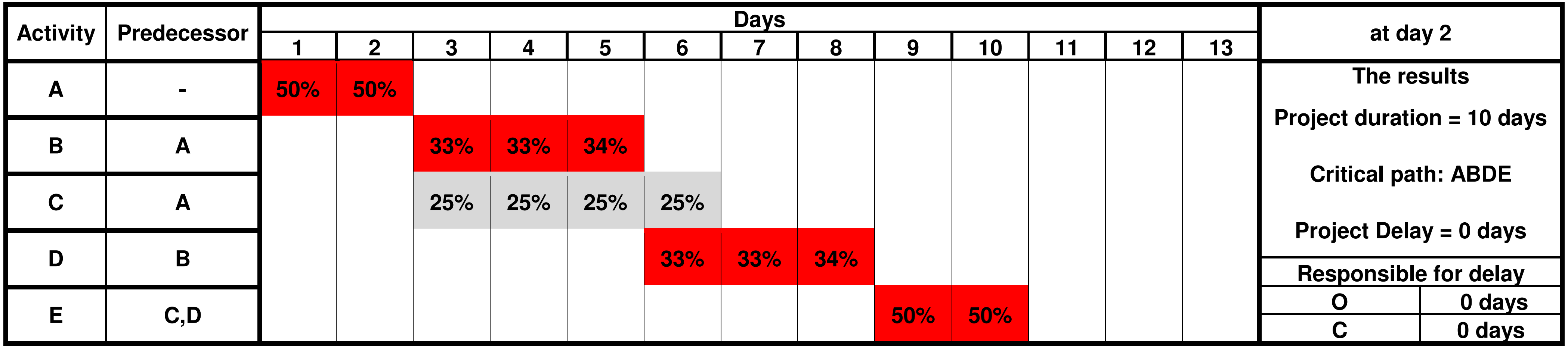
Project Delay = 3 days

Acceleration = 0 days

Responsible for delay	
O	0 days
C	3 days

(b) Schedule of Remaining Project Duration Bar Chart "After Day 1 Was Finished"

Fig. 3.24: Delay Analysis with Schedule Updates Using "Earned Value Equation" (window of day 1)



Activity	Predecessor	Days 1	2	3	4	5	6	7	8	9	10	11	12	13
A	-	50%	50%											
B	A			33%	33%	34%								
C	A			25%	25%	25%	25%							
D	B						33%	33%	34%					
E	C,D									50%	50%			

at day 2

The results

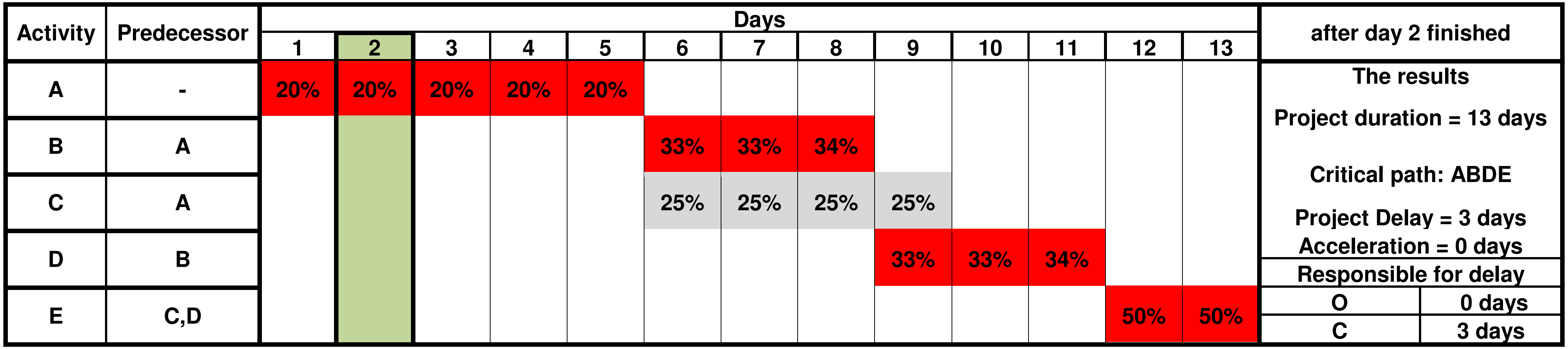
Project duration = 10 days

Critical path: ABDE

Project Delay = 0 days

Responsible for delay	
O	0 days
C	0 days

(a) As-Planned Bar Chart "1st Baseline"



Activity	Predecessor	Days 1	2	3	4	5	6	7	8	9	10	11	12	13
A	-	20%	20%	20%	20%	20%								
B	A						33%	33%	34%					
C	A						25%	25%	25%	25%				
D	B									33%	33%	34%		
E	C,D												50%	50%

after day 2 finished

The results

Project duration = 13 days

Critical path: ABDE

Project Delay = 3 days

Acceleration = 0 days

Responsible for delay	
O	0 days
C	3 days

(b) Schedule of Remaining Project Duration Bar Chart "After Day 2 Was Finished"

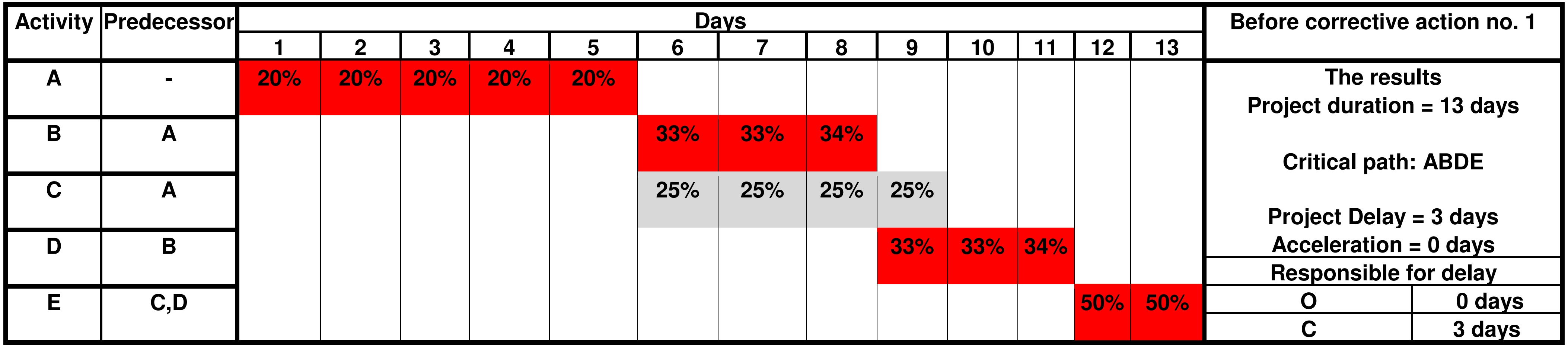
Fig. 3.25: Delay Analysis with Schedule Updates Using "Earned Value Equation" (window of day 2).

c. **Corrective Action no.1 (Fig. 3.26) :** The contractor decided to run activity E in parallel with activity D and immediately after activity C, reduces the duration of activity C to three days instead of four days, and finally reduces the duration of activity D to two days instead of three days as a corrective actions in order to accelerate the project by three days and finish the work within the planned duration. Consequently, a three-days acceleration is accumulated, where the acceleration is the opposite of delay (acceleration = - delay), so when the acceleration equal 3 days means that the delay equal -3 days. The baseline is updated on day 2. The new critical paths are A-B-D and A-C-E, also the new baseline duration is again10 days as shown in (Fig.3.26b).

d. **Day 3 (Fig. 3.27) :** The contractor accelerated his work and finished the 60% remaining of activity A in one day instead of three days (20% for each day). The acceleration of two days in activity A, reduced the project duration to eight days. Accordingly, a two-days acceleration is accumulated (-2 C) as shown in (Fig. 3.27b).

e. **Day 4 (Fig. 3.28) :** The project experienced a concurrent delay (O+C), causing the project completion time to be 9 days rather than 10 days, where the owner and the contractor are responsible for that delay because their delays are on the critical path. But referring to the 2nd baseline schedule (the new as-planned) we find that the total project duration is 10 days. Then that delays have not any effect on the whole project, so no party carry that delays as shown in (Fig. 3.28b).

f. **Day 5 (Fig. 3.29) :** Another concurrent delay (O+C) is experienced in activities B and C leading the project duration to become 10 days rather than 9 days. The owner and the contractor are responsible for this delay as shown previously .But referring to the 2nd baseline schedule (the new as-planned) we find that the total project duration is 10 days. Then that delays have not any effect on the whole project, so no party carry that delays as shown in (Fig. 3.29b).



Activity	Predecessor	1	2	3	4	5	6	7	8	9	10	11	12	13
A	-	20%	20%	20%	20%	20%								
B	A						33%	33%	34%					
C	A						25%	25%	25%	25%				
D	B									33%	33%	34%		
E	C,D												50%	50%

Before corrective action no. 1

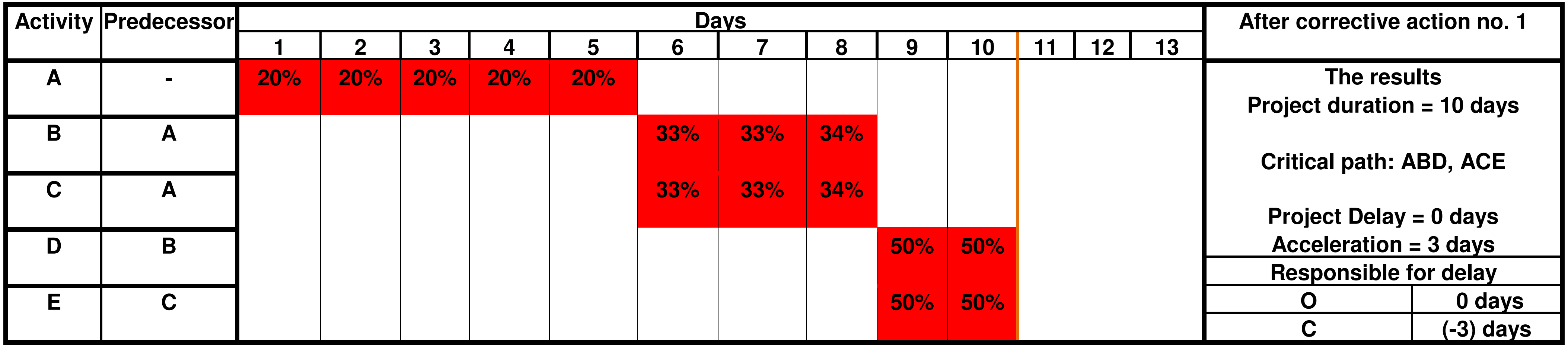
The results
Project duration = 13 days

Critical path: ABDE

Project Delay = 3 days
Acceleration = 0 days

Responsible for delay	
O	0 days
C	3 days

(a) Bar Chart Before Schedule Update



Activity	Predecessor	1	2	3	4	5	6	7	8	9	10	11	12	13
A	-	20%	20%	20%	20%	20%								
B	A						33%	33%	34%					
C	A						33%	33%	34%					
D	B									50%	50%			
E	C									50%	50%			

After corrective action no. 1

The results
Project duration = 10 days

Critical path: ABD, ACE

Project Delay = 0 days
Acceleration = 3 days

Responsible for delay	
O	0 days
C	(-3) days

(b) Bar Chart After Schedule Update "2nd Baseline"

Fig. 3.26: Delay Analysis with Schedule Updates Using "Earned Value Equation" (corrective action no.1)

Activity	Predecessor	Days												
		1	2	3	4	5	6	7	8	9	10	11	12	13
A	-	20%	20%	20%	20%	20%								
B	A						33%	33%	34%					
C	A						33%	33%	34%					
D	B									50%	50%			
E	C									50%	50%			

at day 3	
The results Project duration = 10 days Critical path: ABD, ACE Project Delay = 0 days Acceleration = days	
Responsible for delay	
O	0 days
C	0 days

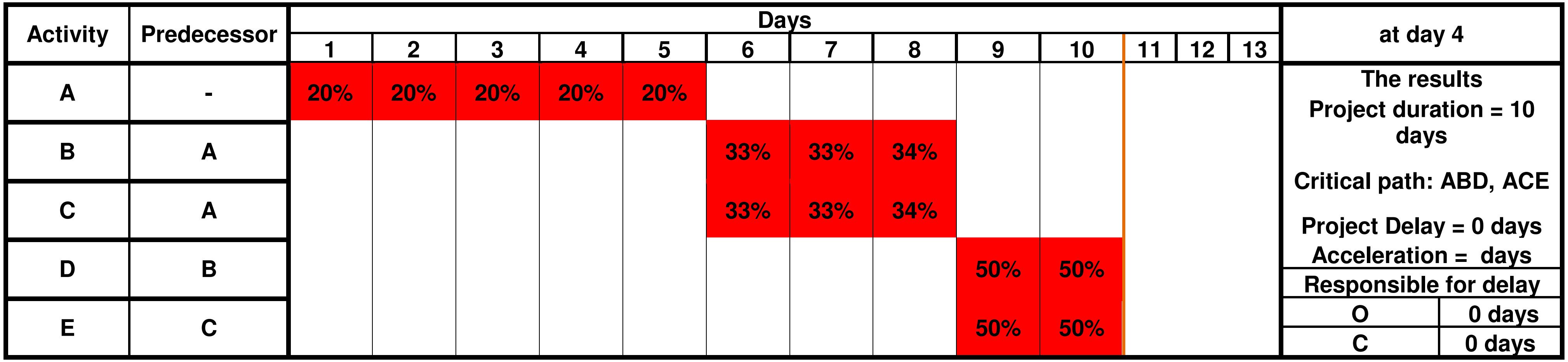
(a) As-Planned Bar Chart "2nd Baseline"

Activity	Predecessor	Days												
		1	2	3	4	5	6	7	8	9	10	11	12	13
A	-	20%	20%	60%										
B	A				33%	33%	34%							
C	A				25%	25%	25%							
D	B							50%	50%					
E	C							50%	50%					

after day 3 finished	
The results Project duration = 8 days Critical path: ABD, ACE Project Delay = 0 days Acceleration = 2 days	
Responsible for delay	
O	0 days
C	(-2) days

(b) Schedule of Remaining Project Duration Bar Chart "After Day 3 Was Finished"

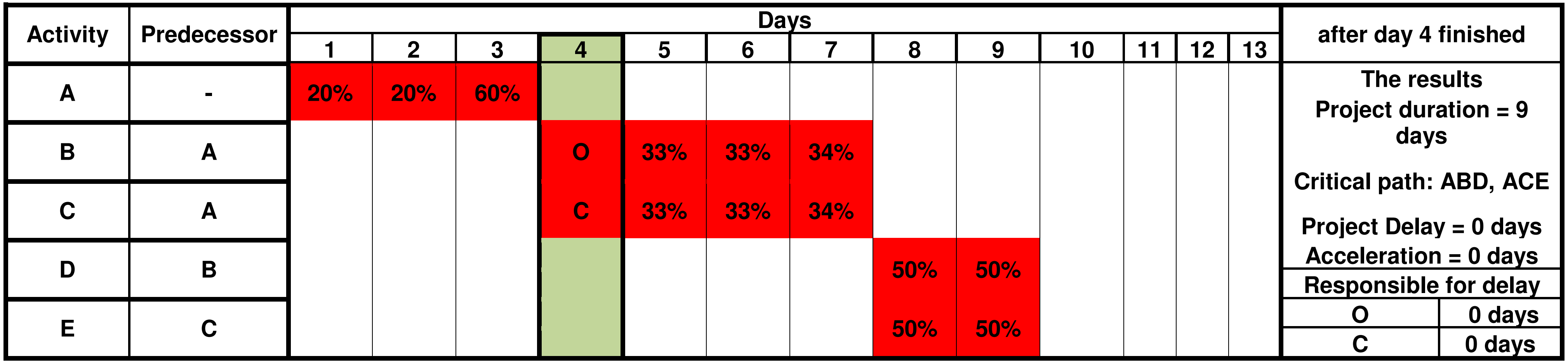
Fig. 3.27: Delay Analysis with Schedule Updates Using "Earned Value Equation" (window of day 3)



Activity	Predecessor	Days												
		1	2	3	4	5	6	7	8	9	10	11	12	13
A	-	20%	20%	20%	20%	20%								
B	A						33%	33%	34%					
C	A						33%	33%	34%					
D	B									50%	50%			
E	C									50%	50%			

at day 4	
The results Project duration = 10 days Critical path: ABD, ACE Project Delay = 0 days Acceleration = days	
Responsible for delay	
O	0 days
C	0 days

(a) As-Planned Bar Chart "2nd Baseline"

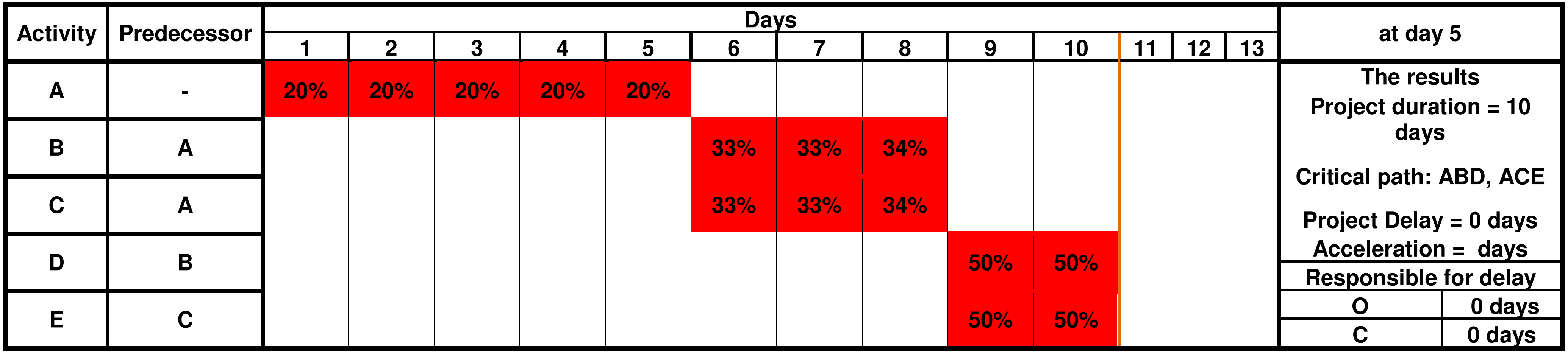


Activity	Predecessor	Days												
		1	2	3	4	5	6	7	8	9	10	11	12	13
A	-	20%	20%	60%										
B	A				O	33%	33%	34%						
C	A				C	33%	33%	34%						
D	B								50%	50%				
E	C								50%	50%				

after day 4 finished	
The results Project duration = 9 days Critical path: ABD, ACE Project Delay = 0 days Acceleration = 0 days	
Responsible for delay	
O	0 days
C	0 days

(b) Schedule of Remaining Project Duration Bar Chart "After Day 4 Was Finished"

Fig. 3.28: Delay Analysis with Schedule Updates Using "Earned Value Equation" (window of day 4)



Activity	Predecessor	Days 1	2	3	4	5	6	7	8	9	10	11	12	13
A	-	20%	20%	20%	20%	20%								
B	A						33%	33%	34%					
C	A						33%	33%	34%					
D	B									50%	50%			
E	C									50%	50%			

at day 5

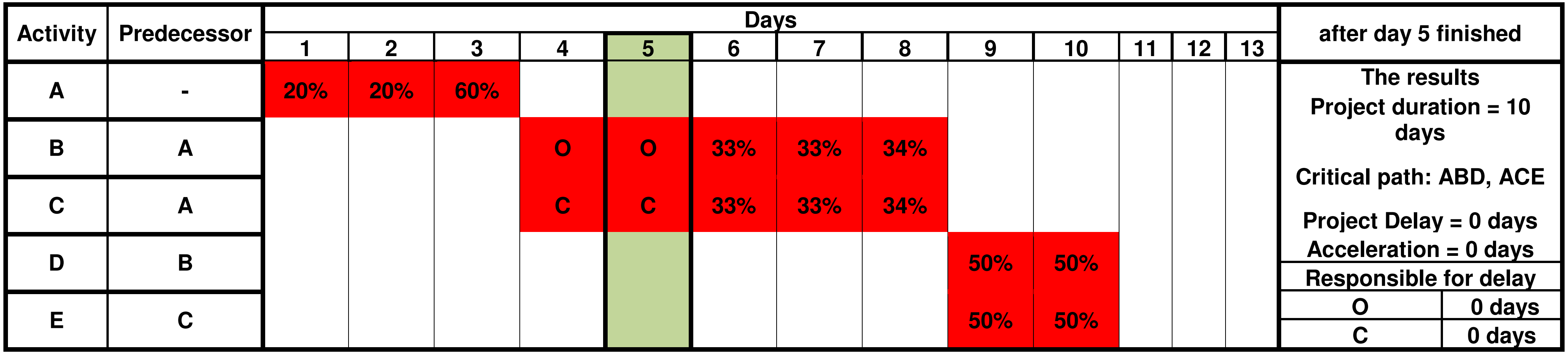
The results
Project duration = 10 days

Critical path: ABD, ACE

Project Delay = 0 days
Acceleration = days

Responsible for delay	
O	0 days
C	0 days

(a) As-Planned Bar Chart "2nd Baseline"



Activity	Predecessor	Days 1	2	3	4	5	6	7	8	9	10	11	12	13
A	-	20%	20%	60%										
B	A				O	O	33%	33%	34%					
C	A				C	C	33%	33%	34%					
D	B									50%	50%			
E	C									50%	50%			

after day 5 finished

The results
Project duration = 10 days

Critical path: ABD, ACE

Project Delay = 0 days
Acceleration = 0 days

Responsible for delay	
O	0 days
C	0 days

(b) Schedule of Remaining Project Duration Bar Chart "After Day 5 Was Finished"

Fig. 3.29: Delay Analysis with Schedule Updates Using "Earned Value Equation" (window of day 5)

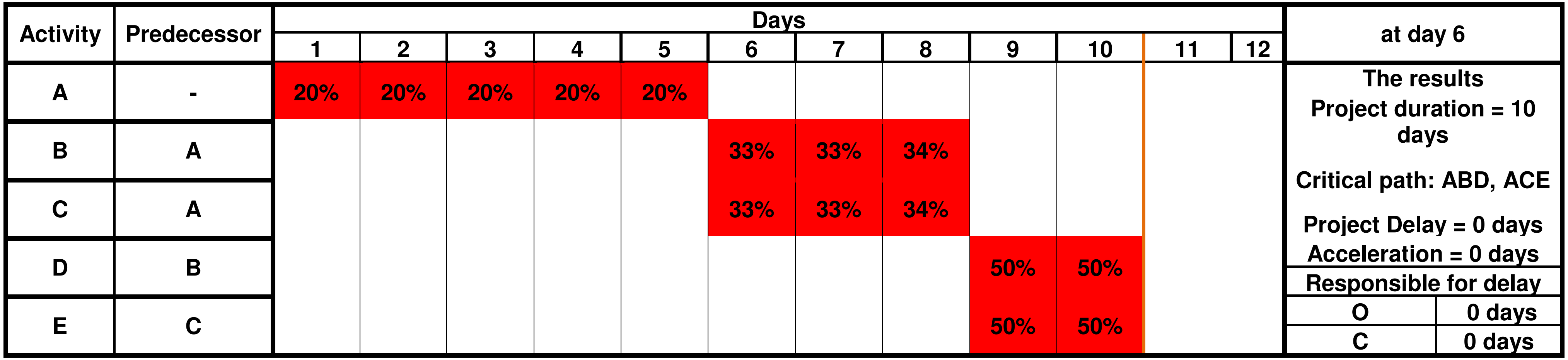
g. **Day 6 (Fig. 3.30) :** Continuing the analysis to the sixth day, the contractor delayed activity C leading the project duration to become 11 days rather than 10 days. The critical path was changed to become only one critical path is A-C-E, (current window duration = 11, previous window = 10). The contractor made a slowdown in activity B, where his progress in this activity was 30% instead of 33% and. By referring to equation (3.6) we can get the remaining duration for activity B is two day (35% for each day) in additional to one day completed and the total duration for this activity is 3 days as the planned duration. Accordingly, a one-day delay is accumulated (1 C) as shown in (Fig. 3.30b).

h. **Day 7 (Fig. 3.31) :** The progress of activity B was again slower than planned (24% instead of 35%). By referring to the percentage of progress in this activity and equation (3.6), the remaining 46% of the activity will be finished in two days (23% for each day), where **PI = 100 / 54 = 1.85 say 2 days**. On the other hand, activity C was achieved as planned in the first day (33%). Thus, the activity B will be delayed another one day and make a new critical path A-B-E in additional to the old path A-C-E. But that delay has not any effect on the whole project because activity B non critical. The project duration not changed (current window duration = 11, previous window =11) as shown in (Fig3.31b).

i. **Corrective Action no.2 (Fig. 3.32) :** On the other hand, the contractor made another corrective action by speeding up activities D, and E to finish them in one day only and finish the project in just 10 days. Accordingly, one-day acceleration is decided. The baseline is updated on day 7, the new critical paths A-B-D and A-C-E are obtained and the project duration again10 days as shown in (Fig.3.32b).

j. **Day 8 to Day 10 :** After the seventh day, the project progressed according to the new baseline and did not experience any further delays or accelerations (Fig. 3.32).

The previous case study shows that "**MDWAM**" considering schedule updates depends on Earned Value equations by using window size of one day to analyze the project delay, and the results of the analysis are shown in Tables (3.6 and 3.7).



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

at day 6

The results

Project duration = 10 days

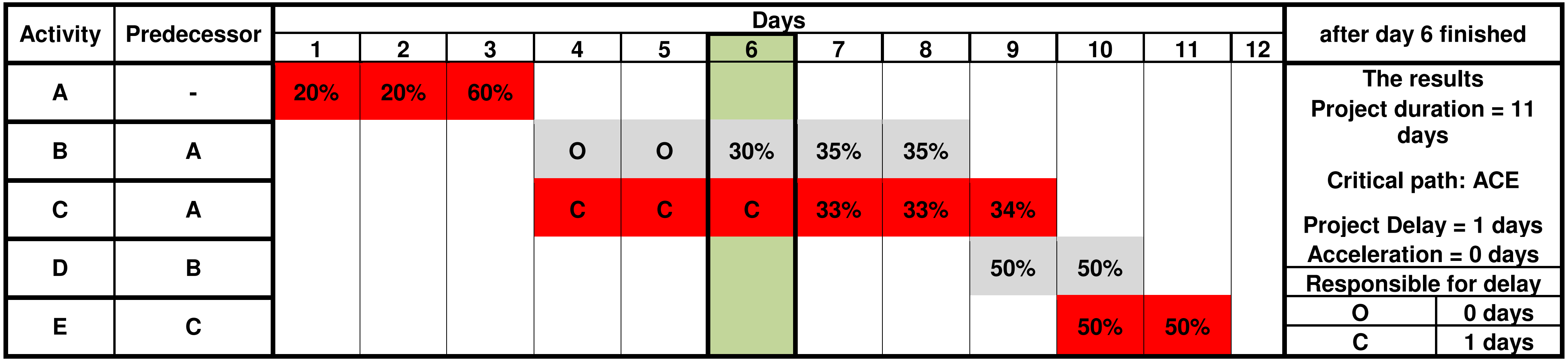
Critical path: ABD, ACE

Project Delay = 0 days

Acceleration = 0 days

Responsible for delay	
O	0 days
C	0 days

(a) As-Planned Bar Chart "2nd Baseline"



Activity	Predecessor	Days 1	2	3	4	5	6	7	8	9	10	11	12
A	-	20%	20%	60%									
B	A				O	O	30%	35%	35%				
C	A				C	C	C	33%	33%	34%			
D	B									50%	50%		
E	C										50%	50%	

after day 6 finished

The results

Project duration = 11 days

Critical path: ACE

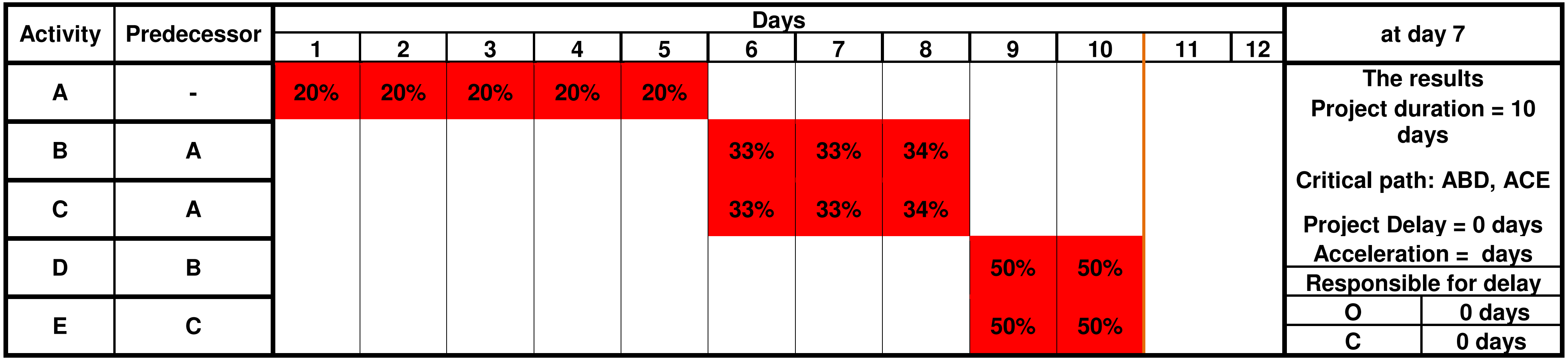
Project Delay = 1 days

Acceleration = 0 days

Responsible for delay	
O	0 days
C	1 days

(b) Schedule of Remaining Project Duration Bar Chart "After Day 6 Was Finished"

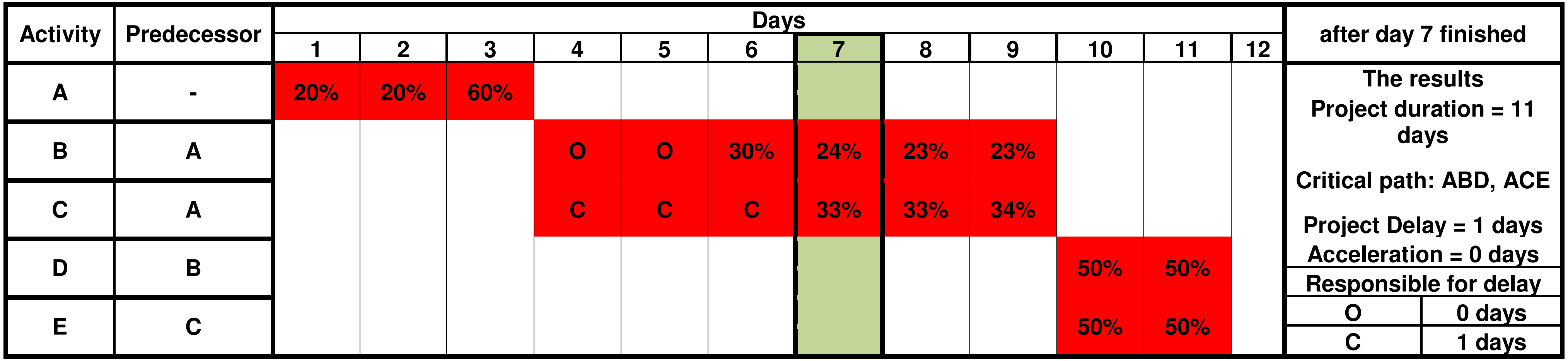
Fig. 3.30: Delay Analysis with Schedule Updates Using "Earned Value Equation" (window of day 6)



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

at day 7	
The results Project duration = 10 days Critical path: ABD, ACE Project Delay = 0 days Acceleration = days	
Responsible for delay	
O	0 days
C	0 days

(a) As-Planned Bar Chart "2nd Baseline"

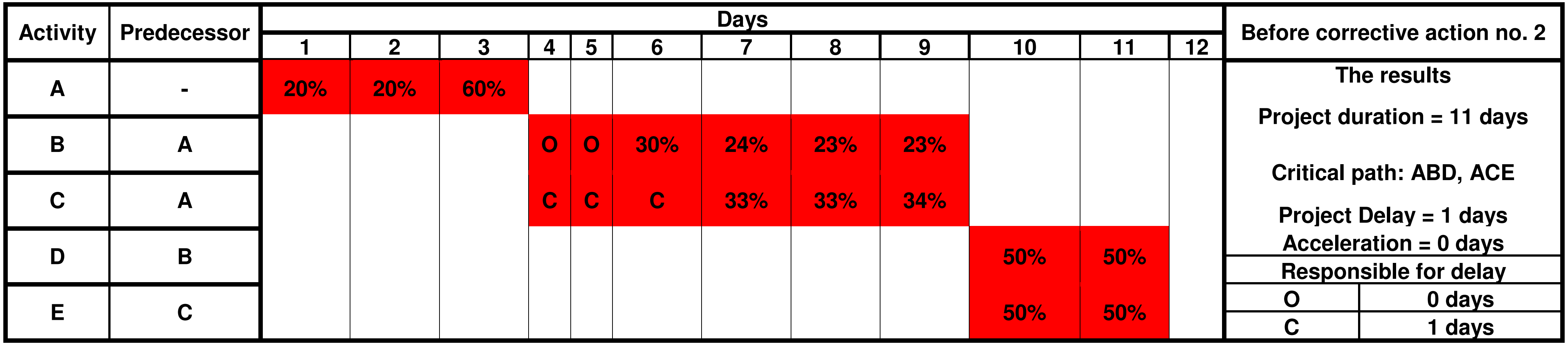


Activity	Predecessor	1	2	3	4	5	6	7	8	9	10	11	12
A	-	20%	20%	60%									
B	A				O	O	30%	24%	23%	23%			
C	A				C	C	C	33%	33%	34%			
D	B										50%	50%	
E	C										50%	50%	

after day 7 finished	
The results Project duration = 11 days Critical path: ABD, ACE Project Delay = 1 days Acceleration = 0 days	
Responsible for delay	
O	0 days
C	1 days

(b) Schedule of Remaining Project Duration Bar Chart "After Day 7 Was Finished"

Fig. 3.31: Delay Analysis with Schedule Updates Using "Earned Value Equation" (window of day 7)



Activity	Predecessor	1	2	3	4	5	6	7	8	9	10	11	12
A	-	20%	20%	60%									
B	A				O	O	30%	24%	23%	23%			
C	A				C	C	C	33%	33%	34%			
D	B										50%	50%	
E	C										50%	50%	

Before corrective action no. 2

The results

Project duration = 11 days

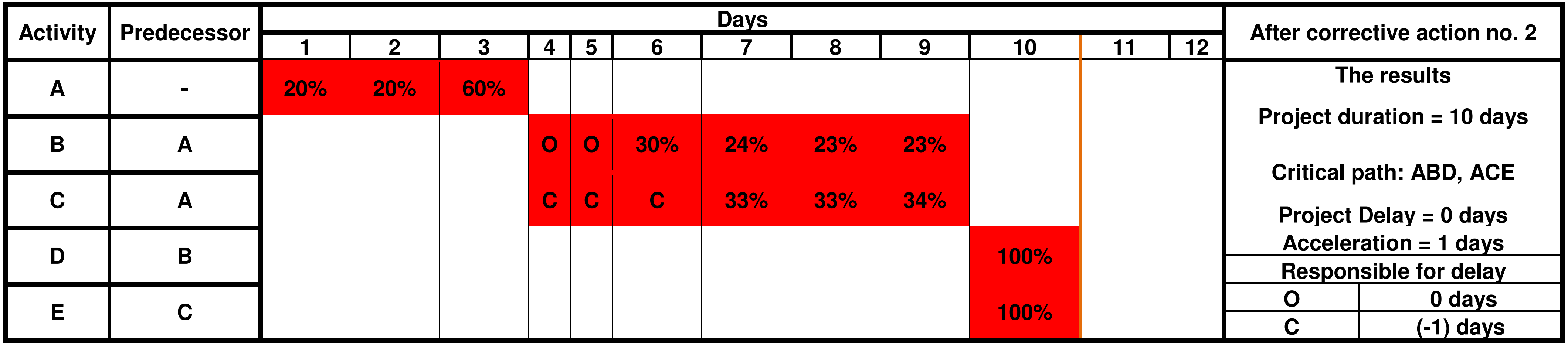
Critical path: ABD, ACE

Project Delay = 1 days

Acceleration = 0 days

Responsible for delay	
O	0 days
C	1 days

(a) Bar Chart Before Schedule Update



Activity	Predecessor	1	2	3	4	5	6	7	8	9	10	11	12
A	-	20%	20%	60%									
B	A				O	O	30%	24%	23%	23%			
C	A				C	C	C	33%	33%	34%			
D	B										100%		
E	C										100%		

After corrective action no. 2

The results

Project duration = 10 days

Critical path: ABD, ACE

Project Delay = 0 days

Acceleration = 1 days

Responsible for delay	
O	0 days
C	(-1) days

(b) Bar Chart After Schedule Update "3rd Baseline"

Fig. 3.32: Delay Analysis with Schedule Updates Using "Earned Value Equation" (corrective action no.2)

Table (3.6): The Analysis of "MDWAM" Using Earned Value Equations

Baseline no.	Event.	Delay / Acceleration		Project Duration
		Contractor	Owner	
1st	Day 1	3	0	13
	Day 2	0	0	13
2nd	Corrective Action 1	(-3)	0	10
	Day 3	(-2)*	0	8
	Day 4	0.5	0.5	9
	Day 5	0.5	0.5	10
	Day 6	1	0	10
	Day 7	0	0	11
3rd	Corrective Action 2	(-1)	0	10
	from 8 to 12	0	0	10

* (-2) means the project was accelerated two days

Table (3.7): The Final Results of "MDWAM" Using Earned Value Equations

The party	Events		Responsibility
	Delay	acceleration	
Contractor	5	6	-1
Owner	1	0	1

The final results show that the contractor made five days delay and accelerated the project by six days and the owner made one day delay. Although, the as-built bar chart shows that the contractor and the owner made 3 days and 2 days delay respectively and the project not experience any delay because the difference between the as-built duration and the as-planned duration equal zero. By combining the events of delay and acceleration through the project we conclude that the contractor accelerate the project by one day (-1 day delay) and the owner delayed the project by one day and the combination results is zero (-1 day +1 day = zero day). Which means that the contractor accelerate that one day delayed by owner, **so the owner is responsible for one day delay**.

3.4.3.3. "MDWAM" Using As-Planned Activity Duration Equation:

The as-planned activity duration equation is a way to determine the anticipated activity or project duration it depends on the planned duration of the activity through the project as shown in the following equation:

Remaining Duration = (Planned Duration – Actual Duration) ……………. (3.7)

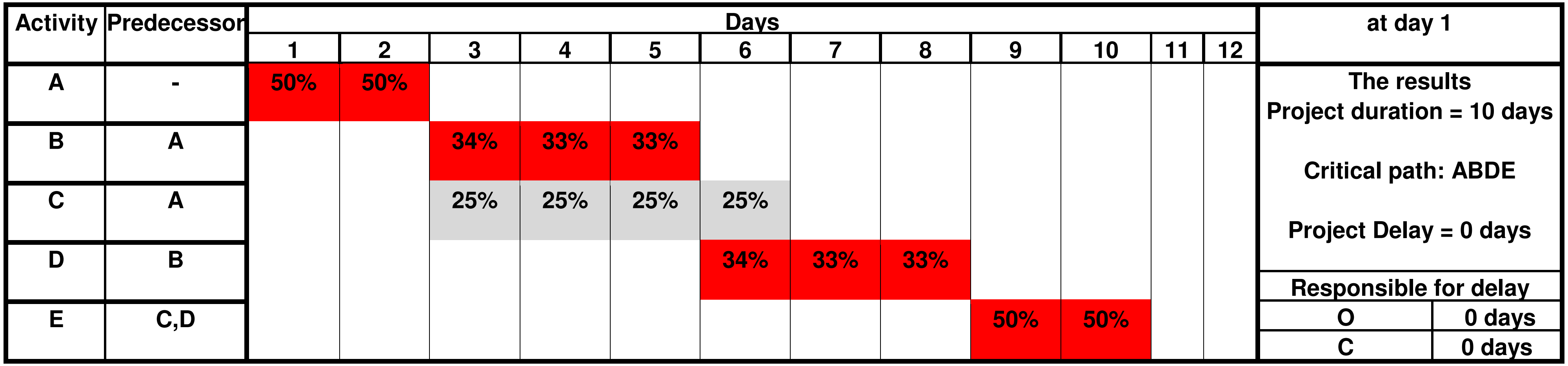
The "**MDWAM**" using as-planned activity duration equation of the sample case is shown in the following procedure.

a. **Day 1 (Fig. 3.33) :** The contractor finished only 20% of activity A instead of the planned 50%. According to equation (3.7), **the remaining duration = 2days (planned) – 1day (actual) = 1day (remaining)**. So the remaining 80% of the activity will be finished in the next day, and activity A will be completed within the planned two days, where the project hasn't experienced any day of delay as shown in (Fig. 3.33b).

b. **Day 2 (Fig. 3.34) :** The progress of activity A was again slower than planned (20% instead of 80%). By referring to the equation (3.7) the planned duration (2 days) of the activity was finished, but according to the principle of this way the remaining 60% of the activity will be finished in the next day as soon as possible. Thus, the project will be delayed one day to becomes 11 days (current window duration = 11, previous window = 10) because of the contractor’s slowdown, as shown in (Fig3.34b).

c. **Corrective Action no.1 (Fig. 3.35) :** The contractor decided to finish activity D within two days instead of three days as a corrective action in order to accelerate the project by one day and finish the work within the planned duration. Consequently, a one-day acceleration is accumulated (-1 C), the new baseline duration again10 days as shown in (Fig.3.35b).

d. **Day 3 (Fig. 3.36) :** The contractor finished the 60% remaining of activity A in one day as planned in 2nd baseline as shown in (Fig. 3.36b).



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

at day 1

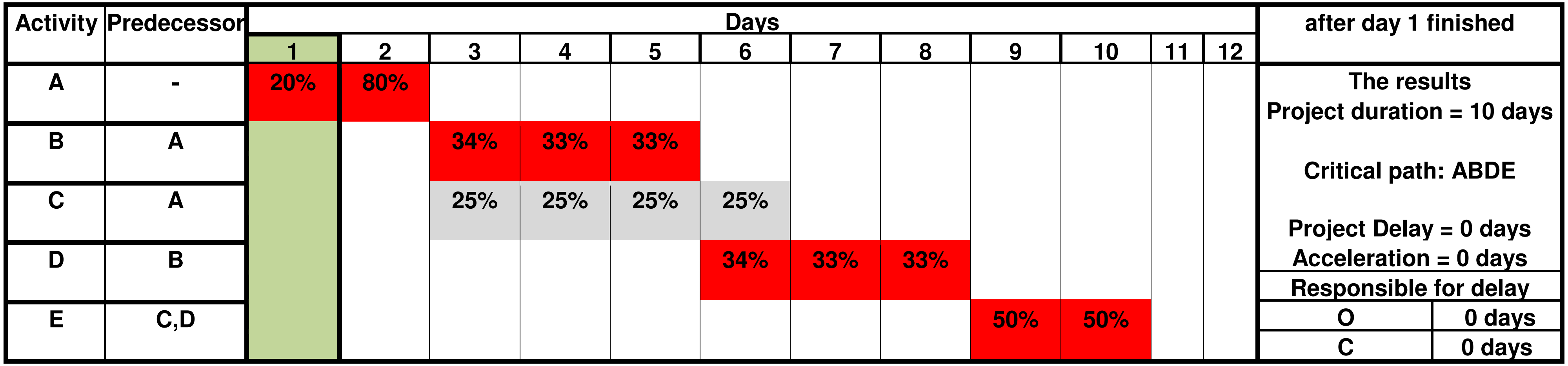
The results
Project duration = 10 days

Critical path: ABDE

Project Delay = 0 days

Responsible for delay	
O	0 days
C	0 days

(a) As- Planned Bar Chart "1st Baseline"



Activity	Predecessor	Days 1	2	3	4	5	6	7	8	9	10	11	12
A	-	20%	80%										
B	A			34%	33%	33%							
C	A			25%	25%	25%	25%						
D	B						34%	33%	33%				
E	C,D									50%	50%		

after day 1 finished

The results
Project duration = 10 days

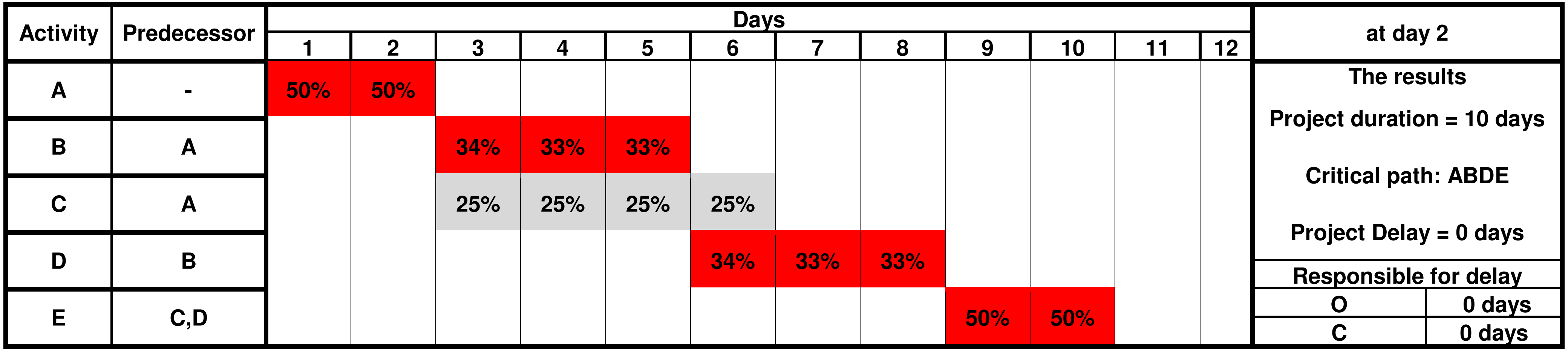
Critical path: ABDE

Project Delay = 0 days
Acceleration = 0 days

Responsible for delay	
O	0 days
C	0 days

(b) Schedule of Remaining Project Duration Bar Chart "After Day 1 Was Finished"

Fig. 3.33: Delay Analysis with Schedule Updates Using "As-Planned Activity Duration Equation" (window of day 1)



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

at day 2

The results

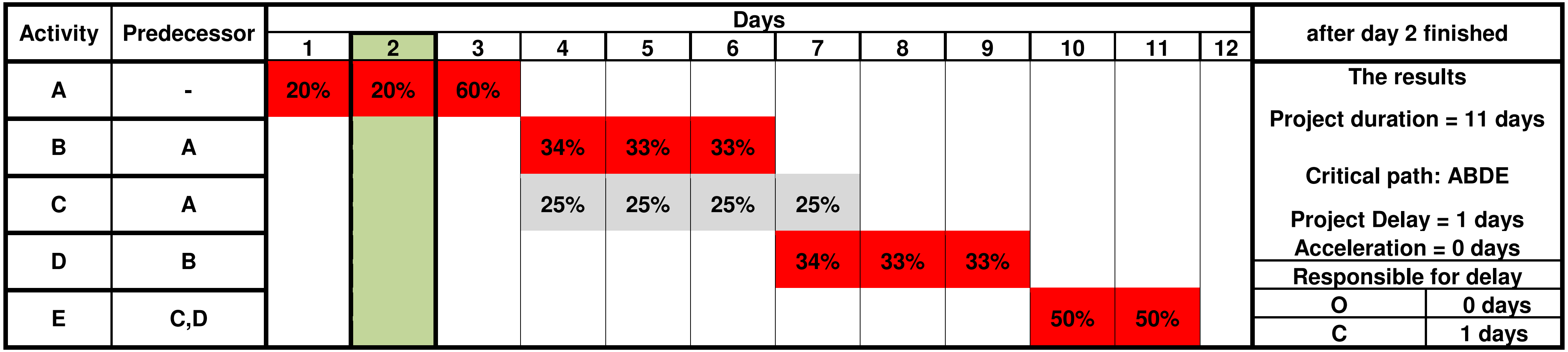
Project duration = 10 days

Critical path: ABDE

Project Delay = 0 days

Responsible for delay	
O	0 days
C	0 days

(a) As- Planned Bar Chart "1st Baseline"



Activity	Predecessor	Days											
		1	2	3	4	5	6	7	8	9	10	11	12
A	-	20%	20%	60%									
B	A				34%	33%	33%						
C	A				25%	25%	25%	25%					
D	B							34%	33%	33%			
E	C,D										50%	50%	

after day 2 finished

The results

Project duration = 11 days

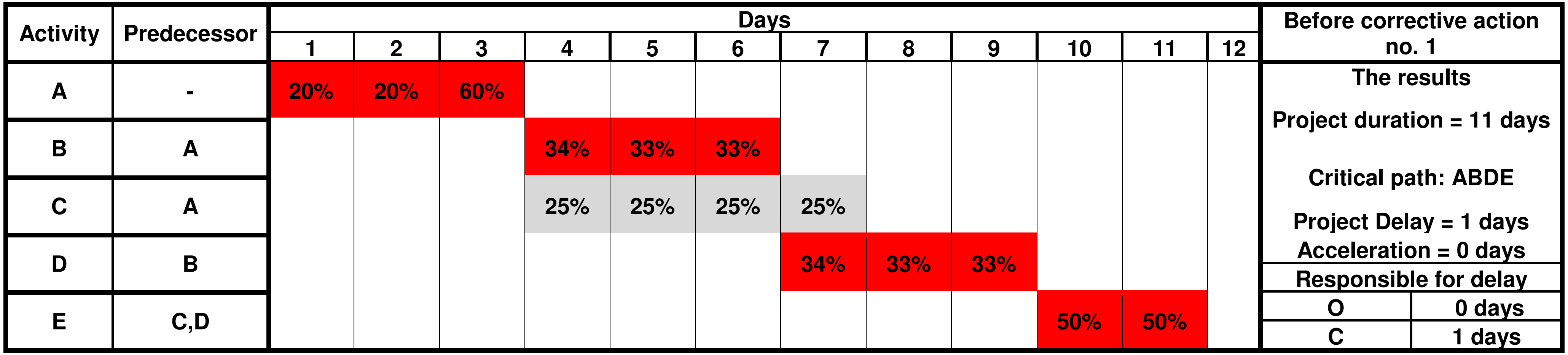
Critical path: ABDE

Project Delay = 1 days
Acceleration = 0 days

Responsible for delay	
O	0 days
C	1 days

(b) Schedule of Remaining Project Duration Bar Chart "After Day 2 Was Finished"

Fig. 3.34: Delay Analysis with Schedule Updates Using "As-Planned Activity Duration Equation" (window of day 2)



Activity	Predecessor	Days 1	2	3	4	5	6	7	8	9	10	11	12
A	-	20%	20%	60%									
B	A				34%	33%	33%						
C	A				25%	25%	25%	25%					
D	B							34%	33%	33%			
E	C,D										50%	50%	

Before corrective action no. 1

The results

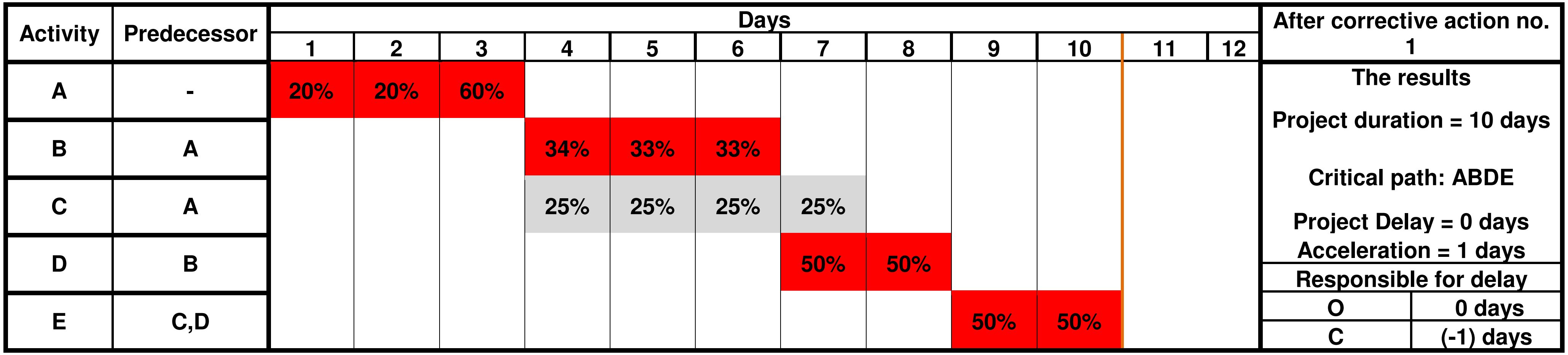
Project duration = 11 days

Critical path: ABDE

Project Delay = 1 days
Acceleration = 0 days

Responsible for delay	
O	0 days
C	1 days

(a) Bar Chart Before Schedule Update



Activity	Predecessor	Days 1	2	3	4	5	6	7	8	9	10	11	12
A	-	20%	20%	60%									
B	A				34%	33%	33%						
C	A				25%	25%	25%	25%					
D	B							50%	50%				
E	C,D									50%	50%		

After corrective action no. 1

The results

Project duration = 10 days

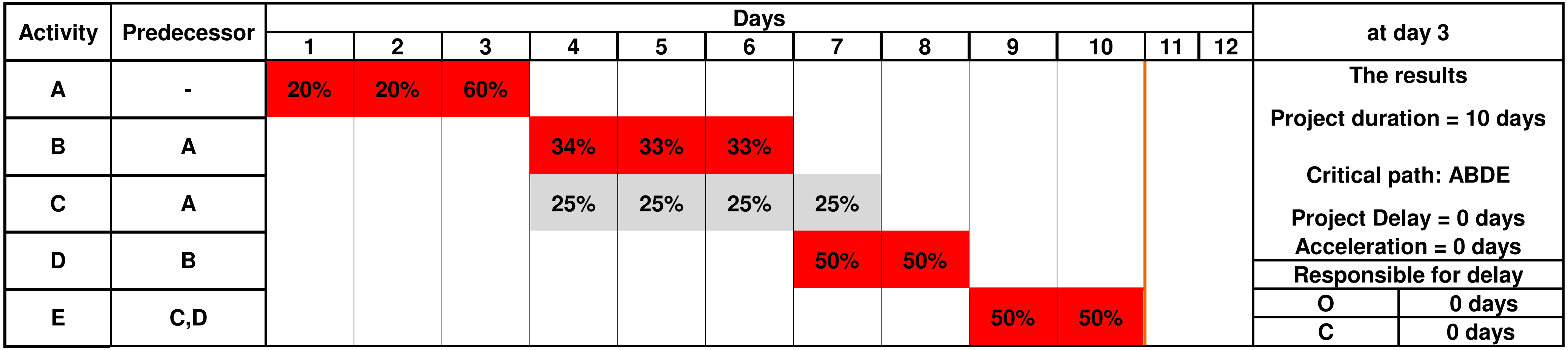
Critical path: ABDE

Project Delay = 0 days
Acceleration = 1 days

Responsible for delay	
O	0 days
C	(-1) days

(b) Bar Chart After Schedule Update "2^{nd} Baseline"

Fig. 3.35: Delay Analysis with Schedule Updates Using "As-Planned Activity Duration Equation" (corrective action no.1)



Activity	Predecessor	Days 1	2	3	4	5	6	7	8	9	10	11	12
A	-	20%	20%	60%									
B	A				34%	33%	33%						
C	A				25%	25%	25%	25%					
D	B							50%	50%				
E	C,D									50%	50%		

at day 3

The results

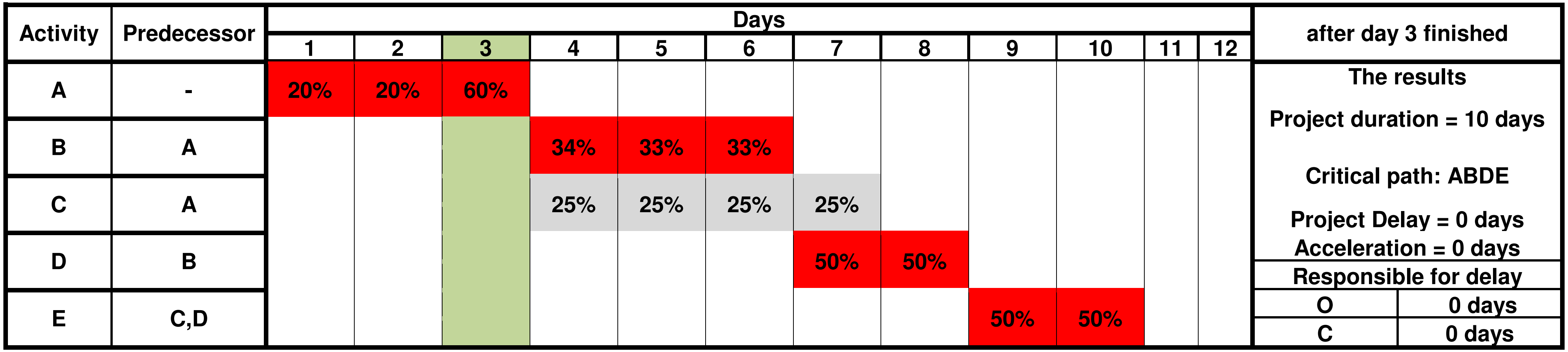
Project duration = 10 days

Critical path: ABDE

Project Delay = 0 days
Acceleration = 0 days

Responsible for delay	
O	0 days
C	0 days

(a) As-Planned Bar Chart "2nd Baseline"



Activity	Predecessor	Days 1	2	3	4	5	6	7	8	9	10	11	12
A	-	20%	20%	60%									
B	A				34%	33%	33%						
C	A				25%	25%	25%	25%					
D	B							50%	50%				
E	C,D									50%	50%		

after day 3 finished

The results

Project duration = 10 days

Critical path: ABDE

Project Delay = 0 days
Acceleration = 0 days

Responsible for delay	
O	0 days
C	0 days

(b) Schedule of Remaining Project Duration Bar Chart "After Day 3 Was Finished"

Fig. 3.36: Delay Analysis with Schedule Updates Using "As-Planned Activity Duration Equation" (window of day 3)

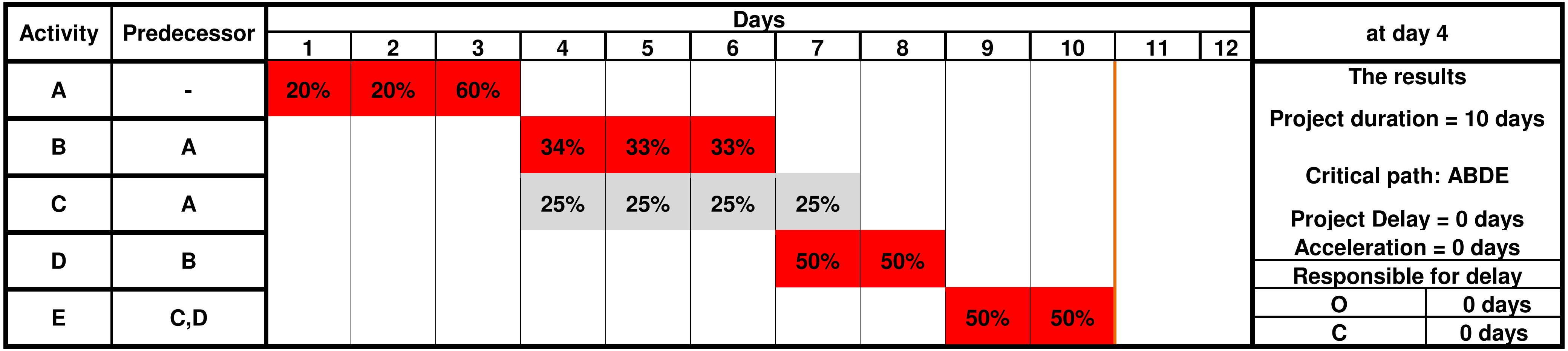
e. **Day 4 (Fig. 3.37) :** The project experienced a concurrent delay (O+C), causing the project completion time to be 11 days rather than 10 days this mean that concurrent delay made a one day of delay for whole project. But referring to the activities on the critical path will be found the activity B on the critical path and activity C is non critical, so the owner is responsible for this delay (1 O) as shown in (Fig. 3.37b).

f. **Day 5 (Fig. 3.38) :** Another concurrent delay (O+C) is experienced in activities B and C leading the project duration to become 12 days. As previous analysis of day 4 the owner is responsible for another one day of project delay (1 O) as shown in (Fig. 3.38b).

g. **Day 6 (Fig. 3.39) :** Continuing the analysis to the sixth day, the contractor delayed activity C and the critical paths were changed to becomes two critical paths A-C-E and A-B-D-E and the project duration remaining 12 days, so the contractor delay in the activity C hasn't any effect on the project. The contractor made a slowdown in activity B, where his progress in this activity was 30% instead of 33% and. By referring to equation (3.7), the remaining duration for activity B (3days – 1day) equal two days (35% for each day), in additional to one day completed. So the total duration for this activity is 3 days as planned duration, as shown in (Fig. 3.39b).

h. **Day 7 (Fig. 3.40) :** The progress of activity B was again slower than planned (24% instead of 35%). By referring to equation (3.7) the remaining 46% of the activity will be finished in the next day. On the other hand, he fast activity C (34% instead of 25%) and by using the same equation we will get the production of the last three days remaining from activity C (22% for each day). Thus, the project will not be delayed another day (current window duration = 12, previous window = 12), as shown in (Fig3.40b).

i. **Corrective Action no.2 (Fig. 3.41) :** On the other hand, the contractor made another corrective action by speeding up activities D, and E to finish them in one day only and finish the project in just 10 days. Accordingly, two-day acceleration is decided. The baseline is updated on day 7, the new critical paths A-B-D and A-C-E are obtained, and the new baseline duration again10 days, as shown in (Fig.3.41b).



Activity	Predecessor	Days											
		1	2	3	4	5	6	7	8	9	10	11	12
A	-	20%	20%	60%									
B	A				34%	33%	33%						
C	A				25%	25%	25%	25%					
D	B							50%	50%				
E	C,D									50%	50%		

at day 4

The results

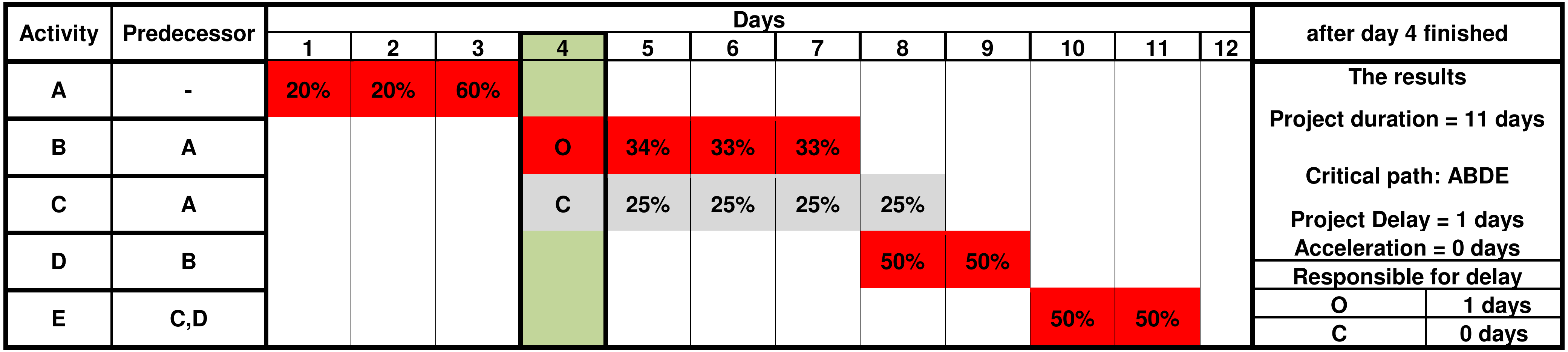
Project duration = 10 days

Critical path: ABDE

Project Delay = 0 days
Acceleration = 0 days

Responsible for delay	
O	0 days
C	0 days

(a) As-Planned Bar Chart "2nd Baseline"



Activity	Predecessor	Days											
		1	2	3	4	5	6	7	8	9	10	11	12
A	-	20%	20%	60%									
B	A				O	34%	33%	33%					
C	A				C	25%	25%	25%	25%				
D	B								50%	50%			
E	C,D										50%	50%	

after day 4 finished

The results

Project duration = 11 days

Critical path: ABDE

Project Delay = 1 days
Acceleration = 0 days

Responsible for delay	
O	1 days
C	0 days

(b) Schedule of Remaining Project Duration Bar Chart "After Day 4 Was Finished"

Fig. 3.37: Delay Analysis with Schedule Updates Using "As-Planned Activity Duration Equation" (window of day 4)

Activity	Predecessor	Days 1	2	3	4	5	6	7	8	9	10	11	12
A	-	20%	20%	60%									
B	A				34%	33%	33%						
C	A				25%	25%	25%	25%					
D	B							50%	50%				
E	C,D									50%	50%		

at day 5

The results

Project duration = 10 days

Critical path: ABDE

Project Delay = 0 days
Acceleration = 0 days

Responsible for delay

O	0 days
C	0 days

(a) As-Planned Bar Chart "2nd Baseline"

Activity	Predecessor	Days 1	2	3	4	5	6	7	8	9	10	11	12
A	-	20%	20%	60%									
B	A				O	O	34%	33%	33%				
C	A				C	C	25%	25%	25%	25%			
D	B									50%	50%		
E	C,D											50%	50%

after day 5 finished

The results

Project duration = 12 days

Critical path: ABDE

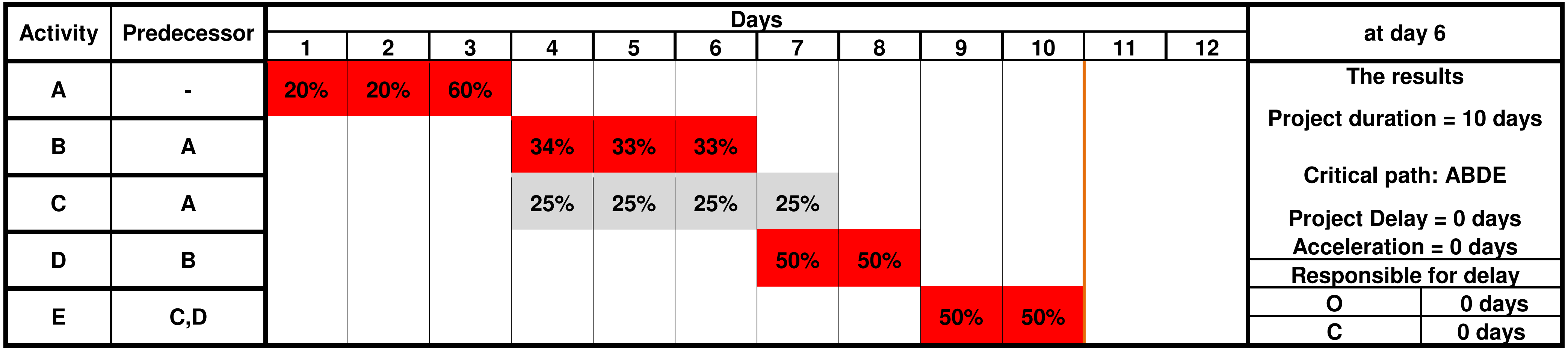
Project Delay = 2 days
Acceleration = 0 days

Responsible for delay

O	0 days
C	2 days

(b) Schedule of Remaining Project Duration Bar Chart "After Day 5 Was Finished"

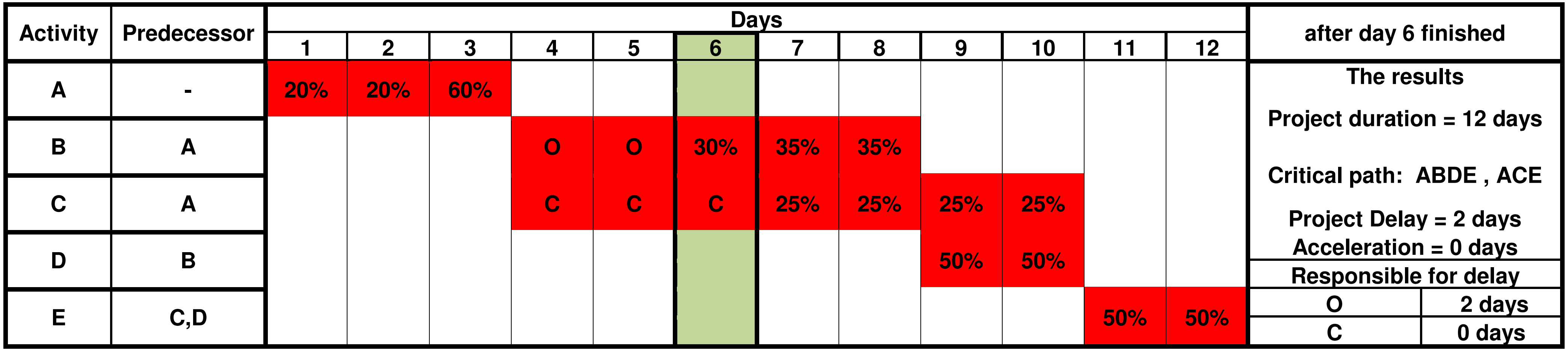
Fig. 3.38: Delay Analysis with Schedule Updates Using "As-Planned Activity Duration Equation" (window of day 5)



Activity	Predecessor	Days 1	2	3	4	5	6	7	8	9	10	11	12
A	-	20%	20%	60%									
B	A				34%	33%	33%						
C	A				25%	25%	25%	25%					
D	B							50%	50%				
E	C,D									50%	50%		

at day 6	
The results Project duration = 10 days Critical path: ABDE Project Delay = 0 days Acceleration = 0 days	
Responsible for delay	
O	0 days
C	0 days

(a) As-Planned Bar Chart "2nd Baseline"

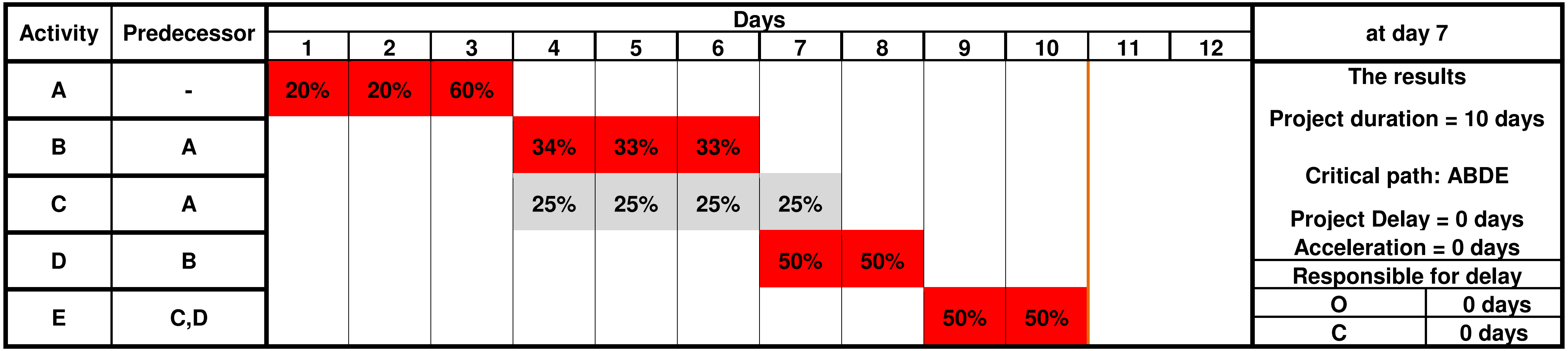


Activity	Predecessor	Days 1	2	3	4	5	6	7	8	9	10	11	12
A	-	20%	20%	60%									
B	A				O	O	30%	35%	35%				
C	A				C	C	C	25%	25%	25%	25%		
D	B									50%	50%		
E	C,D											50%	50%

after day 6 finished	
The results Project duration = 12 days Critical path: ABDE , ACE Project Delay = 2 days Acceleration = 0 days	
Responsible for delay	
O	2 days
C	0 days

(b) Schedule of Remaining Project Duration Bar Chart "After Day 6 Was Finished"

Fig. 3.39: Delay Analysis with Schedule Updates Using "As-Planned Activity Duration Equation" (window of day 6)



Activity	Predecessor	Days 1	2	3	4	5	6	7	8	9	10	11	12
A	-	20%	20%	60%									
B	A				34%	33%	33%						
C	A				25%	25%	25%	25%					
D	B							50%	50%				
E	C,D									50%	50%		

at day 7

The results

Project duration = 10 days

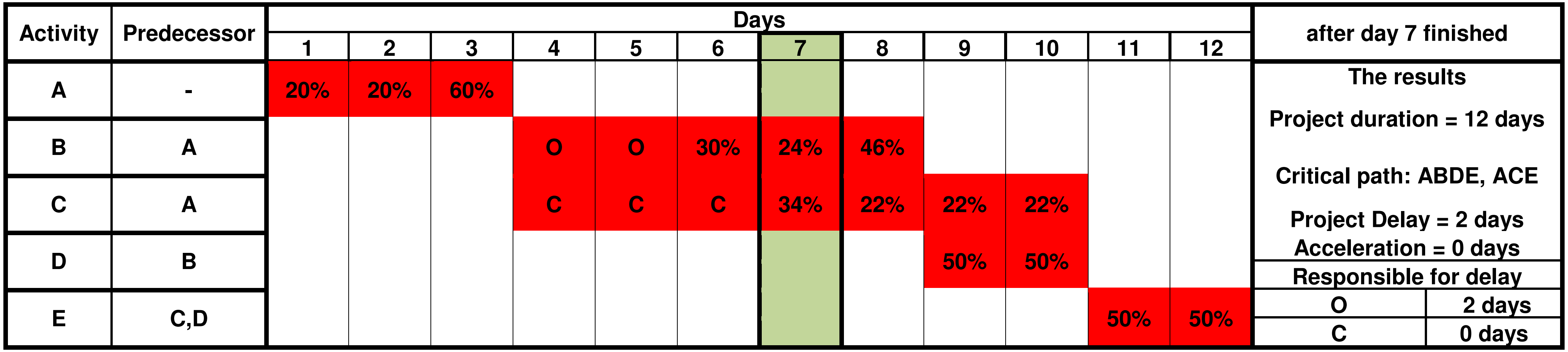
Critical path: ABDE

Project Delay = 0 days

Acceleration = 0 days

Responsible for delay	
O	0 days
C	0 days

(a) As-Planned Bar Chart "2nd Baseline"



Activity	Predecessor	Days 1	2	3	4	5	6	7	8	9	10	11	12
A	-	20%	20%	60%									
B	A				O	O	30%	24%	46%				
C	A				C	C	C	34%	22%	22%	22%		
D	B									50%	50%		
E	C,D											50%	50%

after day 7 finished

The results

Project duration = 12 days

Critical path: ABDE, ACE

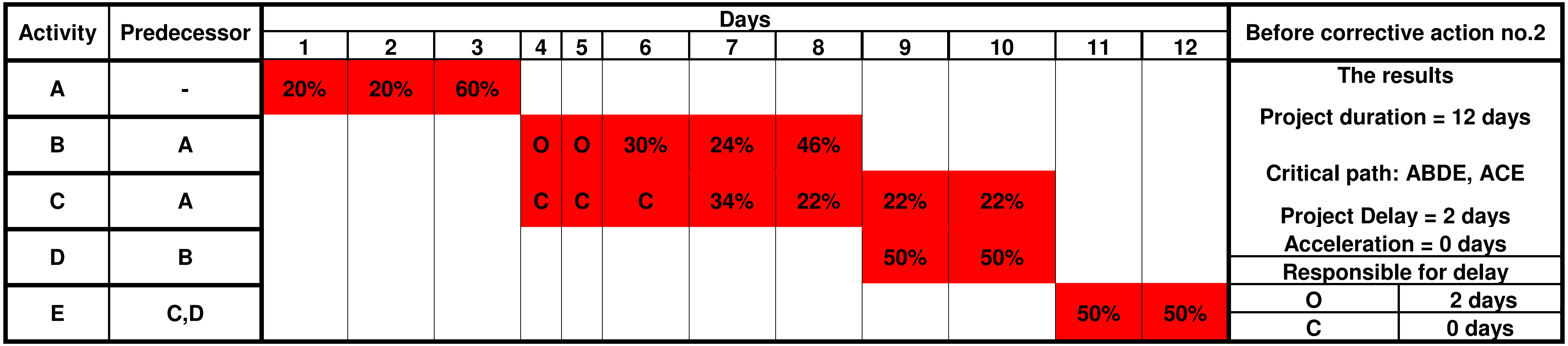
Project Delay = 2 days

Acceleration = 0 days

Responsible for delay	
O	2 days
C	0 days

(b) Schedule of Remaining Project Duration Bar Chart "After Day 7 Was Finished"

Fig. 3.40: Delay Analysis with Schedule Updates Using "As-Planned Activity Duration Equation" (window of day 7)



Activity	Predecessor	Days 1	2	3	4	5	6	7	8	9	10	11	12
A	-	20%	20%	60%									
B	A				O	O	30%	24%	46%				
C	A				C	C	C	34%	22%	22%	22%		
D	B									50%	50%		
E	C,D											50%	50%

Before corrective action no.2

The results

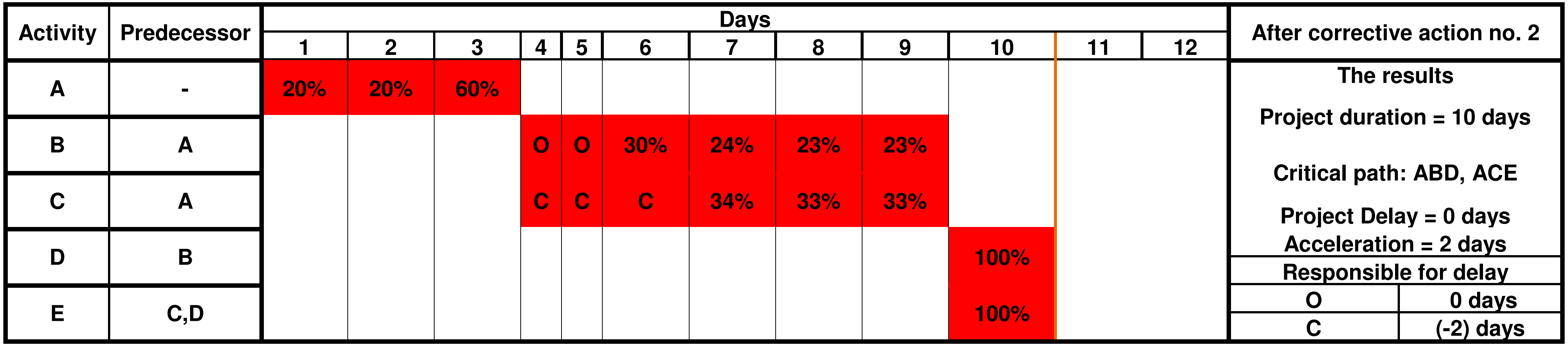
Project duration = 12 days

Critical path: ABDE, ACE

Project Delay = 2 days
Acceleration = 0 days

Responsible for delay	
O	2 days
C	0 days

(a) Bar Chart Before Schedule Update



Activity	Predecessor	Days 1	2	3	4	5	6	7	8	9	10	11	12
A	-	20%	20%	60%									
B	A				O	O	30%	24%	23%	23%			
C	A				C	C	C	34%	33%	33%			
D	B										100%		
E	C,D										100%		

After corrective action no. 2

The results

Project duration = 10 days

Critical path: ABD, ACE

Project Delay = 0 days
Acceleration = 2 days

Responsible for delay	
O	0 days
C	(-2) days

(b) Bar Chart After Schedule Update "3rd Baseline"

Fig. 3.41: Delay Analysis with Schedule Updates Using "As-Planned Activity Duration Equation" (corrective action no.2)

j. **Day 8 to Day 10 :** After the seventh day, the project progressed according to the new baseline and did not experience any further delays or accelerations (Fig. 3.41).

The previous case study shows that "**MDWAM**" considering schedule updates depends on As-Planned Activity Duration equations by using window size of one day to analyze the project delay, and the results of the analysis are shown in Tables (3.8 and 3.9).

Table (3.8): The Analysis of "MDWAM" Using As-Planned Activity Duration Equation.

Baseline no.	Event.	Delay / Acceleration		Project Duration
		Contractor	Owner	
1st	Day 1	0	0	10
	Day 2	1	0	11
2nd	Corrective Action 1	(-1)*	0	10
	Day 3	0	0	10
	Day 4	0	1	11
	Day 5	0	1	12
	Day 6	0	0	12
	Day 7	0	0	12
3rd	Corrective Action 2	(-2)	0	10
	from 8 to 12	0	0	10

* (-1) means the project was accelerated one day

Table (3.9): The Final Results of "MDWAM" Using As-Planned Activity Duration Equation.

The party	Events		Responsibility
	Delay	acceleration	
Contractor	1	3	-2
Owner	2	0	2

The final results show that the contractor made one day delay and accelerated the project by three days and the owner made two days delay. Although, the as-built bar chart shows that the contractor and the owner made 3 days and 2 days delay respectively and the project not experience any delay because the difference between the as-built duration and the as-planned duration equal zero. By combining the events of delay and acceleration through the project we conclude that the contractor accelerate the project by two days (-2 days delay) and the owner delayed the project by two days and the combination results is zero (-2 days +2 days = zero day). Which means that the contractor accelerate that two days delayed by owner, **so the owner is responsible for two days delay**.

3.5. Conclusion

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

MDWAM analyzed the delay using three approaches Remaining Duration Equation, Earned Value Equation, and As-Planned Activity Duration Equation. Where the comparison of the results for that three approaches are shown in Table. 3.10

Table (3.10) : The Comparison Between the Results of the Three Approaches

Final Results	**MDWAM Using**		
	Remaining Duration	**Earned Value**	**As-Planned Duration**
Owner delay	1 day	1 day	2 days
Owner acceleration	0 day	0 day	0 day
Contractor delay	4 days	5 days	1 day
Contractor acceleration	5 days	6 days	3 days
Project total delay	**1 day**	**1 day**	**2 days**
Responsible for delay	**The Owner**	**The Owner**	**The Owner**

MDWAM using Remaining Duration Equation, the final results show that the contractor made four days delay and accelerated the project by five days and the owner made one day delay. Although, the as-built bar chart shows that the contractor and the owner made 3 days and 2 days delay respectively and the project not experience any delay because the difference between the as-built duration and the as-planned duration equal zero. By combining the events of delay and acceleration through the project we conclude that the contractor accelerate the project by one day (-1 day delay) and the owner delayed the project by one day and the combination results is zero (-1 day +1 day = zero day). Which means that the contractor accelerate that one day delayed by owner, **so the owner is responsible for one day delay** (Fig. 3.11).

MDWAM using Earned Value Equation that depends on the Productivity Index "**PI**", the final results show that the contractor made five days delay and accelerated the project by six days and the owner made one day delay. Although, the as-built bar chart shows that the contractor and the owner made 3 days and 2 days delay respectively and the project not experience any delay because the difference between the as-built duration and the as-planned duration equal zero. By combining the events of delay and acceleration through the project we conclude that the contractor accelerate the project by one day (-1 day delay) and the owner delayed the project by one day and the combination results is zero (-1 day +1 day = zero day). Which means that the contractor accelerate that one day delayed by owner, **so the owner is responsible for one day delay**. (Fig. 3.32).

MDWAM using As-Planned Activity Duration Equation, the final results show that the contractor made one day delay and accelerated the project by three days and the owner made two days delay. Although, the as-built bar chart shows that the contractor and the owner made 3 days and 2 days delay respectively and the project not experience any delay because the difference between the as-built duration and the as-planned duration equal zero. By combining the events of delay and acceleration through the project we conclude that the contractor accelerate the project by two days (-2 days delay) and the owner delayed the project by two days and the combination results is zero (-2 days +2 days = zero day). Which means that the contractor accelerate that two days delayed by owner, **so the owner is responsible for two days delay** (Fig. 3.41).

The analysis of "**MDWAM**" using earned value equation considered **the slowest and longest way** for analysis because it depends on the productivity index where considered the daily production is equal for each day of activity duration, this is rarely. Although, the earned value system is the best system to calculate the project cost.

The analysis of "**MDWAM**" using as-planned activity duration equation considered **the fastest and shortest way** for analysis because it deals with the best situation of the project where the activity must finished within the planned duration under any conditions, also this is rarely. Natural, by using this way the result will be shown the owner is responsible for any delay of the project because the contractor will be made any thing associated with the project such as (acceleration, adding resources, etc…).

The analysis of "**MDWAM**" using remaining duration equation considered the average way between earned value and as-planned ways for analysis because it depends on the availability to complete the activity duration, so it is called **the most likely way** for delay analysis by "**MDWAM**" considering schedule updates. Thus, the "**MDWAM**" using this way has more accuracy than other approaches are mentioned before.

CHAPTER 4

MODIFIED DAILY WINDOWS ANALYSIS METHOD CONSIDERING RESOURCE ALLOCATION

4.1. Introduction

As we have seen in network scheduling, the basic inputs to critical-path analysis are the individual project activities, their durations, and their dependency relationships. Accordingly, the forward-path and backward-path calculations determine the start and finish times of the activities. The CPM algorithm, therefore, is duration-driven. Activities' durations here are function of the resources that are required (rather than available) to complete each activity. The CPM formulation, therefore, assumes that all the resources needed for the schedule are available. This assumption, however, is not always true for construction projects. Under resource constraints, the schedule becomes impractical, cost and time are not accurate, and resources may not be available when needed. In order to deal with such issue, a proper management of available resources is required to adjust the schedule accordingly (Eldosouky, 1996).

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

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

4.2. Resource Management

The most important resources that project managers have to plan and manage on day-to-day basis are people, machines, materials, and money. Obviously, if these resources are available in abundance then the project could be accelerated to achieve shorter project duration. On the other hand, if these resources are severely limited, then the result more likely will be a delay in the project completion time. In general, from a scheduling perspective, projects can be classified as either time constrained or resource constrained (Awani, 1983).

4.2.1. Resource Allocation

Resource allocation, also called resource loading, is concerned with assigning the required number of resources identified for each activity in the plan. More than one type of resource may be assigned to a specific activity. For example, fixing steel plates on a bridge deck may require different types of resources such as: welders, laborers and a certain type of welding machine. From a practical view, resource allocation does not have to follow a constant pattern; some activities may initially require fewer resources but may require more of the same resources during the later stages of the project.

4.2.2. Resource Leveling (smoothing)

A project is classified as time constrained in situations where the project completion time can't be delayed even if additional resources are required. However, the additional resource usage should be no more than what is absolutely necessary. Accordingly, the primary focus, for purposes of scheduling, in time constrained projects is to improve resource utilization. This process is called resource leveling or smoothing. It applies when it is desired to reduce the hiring and firing of resources and to smooth the fluctuation in the daily demand of a resource. In this case, resources are not limited and project duration is not allowed to be delayed. The objective in this case is to shift non-critical activities of the original schedule, within their float times so that a better resource profile is achieved. Resource leveling heuristics shift non-critical activities within their float times so as to move resources from the peak periods (high usage) to the valley periods (low usage), without delaying the project (i.e., area underneath the resource profile remains constant). Usually, project managers may prefer having a desired resource profile in which the resource usage starts with low values and then the resources are build up till its maximum values and starts to decrease as the project approaches its end.

4.3. Resolving Resource Over-Allocation

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

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

Alternatively, heuristic approaches have been proposed for solving the resource allocation problem. These approaches apply selected heuristic (rules) that are based on activity characteristics, such as the “minimum total-float” rule, to prioritize the activities that compete for the limited resource. Accordingly, the resource is given to the top-ranked activities and the others are delayed. When ties occur during the implementation of a rule (e.g., when two or more activities have the same total float), another rule, such as “shortest duration” can be used to break the tie.

The scheduling process thus begins with the project’s start time, identifies eligible activities according to the network logic, and resolves the over allocation of resources using the selected set of heuristic rules. The process, therefore, ensures that all project activities are scheduled without violating the logical relationships or the resource constraints. This benefit, however, comes at the expense of the total project duration, which often exceeds the duration determined by the original CPM analysis. Therefore, because it can affect project duration, this scheduling process should be considered when project delays are analyzed.

Heuristic rules have the advantage of being simple to understand, easy to apply, and very inexpensive to use in computer programs. They are able to rationalize the scheduling process and make it manageable for practical-sized projects (Talbot and Patterson, 1979). Furthermore, research has identified rules such as the "least total-float" and the "earliest late-start", which generally provide good solutions (Davis and Patterson, 1975).

Almost all commercial software for planning and scheduling, therefore, utilize heuristic rules to provide resource allocation capabilities. Despite these benefits, however, heuristic rules perform with varying effectiveness when used on different networks and there are no hard guidelines that help in the selection of the best heuristic rule to use for a given network. Accordingly, they cannot guarantee optimum solutions. Furthermore, their drawbacks have contributed to large inconsistencies in the resource constrained capabilities of commercial project-management software, as reported in recent surveys (Johnson, 1992; Hegazy and El-Zamzamy, 1998).

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

4.4. Resources Allocation Methods

Many method were used for solving resource problem through the project periods but there are four method considered the main methods for solving that problem, these method are shown as follow:

1. **Heuristic Approach**
2. **The Series Method**
3. **The Parallel Method**
4. **Brooks Method**

4.4.1. Heuristic Approach

This approach needs big efforts for solving resource problems because it requires too much basic criteria and predetermined priority rules. Predominant Priority Rules: allocate resources to an activity that:

- Has the earliest start time.
- Has the minimum late start time.
- Has the minimum early finish time.
- Has the minimum late finish time.
- Has the least float.
- Has the largest duration.
- Has the shortest duration.
- Has the most immediate successors.
- Has most successors.
- Has the least nonrelated activities.
- Has the least nondependent jobs remaining.
- Has the least immediate successors.
- Has the least successors.
- Can start first considering resources.
- Has the least float per successor.
- Has the longest path following.
- Will finish first.
- Has the largest resource requirement.
- Has the largest resource days requirement.
- Has the largest remaining resource days remaining

4.4.2. The Series Method

The series method is a method for scheduling work by balancing need with availability of resources at a given time. Resources are allocated to activities one activity at a time from start to finish. The method assumption is: Once an activity has been started, it cannot be interrupted.

Rules for Scheduling Activities with limited resources:

1. Schedule activities to start as soon as their predecessors have been completed.

2. If two activities are scheduled concurrently, priority is given to the activity which:
    - Has the minimum late start time.
    - Has the least total float.
    - Has the largest resource requirement.
    - Has already started

4.4.3. The Parallel Method

The parallel method is a method for scheduling work by balancing need with availability of resources at a given time. Resources are allocated to activities one day at a time. The method assumption: The parallel method allows activities to be delayed or interrupted.

Rules for Scheduling Activities with limited resources:

1. Schedule activities to start as soon as their predecessors have been completed.
2. If two activities are scheduled concurrently, priority is given to the activity which:
    - Has the minimum late start time.
    - Has the least total float.
    - Has the largest resource requirement.
    - Has already started

4.4.4. The Brooks Method

Priority given to the activity with the highest total number of days from the late start date to the project completion (ACTIM). Resources are allocated to activities one activity at a time from start to finish. The method assumption: Once an activity has been started, it cannot be interrupted.

Rules for Scheduling Activities with limited resources:

1. Schedule activities to start as soon as their predecessors have been completed.
2. If two activities are scheduled concurrently, priority is given to the activity which:
    - Has the highest "ACTIM.
    - If two activities have the same "ACTIM" value, the priority is given to the activity with the least total float.

4.5. The Selected Method for Solving Resource Over Allocation Problems Through Project Delays Analysis

The previous methods for solving resource over allocation problems shows that all methods deal with limited resources and least total float, where they are very important items in the delay analysis process.

The heuristic approach needs too much efforts to solve the resource over allocation problems because it needs to apply large numbers of basic criteria in additional it considered the oldest approach for solving resource problems, so this approach isn't a qualified approach for solving resource over allocation problems in the delay analysis process.

The series and brooks methods have a reasonable criteria for solving the resource over allocation problems where they are considered the new methods applied for solving resource over allocation problems as well as parallel method. These two methods are depend on the same assumption says: Once an activity has been started, it cannot be interrupted, where this is rarely because any project must subject to the surrounding circumstances in it, so they may be lead to interrupted the activity under any reason such as (contractor or owner delays, weather condition, and so on). Thus, the series and brooks methods are lacks to the main and logical concept of delay analysis process as the opposite of the parallel method. Where, the parallel method depends on the assumption allows activities to be delayed or interrupted this make it more logical than series and brooks method in additional to it consistent with the delay analysis process concept.

Previous discussions leads to conclude that the selected method for solving resource over allocation problems through project delays analysis is **the parallel method** because the following reasons:

1. **Deal with limited resources.**
2. **Deal with activities have least total floats.**
3. **Allow to activates to interrupted or delayed.**

This chapter presents a simple case study analyzed by Daily Windows Analysis Method "**DWAM**" without considering resource over-allocation, then analyzed by Modified Daily Windows Analysis Method "**MDWAM**" considering resource over-allocation problems and depends on the parallel method for solving the over-allocation. A comparison between the two analyses also discussed in this chapter.

A systematic procedure for considering the impact of resource allocation on the apportionment of the responsibility for the delay. The presented approach modifies the daily windows analysis method "**MDWAM**" to include resource allocation both in the case of delay and acceleration.

4.6. Delay Analysis with Resource Allocation

Figure 4.3 shows the activities' CPM network of a simple case study, where the project has five activities A, B, C, D, and E. Activities B and C are directly following activity A, activity D follows activity A with a tag = 2days to avoid the resource over allocation problem, and finally activity E follows all previous activities B,C, and D.

Figure 4.4 shows the as-planned and the as-built schedules. The project has an as-planned duration of 7 days. The contractor has a limit of two resources per day and maximum resource available is two resources. The daily resource needs for each activity is shown on the activities' bars. The as-planned schedule shows how the contractor adjusted the start time of activity D to avoid resource over-allocation. During the course of the actual work, the contractor caused a delay of one day for activity C, while the owner caused a delay of two days for activity B. The total project was delayed one day (ends at day 8, as opposed to day 7 of the as-planned). It is important to correctly analyze which party is responsible for the project delay.

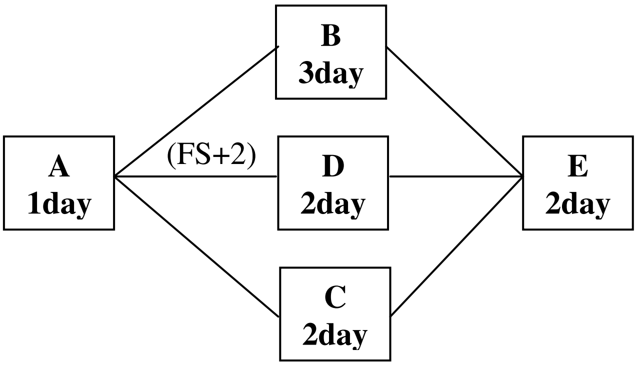
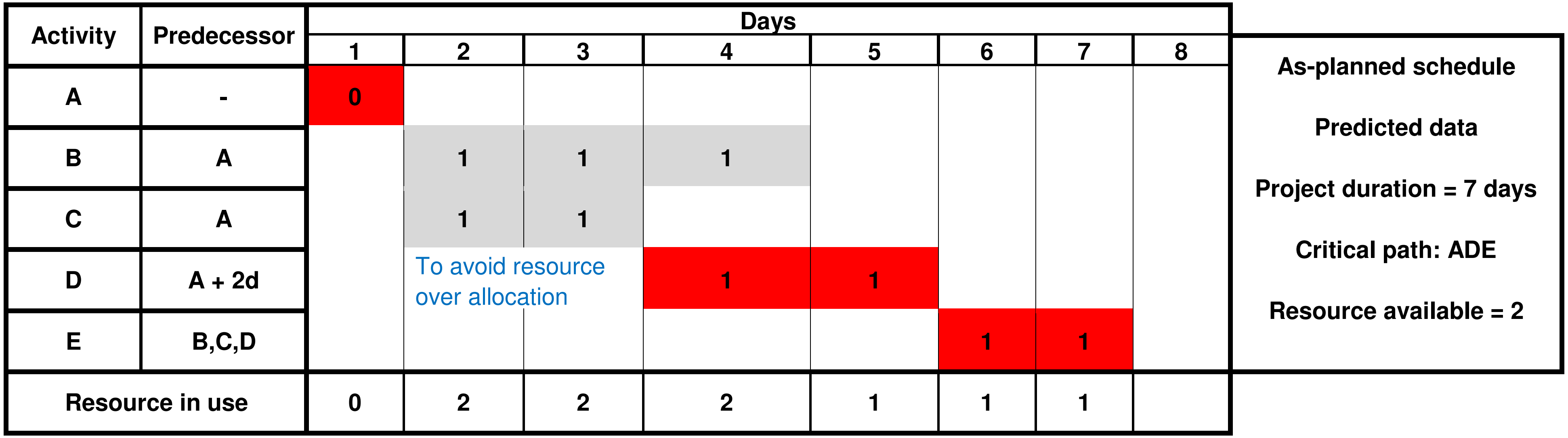


Fig. 4.1: CPM Network Case Study



Activity	Predecessor	Days							
		1	2	3	4	5	6	7	8
A	-	0							
B	A		1	1	1				
C	A		1	1					
D	A + 2d		To avoid resource over allocation		1	1			
E	B,C,D						1	1	
Resource in use		0	2	2	2	1	1	1	

As-planned schedule

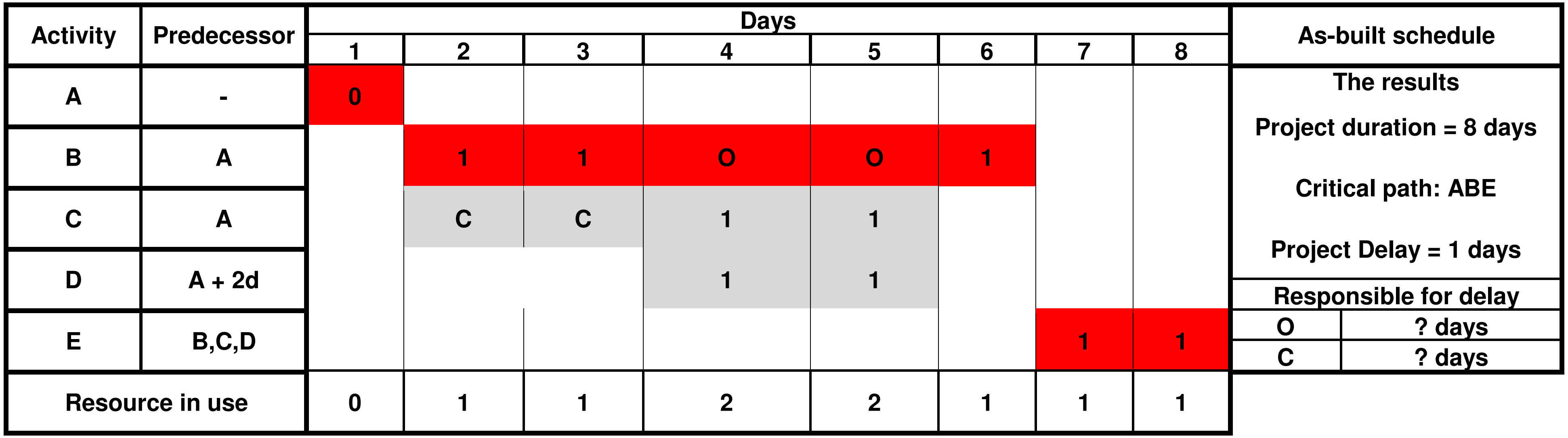
Predicted data

Project duration = 7 days

Critical path: ADE

Resource available = 2

(a) As-Planned Bar Chart



Activity	Predecessor	Days							
		1	2	3	4	5	6	7	8
A	-	0							
B	A		1	1	O	O	1		
C	A		C	C	1	1			
D	A + 2d				1	1			
E	B,C,D							1	1
Resource in use		0	1	1	2	2	1	1	1

As-built schedule

The results

Project duration = 8 days

Critical path: ABE

Project Delay = 1 days

Responsible for delay

O	? days
C	? days

(b) As-Built Bar Chart

Fig. 4.2: Bar Charts for a Sample Case of Daily Windows Analysis Method

4.6.1. Analysis Using Daily Windows Analysis Method "DWAM"

For the Daily Windows Analysis Method "**DWAM**", a total of 8 windows are analyzed without considering resource over allocation problem. In the window of the first day, the project advances according to the baseline schedule, and the project duration remains seven days. The analysis of the next windows are as follows:

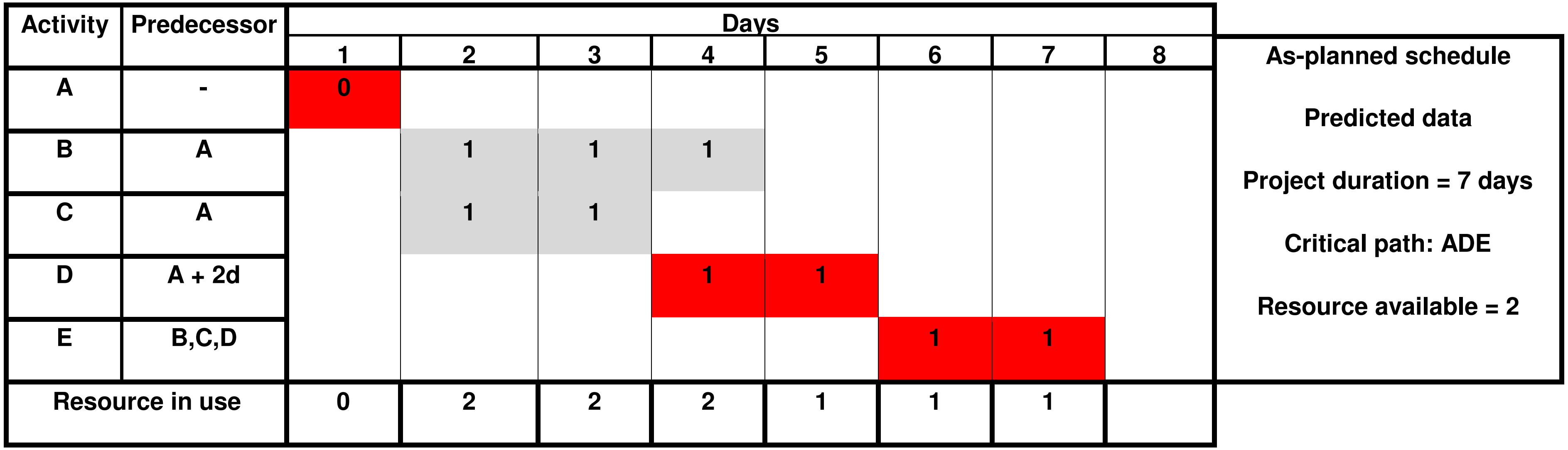
a. **Window of day 2 (Fig. 4.3):** Activity C exhibits a one day contractor delay. However, the contractor isn't responsible for this delay because activity C isn't critical activity and the project duration remains seven days as well as the critical path remains A-D-E. Although, that change was happened without considering the effect of resource allocation that will occurs at day 4, as shown in (Fig. 4.3b).

b. **Window of day 3 (Fig. 4.4):** Activity C exhibits another one day contractor delay. The contractor isn't responsible for this delay because activity C isn't critical activity and the project duration also remains seven days. The new critical path becomes A-C-E in additional to A-D-E, as shown in (Fig. 4.4b).

c. **Window of day 4 (Fig. 4.5):** Activity B exhibits a one day owner delay. However, the owner isn't responsible for this delay because activity B isn't critical activity and the project duration remains seven days. The critical path was changed and becomes A-B-E in additional to A-C-E and A-D-E. Although, that change was happened without considering the effect of resource allocation that will occurs at day 5 as shown in (Fig. 4.5b).

d. **Window of day 5 (Fig. 4.6):** Activity B exhibits another one day owner delay. Where activity B now is critical activity and this delay extended the project duration to becomes eight days. So the owner is responsible for that one day delay. The critical path was changed and becomes only one critical path A-B-E as shown in (Fig. 4.6b).

e. **From day 6 to day 8:** No additional delays occurred, so the project duration remains at eight days.



Activity	Predecessor	Days							
		1	2	3	4	5	6	7	8
A	-	0							
B	A		1	1	1				
C	A		1	1					
D	A + 2d				1	1			
E	B,C,D						1	1	
Resource in use		0	2	2	2	1	1	1	

As-planned schedule

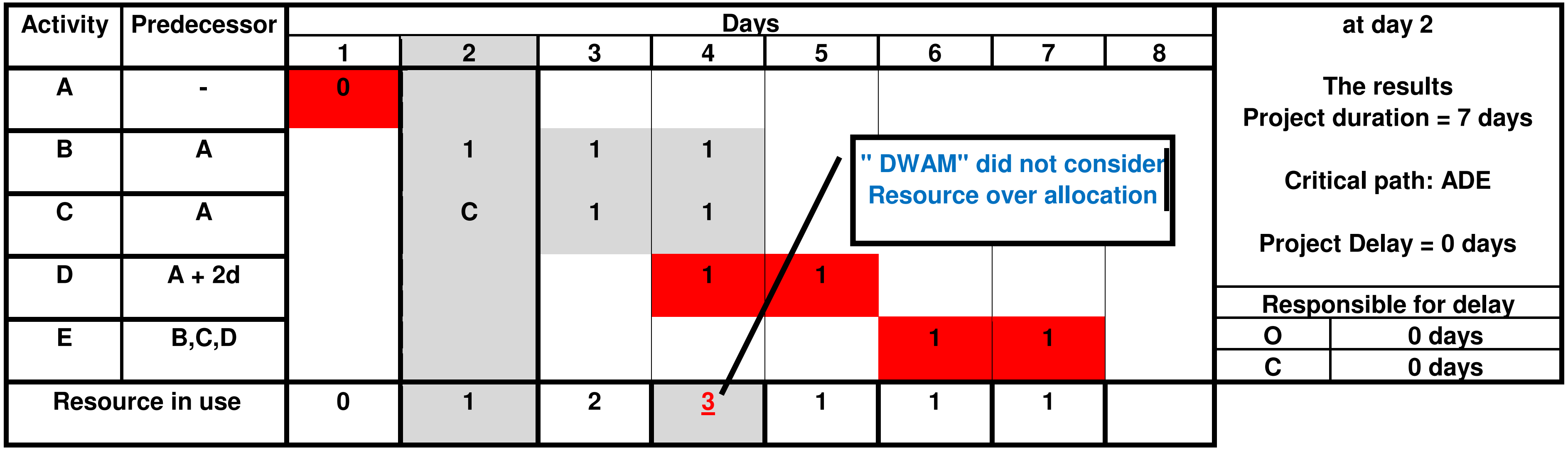
Predicted data

Project duration = 7 days

Critical path: ADE

Resource available = 2

(a) As-Planned Bar Chart



Activity	Predecessor	Days							
		1	2	3	4	5	6	7	8
A	-	0							
B	A		1	1	1				
C	A		C	1	1				
D	A + 2d				1	1			
E	B,C,D						1	1	
Resource in use		0	1	2	3	1	1	1	

" DWAM" did not consider Resource over allocation

at day 2

The results
Project duration = 7 days

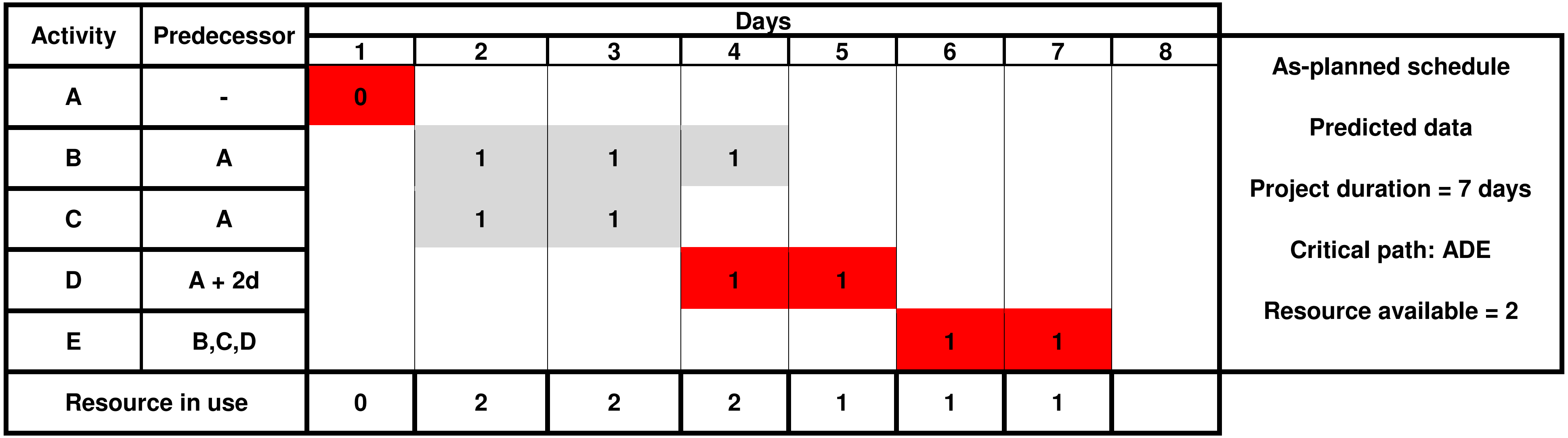
Critical path: ADE

Project Delay = 0 days

Responsible for delay	
O	0 days
C	0 days

(b) Daily Windows Analysis Method at Day 2

Fig. 4.3: Delay Analysis Using "DWAM" Without Considering Resource Over Allocation (windows at day 2)



Activity	Predecessor	Days 1	2	3	4	5	6	7	8
A	-	0							
B	A		1	1	1				
C	A		1	1					
D	A + 2d				1	1			
E	B,C,D						1	1	
Resource in use		0	2	2	2	1	1	1	

As-planned schedule

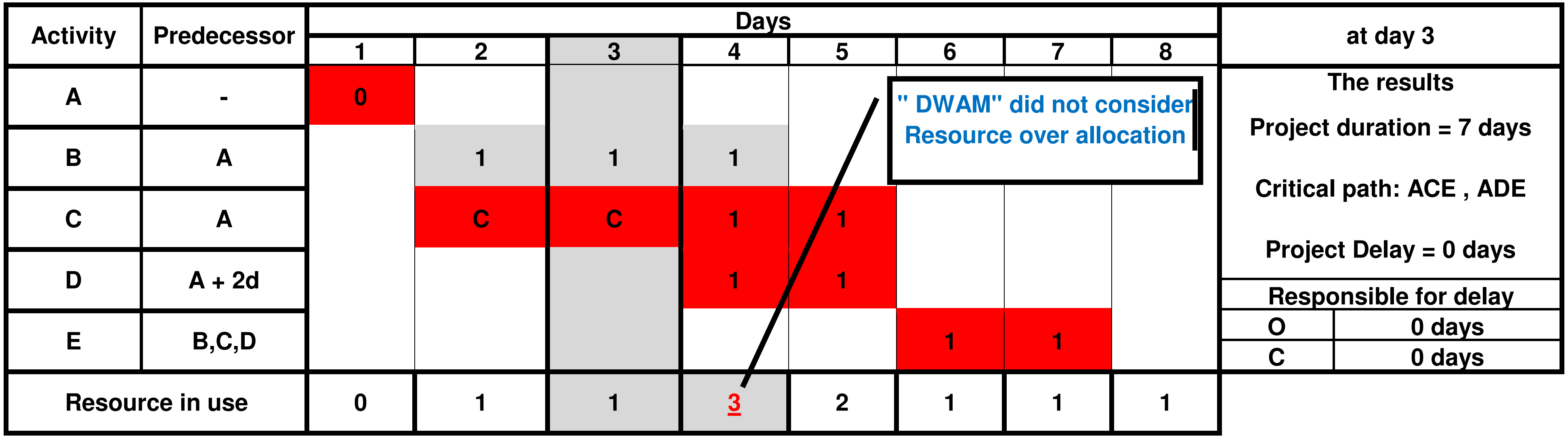
Predicted data

Project duration = 7 days

Critical path: ADE

Resource available = 2

(a) As-Planned Bar Chart



Activity	Predecessor	Days 1	2	3	4	5	6	7	8
A	-	0							
B	A		1	1	1				
C	A		C	C	1	1			
D	A + 2d				1	1			
E	B,C,D						1	1	
Resource in use		0	1	1	3	2	1	1	1

" DWAM" did not consider Resource over allocation

at day 3

The results

Project duration = 7 days

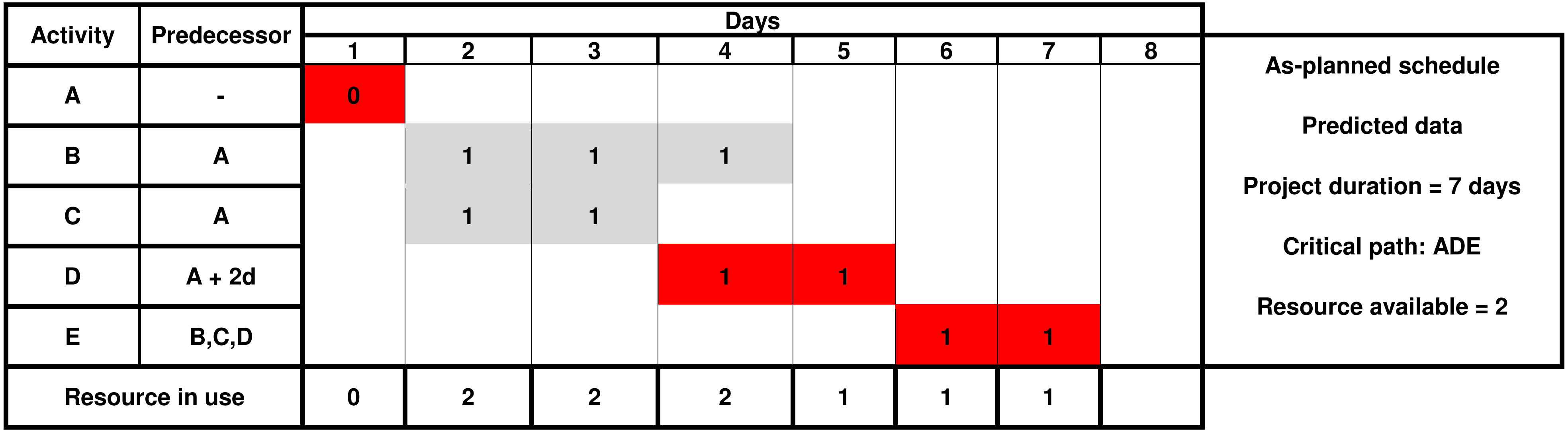
Critical path: ACE , ADE

Project Delay = 0 days

Responsible for delay	
O	0 days
C	0 days

(b) Daily Windows Analysis Method at Day 3

Fig. 4.4: Delay Analysis Using "DWAM" Without Considering Resource Over Allocation (windows at day 3)



Activity	Predecessor	Days							
		1	2	3	4	5	6	7	8
A	-	0							
B	A		1	1	1				
C	A		1	1					
D	A + 2d				1	1			
E	B,C,D						1	1	
Resource in use		0	2	2	2	1	1	1	

As-planned schedule

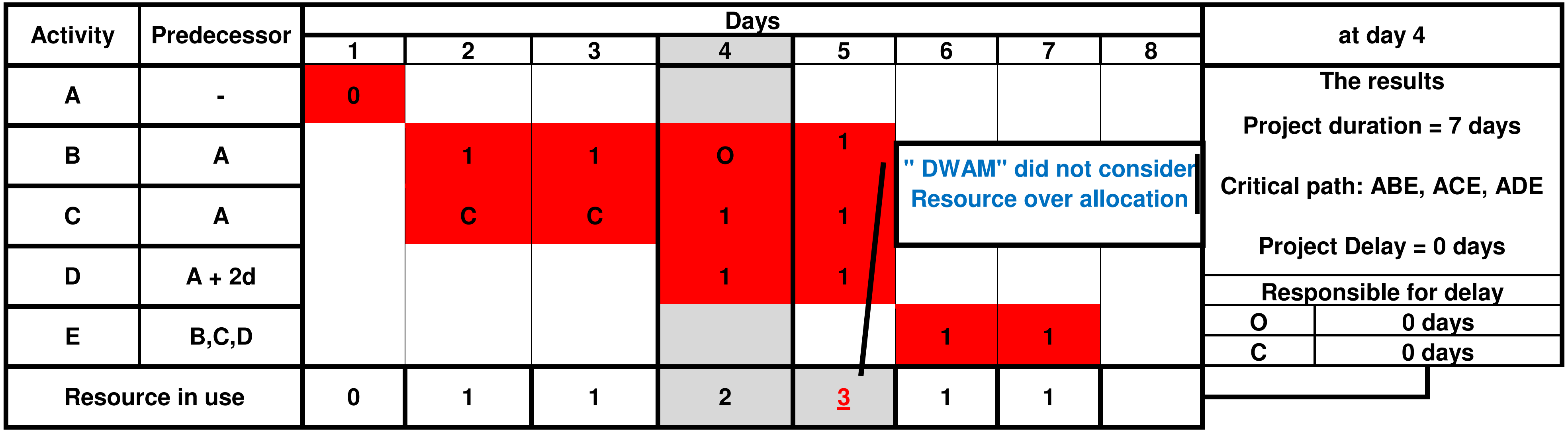
Predicted data

Project duration = 7 days

Critical path: ADE

Resource available = 2

(a) As-Planned Bar Chart



Activity	Predecessor	Days							
		1	2	3	4	5	6	7	8
A	-	0							
B	A		1	1	O	1			
C	A		C	C	1	1			
D	A + 2d				1	1			
E	B,C,D						1	1	
Resource in use		0	1	1	2	3	1	1	

" DWAM" did not consider Resource over allocation

at day 4

The results

Project duration = 7 days

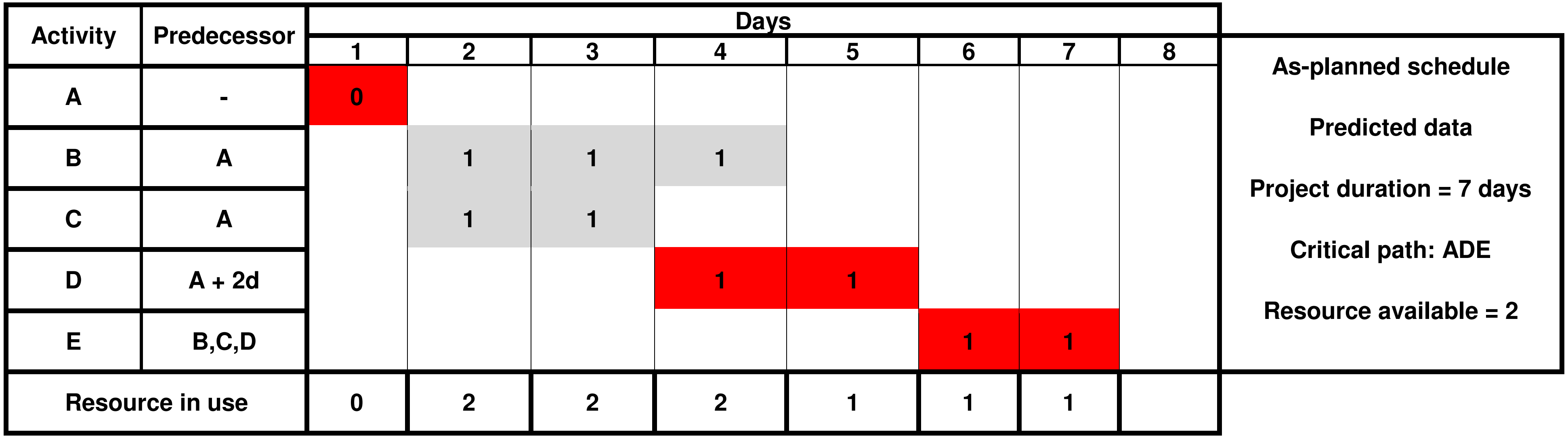
Critical path: ABE, ACE, ADE

Project Delay = 0 days

Responsible for delay	
O	0 days
C	0 days

(b) Daily Windows Analysis Method at Day 4

Fig. 4.5: Delay Analysis Using "DWAM" Without Considering Resource Over Allocation (windows at day 4)



Activity	Predecessor	Days 1	2	3	4	5	6	7	8
A	-	0							
B	A		1	1	1				
C	A		1	1					
D	A + 2d				1	1			
E	B,C,D						1	1	
Resource in use		0	2	2	2	1	1	1	

As-planned schedule

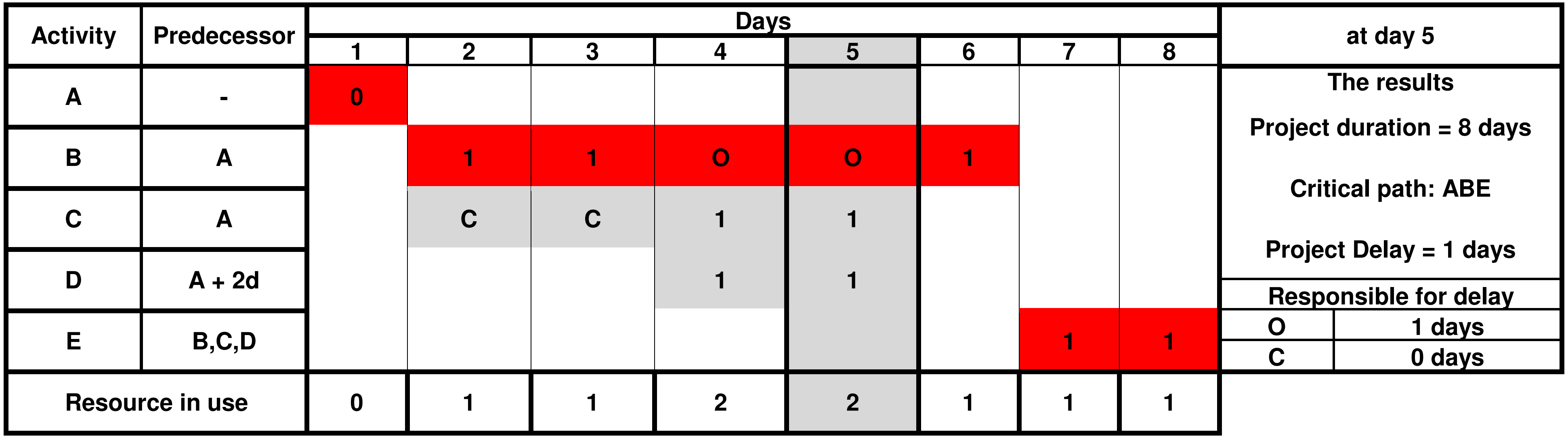
Predicted data

Project duration = 7 days

Critical path: ADE

Resource available = 2

(a) As-Planned Bar Chart



Activity	Predecessor	Days 1	2	3	4	5	6	7	8
A	-	0							
B	A		1	1	O	O	1		
C	A		C	C	1	1			
D	A + 2d				1	1			
E	B,C,D							1	1
Resource in use		0	1	1	2	2	1	1	1

at day 5

The results

Project duration = 8 days

Critical path: ABE

Project Delay = 1 days

Responsible for delay	
O	1 days
C	0 days

(b) Daily Windows Analysis Method at Day 5

Fig. 4.6: Delay Analysis Using "DWAM" Without Considering Resource Over Allocation (windows at day 5)

The previous example illustrated the use of "**DWAM**" to analyze the project delay without considering resource allocation. The summary of the results of the analysis are shown in Tables 4.1 and 4.2

Table (4.1): The Analysis of DWAM

Day no.	Delay		The effects of delay for whole project	
	Contractor	Owner	Contractor	Owner
1	0	0	0	0
2	1	0	0	0
3	1	0	0	0
4	0	1	0	0
5	0	1	0	1
from 6 to 8	0	0	0	0

Table (4.2): The Final Results of the Analysis by DWAM

	Delay events		Responsible for delay	
Project delays	Contractor	Owner	Contractor	Owner
1	2	2	0	1

The final results show that the project delayed one day. Although, the as-built bar chart shows that the contractor and the owner made two days delay for each one. Without considering the effect of resource allocation, the analysis using "**DWAM**" shows that the delay occurred at day five according to the owner delay for activity B (critical activity) led to delay the project by one day. **So the owner is responsible for one day delay**.

4.6.2. Analysis Using Modified Daily Windows Analysis Method "MDWAM"

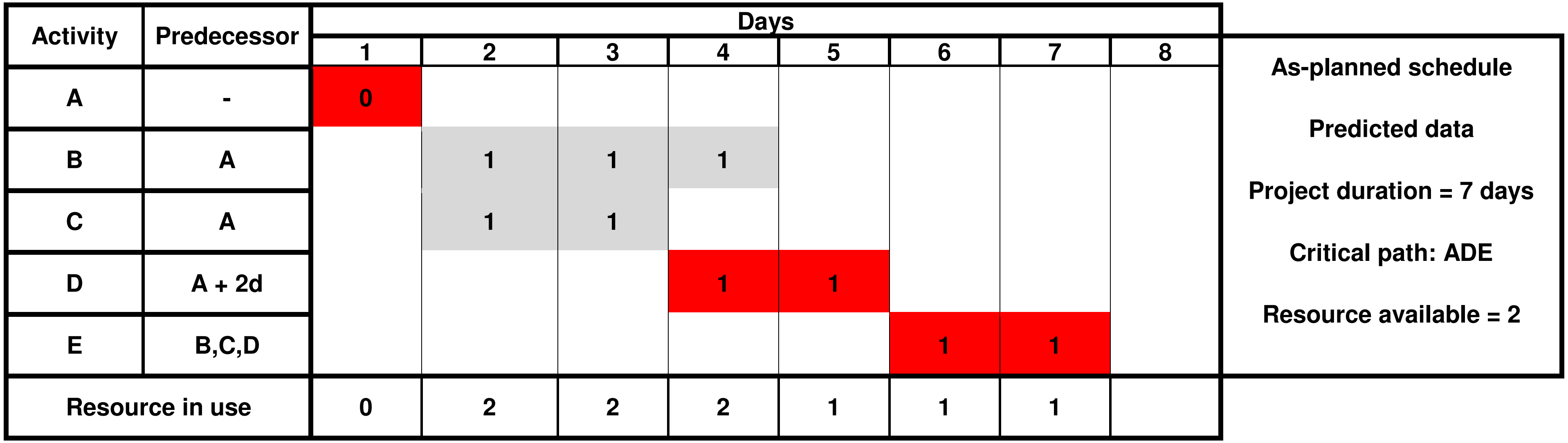
In this research, therefore, changes to the Daily Windows Analysis Method "**DWAM**" have been introduced in order to consider the effect of resource allocation. The Modified Daily Windows Analysis Method "**MDWAM**" requires re-scheduling and re-sequencing the remaining part of the project in order to reflect resource availability and allocation practice. **The parallel method** of resource allocation used in the analysis to re-schedule the remaining part of the project according to the no. of available resources, because it deals with limited resources and allows to activity to interrupted or delayed.

For the Modified Daily Windows Analysis Method "**MDWAM**", a total of 8 windows are analyzed considering resource over allocation problems. In the window of the first day, the project advances according to the baseline schedule, and the project duration remains seven days. The analysis of the next windows are as follows:

a. **Window of day 2 (Fig. 4.7):** Activity C exhibits a one day contractor delay. Although the delay did not affect the critical path, it made the initial resource allocation for the remaining work impractical. The resource would be over-allocated at day 4. Thus, the project would have to be rescheduled as a corrective action to meet the resource limits (2 resources), as shown in (Fig. 4.7b).

b. **Corrective action no.1 (Fig. 4.8):** after day 2 was finished, the resource will be over allocated at day 4 as shown in (Fig. 4.8a). The resource over allocation problem is confined between activities B, C, and D. By applying the rules of parallel method to resolve this problem, activity D will be delayed one day because activity B and C have already started. After rescheduling, the project duration would become eight days because activity D is a critical activity. Accordingly, the contractor becomes responsible for a one-day delay, as shown in (Fig. 4.8b).

c. **Window of day 3 (Fig. 4.9):** Activity C exhibits another one day contractor delay. The contractor isn't responsible for this delay because activity C isn't a critical activity and the project duration hasn't experienced any resource over allocation problems. The project duration remains eight days but the critical path becomes A-C-E in additional to A-D-E, as shown in (Fig. 4.9b).



Activity	Predecessor	Days 1	2	3	4	5	6	7	8
A	-	0							
B	A		1	1	1				
C	A		1	1					
D	A + 2d				1	1			
E	B,C,D						1	1	
Resource in use		0	2	2	2	1	1	1	

As-planned schedule

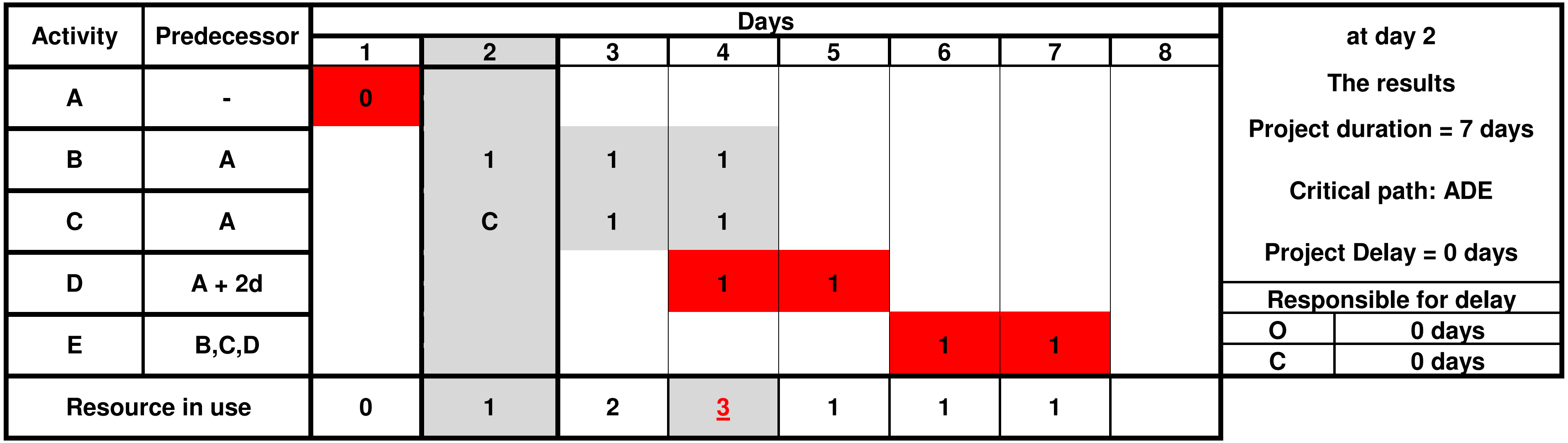
Predicted data

Project duration = 7 days

Critical path: ADE

Resource available = 2

(a) As-Planned Bar Chart



Activity	Predecessor	Days 1	2	3	4	5	6	7	8
A	-	0							
B	A		1	1	1				
C	A		C	1	1				
D	A + 2d				1	1			
E	B,C,D						1	1	
Resource in use		0	1	2	3	1	1	1	

at day 2

The results

Project duration = 7 days

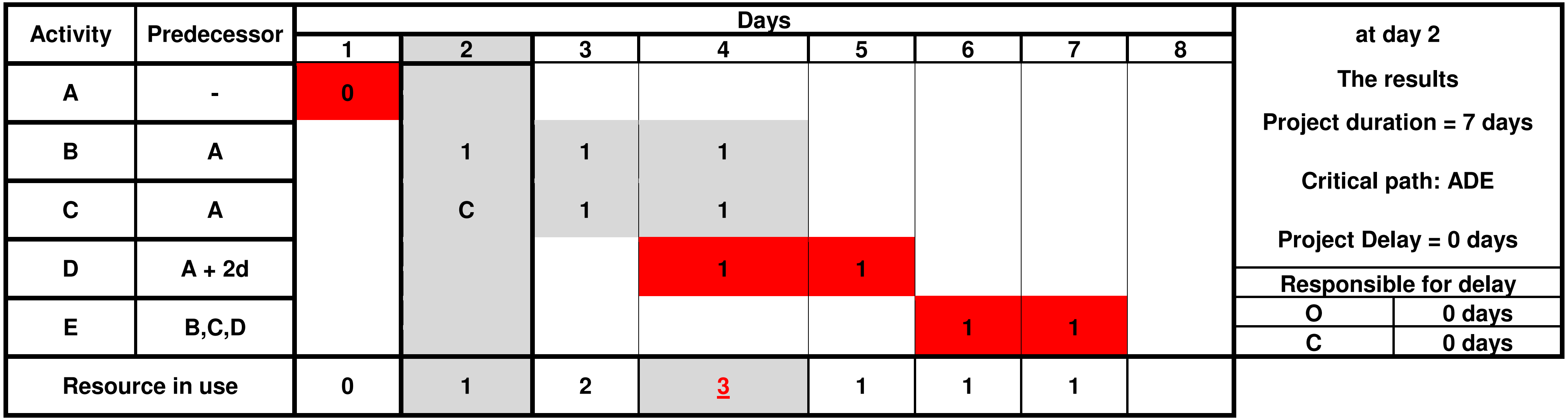
Critical path: ADE

Project Delay = 0 days

Responsible for delay	
O	0 days
C	0 days

(b) Modified Daily Windows Analysis Method at Day 2

Fig. 4.7: Delay Analysis Using "MDWAM" Considering Resource Over Allocation (windows at day 2)



Activity	Predecessor	Days							
		1	2	3	4	5	6	7	8
A	-	0							
B	A		1	1	1				
C	A		C	1	1				
D	A + 2d				1	1			
E	B,C,D						1	1	
Resource in use		0	1	2	3	1	1	1	

at day 2

The results

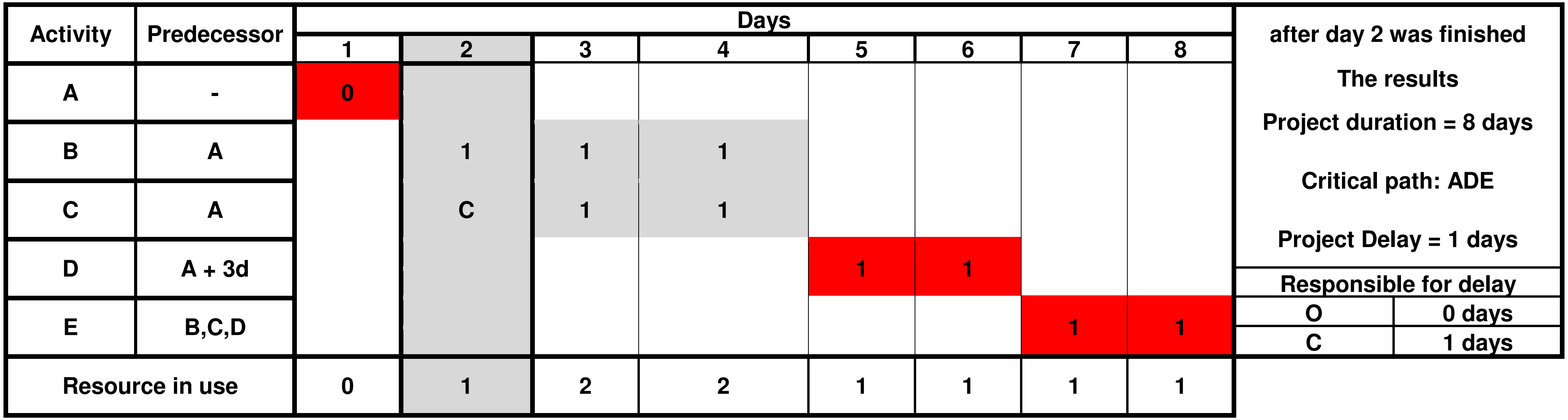
Project duration = 7 days

Critical path: ADE

Project Delay = 0 days

Responsible for delay	
O	0 days
C	0 days

(a) Before Resource Allocation



Activity	Predecessor	Days							
		1	2	3	4	5	6	7	8
A	-	0							
B	A		1	1	1				
C	A		C	1	1				
D	A + 3d					1	1		
E	B,C,D							1	1
Resource in use		0	1	2	2	1	1	1	1

after day 2 was finished

The results

Project duration = 8 days

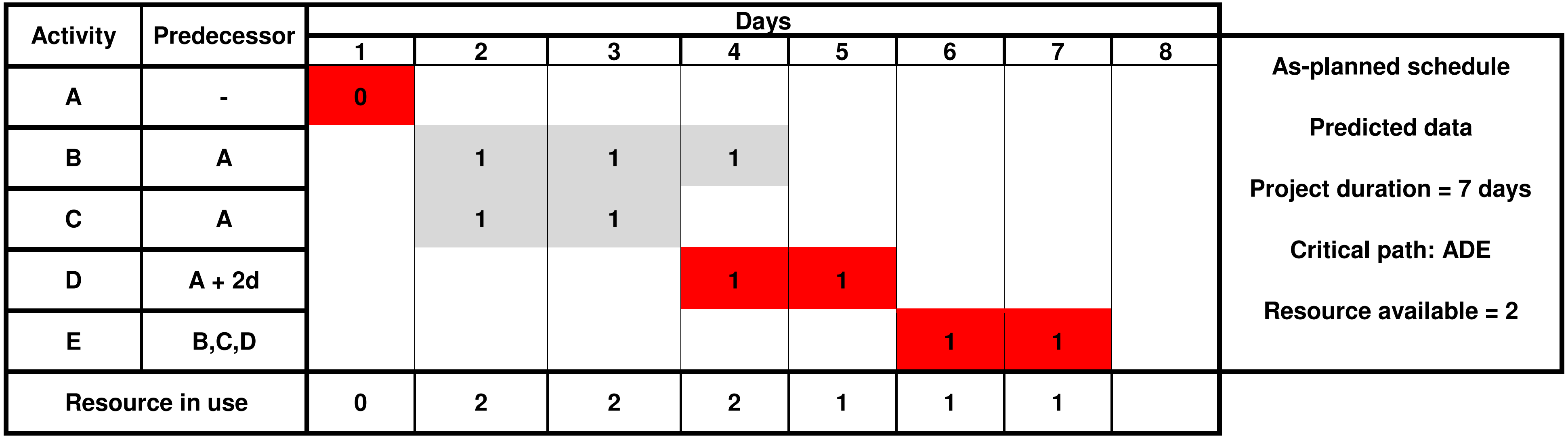
Critical path: ADE

Project Delay = 1 days

Responsible for delay	
O	0 days
C	1 days

(b) After Resource Allocation

Fig. 4.8: Delay Analysis Using "MDWAM" Considering Resource Over Allocation (corrective action no.1)



Activity	Predecessor	Days 1	2	3	4	5	6	7	8
A	-	0							
B	A		1	1	1				
C	A		1	1					
D	A + 2d				1	1			
E	B,C,D						1	1	
Resource in use		0	2	2	2	1	1	1	

As-planned schedule

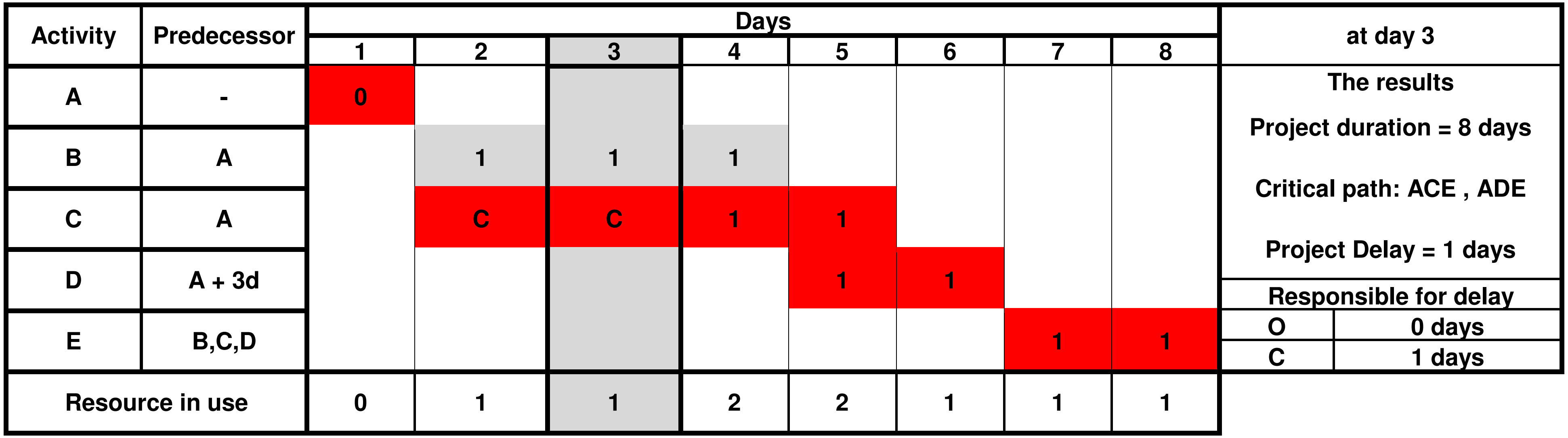
Predicted data

Project duration = 7 days

Critical path: ADE

Resource available = 2

(a) As-Planned Bar Chart



Activity	Predecessor	Days 1	2	3	4	5	6	7	8
A	-	0							
B	A		1	1	1				
C	A		C	C	1	1			
D	A + 3d					1	1		
E	B,C,D							1	1
Resource in use		0	1	1	2	2	1	1	1

at day 3

The results

Project duration = 8 days

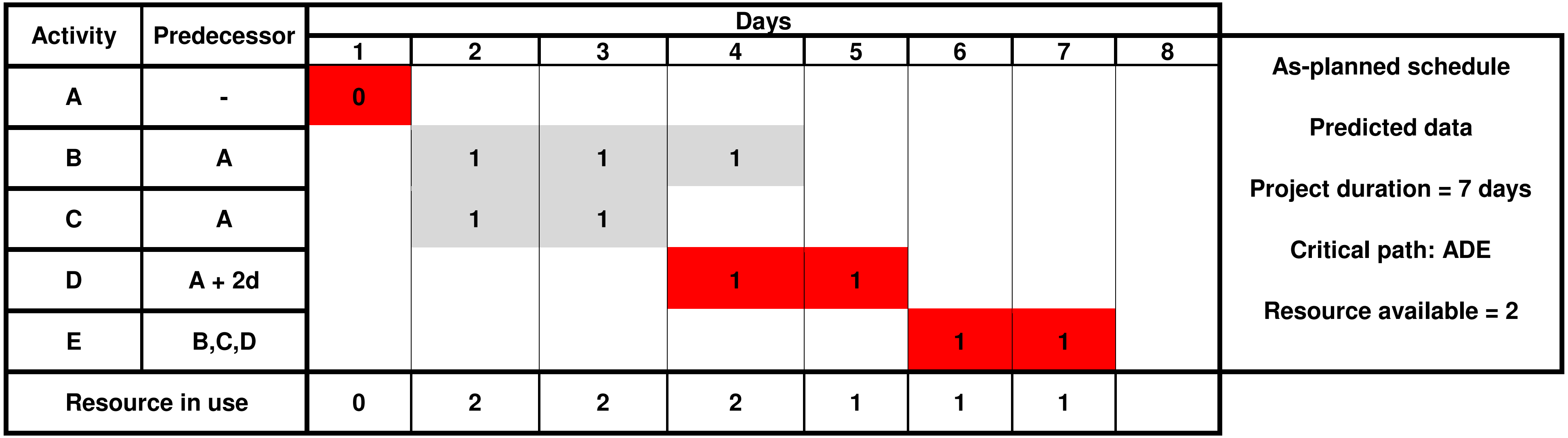
Critical path: ACE , ADE

Project Delay = 1 days

Responsible for delay	
O	0 days
C	1 days

(b) Modified Daily Windows Analysis Method at Day 3

Fig. 4.9: Delay Analysis Using "MDWAM" Considering Resource Over Allocation (windows at day 3)



Activity	Predecessor	Days 1	2	3	4	5	6	7	8
A	-	0							
B	A		1	1	1				
C	A		1	1					
D	A + 2d				1	1			
E	B,C,D						1	1	
Resource in use		0	2	2	2	1	1	1	

As-planned schedule

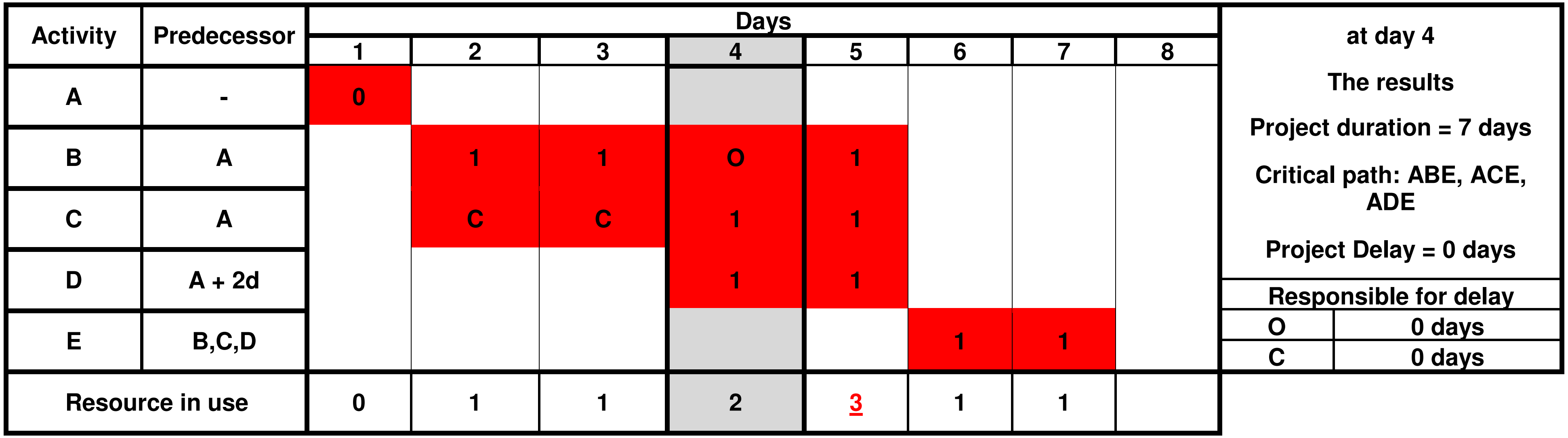
Predicted data

Project duration = 7 days

Critical path: ADE

Resource available = 2

(a) As-Planned Bar Chart



Activity	Predecessor	Days 1	2	3	4	5	6	7	8
A	-	0							
B	A		1	1	O	1			
C	A		C	C	1	1			
D	A + 2d				1	1			
E	B,C,D						1	1	
Resource in use		0	1	1	2	3	1	1	

at day 4

The results

Project duration = 7 days

Critical path: ABE, ACE, ADE

Project Delay = 0 days

Responsible for delay	
O	0 days
C	0 days

(b) Modified Daily Windows Analysis Method at Day 4

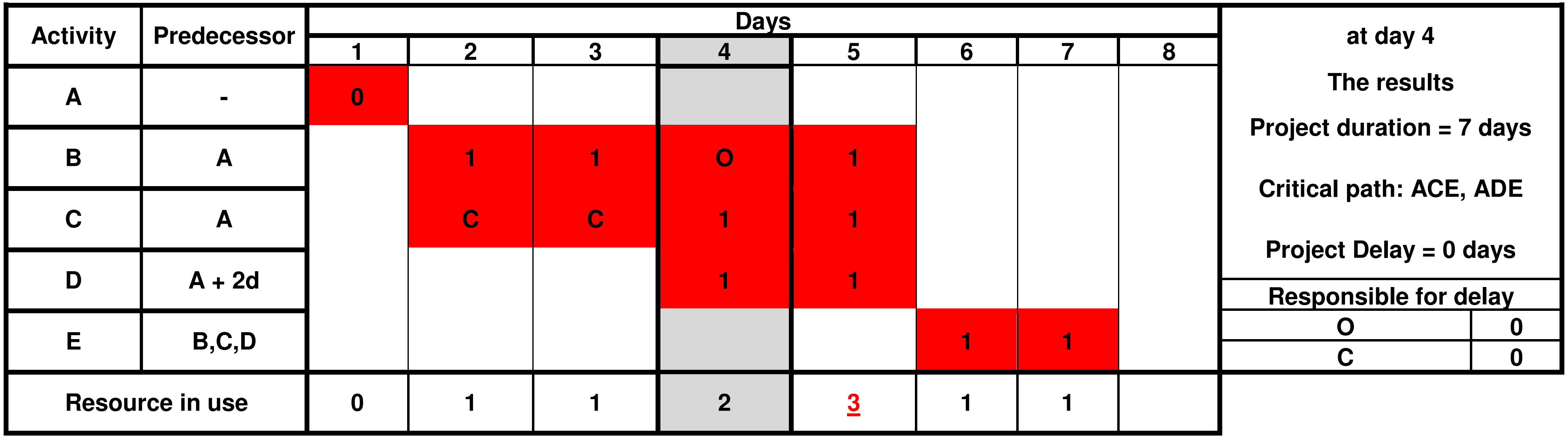
Fig. 4.10: Delay Analysis Using "MDWAM" Considering Resource Over Allocation (windows at day 4)

d. **Window of day 4 (Fig. 4.10):** Activity B exhibits a one day owner delay. The availability of resources are two resources, this leads to start activity D in this day according to the parallel method principle without any conflict in the activities relationship. The resource would be over-allocated at day 5, the project duration becomes seven days, and all activities become critical activities. Thus, the project would have to be rescheduled as a corrective action to meet the resource limits (2 resources), as shown in (Fig. 4.10b).

e. **Corrective action no.2 (Fig. 4.11):** after day 4 was finished, the resource will be over allocated at day 5 as shown in (Fig. 4.11a). The resource over-allocation problem is confined between activities B, C, and D. By applying the rules of parallel method to resolve this problem, activities B, C, and D have already started but activity D will be delayed or interrupted one day because activities B and C have a least total floats. After rescheduling, the project duration would become eight days again because activity D is a critical activity. The new critical path is A-D-E. Accordingly, the contractor is responsible for a one-day delay because activity D was shifted by him from the first over-allocation problem, as shown in (Fig. 4.11b).

f. **Window of day 5 (Fig. 4.12):** Activity B exhibits another one day owner delay. The availability of resources are two resources, this leads to continue and finish activity D in this day according to the parallel method principle without any conflict in the activities relationship. Where, that delay affected neither the project duration nor the resource allocation. The new critical path becomes A-B-E, and the project duration eight days corresponding the as-built bar chart, as shown in (Fig. 4.12b).

g. **From day 6 to day 8:** No additional delays occurred, so the project duration remains at eight days.



Activity	Predecessor	Days 1	2	3	4	5	6	7	8
A	-	0							
B	A		1	1	O	1			
C	A		C	C	1	1			
D	A + 2d				1	1			
E	B,C,D						1	1	
Resource in use		0	1	1	2	3	1	1	

at day 4

The results

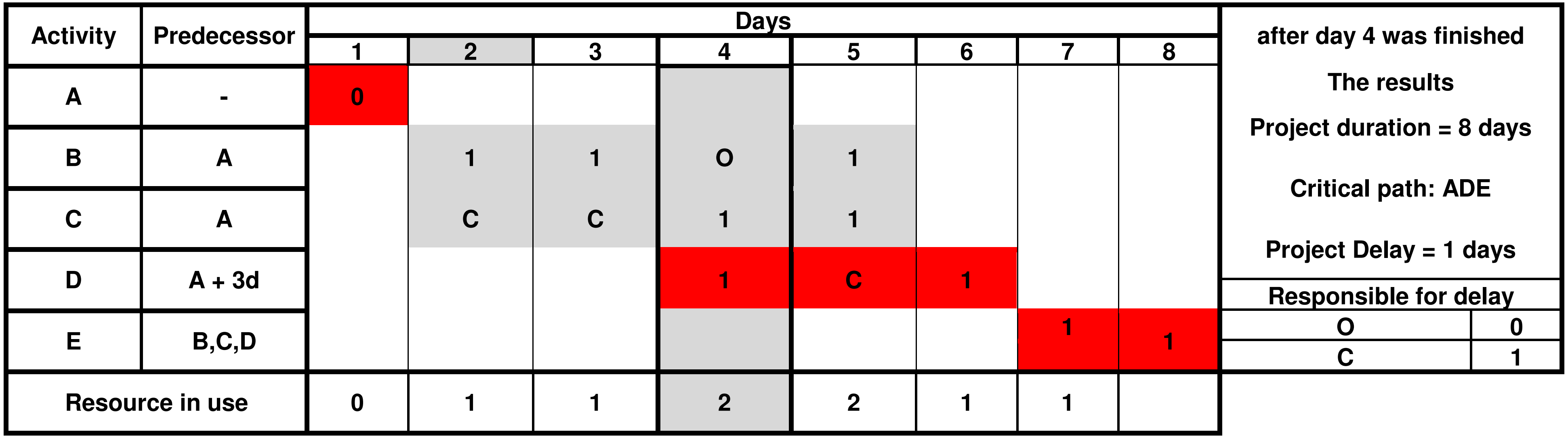
Project duration = 7 days

Critical path: ACE, ADE

Project Delay = 0 days

Responsible for delay	
O	0
C	0

(a) Before Resource Allocation



Activity	Predecessor	Days 1	2	3	4	5	6	7	8
A	-	0							
B	A		1	1	O	1			
C	A		C	C	1	1			
D	A + 3d				1	C	1		
E	B,C,D							1	1
Resource in use		0	1	1	2	2	1	1	

after day 4 was finished

The results

Project duration = 8 days

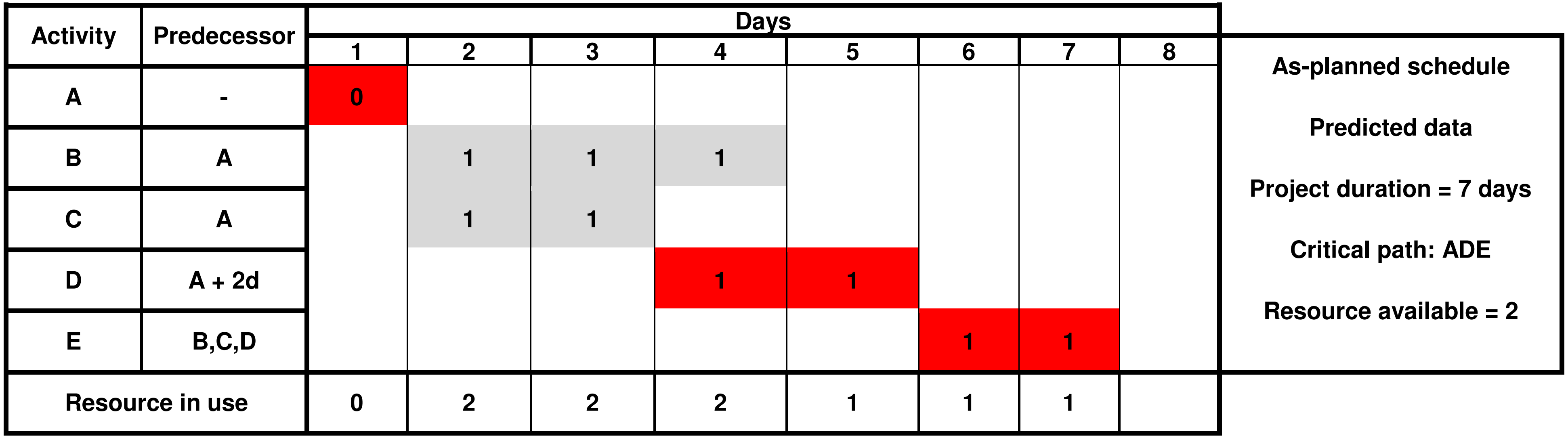
Critical path: ADE

Project Delay = 1 days

Responsible for delay	
O	0
C	1

(b) After Resource Allocation

Fig. 4.11: Delay Analysis Using "MDWAM" Considering Resource Over Allocation (corrective action no.2)



Activity	Predecessor	Days 1	2	3	4	5	6	7	8
A	-	0							
B	A		1	1	1				
C	A		1	1					
D	A + 2d				1	1			
E	B,C,D						1	1	
Resource in use		0	2	2	2	1	1	1	

As-planned schedule

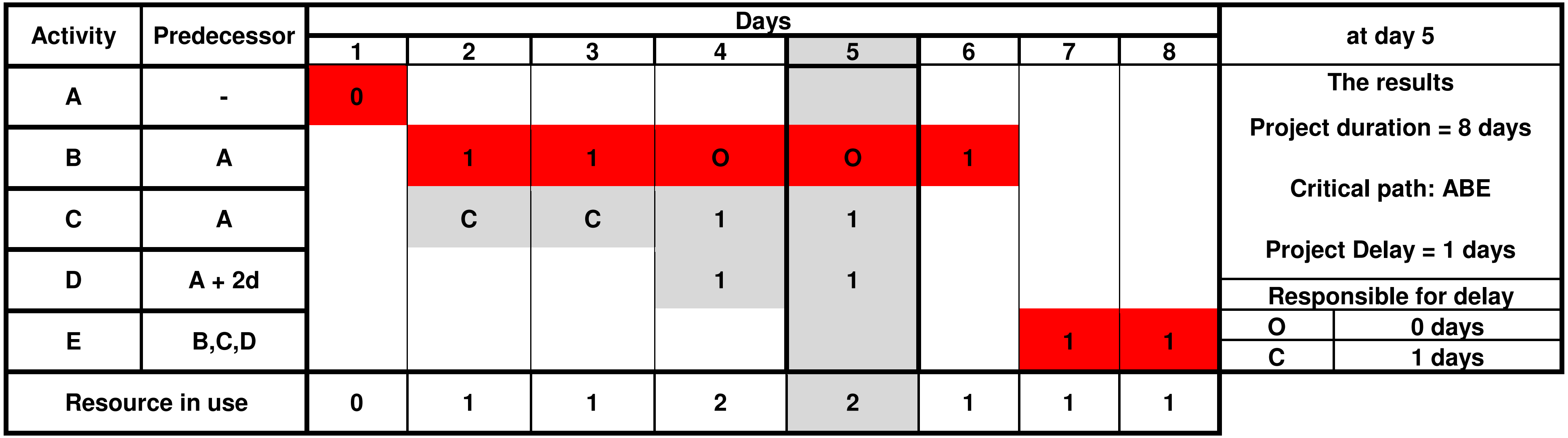
Predicted data

Project duration = 7 days

Critical path: ADE

Resource available = 2

(a) As-Planned Bar Chart



Activity	Predecessor	Days 1	2	3	4	5	6	7	8
A	-	0							
B	A		1	1	O	O	1		
C	A		C	C	1	1			
D	A + 2d				1	1			
E	B,C,D							1	1
Resource in use		0	1	1	2	2	1	1	1

at day 5

The results

Project duration = 8 days

Critical path: ABE

Project Delay = 1 days

Responsible for delay

O	0 days
C	1 days

(b) Modified Daily Windows Analysis Method at Day 5

Fig. 4.12: Delay Analysis Using "MDWAM" Considering Resource Over Allocation (windows at day 5)

The previous example demonstrated the use of "**MDWAM**" to analyze the project delay considering resource allocation, and the results of the analysis are shown in Tables 4.3 and 4.4.

Table (4.3): The Analysis of "MDWAM"

Day no.	Delay		The effects of delay for whole project	
	Contractor	Owner	Contractor	Owner
1	0	0	0	0
2	1	0	1	0
3	1	0	0	0
4	0	1	0	0
5	0	1	0	0
from 6 to 8	0	0	0	0

Table (4.4): The Final Results of the Analysis by "MDWAM"

	Delay events		Responsible for delay	
Project delays	Contractor	Owner	Contractor	Owner
1	2	2	1	0

The final results show that the project delayed one day. Although, the as-built bar chart shows that the contractor and the owner made two days delay for each one. With considering the effect of resource allocation, the analysis using "**MDWAM**" shows that the delay occurred at day two according to the contractor delay for activity C (critical activity) led to delay the project by one day. **So the contractor is responsible for one day delay.**

This simple example shows that the Modified Daily Windows Analysis Method "**MDWAM**" may produce better results because it consider the resource over allocation problems in the analysis utilizing **the parallel method**.

4.7. Systematic Detailed Procedure

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

1. A copy of the as-built schedule is saved, and then all actual progress is cleared to get the as-planned schedule.
2. For each day (i), starting from day 1 to the last day of the project, the following steps are performed:
   - **A.** Critical path(s) and near critical path(s) are identified, and the smallest float S_F among all the non-critical path(s) is calculated.
   - **B.** The actual events (percentage completed or delays) of day (i) are added to the project baseline at that day and the remaining schedule is calculated.
   - **C.** The project duration after adding the actual events is compared with the initial duration. Any change in the project duration (delay or acceleration) is analyzed and apportioned, including concurrent delays and accelerations, among the parties, as follows:
     - (1) If the project experiences a delay as compared to the previous day's analysis, the current day's critical path(s) and near-critical path(s) are analyzed as follows:
       - a. If the delay $D(i) <= S_F(i)$, the smallest float $S_F(i)$ is equally attributed to the new critical path(s) only.
       - b. If $D(i) > S_F(i)$, $S_F(i)$ is equally attributed to the new critical path(s) only, and $(D(i) - S_F(i))$ is equally attributed to the new critical path(s) and the near-critical path.
       - c. According to the causation of delay(s) on critical path(s) and near-critical path(s), the project delay is apportioned to the owner, the contractor and/or a third party.
     - (2) If the project experiences acceleration as compared to the previous day's analysis, the current day's critical path(s) and near-critical path(s) are analyzed as follows:
       - a. If the project acceleration $A(i) <= S_F(i)$, the project acceleration $A(i)$ is equally attributed to the original critical path(s) only.

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

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

D. The resource allocation for the remaining work is checked.

(1) If the resources are over-allocated in the remaining schedule (the available resource $R_A\ (i) <$ used resource $R_U\ (i)$), the remaining activities are rescheduled and re-sequenced to meet the resource limits as follow.

a. Continue the activity which has already started; if all the same

b. Delay the activity which has the maximum late start time L_S; if all the same

c. Delay the activity which has the largest total float L_F; if all the same

d. Delay the activity which has the minimum no. of resources; if all the same

e. Delay any one.

(2) If the resources are not over-allocated in the remaining schedule (the available resource $R_A\ (i) >=$ used resource $R_U\ (i)$), continue.

E. The remaining schedule is calculated again after the reallocation.

F. The project duration after rescheduling is compared with the base duration. Any change in the project duration is analyzed and apportioned among the parties.

G. The counter is incremented to the next day.

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

4.8. Conclusion

In this chapter, improvements to the Daily Windows Analysis Method "**DWAM**" are proposed in order to ensure that delay analysis considers the impact of resource allocation. The Modified Daily Windows Analysis Method "**MDWAM**" utilizing the **parallel method** identifies any changes in the resource allocation for the remaining work due to any delays or slowdowns and takes the impact of these changes on the project duration into consideration in the analysis. **The parallel method** was selected to resolve the over-allocation problem because it deals with limited resources and allows to activity to interrupted or delayed. A simple case study was used to compare the methods and results of the "**DWAM**" and the "**MDWAM**" and the comparison of the results for that two approaches are shown in Table 4.5.

Table (4.5) : The Comparison Between the Results of the Two Approaches

Approach	**Delay Responsibility**	
	Owner (O)	**Contractor (C)**
DWAM	**1**	**0**
MDWAM	**0**	**1**

The results show the difference between the two approach "**DWAM**" and "**MDWAM**". Using "**DWAM**" without considering resource over-allocation problem gives the responsibility for that one day delay to the owner. Using "**MDWAM**" considering resource over-allocation the results gives the responsibility for that one day delay to the contractor.

This simple example shows that the "**DWAM**" may produce inaccurate results because it does not consider the resource allocation in the analysis. On the other hand, shows that the "**MDWAM**" may produce better results because it consider the resource over allocation problems in the analysis utilizing **the parallel method**.

A systematic procedure for a Modified Daily Windows Analysis Method "**MDWAM**" that considers resource allocation is presented in order to facilitate its computer implementation.

CHAPTER 5

CONCLUSION and RECOMMENDATION

5.1. Introduction

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

5.2. Conclusion

Using a window size of one day and a legible representation of the progress information, a new delay analysis model has been introduced. This model takes into consideration schedule updates and accurately apportions delays and accelerations among the project parties. Modified Daily Windows Analysis Method "**MDWAM**" with schedule updates considers every change in the relationships and durations of the activities because of its legible representation and its ability to analyze the schedule using multiple baselines, and thus can arrive at more accurate results.

The Modified Daily Windows Analysis Method "**MDWAM**" has been validated on a small case study. **MDWAM** analyzed the delay using three approaches Remaining Duration Equation, Earned Value Equation, and As-Planned Activity Duration Equation.

The analysis of "**MDWAM**" using earned value equation considered **the slowest and longest way** for analysis. The analysis of "**MDWAM**" using as-planned activity duration equation considered **the fastest and shortest way** for analysis. The analysis of "**MDWAM**" using remaining duration equation considered the average way between earned value and as-planned ways for analysis because it depends on the availability to complete the activity duration, so it is called **the most likely way** for delay analysis by "**MDWAM**" considering schedule updates. Thus, the "**MDWAM**" using this way has more accuracy than the other two approaches.

The Modified Daily Windows Analysis Method "**MDWAM**" utilizing the **parallel method** identifies any changes in the resource allocation for the remaining work due to any delays or slowdowns and takes the impact of these changes on the project duration into consideration in the analysis. **The parallel method** was selected to resolve the over-allocation problem because it deals with limited resources and allows to activity to interrupted or delayed. A simple example illustrated that the "**DWAM**" may produce inaccurate results because it does not consider the resource allocation in the analysis. On the other hand, show that the "**MDWAM**" may produce better results because it consider the resource over allocation problems in the analysis utilizing **the parallel method**.

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

- The project schedule is updated each day, including all the delays and changes in total floats until the as-built schedule is reached.
- The baseline is updated whenever the logical relationships between the activities and/or the activities' durations are changed.
- When a new baseline is entered, the new baseline duration is calculated and compared with the previous duration. The difference is credited to the party responsible for delay or acceleration.
- The type of delay and the corresponding responsibility, including concurrent delays, are identified.

- The responsibility for delays, slowdowns, and accelerations is identified and assigned.
- Any changes in the resource allocation because of delays or slowdowns are identified using the parallel method.
- The project is rescheduled to meet the resource limits depending on the rules of the parallel method, and the duration of the new schedule is compared with the previous one. Any additional delays are allocated to the party responsible.
- While the model becomes most accurate if progress data is entered daily, the model is still usable even at the end of the project. It is possible to create the as-built schedule simply using the activities' start and finish dates and the dates of the unusual site events. In this case, daily percentages can be easily calculated and any delays recorded in their dates.

5.3. Recommendations

- Engineers and supervisors are recommended to recode all data as well as all events be occurred on the site
- Engineers and supervisors are recommended to follow the daily progress and make a comparison between the actual duration and the planned duration and make a corrective actions when needed to complete the project within the planned duration as soon as possible.
- Analyzers or specialists are recommended to use "**MDWAM**" for delay analysis instead of "**TWAM**" because it's deal with all changes through the project period.
- Analyzers or specialists are recommended to use "**MDWAM**" for delay analysis instead of "**DWAM**" when the as-planned and as-built charts are the same because it's the only way for analysis this cases.
- Analyzers or specialists are recommended to use "**MDWAM**" for delay analysis **using remaining duration way** because it's the most likely way as well as the best way gives the accurate results.
- Analyzers or specialists are recommended to use "**MDWAM**" for delay analysis **using parallel method** because it deals with limited resources and allows to activity to interrupted or delayed.

5.4. Future Research and Developments

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

1. The resource allocation algorithm applied in this model reschedules the project using the best five rules available for resource allocation, which are the earliest latest-start, shortest duration, longest duration, smallest ID, and Longest ID rules. It then selects the best schedule from the resulting five schedules. However, in some cases, using these rules may not produce the optimum schedule. This algorithm could be improved so that it produces the optimum schedule that meets the project deadline and satisfies the resource limits with the least cost.
2. The resource allocation algorithm moves only the activities that did not start before or at the day of rescheduling and it deals with the activity duration as one block of activity, so it delays only the start of the activity. Splitting each activity into a number of blocks that equal the activity's total duration (i.e., an activity with a duration of three days can be split into three blocks) may produce better schedules since the algorithm will be able to move each part of the activity while it is searching for the optimum schedule.
3. The resource allocation process implemented within the proposed model is based on a maximum of three key resources. This limitation could be improved through the consideration of all the resources required for the project.
4. The scheduling process used in the proposed model is based only on FS (Finish to Start) relationships. Although SS (Start to Start), FF (Finish to Finish), and SF (Start to Finish) relationships can be indirectly represented by the FS (Finish to Start) relationship, it could be possible to allow the user to directly specify all the relationships in the model in order to improve efficiency and usability.
5. The application of the proposed model to real life projects is necessary in order to examine whether courts and boards would accept the use of this model and to validate the approaches developed in this research.
6. The proposed model was developed to identify schedule delays and accelerations and to apportion them among the parties responsible. It could be possible to link the proposed model to commercial estimating software in order to determine the relevant cost of these delays and accelerations.

REFERENCES

Alkass, S., Mazerolle, M., and Harris, F. (1995). "Computer Aided Construction Delay Analysis and Claims Preparation." *Construction Management and Economics,* 13, 335-352.

Alkass, S., Mazerolle, M., and Harris, F. (1996). "Construction Delay Analysis Techniques." *Construction Management and Economics,* 14 (5), 375-394.

Al-Khal, M. I., and Al-Ghafly, M. (1999). "Important Causes of Delay in Public Utility Projects in Saudi Arabia." *Construction Management and Economics,* 17(5), 647-655.

Allam, S.I.G. (1988) "Multi-Project Scheduling: A New Categorization for Heuristic Scheduling Rules in Construction Scheduling Problems." *Construction Management and Economics*, 6(2), 93-115.

Al-Momani, A. H. (2000). "Construction Delay: A Quantitative Analysis." *International Journal of Project Management,* 18 (1), 51-59.

Arditi, D., Akan, G. T., and Gurdamar, S. (1985). "Reasons for Delays in Public Projects in Turkey." *Construction Management and Economics,* 3, 171- 81.

Arditi, D., and Robinson, M. A. (1995). "Concurrent Delays in Construction Litigation." *Cost Engineering Journal, AACE International,* 37(7), 20-31.

Arditi, D. and Pattanakitchamroon, T. (2006). "Selecting a Delay Analysis Method in Resolving Construction Claims." *International Journal of Project Management,* 24, 145-155.

Assaf, S. A., Al-khalil, M., and Al-Hazmi, M. (1995). "Causes of Delay in Large Building Construction Projects." *Journal of Management in Engineering, ASCE,* 11(2), 45-50.

Assaf, S. A., and Al-Hejji, S. (2006). "Causes of Delay in Large Construction Projects." *International Journal of Project Management,* 24, 349-357.

Awani, Alfred O. (1983). "Project Management Techniques." *Petrocelli Books Inc.*

Baldwin, J. R., Mathei, J. M., Rothbart, H., and Harris, R. B. (1971). "Causes of Delay in the Construction Industry." *Journal of Construction Division,* ASCE, 97(2), 177-187.

Baram, GE. (1994). "Delay Analysis-Issue not for Granted." 1994 AACE Transactions, AACE, DCL.5.1-DCL.5.9.

Bordoli, D. W., and Baldwin, A. N. (1998). "A Methodology for Assessing Construction Project Delays." *Construction Management and Economics,* 16, 327-337.

Bubshait, A., and Cunningham, M. (1998) "Comparison of Delay Analysis Methodologies." *Journal of Construction Engineering and Management, ASCE,* 124(4), 315-322.

Carlos, T. (2007). "Earned Value Management - Financial analysis that goes one step beyond Budget versus Actual." www.projectperfect.com.au

Chan, D. W. M., and Kumaraswamy, M. M. (1996). "Reasons for Delay in Civil Engineering Projects-The case of Hong Kong." *Hong Kong Institution of Engineers Transactions,* 2(3), 1-8.

Chua, D. K. H., and Shen, L. J. (2005). "Key Constraints Analysis with Integrated Production Scheduler." *Journal of Construction Engineering and Management, ASCE,* 131(7), 753-764.

Davis, E. W. (1974). "Networks: Resource Allocation." *Journal of Industrial Engineering,* 6(4), 22-32.

Davis, E. W., and Patterson, J. H. (1975) "A Comparison of Heuristic and Optimum Solutions in Resource-Constrained Project Scheduling." *Management Science,* 21(8), 944-955.

Dlakwa, M. M., and Culpin, M. F. (1990). "Reasons for Overrun in Public Sector Construction Projects in Nigeria." *International Journal of Project Management,* 8 (4), 237-241.

Eldosouky, Adel I. (1996). "Principles of Construction Project Management." *Mansoura University Press*, Mansoura, Egypt.

Faridi, A. S., and El-Sayegh, S. M. (2006). "Significant Factors Causing Delay in the UAE Construction Industry." *Construction Management and Economics,* 24, 1167-1176.

Finke, M. (1997). "Contemporaneous Analysis of Excusable Delays." *Cost Engineering Journal, AACE International,* 39(12), 26-31.

Finke, M. (1999). "Window Analysis of Compensable Delays." *Journal of Construction Engineering and Management, ASCE,* 125(2), 96-100.

Fondahl, J. W. (1991). "The Development of the Construction Engineer: Past Progress and Future Problems." *Journal of Construction Engineering and Management, ASCE,* 117(3), 380-392.

Fruchtman, E. (2000). "Delay Analysis - Eliminating the Smoke and Mirrors." 2000 AACE Transactions, AACE, CDR.6.1-CDR.6.4.

Gavish, B. and Pirkul, H. (1991). "Algorithms for Multi-Resource Generalized Assignment Problem." *Management Science,* 37(6), 695-713.

Gothand, K. D., (2003). “Schedule Delay Analysis: Modified Windows Approach.” *Cost Engineering Journal, AACE International,* 45(9), 18-23.

Harris, R. A., and Scott, S. (2001). “UK Practice in Dealing with Claims for Delay.” *Engineering, Construction and Architectural Management,* 8(5-6): 317-324.

Hegazy, T. and El-Zamzamy, H. (1998) “Project Management Software that Meet the Challenge,” *Cost Engineering Journal, AACE International,* 4(5), 25- 3.

Hegazy, T. (1999). “Optimization of Resource Allocation and Levelling Using Genetic Algorithms.” *Journal of Construction Engineering and Management, ASCE,* 125(3), 167-175.

Hegazy, T., and Zhang, K. (2005). “Daily Windows Delay Analysis.” *Journal of Construction Engineering and Management, ASCE,* 131(5), 505-512.

Hegazy, T., Elbeltagi, E., and Zhang, K. (2005). “Keeping Better Site Records Using Intelligent Bar Charts.” *Journal of Construction Engineering and Management, ASCE,* 131(5), 513-521.

Hegazy, T. (2007). “EasyPlan Project Management System.” Available from: http://www.civil.uwaterloo.ca/tarek/EasyPlan.html.

Holloway, S. (2002). “Introductory Concepts in Delay Claims.” *Construction Law and Business*, 2(6), 3-6.

Ibbs, W., and Nguyen, L. D. (2007). “Schedule Analysis under the Effect of Resource Allocation.” *Journal of Construction Engineering and Management, ASCE,* 133(2), 131-138.

Iyer, K. C., and Jha, K. N. (2006). “Critical Factors Affecting Schedule Performance: Evidence from Indian Construction Projects.” *Journal of Construction Engineering and Management, ASCE,* 132(8), 871-881.

Johnson, R. (1992). “Resource Constrained Scheduling Capabilities of Commercial Project Management Software.” *Project management Journal, PMI,* XXII(4), 39-43.

Kartam, S. (1999). “Generic Methodology for Analyzing Delay Claims.” *Journal of Construction Engineering and Management, ASCE,* 125(6), 409-419.

Kassab, M., Hipel, K., and Hegazy, T. (2006). “Conflict Resolution in Construction Disputes Using the Graph Model.” *Journal of Construction Engineering and Management, ASCE,* 132(10), 1043-1052.

Kidston, P. (2005) "Controlling Construction Projects using Earned Value Analysis" New York (NY): Wiley Law Publications

Kim, K., and de la Garza, J. M. (2003). “Phantom Float.” *Journal of Construction Engineering and Management, ASCE,* 129(5), 507-517.

Kim, K., and de la Garza, J. M. (2005). "Evaluation of the Resource-Constrained Critical Path Method Algorithms." *Journal of Construction Engineering and Management, ASCE,* 131(5), 522-532.

Kim, Y., Kim, K., and Shin, D. (2005). "Delay Analysis Method Using Delay Section." *Journal of Construction Engineering and Management, ASCE,* 131(11), 1155-1164.

Lee, Hyun S., Ryu, Han G., Yu, Jung H., and Kim, Jae J. (2005). "Method for Calculating Schedule Delay Considering Productivity." *Journal of Construction Engineering and Management, ASCE,* 131(11), 1147-1154.

Levin, P. (1998). "Construction Contract Claims, Changes and Dispute Resolution." 2nd ed. New York (NY): ASCE Press.

Lo, T. Y., Fung, I. W. H., and Tung, K. C. F. (2006). "Construction Delays in Hong Kong Civil Engineering Projects." *Journal of Construction Engineering and Management, ASCE,* 132(6), 636-649.

Lovejoy, V. A. (2004). "Claims Schedule Development and Analysis: Collapsed As-built Schedule for Beginners." *Cost Engineering Journal, AACE International,* 46(1), 27-30.

Lowsley, S., and Linnett, C. (2006). "About Time: Delay Analysis in Construction." RICS Business Services Limited.

Lu, M., and Li, H. (2003). "Resource-Activity Critical-Path Method for Construction Planning." *Journal of Construction Engineering and Management, ASCE,* 129(4), 412-420.

Lucas, D. (2002). "Schedule Analyzer Pro-an Aid in the Analysis of Delay Time Impact Analysis." *Cost Engineering Journal, AACE International,* 44(8), 30-36.

Mansfield, N. R., Ugwu, O. O., and Doran, T. (1994). "Causes of Delay and Cost Overruns in Nigerian Construction Projects." *International Journal of Project Management,* 12 (4), 254-260.

Mbabazi, A., Hegazy, T. and Saccomanno, F. (2005). "Modified But-For Method for Delay Analysis." *Journal of Construction Engineering and Management, ASCE,* 131(10), 1142-1144.

McCullough, R. B. (1999). "CPM Schedules in Construction Claims from Contractors Perspective." 1999 AACE Transactions, AACE, CDR.2.1-CDR.2.4.

Mohan, S. B., and Al-Gahtani. K. S. (2006). "Concurrent Delays in Construction Litigation." *Cost Engineering Journal, AACE International,* 48(9), 12-21.

Moselhi, A. and Lorterapong, P. (1993). "Least Impact Algorithm for Resource Allocation." *Canadian Journal of Civil Engineering,* CSCE, 20(2), 180-188.

Noori, S., Bagherpour, M., & Zareei, A. (2008) "Applying Fuzzy Control Chart in Earned Value Analysis: A New Application." *World Applied Sciences*, 3 (4), 684-690.

Odusami, K.T. and Olusanya, O.O. (2000). "Client’s contribution to delays on building projects". *The Quantity Surveyor*, 30, 30–3.

Ogunlana, S. O., Promkuntong, K., and Jearkjirm, V. (1996). “Construction Delays in a Fast-Growing Economy: Comparing Thailand with Other Economies.” *International Journal of Project Management,* 14 (1), 37-45.

Okpala, F. C., and Aniekwu, A. N. (1988). “Causes of High Costs of Construction in Nigeria.” *Journal of Construction Engineering and Management, ASCE,* 114(2), 233-244.

Oliveros, A. and Fayek. Amina R. (2005). “Fuzzy Logic Approach for Activity Delay Analysis and Schedule Updating.” *Journal of Construction Engineering and Management, ASCE,* 131(1), 42-51.

Ostrowski, V., and Midgette, M. T. (2006). “Concurrent Delay Analysis in Litigation.” *Cost Engineering Journal, AACE International,* 48(1), 30-37.

Pincock, Allen & Holt. (2007). "Project Cost and Schedule Overruns". *Consultants for Mining and Financial Solutions*, 86, 1-4.

Pogorilich, D. A. (1992). “The Daily Report as a Job Management Tool.” *Cost Engineering Journal, AACE International, AACE,* 34(2), 23-25.

Sagarlata, M. A., and Brasco, C. J. (2004). “Successful Claims Resolution Through An Understanding of the Law Governing Allocation of Risk for Delay and Disruption.” CM ejournal, CMAA, Available from http://cmaanet.org/ejournal.php.

Sandlin, L. S., Sapple J. R., and Gautreaux, R. M. (2004). “Phased Root Cause Analysis: A Distinctive View on Construction Claims.” *Cost Engineering Journal, AACE International, AACE,* 46(6), 16-20.

Schumacher, Lee, PE. (1995). “Quantifying and Apportioning Delay on Construction Projects.” *Cost Engineering Journal, AACE International,* 37(2), 11-13.

SCL – Society of Construction Law. (2002). “Delay and Disruption Protocol.” Available from: www.eotprotocol.com.

Scott, S. (1990). “Keeping Better Site Records.” *International Journal of Project Management,* 8(4), 243-249.

Semple, C., Hartman, F. T., and Jergeas, G. (1994). “Construction Claims and Disputes: Causes and Cost/Time Overruns.” *Journal of Construction Engineering and Management, ASCE,* 120(4), 785-795.

Shi, J., Cheung, S., and Arditi. D (2001). "Construction Delay Computation Method." *Journal of Construction Engineering and Management, ASCE,* 127(1), 60-65.

Stumpf, George R. (2000). "Schedule Delay Analysis." *Cost Engineering Journal, AACE International,* 42(7), 32-43.

Talbot, F. and Patterson, J. (Dec. 1979). "Optimal Methods for Scheduling Projects under Resource Constrains." *Project Management Quarterly,* 26-33.

Wickwire, J., Driscoll, T., and Hurlbut, S. (1991). "Construction, Liability, and Claims." New York (NY): Wiley Law Publications.

Wiest, D. (1964). "Some Properties of Schedules for Large Projects with Limited Resource." *Operations Research,* 12, 395-416.

Wiest, J. D. (1967). "A Heuristic Model for Scheduling Large Projects with Limited Resources." *Management Science,* 13(6), B359-B377.

Willis, R. J. (1985). "Critical Path Analysis and Resource Constrained Project Scheduling-Theory and Practice." *European Journal of Operational Research*, 21, 149-155.

World Bank (1990). "Annual Review of Project Performance Results." *World Bank.*

Zack, J. G., Jr. (1999). "Pacing Delays - the Practical Effect." 1999 AACE Transactions, AACE, CDR.1.1-CDR.1.6.

Zack, Jr. J. (2001). "But-for Schedule- Analysis and Defense." *Cost Engineering Journal, AACE International,* 43(8), 13-17.