Development of the Change Management Method for Small and Medium Construction Projects

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ABSTRACT

Development of the Change Management Method for Small and Medium Construction Projects

Jianjun Chen

Changes often happen during the process of the construction project. Main changes could be absence of workers, breakdown of machines, and adverse weather. These changes can impact the project at all kinds of levels. Meanwhile, the project manager needs to make appropriate decisions to minimize the impact of changes. Typical decisions would be re-allocation of resources and re-arrangement of the tasks. However, how to make appropriate decisions for change management is not easy to answer.

In this context, we propose the Decision-based Change Management (DCM) approach as a change management tool to deal with the change scenarios in construction engineering. The DCM approach is intended to help the project managers (especially new project management practitioners) to assess the level of change impacts and select an appropriate change option for project revision. The DCM approach in this thesis is applied to the cases of sub-project of pipeline installation in the Wastewater Treatment Plant Project, which addresses how to find an appropriate change option to deal with the change scenarios concerning absence of the workers for a period of time. In specific, three change options are categorized for the DCM approach based on two types of schedule revision activities (Patch Actions & Repair Actions). When a change scenario occurs, three key change impact factors are used to estimate the level of change impact for this change scenario during the implement procedure of the DCM approach. Then, a proper change option can be chosen to revise the schedule based on the estimated level of change impact.

At last, we propose evaluating two criteria (project delay and re-organization efforts) to examine the quality of the revised schedules. Experimental results of the cases indicate validity of the DCM approach to tackle most of the change scenarios concerning absence of the workers in the construction project.

Key-words: Engineering Change Management(ECM); Project Time Management; The Schedule Control; The Decision-based Change Management approach (DCM); The Workers Allocation Schedule; Critical Path Method (CPM); Project Evaluation & Review Technique (PERT); Project Delay &Re-organization Effort; Change Scenario; Change Action; Change Option; Design Change Propagation.

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Chapter 1

Introduction

1.1. Background

This research is about change management for a construction project. The construction project in this study is based on the phase 2 construction of Langdong Wastewater Treatment Plant of Nanning. The purpose of this project is to collect wastewater from the downtown area of Nanning to the wastewater treatment plant. The capacity of the plant is to treat 100,000 cube meters of wastewater per day, and it is going to serve 343,000 residents in the area of 30.3 square kilometres. The treated water would be discharged to Nanhu Lake and Yongjiang River. The investment of the project is about 26 millions U.S. dollars. It began on October 2005 and lasted for about 2 years (Nanning Jianning Water Group Co 2010).

To keep the scope of the research manageable, this research will only focus on one sub-project for the study. The sub-project of interest is the pipeline installation. This sub-project includes the installation of the main wastewater inlet pipes, the outlet pipes within and across the construction area. The specific requirements of this sub-project include pipeline burying, the use of large and heavy steel pipes, high quality welding, and corrosion prevention treatments.

In general, changes often take place during the project's period, and typical changes could be absence of workers, unexpected machine downtimes, and poor weather. These changes can impact the project at various degrees. At the same time, the project manager is required to make proper decisions to minimize the impact of changes, such as re-allocating resources and re-arranging the tasks. Yet, how to make proper decisions for change management is not trivial, and this research is intended to address this issue.

1.2. Literature Review

1.2.1. Project Time Management

Project time management is a systematic management approach to monitor and control the project in rational process. It analyzes the activities of the project and their interrelationship. It evaluates necessary duration of each activity and also arranges appropriate start and end time within the allowable float time of the project (Schwalbe 2007). Target of project time management is to assure completion of the project on planning, to appropriately allocate all kinds of resources, and acquire higher efficiency (Kerzner 2009).

In general, the implementation process in project time management has five steps (Schwalbe 2007, Kerzner 2009, and The Project Management Institute 2000). First, the project is decomposed to define its activities (or tasks), which are implementable and assured to complete the designated assignments. Second, the tasks should be logically sequenced. Tasks should be rationally sequenced to satisfy requirements for structuring the future process schedule. In the views of the requirement of the project and tasks lists, interrelationship and sequence between the tasks should be found. Third, tasks duration should be estimated. Elements including scope of the project and amounts of the resources are considered for estimation of total tasks duration. To evaluate each task's duration, changes should be considered as an important impact condition. Fourth, the project schedule will be constructed. Constructing the project schedule is a reciprocate process to define the specific start time and end time of the project tasks. To construct this schedule, all kinds of potential parameters related with the project duration should be considered. Each task's duration should be calculated in order to build an initial time network chart. Then, tasks duration will be adjusted until an optimal task schedule is formed. Finally, the schedule control will be implemented in the process of the project. The process of the schedule control mainly monitors the implementation of the project process, timely finds and modifies the delay and error of the project. The project managers need to address those change impact factors by observing the process changes. Then, they take actual actions to deal with the schedule changes.

The implementation of the schedule control is a critical phase in project time management of the construction project to cope with the changes of the project. The construction changes directly impact the whole project process and schedule. During this phase of the project, all kinds of changes often happen. The project managers require monitoring and timely inspecting the implementation process and schedule of the project. To deal with the construction changes, the project managers should adopt the proper schedule control strategies.

The traditional process of implementing the schedule control approach has the following phases (Schwalbe 2007, The Project Management Institute 2000). In the first phase, the actual implementation condition of the schedule is monitored and checked. These implementation conditions are major information resources to feedback the actual implementation of the schedule and the database to further analyze and adjust the schedule. In the second phase, the actual schedule data should be categorized and processed. To compare the actual schedule with the planned one, the collected actual schedule data should be categorized and processed to formalize such data that can compare with the data of the planned schedule. For example, through categorizing, summarizing, and analyzing the data about the actual completion workload, the project manager knows the cumulated workloads of completion, percentage of the workloads of the completion to total workloads in certain period of the project. In the third phase, the actual schedule should be compared and analyzed with the planned one. Through comparing and analyzing the actual schedule with the planned one, the discrepancies between the actual implementation condition and the planned target are found. Therefore, the project managers will know whether the actual schedule is earlier, delayed or on planning.

In the construction projects, some comparison methods between the actual schedule and the planned one have been used for the schedule control. Trauner et al. (2009) used the comparison approach of Gantt chart to monitor the construction delay. This approach is to draw directly a new horizon line that represents the collected actual data about the schedule implementation under the old horizon line of the planned schedule so as to compare these two schedules. Cheng et al. (2010) and Blyth & Kaka (2006) applied the comparison approach of sigmoid curve in their papers. In such a diagram that shows X-coordinate as time and Y-coordinate as cumulated completion of the workloads, this approach is to draw a diagram of sigmoid curve about the cumulated completion of the workloads based on the planned schedule. Then, another sigmoid curve about actual cumulated completion of the workloads is drawn in the same coordinate system to compare with the planned schedule. Barraza et al. (2000) implement the comparison approach of "Banana" curves (SS-curves) to monitor the project performance. This approach is to draw a sigmoid curve based on the earliest start time that is called ES curve and then draw another sigmoid curve based on the latest start time that is called LS curve in the same coordinate system. Therefore, two curves are organized as the closed curve with the same start point and end point. The rational and scientific schedule should be found within the area of "banana" curve. Ahsan and Gunawan (2010) used the comparison approach of Tabulation to compare the actual duration with the planned one.

1.2.2. Change Management in Project Time Management

Engineering change management (ECM) is a systematic change management technique that addresses how to apply and follow the engineering changes effectively (Li &Chen 2009). During the period of the construction project, an unpredictable and undesirable change (Sutton 2010) often happens. Keeping a project process on planning is based on many interrelated external factors, such as workers, machines, materials, technique, investment, weather, law and social environment. Any change of an external factor can result in changes of other parts of the project. Li (2009) and Li &Chen (2009) discussed the changes in the engineering that cause large amounts of the unacceptable and unwanted change propagation. The change propagation easily interrupts the initial project plan and continuously switches the interdependencies of those external factors, which leads to the complexity in the project. For instance, the project schedule needs to be revised and the resources require re-allocation. Because the impact of the unexpected and extra change in the project always propagates across and within the domains of labour resources, machines, materials, technique, investment, and social issue, it is a big challenge for the project managers in managing the project.

To analyze the complexity of the construction system caused by the changes of the external factors, some critical impact factors related to the complexity of the construction project are discussed in several researches. Austin et al. (2002) said that manipulating the complexity of the project should focus on the project process. Krackhardt & Carley (1998) and Carley & Krackhardt (1999) analyze the complexity of workers and machines resources. Love et al. (1999) discussed the impact between change of construction cost and the complexity level of the project. Changes in the construction costs and expenses may lead to re-arrangement of the existing tasks and re-allocation of the existing resources, which cause complexity in the initial project schedule. Suh (2005) considered that reducing the amounts of engineering requirements could decrease the complexity of a project system. Rojas et al. (2003) described that adverse weather condition leads to the complexity of the project because it may decrease the productivity of construction workers, leading to often re-allocate the project resources.

In order to effectively minimize the impacts of the complexity of the project caused by change propagation, engineering change management (ECM) is developed to properly manage and control engineering changes (ECs) (Li & Chen 2009). Lee et al. (2006) concluded the major root causes of engineering changes as follows: unintended error, lack of communication and negotiation, propagation change, cost savings, easy to manufacturing, and product function modification. However, not all changes are harmful and some of them are beneficial. We should not wish to simply delete the changes but try to manage them efficiently for reducing the cost and time in product development (Clark & Fujimoto 1991). Further improvements for ECM application are implemented by reducing inputs of labour resources, changing resources allocation, decreasing the construction process, and reducing side effects to the minimum level.

Huang et al. (2001) (2003) also summarized the characteristics and problems in the engineering change process. First, complicated process leads to additional paperwork, complicated pass process, and spend more time to learn. Second, the complexity of the product causes uncertainty of downstream products or parts, or causes tasks mapping. Third, temporary actions lead to capability restriction of single engineer, and loss of the critical time. Fourth, dealing with separated conditions requires multi-functional teamwork, alternative decisions. Fifth, knowledge improvement to deal with the changes should apply, modify and fully utilize information for higher-level management needs.

In order to deal with the problems of engineering change, Huang et al. (2001) (2003) suggested that managing the changes can follow four phases: first, a change requirement is formalized. Second, this change requirement should be measured. Third, change strategies should be adopted for the related persons. Fourth, a change strategy for management should be saved and measured.

1.3. Research Motivation

Changes often take place during the project's period in an unexpected manner (such as adverse weather, absence of workers due to illness, etc). The difficulty of managing such changes can be attributed to the complex interdependency among different entities in a project. When changes take place in a project, they can intractably propagate to other parts of the project, leading to some undesirable impact such as long duration delay and over budget.

In this context, the project manager often plays a significant role. It is expected that the project manager should have an overall picture of the project, keeping track of the project duration, allocation of resources and budget. When changes take place, the project manger is required to react promptly and effectively so that the impact of changes can be minimized. Traditionally, such ability is obtained by experience. Roughly speaking, the manager's experience can be understood as their intrinsic understanding of the complex relationships of the project. For instance, the manager should have good understanding of the influence of the workers in the project if they are absent at certain times. The influence of the workers in this context can be estimated by checking the workers' relationships with the project's tasks and the importance of these tasks.

In practice, the experience of the project managers is probably the most valuable asset for change management. Yet, making prompt and effective decisions for change management is still difficult and challenging. Firstly, experience is gained based on routine practice. If the project has new contents and contexts, the project manager will feel difficult to make proper decisions for change management. Secondly, an engineering project becomes more complex than ever in view of increasing number of workers, the diversity of knowledge, the complexity of engineering tasks and etc. Thus, it is motivated to investigate and develop a systematic approach for coping with changes in project management.

1.4. Thesis Objective and Organization

The primary goal of this research is to systematically cope with changes during the project's period so that the impact from changes can be properly controlled and minimized. To achieve this goal, the method of approach is to capture the dependency relationships of the project and to investigate the key factors pertaining to change management. Since the topic of change management for construction projects can involve numerous difficult issues, the scope of the thesis is confined to the project scheduling issue of the wastewater construction project. Furthermore, we will only investigate one change type: unexpected absence of workers.

The rest of the thesis is organized as follows. Chapter 2 provides more project information about the wastewater construction project in order to set up the ground for the systematic change management approach. Chapter 3 discusses the change management concepts in the context of project scheduling. Chapter 4 proposes the Decision-based Change Management approach that is developed to address the changes due to unexpected absence of the workers. Chapter 5 demonstrates the Decision-based Change Management approach applied in the construction project of wastewater treatment plant. Chapter 6 provides the conclusions of the thesis and future work.

Chapter 2

Project Planning and Scheduling for Change Management

The construction project of wastewater treatment plant consists of several sub-projects such as installation of mechanical and electrical equipments, and these sub-projects are illustrated in Figure 2-1. To keep the scope of this research manageable, this thesis will focus on the sub-project of pipelines installation. In this chapter, the management of the pipelines installation will cover the issues of project planning and scheduling. The purpose of this chapter is to provide the specific context of the construction project that allows us to investigate the systematic change management approach.

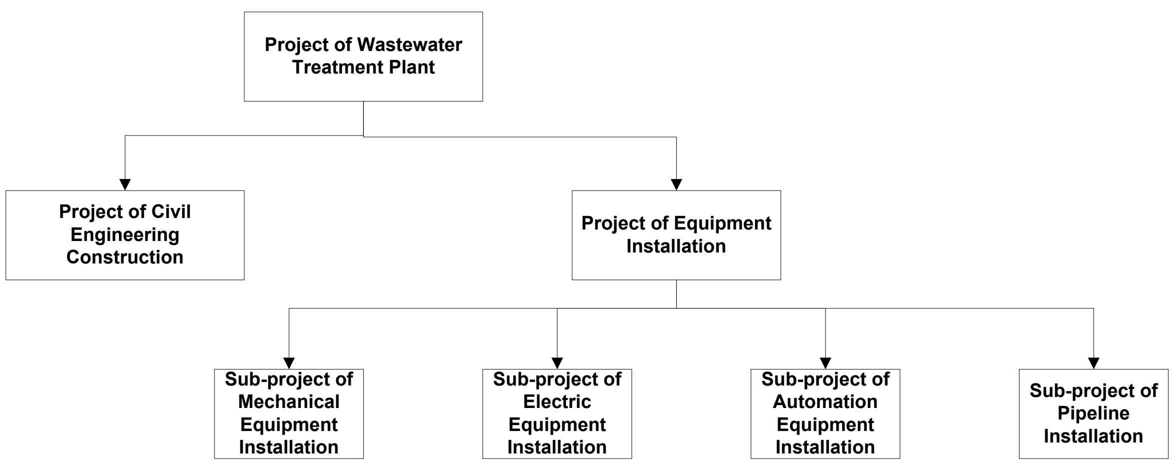

Figure 2-1: sub-projects of the wastewater treatment plant project

2.1. Project Planning

The major duty of the pipeline installation sub-project is to install the main wastewater inlet pipes and the outlet pipes within the construction area and across the workshop buildings according to all kinds of technical requirements. The key technical requirements include burying large-size and heavy pipelines, high quality welding and corrosion prevention. Technically, the pipeline installation procedures are as follows: at the beginning of the project, all kinds of raw materials, including different sizes of the pipes, are transported into three construction sites. Then, piping prefabrication and pipeline anti-corrosion are made. After the pipe ditch is excavated, the supports and racks for piping are made. Then, the pipes are laid down into the pipe ditches. When the work of main pipes installation is done, other piping accessories, including valves, are installed to connect the pipes. Such similar technical installation procedures occur in the three construction sites. After all main piping works complete, the pipeline wash and anti-corrosion painting are required. Finally, pipeline water pressure tests are needed for final inspection. The detail tasks are listed in table 2-1.

Based on the planning from the project manager, the pipeline installation sub-project requires about 72 days to complete and is divided into three phases: start time, peak time and end time. The start time ranges from Day 1 to Day 9, covering the work of task 1 and 2. The peak time ranges from Day 10 and Day 56, covering the work from task 2 until task 13. The end time ranges from Day 57 to Day 72, covering the work of task 14 and 15. The task schedule of the project is then derived and shown in Figure 2-2.

Task Code	**Task Name**	**Duration (days)**
T1	Transporting the pipes into the sites.	5
T2	Making piping prefabrication and anti-corrosion in No. 1 installation site.	6
T3	Excavating pipe ditch and making pipe supports in No.1 installation site.	21
T4	Laying down pipes under the ground in No. 1 installation site.	12
T5	Connecting pipe with pipe accessories in No. 1installation site.	10
T6	Making piping prefabrication and anti-corrosion in No. 2 installation site.	7
T7	Excavating pipe ditch and making supports in No. 2 installation site.	12
T8	Laying down pipes under the ground in No. 2 installation site.	8
T9	Connecting pipe with accessories in No. 2 installation site.	12
T10	Making piping prefabrication and anti-corrosion in No. 3 installation site.	9
T11	Excavating pipe ditch and making supports in No. 3 installation site.	16
T12	Laying down pipes under the ground in No. 3 installation site.	14
T13	Connecting pipe with accessories in No. 3 installation site.	12
T14	Making pipeline wash clean and anti-corrosion.	4
T15	Implementing pipeline water pressure test.	12

Table 2-1: list of tasks of pipeline installation sub-project

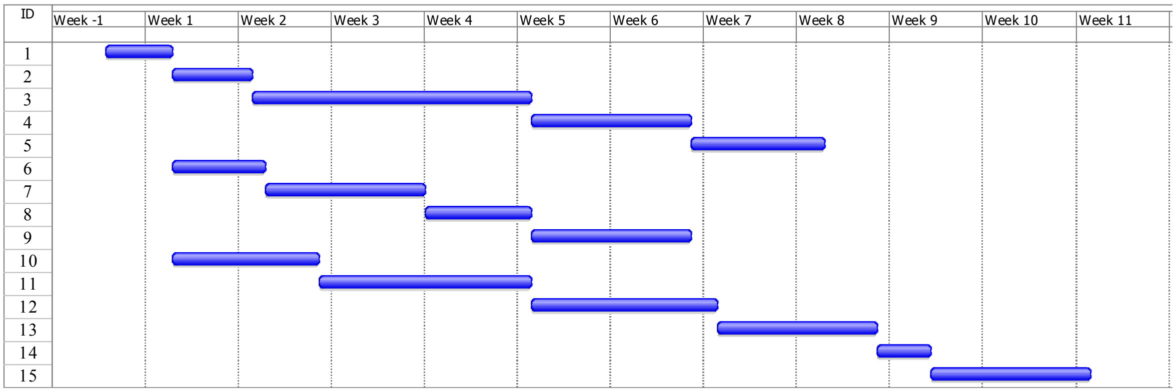

Figure 2-2: tasks schedule of sub-project of pipeline installation

Seven technical teams with 45 technical workers (bench worker, riveter, plumber, welder, gas welder, lifting worker, and painter) participate into this project, among which the number of plumbers is the largest. In order to effectively reduce the labour cost and rationally allocate the existing worker resource, fewer workers are assigned to working positions at the start time of the project. Then, more workers who operate at full capacity are assigned at the peak time of the project because of more working positions requirements. At the end time of the process, the number of workers will be gradually reduced to avoid dismiss of too much workers immediately. Such actions lead to the different workload requirements from workers in the three project phases. The number of workers allocated in different days is shown in Figure 2-3. It can be seen that less replacement workers are found while more workers are required during the peak time phase.

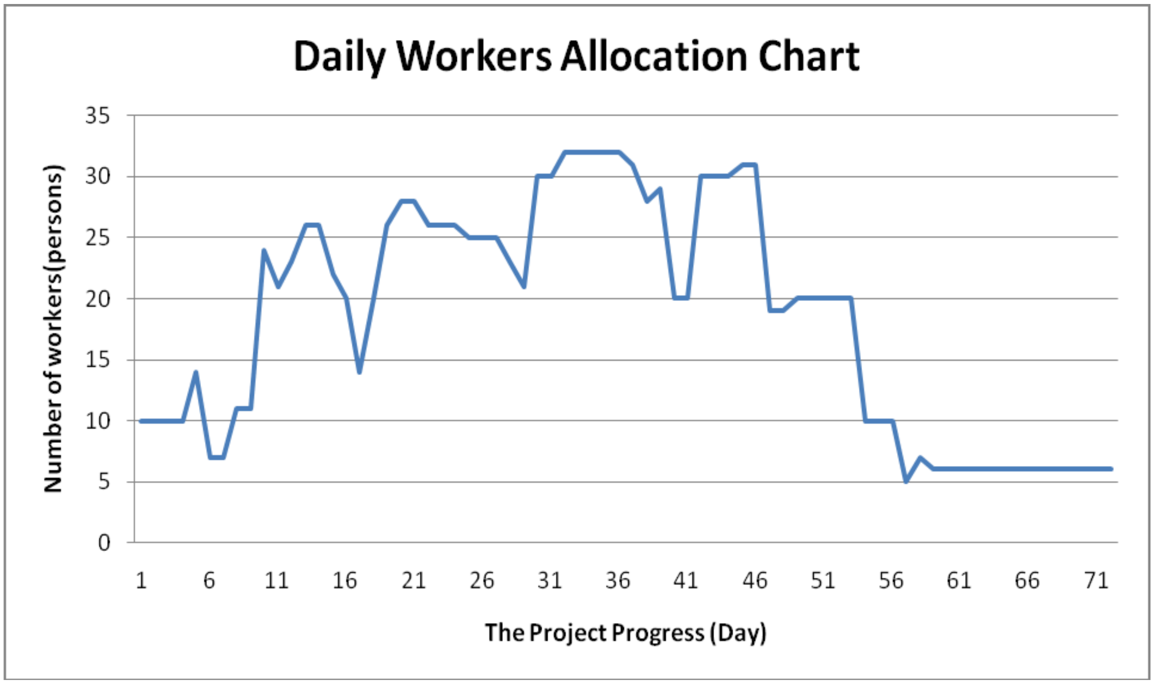

Figure 2-3: distribution chart of labour resource allocation

2.2. Project Scheduling

The task schedule shown in Figure 2-2 captures the information of start and completion times of each task. To address the change propagation effect on the project's schedule (e.g., delay of one task causing the delay of another downstream task), we need other types of project schedules. In this research, we consider two more types of schedules: PERT chart and the worker allocation schedule.

Project Evaluation and Review Technique (PERT) is a project management tool used to analyze, estimate and schedule different kinds of tasks, system and processes (Schwalbe 2007, Kerzner 2009, The Project Management Institute 2000, and Modell 1996). Figure

2-4 shows the PERT chart of the pipeline construction sub-project. In the PERT chart, the arrows represent the project tasks, and the circles denote to the milestones of the project. As indicated in Figure 2-4, Tasks 2-3-4-5, Tasks 6-7-8-9 and Tasks 10-11-12-13 are identified as three different paths of the project tasks.

Based on the PERT chart, the critical path method (CPM) can be applied to estimate and manage the project's duration (Schwalbe 2007, Kerzner 2009, The Project Management Institute 2000, and Modell 1996). Particularly, the critical path in the CPM is the longest route in the PERT chart. In Figure 2-4, the tasks 1, 10, 11, 12, 13, 14, and 15 form the critical path, which leads to 72 days of the project duration. To indicate, the blocks of the tasks on this critical path are highlighted with bold borders in Figure 2-4.

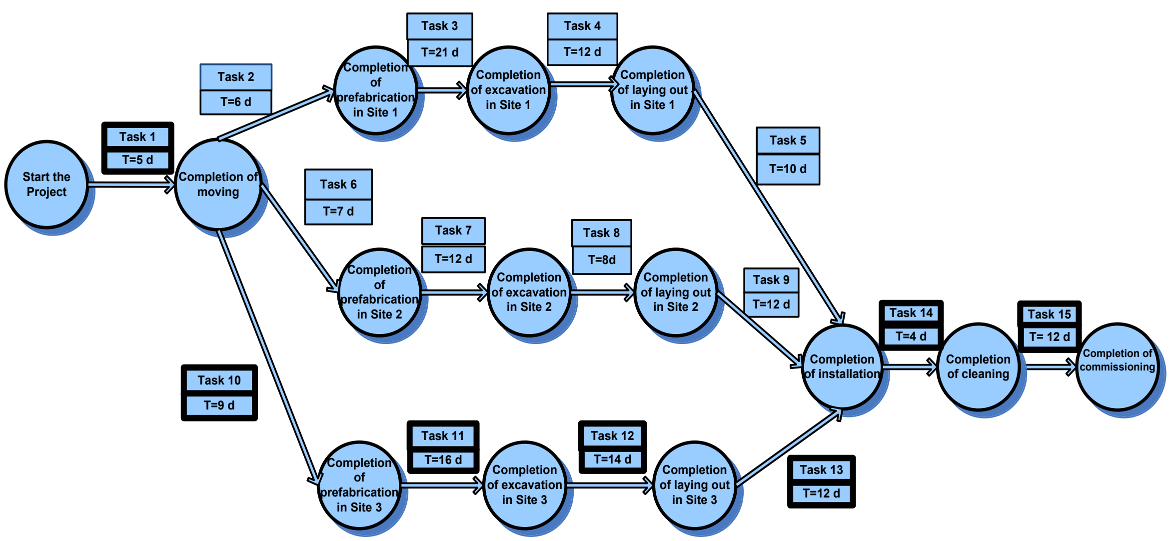

Figure 2-4: PERT chart showing the tasks in the critical path

In view of change management, the PERT chart and the CPM convey some important information to analyze the project's duration. Particularly, if one project task is delayed for some reason, the PERT chart and the CPM can help to analyze whether such a task delay will cause the delay of the entire project. In this type of analysis, we need to identify whether the delayed tasks are critical or non-critical in the context of the CPM. In our change management approach, we apply the PERT chart and the CPM to check whether the tasks are critical and non-critical for assessing the change impact.

Besides the PERT chart, the worker allocation schedule is also used for change management (Liu 2003). Compared with the task schedule in Figure 2-2 and the PERT chart in Figure 2-4, the worker allocation schedule includes the information of workers that we can use it to handle the changes pertaining to the unexpected absence of workers. Figure 2-5 shows the partial worker allocation schedule of the pipeline installation sub-project. On this schedule format, the top row lists the days of the project, and the left column displays the workers involved in the project. Then, each schedule entry indicates the responsible task of the worker on the specific day. For instance, Figure 2-5 shows that plumber A is responsible for task 1 starting from Day 1 to Day 5.

In the context of change management, it is considered that the worker allocation schedule conveys the comprehensive information for re-allocating workers subject to unexpected absence of the workers. This schedule format is used extensively in this research. Then, the change management problem in this research can be considered as follows. Given the worker allocation schedule as the original project plan, the change management problem is to re-allocate the existing workers via the revision of the worker allocation schedule so that the impact due to the unexpected absence of workers can be properly controlled and minimized. The next chapter will introduce more change management concepts for the development of the systematic change management method.

Worker	Duration / Worker	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12	Day 13	Day 14	Day 15	Day 16	Day 17	Day 18	Day 19	Day 20	Day 21	Day 22	Day 23	Day 24	Day 25	Day 26	Day 27	Day 28	Day 29	Day 30	Day 31	Day 32	Day 33	Day 34	Day 35	Day 36
W1	Benchworker A																		3	3	3	3	3	3	3	11	11	11									
W2	Benchworker B																				3	3	3	3	3								7	7	7	7	7
W3	Benchworker C																														5	5	5	5	5	5	5
W4	Riveter A						10	10	10	10	10	10	10	10	10				11	11	11	11											7	7	7	7	7
W5	Riveter B						10	10	10	10	10	10	10	10	10				11	11	11	11															
W6	Riveter C					2	2	2	2	2	10	10	10	10	10																5	5	5	5	5	5	5
W7	Riveter D					2	2	2	2		6	6	6	6	6																5	5	5	5	5	5	5
W8	Riveter E					2	2	2	2	2	6	6	6	6	6	6	6		3	3	3	3	3	3	3												
W9	Riveter F					2	2	2	2	2	6	6	6	6	6	6	6				3	3	3	3	3												
W10	Plumber A	1	1	1	1	1					3	3	3	3	3	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12
W11	Plumber B	1	1	1	1	1					3	3	3	3	3	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12
W12	Plumber C	1	1	1	1	1					3	3	3	3	3	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12
W13	Plumber D	1	1	1	1	1					3	3	3	3	3	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12
W14	Plumber E	1	1	1	1	1					3	3	3	3	3	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12
W15	Plumber F										3	3	3	3	3	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12
W16	Plumber G										3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	7	7	7	7	12	12	12	12	12	12
W17	Plumber H										3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	7	7	7	7	7	7	7	7	7	7
W18	Plumber I										3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	7	7	7	7	7	7	7	7	7	7
W19	Plumber J											3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	7	7	7	7	7	7	7
W20	Plumber K											3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	7	7	7	7	7	7
W21	Plumber L											3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	7	7	7	7	7	7
W22	Plumber M															11				4	4	4	4	4	4	4	4	4	4	4	4	7	7	7	7	7	7
W23	Plumber N															11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	7	7	7	7	7	7
W24	Plumber O															11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	7	7	7	7	7	7
W25	Welder A						2	2	2	2	2	6	6	6	6	6										11	11	11	11								
W26	Welder B								2					6												11	11	11	11								
W27	Welder C									10	10	10	10	10	10				3	3	3	3	3	3	3	11	11	11									
W28	Welder D									10	10	10	10																		7	7	7	7	7	7	7
W29	Welder E																														5	5	5	5	5	5	5
W30	Welder F																														5	5	5	5	5	5	5
W31	Welder G																														5	5	5	5	5	5	5
W32	Gas welder A								10	10	2				6																7	7	7	7	7	7	7

Figure 2-5: part of worker allocation schedule of pipeline installation sub-project

Chapter 3

The Decision-based Change Management Approach

3.1. Premise

Given the worker allocation schedule as the primary schedule of the construction project, when changes take place, it is intended to investigate how to revise the construction project systematically. In this context, the specific research topic focuses on the early-phase change decisions. For instance, during the project's period, when a worker reports for his absence for a specific period of time, the project managers require to decide whether they should revise the schedule radically or just simply ask the remaining workers to cover the work in order to minimize the change impact.

When the project managers face a change scenario (e.g., knowing a worker to be absent for a specific time), they need to assess the impact of changes in view of the importance of the absent worker in the project and the length of the absence. For instance, if the absent worker is insignificant and he/she would only be absent for one day, the project managers would probably just ask the remaining workers to adapt the changes. In contrast, if the absent worker plays a key role in the project and he/she would be absent for many days, the project managers would likely consider a major revision of the schedule to re-allocate the remaining workers to minimize the change impact.

In summary, given a change scenario, the project managers need to assess the change impact of the change scenario. Accordingly, they need to decide whether they should revise the schedule radically or just simply ask the remaining workers to cover the work. Such decision is often required for the schedule revision and the implementation of the revised schedule. If the details of the project are complex, assessing the change impact is not a trivial task. Poor decisions in this context of change management can lead to unexpected outcomes such as project delay. Then, the purpose of the Decision-based Change Management approach is to handle this decision-making scenario systematically for better decision support in change management.

3.2. Assessment of Change Impact

Given a change scenario indicating a worker to be absent for a specified period, three factors are used to assess the impact due to this change scenario. The first factor is about task criticality, which determines whether the tasks to be done by the absent worker are critical or not. When a change scenario is known, we can check which tasks are supposed to be accomplished by the absent worker via the worker allocation schedule. Let us denote such tasks as outstanding tasks. For instance, suppose that plumber E is absent from Day 10 to Day 14. Then, the outstanding task due to absence of plumber E is task 3 from Day 10 to Day 14 by checking Figure 2-5 of the worker allocation schedule.

In the above context, the criticality of outstanding tasks is determined using the critical path on the PERT chart. As a recall, the critical path on the PERT chart discussed in Section 2-2 basically defines the project's duration. Any delay of the tasks on the critical path would lead the delay of the project's duration. In this sense, if the change scenario causes the impact on the tasks on the critical path (namely, critical tasks), we consider that the corresponding change scenario would have high change impact.

The second factor for assessing change impact is about the proportion of affected workloads. In this context, workloads are referred to any non-zero entries on the worker allocation schedule, and each of these entries represents one worker working on a single day (i.e., one workload). Given the worker allocation schedule, we can determine total workloads of the project. At the same time, a change scenario defines the workloads that are left by the absent worker. For example, the change scenario in the case study of chapter 5 indicates that there are 28 workloads of outstanding tasks left by the absent worker, which are highlighted in the blocks with *bolder borders & light shaded areas* in Figure 5-1. We termed these workloads as the affected workloads. The impact due to affected workloads is relevant to the total workloads of the project. In general, if the ratio of affected workloads to total workloads is high, we can state that the corresponding change scenario would have high change impact.

The third factor is about worker importance. Naturally, if the worker has some high skills that other workers do not have, this worker is important due to the difficulty of finding a replacement worker. To confine the scope of the research, it is proposed that the criticality of a worker is related to the number of replacement workers for a specific task. For instance, welder A and B in the welder team have high skills of welding while welder C, D, E, F, and G are general welders. If welder A is absent for 1 day, only welder B can replace him. While welder G is absent for 1 day, the replacement welder A, B, C, D, E, and F can be found. It means that absence of welder A is easier to delay duration of the outstanding tasks than welder G does because less workers can replace welder A. Therefore, welder A is considered as more important than welder G. For another instance, since the plumber team has more team members than the gas welder team does, it is easier to find more replacement workers from the plumber team than the gas welder team for a specific task. This change about absence of the worker is easier to be treated by the manager if more replacements exist. Therefore, we consider that a gas welder is more important than a plumber at the time of change.

When applying to a change scenario, the criticality of the absent worker is assessed by calculating the maximum additional workloads that have to be assigned to a remaining worker， “maximum additional workload” for short. If the absent worker is important, there would be less replacement workers. Consequently, the affected workloads need to be shared by less remaining workers. For instance, we roughly discuss that welder A is more important than welder G in the above paragraph due to less replacement workers can be found for welder A. That is, only welder B can replace him if welder A is absent and six replacement welders can be found when welder G is absent. Then, assume welder A and welder G both are absent for 1 day, we know that maximum additional workload in view of absence of welder A is 1 workload while maximum additional workload in view of absence of welder G is 1/6 workload. This result indicates that maximum additional workload is higher if the absent worker has less replacement workers. Fewer replacements are easier to delay the affected task duration. Therefore, welder A is considered as more important than welder G.

Another instance indicates that, given plumber M and gas welder D both be absent for 1 day, we can find 14 replacement plumbers from the plumber team but only 3 replacement gas welders from the gas welder team, maximum additional workload in view of absence of plumber M is 1/14 workloads comparing with the one in view of absence of gas welder D is 1/3 workloads. The result indicates that maximum additional workload is higher if the absent worker has less replacement workers. Fewer replacements are easier to delay the affected task duration. Therefore, gas welder D is considered as more important than plumber M under the condition of changes. Apparently, when maximum additional workload is higher, we can consider that the corresponding change scenario would have high change impact.

The implementation details of these factors for assessing the change impact will be discussed in section 4.3.

3.3. Definition of Change Options

As discussed earlier, decision-making in change management is the major focus in this work. The impact from a change scenario is caused by intractable change propagation through the interdependent relationships of project elements (e.g., precedence relationships of tasks, allocation of workers to tasks, etc). If there are no decisions available for project managers to address a change scenario, the corresponding change propagation can be viewed as a single and unavoidable path that the project managers cannot alter. At this point, the research issue is about what decision options are available to address a change scenario.

Before defining the change options, two types of actions are firstly defined for the revision of the worker allocation schedule: patch actions and repair actions. Patch actions are referred to the reactive revisions that minimize the disturbance of remaining workers. In specific, the patch actions allow the remaining workers to work on the affected workloads only after the current tasks of these workers at hand are completed. For example, 14 replacement plumbers in the plumber team can be found for the absent plumber H to work on the affected task 3 in Day 16 by checking the worker allocation schedule shown in figure 2-5. In order to minimize the disturbance to remaining workers, patch actions permit 5 replacement plumbers (G, I, J, K, and L) to work on affected workloads of task 3 only after these workers' current task 3 assignments are completed.

In contrast, repair actions are such proactive revisions via more radical modifications of the schedule to tackle high change impact. In specific, the repair actions allow the revised schedule to interrupt the current tasks of remaining workers in order to work on affected workloads. For instance, given plumber E is absent in Day 20. By checking the worker allocation schedule of figure 2-5, 14 replacement plumbers can be found in the plumber team to work on the outstanding task 11. When repair actions are taken, 7 plumbers (G, H, I, J, K, L, and M) are permitted to suspend their current tasks so as to work on affected workloads. Comparatively, repair actions are more flexible than patch actions to revise the schedule given a change scenario.

Based on the above two types of revision actions, three change options are defined in this research, and these change options are listed as follows.

- Option A: allow only patch actions to revise the worker allocation schedule.
- Option B: allow only one worker to take repair actions.
- Option C: allow multiple workers to take repair actions.

Since Option A only allows patch actions, it represents the latest flexibility for schedule revision. This option is suitable when the change impact is assessed as low. Then, Option A can lead to the least disturbance to the remaining workers. In contrast, since Option C allows repair actions on multiple workers, it represents the most flexible option to revise the schedule. The drawback of this option is that it may cause some unnecessary disturbance to the remaining workers. Option B in this case lies between

Option A and Option C in view of revision flexibility and disturbance to remaining workers.

After the definition of three change options, the research issue is how to select the proper option to revise the schedule when a change scenario takes place. The method of approach is to map the assessment of change impact to the choice of change options. The methodical details are provided in Chapter 4.

3.4. Evaluation of Revised Schedules

Suppose that a change option is selected. The project managers can revise the worker allocation schedule accordingly. In this work, it is assumed that one selected change option would lead to one revised schedule. The details of the revision process rely on the project manager's knowledge, and they will be discussed in Chapter 4 and 5. As three change options are available for a change scenario, there could be three revised schedules in principle. Then, the question is which schedule is the best. In this section, we will discuss the evaluation of revised schedules to justify the selection of change options.

To examine the quality of the revised schedules, two criteria are evaluated, namely, project delay and re-organization effort. Apparently, meeting the deadline is one important requirement that the project managers need to achieve. Any project delay can imply increased cost and customer dissatisfaction. In this work, the project delay is initially triggered by the change scenario that directly causes the delay of some involved tasks. These delayed tasks cause the delay of other tasks, leading to the delay of the entire project. Given limited resources (e.g., the project managers cannot hire a new worker to replace the absent worker), sometimes project delay is unavoidable. Then, we want to examine which revised schedules will lead to the minimum of project delay. In this context, project delay is defined as the number of extended days pertaining to the final task(s) of the project.

Besides the project delay, the project managers are also intended to minimize the modifications of the original schedule. Given a complex project, the original schedule is a result of deliberate efforts from many experts, including engineers, financial controllers and administrators. Modifications of the original schedule can incur different levels of re-organization. Such re-organization activities may include notification of workers for changing their original tasks and intensive communications to re-structure the entire flow of project tasks. To minimize the risk of changing errors and miscommunications, the project managers have a strong motive to minimize the re-organization effort to address a change scenario.

In this research, the re-organization effort is determined by the number of modified entries in the revised worker allocation schedule. There are four categories of modification implemented in the worker allocation schedule. The first category of modification refers to a task concerning a worker on one day is cancelled. This category of modification is associated with the earlier changes which affect the project schedule.

The modified entries of this category of modification are represented as a single task number in a block of the worker allocation schedule with *bold* borders and *light* shaded areas. The second category of modification refers to interrupted modification that switches a task from a worker on one day as this worker requires interrupting the current task's assignments to work on another task. The modified entries of this category of modification are shown as two different numbers (i.e., the first number is referred to a new assigned task and the second number with strikethrough means the initial task) in a block with *dark* shaded areas. The third category of modification represents continuous modification that the worker has to finish one task before working on another one. The modified entries of this category of modification are two different numbers (i.e., the first number represents a new assigned task and the second number with strikethrough means the initial task) in a block with *light* shaded areas. The fourth category of modification is related with one day of the extra work after a worker completed initial assigned task. The modified entries of this category of modification are a single task number in a block of the schedule with *light* shaded areas.

In this context, we consider that re-organization effort is determined by the number of modified entries of the last three categories of modifications. The number of modified entries demonstrates the level of the disturbance to the existing organization about changes of the original tasks, re-assignment of new tasks or re-construction of new whole process of the project. Therefore, total modified entries in the revised schedule can be used to estimate the level of the re-organization effort, which are tallied based on the amounts of different categories of the modified entries.

The next section will discuss the step-by-step procedure to execute the decision-based change management approach.

Chapter 4

Procedure for the Decision-based Change Management Approach

The purpose of this chapter is to describe the procedure for the Decision-based Change Management (DCM) approach. To select a change option by assessing the impact of changes, the DCM approach adopts three change impact factors: the criticality of task, the amounts of affected workload and the importance of the worker to assess the impact of changes when the workers are absent for a specific period. Then, it applies the selected change option to revise the worker allocation schedule.

To implement the procedure for the Decision-based Change Management approach, two types of schedules (i.e. the PERT chart and the worker allocation schedule) and the Critical Path Method discussed in chapter 2 are required at first. In details, the PERT chart and the CPM help us judge the criticality of the tasks affected by absence of the workers. The worker allocation schedule assists us find comprehensive information of workers and implement schedule modification of worker allocation and comparison. Then, three impact factors (the criticality of task, the proportion of affected workloads, and worker importance) discussed in chapter 3 are used to assess the impact of changes for a change scenario. In order to find a change option to revise the schedule in this chapter, two types of schedule revision actions (patch actions and repair actions) also discussed in chapter 3 help us define three change options.

4.1. Procedure Overview

This section intends to roughly describe the procedure of the DCM approach applying in the construction project. In specific, several steps of the procedure of the DCM approach in an actual change scenario are implemented as follows.

Given a change scenario about absence of the workers happens. First, we need to know some information about this change scenario by checking the worker allocation schedule, such as the absent workers, the length of the absence, the affected tasks, and the number of the replacement workers. Second, three change impact factors of the DCM approach are used for selecting a change option. The first impact factor—the criticality of task is used to check criticality of the outstanding tasks, identifying the outstanding tasks is critical or non-critical. The rest two impact factors—the proportion of affected workloads and worker importance are used to assess the level of change impact existing in this change scenario. In view of critical or non-critical outstanding tasks, the level of change impact is assessed by comparing value of the second and/or the third change impact factor in this actual change scenario with threshold value of the corresponding change impact factor in threshold value table shown in table 4-1. Then, a change option is selected in view of the level of change impact. Finally, the selected change option is applied in the worker allocation schedule to get a revised schedule.

Here is a simple project to highlight the procedure of the DCM approach. Suppose two workers are absent for some times during the process of sub-project of mechanical equipment installation. First, the project manager needs to acquire some information about this change scenario. For example, the manager will search who are absent, which tasks are affected, and the length of absence by checking the worker allocation schedule. Following the above information, he will identify the criticality of outstanding tasks and also calculate the amounts of workloads affected by absence of workers. Then, the manager will search how many replacement workers can work on the outstanding tasks to calculate maximum additional workload. In view of the criticality of outstanding tasks, the manager will consider taking repair actions or patch actions. Meanwhile, the manager will assess the level of change impact by estimating the rest two impact factors (the proportion of affected workloads and worker importance). By comparing value of the second and/or the third change impact factor in this actual change scenario with threshold value of the corresponding impact factor in threshold value table shown in table 4-1, the manager knows what level of change impact this actual change scenario has and then selects a corresponding change option. Finally, the manager can implement the selected change option in the worker allocation schedule to modify the schedule.

4.2. Definition of Change Scenarios

In this context, we define the change scenarios as such change scenarios concerning absence of the workers for a period of time in sub-project of pipeline installation of

Wastewater Treatment Plant Project. Because many interrelated external factors (such as worker, equipment, raw material, technique, investment, weather, law, and social environment) are related to the change of the project, any change happened in an external factor can be considered as a change scenario concerning changes of certain external factor. For instance, if lack of certain raw material occurs, we can define this change scenario as a change scenario concerning shortage of certain kind of raw material for a period of time. In this thesis, we address such a change scenario that the worker(s) is (are) absent for some times in the construction project process.

4.3. Selection of the Change Options

This section intends to discuss how to select a change option by assessing the level of change impact in details.

As discussed in Section 3-2, three change impact factors are required to estimate the level of change impact. The first impact factor—the criticality of task uses the critical path method and the PERT chart to determine whether the outstanding tasks are critical or not. As any delay of the affected critical tasks easily results in the delay of the project duration, we consider that the change scenario with critical outstanding tasks would have high or medium change impact. The second impact factor–the proportion of affected workloads is determined by the ratio of affected workloads to total project workloads under the condition of the absent worker for some times. As the change impact of affected workloads is related to total workloads, we consider that the change scenario with higher proportion of affected workloads would have high change impact. The third factor—worker importance indicates the criticality of workers in difficulty of finding a replacement worker, which is related to the number of replacement workers for each affected outstanding task. In this context, worker importance is estimated by calculating maximum additional workloads that has to be assigned to a remaining worker. In general, if maximum additional workload is higher, we can say that this absent worker is more important and the corresponding change scenario would have high change impact.

Threshold values of the three change impact factors shown in table 4-1 are applied to help estimating the level of change impact. To effectively estimate threshold value of the three change impact factors, we use the traditional quantitative methods---statistical decision-making approach (Borror 2009). Estimation of threshold values of the three change impact factors of the DCM approach is shown in Appendix B. Two sets of threshold value for the proportion of affected workload and maximum additional workload, depending on whether the outstanding tasks are critical or non-critical, are used to form a threshold value table for selection of the change option. This table is shown in table 4-1. This table can help us quickly estimate the level of change impact by comparing values of the criticality of task, the proportion of affected workloads and/or worker importance in an actual change scenario. Then, select corresponding change option based on the level of change impact.

In this context, selecting a proper change option requires three steps. First, values of the three change impact factors (the criticality of task, the proportion of affected workloads, worker importance) are estimated. Second, by comparing values of three change impact factors of the actual change scenario with threshold values of three corresponding change impact factors, the level of change impact for this change scenario is assessed. Third, a change option (Option A, B or C) is selected based on the assessed level of the change impact. The details of selection procedure will be shown as follows.

Estimated threshold values of three change impact factors			**Estimate Results**	**Change Option**
Task criticality	***Proportion of affected workloads***	***Worker importance***		
Critical tasks	>0.0117	>2.14	High change impact	C
	<0.0117	<2.14	Medium change impact	B
Non-critical tasks	>0.0112	>2.76	High change impact	C
	<0.0112	<2.76	Low change impact	A

Table 4-1: threshold value table for selection of the change option

Given a change scenario (e.g. a worker is absent for some times) happens, the absent worker, the length of affected duration and the affected tasks can be found from the worker allocation schedule. Table 4-2 displays a simple example of a change scenario happened in the schedule.

In this example, W is denoted to worker and T is referred to task. W1 is absent for 3 days and affected workloads of T1 and T4 are 2 and 1 each. Total workload is equal to 25.

Workers	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
W1	T1	T1	T1	T1	T4	T4	
W2	T1	T1	T3	T3	T4	T4	
W3	T1	T2	T2	T3	T5	T5	T6
W4		T2	T2	T3	T5	T5	T6

Table 4-2: simple example of a change scenario in the worker allocation schedule

Procedure 1: estimating three change impact factors

At first, we use the first impact factor- the criticality of task to check criticality of the outstanding tasks with the help of the PERT chart and the worker allocation schedule. Then, we need to check two other impact factors. There are several steps to check the second impact factor—the proportion of affected workloads for the change scenario addressed in this thesis.

Step 1: we record the amounts of affected workloads that are 3 workloads, and total amounts of the project workloads that are 25 workloads.

Step 2: we calculate the proportion of affected workloads to total project workloads, which is 3/25.

Step 3: we compare the value of the proportion of affected workloads (3/25) with threshold value of the proportion of affected workloads in table 4-1.

Step 4: we know the level of change impact existing in this actual change scenario based on the proportion of affected workload.

Meanwhile, the third impact factor—worker importance, which is related to the number of remaining replacement workers for a specific task, is also checked to assess the level of change impact of this change scenario. In this context, we assess worker importance by using the maximum additional workloads that has to be assigned to a remaining worker. To explain the evaluation process for the factor of worker importance clearly, we use the same example in table 4-2. Several steps to measure maximum additional workload are displayed as follows.

Step 1: we find 3 affected workloads. The potential replacement workers W2 and W3 are found to replace W1 for the outstanding task 1 and W2 for task 4.

Step 2: we calculate the amount of each affected task that each replacement worker has to be allocated: W2 shares 1 workload in view of Task 1 and 1 workload in view of Task 4. Total amounts of affected tasks shared by the replacement W2 are 2 workloads. W3 shares 1 workload in view of Task 1 and 1 workload for W3 in total. W4 cannot share the outstanding tasks because W4 doesn't work on Task 1 and 4.

Step 3: we find the maximum additional workload that has to be assigned to each remaining worker by comparing the amounts of outstanding tasks potentially shared by each remaining replacement worker. Here, W2 shares 2 of maximum additional workloads.

Step 4: we compare this value of maximum additional workload with threshold value of the maximum additional workload in table 4-1.

Step 5: we know the level of change impact this actual change scenario has based on factor of worker importance.

Procedure 2: estimating the level of change impact

In this procedure, we summarize comprehensive estimation information of three impact factors to assess the level of change impact for this change scenario shown in table 4-1.

In order to clearly explain how to use table 4-1 in selection procedure of a change option, two examples are shown as follows. In the first example, given a worker is absent for a period of time, we check factor of the criticality of task and know that outstanding tasks are critical. Then, we calculate factor of the proportion of affected workloads and worker importance for this actual change scenario and then compare their values with threshold value in table 4-1. If factor of the proportion of affected workloads is larger than 0.0117 and/or factor of worker importance is larger than 2.14, high change impact exists in this change scenario. Another example is that two workers are absent for a period of time, we check factor of the criticality of task and know the outstanding tasks are non-critical. Then, we calculate factor of the proportion of affected workloads and worker importance of this actual change scenario and then compare their values with threshold value in table 4-1. When factor of the proportion of affected workloads is less than 0.0112 and/or factor of worker importance is less than 2.76, this change scenario has low change impact.

Procedure 3: selecting a change option

Continuing the first example in procedure 2, as this change scenario has high change impact, Option C should be applied. Otherwise, Option B should be chosen. In another example of procedure 2, this change scenario has low change impact. Then, Option A should be chosen. Otherwise, Option C should be applied to this change scenario shown in table 4-1.

4.4. Implementation of Change Options

In this section, we discuss how to implement the selected change option (Option A, Option B, or Option C) in the worker allocation schedule to revise the schedule. In specific, we implement change options in the worker allocation schedule through a group of one or several patch actions and/or repair actions. As this thesis emphasizes on decisions-making for selecting a change option to tackle the early stage of change scenario, the appropriate implementation of a change option at the earlier stage of change scenario can minimize the project delay and/or the disturbance to the existing organization. The detail implementation steps for the three change options are described as follows to cope with this change scenario (e.g. the workers are absent for some times).

To apply Option A in the worker allocation schedule, we firstly highlight the outstanding tasks in the blocks with bolder borders and light shaded areas after we check the absent worker and the absent period. Second, we need to search out one or more replacement workers with similar skills to work on the outstanding tasks. Third, after calculating and distributing the affected workloads to each remaining replacement worker, we will take patch actions. Patch actions to the corresponding replacement workers at the early stage of the change scenario are shown in the blocks with light shaded areas. Fourth, to minimize the disturbance of the existing organization, patch actions are repeat adopted in the later actions until the last affected task. For example, T1& T4 in table 4-3 are two outstanding tasks. While applying Option A, W2 will be found to work on 2 workloads of affected T1 and then 1 workload of affected T4 after he accomplish the existing work highlighted with light shaded area in table 4-3. The number inside the bracket is denoted to the replacement workers' original tasks and the number outsider the bracket is referred to new assigned tasks of the replacement workers. Then, change propagates to the later tasks after patch actions are taken shown in table 4-3. Patch actions are taken for all affected tasks until the last affected task.

Workers	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8
W1	T1	T1	T1	T1	T4	T4		
W2	T1	T1	T1 (T3)	T1 (T3)	T4	T4	T4	
W3	T1	T2	T2	T3	T3(T5)	T5	T5(T6)	T6
W4		T2	T2	T3	T3(T5)	T5	T5(T6)	T6

Table 4-3: example of schedule revision while applying Option A

To use Option B in the worker allocation schedule, we show the outstanding tasks in the blocks with bolder borders and light shaded areas after we check the absent worker and the absent period. Then, we need to know one potential replacement worker with similar skills to work on the outstanding tasks. Thirdly, after calculating the affected workloads assigned to this replacement worker, he will take repair actions at early stage of the change scenario. These repair actions are shown in the blocks with dark shaded areas. Fourth, to minimize the disturbance of the existing organization, patch actions are still adopted in the later actions until the last affected task. Procedure for the later affected tasks repeats the procedure of implementation of patch actions. For instance, applying Option B to revise the schedule in table 4-4 based on the same change scenario in table 4-3. Here, W3 interrupts his work in T2, T3, and T5 to work on the affected T1 and T4 by repair actions, which are highlighted in the blocks with dark shaded areas in table 4-4. Then, patch actions will be applied for the later affected tasks. Such change propagates to the later affected tasks shown with light shaded areas in table 4-4 until the last affected task.

Workers	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8
W1	T1	T1	T1	T1	T4	T4		
W2	T1	T1	T3	T3	T3(T4)	T3(T4)	T4	T4
W3	T1	T2	T1(T2)	T1(T3)	T4(T5)	T5	T5(T6)	T6
W4		T2	T2	T2(T3)	T5	T5	T5	

Table 4-4: example of schedule revision while applying Option B

To implement Option C in the worker allocation schedule, we highlight the outstanding tasks in the blocks with bolder borders and light shaded areas after we check the absent worker and the absent period at first. Then, we need to find out several replacement workers with similar skills to work on the outstanding tasks. Moreover, after calculating and distributing the affected workloads to each replacement worker, repair actions to the corresponding replacement workers are taken at the early stage of the change scenario. These actions are shown in the blocks with dark shaded areas. Furthermore, to minimize the disturbance of the existing organization, patch actions are still applied to the later actions until the last affected task. In specific, to repeat the procedure of implementation of patch actions in the later affected tasks. For instance, Option C is applied in table 4-5. W3 & W4 interrupt their current work to replace the absent W1 by taking repair actions highlighted in the blocks with dark shaded areas in table 4-5. Then, patch actions will be applied to the later affected tasks. Such changes propagate to the later affected tasks shown in the blocks with light shaded areas in table 4-5 until the last affected task.

Workers	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**	**Day 7**	**Day 8**
W1	T1	T1	T1	T1	T4	T4		
W2	T1	T1	T3	T3	T3(T4)	T3(T4)	T4	T4
W3	T1	T2	T1(T2)	T2(T3)	T4(T5)	T5	T5(T6)	T6
W4		T2	T1(T2)	T2(T3)	T5	T5	T6	

Table 4-5: example of schedule revision while applying Option C

Chapter 5

Application

The purpose of this chapter is to examine the Decision-based Change Management (DCM) approach to systematically cope with changes in the sub-project of pipeline installation so as to properly control and minimize the impact from changes.

As changes often happen during the project, the project managers require assessing the impact from the changes when changes occur. When the project managers face a change scenario, such as absence of the worker in this research, they require evaluating the impact of changes based on the importance of the absent worker and the length of the absence in the project. Accordingly, they need to decide whether they should modify the project schedule dramatically or just simply appoint the remaining workers to take on the work so that the impact of change can be minimized. Such decision is often needed to modify the project schedule and implement the revised schedule. The worker allocation schedule is the main schedule of worker assignment for this sub-project in this thesis. As a project is a complex entity, poor decisions can lead to unexpected results (i.e. project delay).

In this chapter, we use the DCM approach to systematically cope with the decision-making scenario for a better option in change management. To apply the DCM approach, three factors (i.e. the criticality of task, the proportion of affected workloads and worker importance) firstly are applied to estimate the impact of changes in the cases studies. After assessing the level of the impact of change, one of three change options, which are defined based on the action of either radical modification of the schedule or just simply asking the remaining workers to cover the work, is selected to revise the project schedule. Finally, to evaluate the revised schedules, two criteria (that is project delay and re-organization effort) are utilized in the cases studies.

The structure of this chapter is organized as follows: we classify the cases concerning absence of the workers as 4 types in section 5.1. In section 5.2, we select one case study applied in the case type 1 to show the implementation procedure of the DCM approach in the sub-project of pipeline installation. Then, we use two criteria to evaluate whether the selected change option by applying the DCM approach can minimize the project delay and/or re-organization effort in section 5.3. Detail discussions about quality of the revised schedules in four types of change cases are depicted in section 5.4. Specific cases are discussed in section 5.5. In the last section 5.6, validity of three change impact factors of the DCM approach is evaluated.

5.1 Classification of the Cases

The purpose of this section is to classify all kinds of cases concerning absence of the workers in the sub-project of pipeline installation as different types of cases and each type of change cases has the similar level of change impact.

As we discussed in section 4.3 above, we have two sets of threshold value of factor of the proportion of affected workload and maximum additional workload, depending on the criticality of the outstanding tasks (i.e. critical outstanding tasks or non-critical outstanding tasks). In case of critical outstanding task, threshold value of the proportion of affected workload is 0.0117 and maximum additional workload is 2.14. In case of non-critical outstanding task, threshold value of the proportion of affected workload is 0.0112 and maximum additional workload is 2.76.

Task criticality	**Proportion of affected workloads**	**Worker importance**	**Selected Change Option**	**Case Type**
Critical tasks	>0.0117	>2.14	C	1
	<0.0117	<2.14	B	2
Non-critical tasks	>0.0112	>2.76	C	3
	<0.0112	<2.76	A	4

Table 5-1: classification of the cases based on different selection situations.

Then, the selection situations showing different level of change impact are concluded in table 5-1. To better summarize the attributes of different kinds of the cases, we classify the types of cases based on different selection situations. In this context, four selection situations are used for the cases studies. We classify those cases that apply at the same selection situation as the same type of cases in this research. Therefore, four types of cases in views of four selection situations are classified, which are denoted to the case type 1, 2, 3, and 4 in table 5-1.

5.2 Demonstration

We demonstrate the procedure of applying the Decision-based Change Management approach discussed in Chapter 4 to one case study in this section. This change scenario case about absence of the worker for certain period is described as follows: plumber E (W14) will be absent from Day 17 to Day 44.

By checking the worker allocation schedule, we know that absence of the worker (W14) causes total 28 affected workloads of outstanding task 11 and 12, which are highlighted in the blocks with bolder borders & light shaded areas in Figure 5-1.

Step 1: Selection of the change option

Step 1.1 evaluating three change impact factors

We firstly check factor of the criticality of task: the outstanding task 11 &12 are critical checked by PERT Chart in Figure 2-4. Then, we calculate value of the proportion of affected workloads. As affected workloads are 28 and total project workloads are 1329, the proportion of affected workloads is equal to 0.0211 (or 28/1329).

To calculate maximum additional workloads that has to be assigned to a remaining worker, we consider allocating the outstanding task 11 to 7 potential remaining workers (W10, 11, 12, 13, 15, 23, and 24) that each one shares 2.00 workloads. The outstanding task 12 is shared by 7 potential replacement workers (W10, 11, 12, 13, 15, 16, and 17) for 2.00 workloads each. This calculation is listed in Table 5-3.

	T11	T12	subtotal
W10	2.00	2.00	4.00
W11	2.00	2.00	4.00
W12	2.00	2.00	4.00
W13	2.00	2.00	4.00
W15	2.00	2.00	4.00
W16		2.00	2.00
W17		2.00	2.00
W23	2.00		2.00
W24	2.00		2.00
	14.00	14.00	28.00
Prop. of W.			0.0211
Max. extra W.			4.00

Table 5-2: calculation of maximum additional workload

Step 1.2 assessing the level of change impact

To estimate level of change impact of this case, the criticality of outstanding task, values of proportion of affected workloads and maximum additional workload required to compare. By comparison, the outstanding task 11, 12 are critical; the proportion of affected workloads is larger than 0.0117. Meanwhile, we calculate value of maximum additional workload. At last, we compare the amounts of additional workloads shared by each remaining worker and find maximum additional workloads that has to be assigned to a remaining worker is 4.00 workloads. By comparing with threshold value of maximum additional workload in table 4-1, factor of worker importance is larger than 2.14. Therefore, we judge that this change scenario has high change impact.

Step 1.3 selection of a change option

As this change scenario has high change impact by estimating factor of the criticality of task, the proportion of affected workloads, and maximum additional workload, we consider that option C should be selected to deal with this change scenario in this case.

Step 2: Implementation

While applying Option C to revise the schedule, the outstanding task 11 should be done immediately by the replacement workers (W18, 19) through repair actions highlighted in the blocks with dark shaded areas in Figure 5-1. Then, the affected task 12 will be finished by the replacement workers (W18, 19) through repair actions highlighted in the blocks with dark shaded areas in Figure 5-1. After implementing the selected change option at the early stage of change scenario, we revise the schedule by patch actions in the later revision actions to minimize the disturbance to the existing organization. The delayed task 3 will be done by the replacement workers (W20, 21, and 22) and then the delayed task 4 will be done by the replacement workers (W19, 20, 21, and 22). Moreover, the delayed task 7 will be done by 7 replacement workers (W18 to W24). Total duration of task 7 is delayed for 4 days. This kind of changes propagates to the last delayed task 8 shown in the revised workers allocation schedule. The last delayed task 8 is finally 4-day delay and required extra 28 workloads to complete. As task 8 is a non-critical task and its delay is within the allowable float time of the project, the whole project's duration is not delayed.

Worker	Duration / Worker	Day 10	Day 11	Day 12	Day 13	Day 14	Day 15	Day 16	Day 17	Day 18	Day 19	Day 20	Day 21	Day 22	Day 23	Day 24	Day 25	Day 26	Day 27	Day 28	Day 29	Day 30	Day 31	Day 32	Day 33	Day 34	Day 35	Day 36	Day 37	Day 38	Day 39	Day 40	Day 41	Day 42	Day 43	Day 44	Day 45	Day 46	Day 47	Day 48	Day 49	Day 50	Day 51	Day 52
W10	Plumber A	3	3	3	3	3	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12								
W11	Plumber B	3	3	3	3	3	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12								
W12	Plumber C	3	3	3	3	3	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12								
W13	Plumber D	3	3	3	3	3	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12								
W14	Plumber E	3	3	3	3	3	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12								
W15	Plumber F	3	3	3	3	3	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12								
W16	Plumber G	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	7	7	7	7	12	12	12	12	12	12	12		12	12	12	12	12	12								
W17	Plumber H	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	7	7	7	7	7	7	7	7	7	7	12	12	12	12	12	12	8	8	8	8	8	8	8			
W18	Plumber I	3	3	3	3	3	3	3	11 ~~3~~	11 ~~3~~	11 ~~3~~	11 ~~3~~	11 ~~3~~	11 ~~3~~	11 ~~3~~	3	3	3	7	7	7	7	7	12 ~~7~~	12 ~~7~~	12 ~~7~~	12 ~~7~~	12 ~~7~~	12 ~~7~~	12 ~~7~~	12 ~~7~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8			
W19	Plumber J		3	3	3	3	3	3	11 ~~3~~	11 ~~3~~	11 ~~3~~	11 ~~3~~	11 ~~3~~	11 ~~3~~	11 ~~3~~	3	3	4	4	4	4	4 ~~7~~	4 ~~7~~	4 ~~7~~	4 ~~7~~	12 ~~7~~	12 ~~7~~	12 ~~7~~	12 ~~7~~	12 ~~7~~	12 ~~7~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8	8		
W20	Plumber K		3	3	3	3	3	3	3	3	3 4	3 4	3 4	3 4	3 4	4	4	4	4	4	4	4	4 ~~7~~	4 ~~7~~	4 ~~7~~	7	7	7	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8	8		
W21	Plumber L		3	3	3	3	3	3	3	3	3 4	3 4	3 4	3 4	3 4	4	4	4	4	4	4	4	4 ~~7~~	4 ~~7~~	4 ~~7~~	7	7	7	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8	8		
W22	Plumber M						11				3 4	3 4	3 4	3 4	4	4	4	4	4	4	4	4	4 ~~7~~	4 ~~7~~	4 ~~7~~	4 ~~7~~	7	7	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8	8			
W23	Plumber N						11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	7	7	7	7	7	7	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8	8			
W24	Plumber O						11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	7	7	7	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8	8			
W25	Welder A	2	6	6	6	6	6										11	11	11	11															9	9	9	9	9	9	9	9	9	9
W26	Welder B				6												11	11	11	11																	13	13	13	13	13	13	13	13
W27	Welder C	10	10	10	10	10				3	3	3	3	3	3	3	11	11	11																		13	13	13	13	13	13	13	13

Figure 5-1: revised schedule applying Option C in the case type 1

5.3 Comparison

To compare the results of applying different change options to revise the schedule, we demonstrate two other schedule revision processes acquired by applying the rest two change options as follows.

While applying Option B, a replacement worker (W18) is assigned to work on the affected workloads of W14 immediately. The outstanding task 11 and 12 should be done by W18 through repair actions highlighted in the blocks with dark shaded areas in Figure 5-2. After implementing the selected change option at the early stage of change scenario, we revise the schedule based on the existing sequence of the tasks by patch actions. The replacement workers (W20, 21) will complete the delayed task 3 and then the delayed task 4 will be done by 4 replacement workers (W19 to W22). However, the affected task 7 caused by the replacement worker (W18) is delayed so early when applying option B at the early stage of the change scenario. More delayed workloads of task 7 are cumulated at the early stage of the change scenario. To minimize the disturbance to the existing organization caused by too longer duration delay of affected task 7 at the later stage of the change scenario, the project manager often takes such precaution actions. That is, 13 workloads of the delayed task 7 will be done by the replacement workers (W16, 17) through patch actions. The changes cause the 2-day delay of the later task 12. As task 12 is the last delayed critical task, its delay causes 2-day delay of the project duration. Other changes propagate to the last non-critical task 8. Total 28 extra workloads are required.

While applying Option A, the outstanding task 11 will be done by 7 replacement workers (W10, W11, W12, W13, W15, W23, and W24) through patch actions, which are highlighted in the blocks with light shaded area in Figure 5-3. The delayed task 7 will be done by the replacement worker (W24) through patch actions. Then, the delayed task 8 will be completed by 4 replacement workers (W19 to W22) through patch actions. Meanwhile, the delay of task 11 causes the delay of the later critical tasks. This kind of changes propagates to the last delayed critical task 12. Task 12 is finally 5-day delay and total extra 32 workloads are required. As task 12 is a critical task, its 5-day delay will cause the whole project's 5 days delay.

Worker	Duration / Worker	Day 10	Day 11	Day 12	Day 13	Day 14	Day 15	Day 16	Day 17	Day 18	Day 19	Day 20	Day 21	Day 22	Day 23	Day 24	Day 25	Day 26	Day 27	Day 28	Day 29	Day 30	Day 31	Day 32	Day 33	Day 34	Day 35	Day 36	Day 37	Day 38	Day 39	Day 40	Day 41	Day 42	Day 43	Day 44	Day 45	Day 46	Day 47	Day 48	Day 49	Day 50	Day 51
W8	Riveter E	6	6	6	6	6	6	6		3	3	3	3	3	3	3																		9	9	9	9	9	9	9	9	9	9
W9	Riveter F	6	6	6	6	6	6	6				3	3	3	3	3																		9	9	9	9	9	9	9	9	9	9
W10	Plumber A	3	3	3	3	3	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12					
W11	Plumber B	3	3	3	3	3	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12					
W12	Plumber C	3	3	3	3	3	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12					
W13	Plumber D	3	3	3	3	3	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12					
W14	Plumber E	3	3	3	3	3	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12							
W15	Plumber F	3	3	3	3	3	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12					
W16	Plumber G	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	7	7	7	7	7 ~~12~~	7 ~~12~~	7 ~~12~~	7 ~~12~~	7 ~~12~~	7 ~~12~~	7 ~~12~~	7	7 ~~12~~	12	12	12	12	12							
W17	Plumber H	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	7	7	7	7	7	7	7	7	7	7	7 ~~12~~	7 ~~12~~	7 ~~12~~	7 ~~12~~	12	12	12 ~~8~~	12 ~~8~~	8	8	8	8			
W18	Plumber I	3	3	3	3	3	3	3	11 ~~3~~	11 ~~3~~	11 ~~3~~	11 ~~3~~	11 ~~3~~	11 ~~3~~	11 ~~3~~	11 ~~3~~	11 ~~3~~	11 ~~3~~	11 ~~7~~	11 ~~7~~	11 ~~7~~	11 ~~7~~	12 ~~7~~	12 ~~7~~	12 ~~7~~	12 ~~7~~	12 ~~7~~	12 ~~7~~	12 ~~7~~	12 ~~7~~	12 ~~7~~	12 ~~8~~	12 ~~8~~	12 ~~8~~	12 ~~8~~	12 ~~8~~	8	8	8	8			
W19	Plumber J		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4 ~~7~~	4 ~~7~~	4 ~~7~~	7	7	7	7	7	7	7	7 ~~8~~	8	8	8	8	8	8	8	8			
W20	Plumber K		3	3	3	3	3	3	3	3	3 4	3 4	3 4	3 4	3 4	4	4	4	4	4	4	4	4 ~~7~~	4 ~~7~~	7	7	7	7	7	7	7	7 ~~8~~	8	8	8	8	8	8	8	8			
W21	Plumber L		3	3	3	3	3	3	3	3	3 4	3 4	3 4	3 4	3 4	4	4	4	4	4	4	4	4 ~~7~~	4 ~~7~~	4 ~~7~~	7	7	7	7	7	7	7 ~~8~~	8	8	8	8	8	8	8	8			
W22	Plumber M						11				4	4	4	4	4	4	4	4	4	4	4	4	4 ~~7~~	4 ~~7~~	7	7	7	7	7	7	7	7 ~~8~~	8	8	8	8	8	8	8	8			
W23	Plumber N						11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	7	7	7	7	7	7	7	7	7	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8	8			
W24	Plumber O						11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	7	7	7	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8	8	8			
W25	Welder A	2	6	6	6	6	6										11	11	11	11														9	9	9	9	9	9	9	9	9	9
W26	Welder B				6												11	11	11	11																	13	13	13	13	13	13	13

Figure 5-2: revised schedule applying Option B in the case type 1

Worker	Duration / Worker	Day 10	Day 11	Day 12	Day 13	Day 14	Day 15	Day 16	Day 17	Day 18	Day 19	Day 20	Day 21	Day 22	Day 23	Day 24	Day 25	Day 26	Day 27	Day 28	Day 29	Day 30	Day 31	Day 32	Day 33	Day 34	Day 35	Day 36	Day 37	Day 38	Day 39	Day 40	Day 41	Day 42	Day 43	Day 44	Day 45	Day 46	Day 47	Day 48	Day 49	Day 50	Day 51
W8	Riveter E	6	6	6	6	6	6	6		3	3	3	3	3	3	3																		9	9	9	9	9	9	9	9	9	9
W9	Riveter F	6	6	6	6	6	6	6				3	3	3	3	3																		9	9	9	9	9	9	9	9	9	9
W10	Plumber A	3	3	3	3	3	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11 ~~12~~	11 ~~12~~	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12			
W11	Plumber B	3	3	3	3	3	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11 ~~12~~	11 ~~12~~	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12		
W12	Plumber C	3	3	3	3	3	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11 ~~12~~	11 ~~12~~	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12		
W13	Plumber D	3	3	3	3	3	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11 ~~12~~	11 ~~12~~	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12		
W14	Plumber E	3	3	3	3	3	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12							
W15	Plumber F	3	3	3	3	3	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11 ~~12~~	11 ~~12~~	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12			
W16	Plumber G	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	7	7	7	7	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12			
W17	Plumber H	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	7	7	7	7	7	7	7	7	7	7	12	12	12	12	12	12	8	8	8						
W18	Plumber I	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	7	7	7	7	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8	8					
W19	Plumber J		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	7	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8	8	8				
W20	Plumber K		3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8	8	8				
W21	Plumber L		3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8	8	8				
W22	Plumber M						11				4	4	4	4	4	4	4	4	4	4	4	4	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8	8	8				
W23	Plumber N						11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11 ~~7~~	11 ~~7~~	7	7	7	7	7	7	7	8	8	8	8	8	8	8					
W24	Plumber O						11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11 ~~7~~	11 ~~7~~	7	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8					
W25	Welder A	2	6	6	6	6	6										11	11	11	11														9	9	9	9	9	9	9	9	9	9
W26	Welder B				6												11	11	11	11																	13	13	13	13	13	13	13

Figure 5-3: revised schedule applying Option A in the case type 1

5.3.1 Analysis of comparison

To examine the quality of the revised schedules, two criteria are evaluated, namely, project delay and re-organization effort. In specific, to compare the different revised schedules produced by using different change options, we check two factors which are related with two criteria. First, we check the number of extended days pertaining to the final task(s) of the project in view of project delay. This factor reflects the delay of the project's duration. Second, we check the number of modified entries in the worker allocation schedule. The number of modified entries is defined in view of re-organization effort, which captures the situation that the original task of a worker is changed to another task.

Table 5-3 summarizes the results of implementation of three change options. Because Option C is the earliest and most flexible in choosing the replacement workers among three options, the outstanding task 11 and 12 will be done by the replacement W18 and W19 without delay in Figure 5-1 when we apply Option C. Obviously, there is no delay in the project duration.

In view of large amounts of affected workload in this change scenario, when applying Option B, large amounts of affected workloads of the delayed task 7 is cumulated until Day 30 because less flexible Option B causes the delayed tasks occur earlier than Option C does. As considering that Option B is less flexible to adjust the replacement effectively in the future, we try to balance the delayed duration of task 7 with other tasks that are worked at the same time. And we take patch actions to minimize the disturbance to the existing organization. That is, plumber G (W16) continues to work on part of workload of the delayed task 7 from Day 31 after he completes the current task 7. Such actions impact the later task 12. As task 12 is a critical task that affects the project duration, its 2-day delay leads to 2-day delay of the project.

To the least flexible Option A, taking patch actions doesn't improve the situation of the delayed critical task 11 and 12 but gets worse. Although the number of modified entries acquired by applying Option A is the least among three revised schedules, delay of the critical task 12 results to 5-day delay of the project.

Criteria	**Option C**	**Option B**	**Option A**
Number of extended days pertaining to the final task(s) of the project	0	2	5
Number of the modified entries	112	100	50

Table 5-3: results applying three change options in the case type 1

By comparing the number of extended days pertaining to the final task(s) of the project, we understand that Option C is the best choice among three schedule revision options in this case. This result matches the one acquired by applying the DCM approach to deal with this change scenario. The DCM approach is considered as effectiveness to deal with this change scenario in this case. Moreover, we generally consider that change Option C is a better change option to address the case type 1.

5.4. Discussion of four types of change cases

The purpose of evaluating quality of the revised schedule is to examine whether the proposed Decision-based Change Management approach helps to select a proper change decision option that can minimize the impact of changes. After a change option is chosen, the project manager can modify the worker allocation schedule. In this thesis, we recommend three change options that are available for a change scenario and three revised schedules can be produced accordingly. Under this condition, we will evaluate which one of three revised schedules is the most available. By evaluating the quality of the revised schedule, we can examine the validity of selection of change options.

To easily understand the qualitative attributes of each type of cases, we can also depict the types of cases as follows.

Case Type	Task criticality	Proportion of affected workloads	Worker importance
1	Critical tasks	Large	More
2	Critical tasks	Small	Less
3	Non-critical tasks	Large	More
4	Non-critical tasks	Small	Less

Table 5-4: qualitative classification of the cases

This section describes quality of the revised schedules implemented by the Decision-based Change Management approach in different types of change scenario cases. We use two criteria (i.e. project delay & the re-organization effort) to evaluate the quality of the revised schedule. In specific, we compare the change option selected by using the DCM approach with the one acquired by evaluating two criteria shown from table 5-5 to 5-11. Then, we examine whether two results match each other.

Project delay is an important criterion that the project managers address. Any project delay can lead to customer dissatisfaction and the increase of the cost. In this context, we consider the delay of some tasks affected by a change scenario can directly cause the delay of other related tasks, leading to the whole project delay. Sometimes, the project delay is unavoidable due to lack of the resources. Under this condition, we can check which revised schedule results in the minimum of project delay. Meanwhile, the managers also wish to minimize the modification of the existing schedule. The existing schedule of the project is a comprehensive achievement of all kinds of entities of the construction project. Re-scheduling can cause changes of different level of the existing organization, which is referred as the re-organization effort in this context. The project managers wish to minimize the re-organization effort to decrease the influence of changing mistakes.

In this thesis, project delay is determined by the number of extended days pertaining to the final tasks of the project. The re-organization effort is defined as the number of modified entries in the revised worker allocation schedule. The detail evaluations of quality of the revised schedules in four types of change scenario cases are represented as follows.

5.4.1. The case type 1

At first, we observe that quality of the revised schedules in the case type 1 meets our expectations. To evaluate quality of the revised schedule in the case type 1, three cases are demonstrated to apply the DCM approach. The results selected by evaluating two criteria shown in table 5-5 indicate that the DCM approach can help to select the same change option. It demonstrates higher validity of applying the DCM approach to such type of change scenario cases.

In the cases of critical outstanding tasks shown in table 5-5, we understand that Option A isn't a better choice because the project duration is extended by the delay of critical outstanding tasks if no repair actions are taken. However, Option B or Option C responds such change scenario quickly by applying earlier and flexible revision actions to minimize the delay of project duration. It indicates that two proactive actions are a better choice when the outstanding tasks are critical. Furthermore, if the affected workloads are larger and/or the absent workers are more important, the project delay happens more easily and the level of change impact gets higher. This condition requires earlier and more flexible change option to minimize the project delay and Option C is a better choice than Option B. Option C is also selected by evaluating two criteria in table 5-5.

Note: P- proportion of affected workload; M –maximum additional workload

Case No.	**The DCM Approach**		**Verification**			
	Values of Three Impact Factors	*Option Selected by level of change impact*	*Three Options*	*The Final Delayed Days*	*The Modified Entries*	*Option Selected by Two Criteria*
A. in case of critical outstanding tasks Type 1: the case in large amounts of affected workload						
1	Critical tasks P=0.0256 M=2.83	**C**	C	0	136	*C*
			B	3	121	
			A	6	63	
2	Critical tasks P=0.0166 M=3.14	**C**	C	0	88	*C*
			B	1	89	
			A	2	52	
3	Critical tasks P=0.0135 M=2.57	**C**	C	0	62	*C*
			B	1	52	
			A	2	30	

Table 5-5: summaries of the cases studies in the case type 1

5.4.2. The case type 2

In the cases of critical outstanding tasks shown in table 5-6, quality of the revised schedules in the case type 2 are shown to meet our expectations. To evaluate quality of the revised schedule in the case type 2, three cases are demonstrated to apply the DCM approach. The results selected by evaluating two criteria shown in table 5-6 indicate that the DCM approach can help to select the same change option. It demonstrates higher validity of applying the DCM approach to such type of change scenario cases.

For the case type 2, Option B responds such change scenario quickly by applying earlier and flexible revision actions to minimize the project duration. It indicates that a proactive action is a better choice when the outstanding tasks are critical ones. Meanwhile, while the affected workloads are smaller and/or the absent worker is not important, we address the least disturbance of the existing schedule because the project delay doesn't easily happen. Option B can cause less re-organization effort than Option C does. Under this condition, applying Option B is a better choice. Option B is also selected by evaluating two criteria in table 5-6.

Note: P- proportion of affected workload; M –maximum additional workload.

Case No.	**The DCM Approach**		**Verification**			
	Values of Three Impact Factors	*Option Selected by level of change impact*	*Three Options*	*The Final Delayed Days*	*The Modified Entries*	*Option Selected by Two Criteria*
A. in case of critical outstanding tasks Type 2: the case in small amounts of affected workload						
4	Critical tasks P=0.0068 M=1.29	**B**	B	0	33	*B*
			C	0	36	
			A	1	21	
5	Critical tasks P=0.0030 M=1.00	**B**	B	0	14	*B*
			C	1	21	
			A	2	14	
6	Critical tasks P=0.0045 M=2.00	**B**	B	0	14	*B*
			C	0	18	
			A	2	6	

Table 5-6: summaries of the cases studies in the case type 2

5.4.3. The case type 3

In view of the cases with non-critical outstanding tasks shown in table 5-7, we observe that quality of the revised schedules in the case type 3 meets our expectations. To evaluate quality of the revised schedule in the case type 3, three cases are demonstrated to apply the DCM approach. The results of the cases studies indicate that the DCM approach can help to select the same change option as the one selected by evaluating two criteria shown in table 5-7. It demonstrates higher validity of applying the DCM approach to such type of change scenario cases.

Note: P- proportion of affected workload; M –maximum additional workload

Case No.	**The DCM Approach**		**Verification**			
	Values of Three Impact Factors	*Option Selected by level of change impact*	*Three Options*	*The Final Delayed Days*	*The Modified Entries*	*Option Selected by Two Criteria*
B. in case of non-critical outstanding tasks Type 3: the case in large amounts of affected workload						
7	Non-critical tasks P=0.0211 M=4.98	**C**	C	0	67	*C*
			B	1	67	
			A	1	62	
8	Non-critical tasks P=0.0150 M=3.03	**C**	C	0	54	*C*
			B	0	62	
			A	2	49	
9	Non-critical tasks P=0.0128 M=2.73	**C**	C	0	50	*C*
			B	0	58	
			A	2	45	

Table 5-7: summaries of the cases studies in the case type 3

We found that Option B isn't the best choice for this type of cases if affected workloads are larger and/or the absent worker is important. It can impact more downstream tasks than Option C does Because of its less flexibility of adjustment to those affected non-critical tasks. When the project delay will be mainly considered by the manager, the earliest and most flexible Option C is a better choice to deal with this change scenario. Option C is also selected by evaluating two criteria in table 5-7.

5.4.4. The case type 4

In view of the cases with non-critical outstanding tasks shown in table 5-8, quality of the revised schedules in the case type 4 match our assumptions. To evaluate quality of the revised schedule in the case type 4, three cases are demonstrated to apply the DCM approach. The results of the cases studies indicate that the DCM approach can help to select the same change option as the one selected by evaluating two criteria shown in table 5-8. It demonstrates higher validity of applying the DCM approach to such type of change scenario cases.

If the affected workloads are smaller and/or the absent worker isn't important, the delayed duration of non-critical outstanding tasks is easily controlled within the allowable float times of the project duration at the most of time. As the project delay does not easily occur in this change scenario, Option B easily results in more disturbance of the existing organization than Option A does. Option A is appropriate to deal with this change scenario for minimizing re-organization efforts. Option A is also selected by evaluating two criteria in table 5-8.

Note: P- proportion of affected workload; M –maximum additional workload.

Case No.	**The DCM Approach**		**Verification**			
	Values of Three Impact Factors	*Option Selected by level of change impact*	*Three Options*	*The Final Delayed Days*	*The Modified Entries*	*Option Selected by Two Criteria*
B. in case of non-critical outstanding tasks Type 4: the case in small amounts of affected workload						
10	Non-critical tasks P=0.0075 M=2.50	**A**	A	0	27	*A*
			B	0	35	
			C	0	39	
11	Non-critical tasks P=0.0060 M=1.33	**A**	A	0	24	*A*
			B	1	27	
			C	1	28	
12	Non-critical tasks P=0.0045 M=2.00	**A**	A	0	6	*A*
			B	2	12	
			C	2	12	

Table 5-8: summaries of the cases studies in the case type 4

5.5. Discussion of the specific cases

The quality of the revised schedules of the specific cases is discussed in this context. These specific cases have different attributes with the case type 1, 2, 3, and 4. Here, we define three specific types of the cases. The specific case type a is defined as the case that worker importance is higher but small amounts of workload are affected. The specific case type b is defined as the case that only one replacement worker is found. And the specific case type c is defined as the case that the replacement workers have to interrupt their critical tasks' work to work on the non-critical outstanding tasks.

5.5.1. The specific case type a

The quality of the revised schedules applying the DCM approach under the condition of absence of the important worker is evaluated by two criteria in the specific case type a.

Note: P- proportion of affected workload; M –maximum additional workload

Case No.	**The DCM Approach**		**Verification**			
	Values of Three Impact Factors	*Option Selected by Assessing Impact Factors*	*Three Options*	*The Final Delayed Days*	*The Modified Entries*	*Option Selected by Two Criteria*
The Specific cases *a. worker importance*						
13	Critical tasks P=0.0060 M=4.00	**C**	C	0	13	*C*
			B	0	20	
			A	5	8	
14	Non-critical tasks P=0.0045 M=6.00	**C**	C	0	18	*C*
			B	0	18	
			A	1	18	

Table 5-9: summaries of the cases in the specific case type a

The change option selected by the DCM approach to revise the schedule matches the one selected by two criteria in the cases of critical outstanding tasks and non-critical outstanding ones. When affected workloads are smaller but the absent worker is very important, this change scenario has high change impact. Option C is selected to revise the schedule. The specific case type a shows that factor of worker importance can effectively assess the level of change impact. The result meets our expectation and demonstrates high-level validity of applying the DCM approach in the cases shown in table 5-9.

5.5.2. The specific case type b

In order to evaluate quality of the revised schedule in the cases of single replacement worker, we firstly observe that only Option A or Option B can be applied when only one replacement worker is found to replace in the specific case type b. As we discussed before, if applying the DCM approach for revision of the schedule to deal with the change scenario with critical outstanding tasks, we prefer to choose Option B or Option C because one of them is a better choice comparing with Option A. When the proportion of affected workload is larger, we should choose Option C. However, we cannot choose Option C to revise the schedule, which means the DCM approach doesn't work in this change scenario with larger affected workloads. Similarly, as the DCM approach is implemented in such cases of change scenario with non-critical outstanding tasks, we consider selecting Option A or Option C. If the affected workload is larger, we should choose Option C. But we cannot choose Option C to revise the schedule, which means the DCM approach doesn't work in this change scenario with larger affected workloads.

Note: P- proportion of affected workload; M –maximum additional workload.

Case No.	The DCM Approach		Verification			
	Values of Three Impact Factors	*Option Selected by Assessing Impact Factors*	*Three Options*	*The Final Delayed Days*	*The Modified Entries*	*Option Selected by Two Criteria*
The Specific cases *b. single replacement worker*						
15	Critical tasks P=0.0038 M=1.00	**B**	B	0	10	*B*
			A	1	10	
16	Non-critical tasks P=0.0075 M=1.43	**A**	A	0	13	*A or B*
			B	0	13	

Table 5-10: summaries of the cases in the specific case type b

However, we find that quality of the revised schedule by applying the DCM approach in the cases of single replacement worker matches our expectation shown in table 5-10. That is, the change option selected by using the DCM approach for the change scenario with smaller affected workload matches the one selected by evaluating two criteria. Therefore, when the outstanding tasks are critical, Option B can be applied in this type of cases. While outstanding tasks are non-critical ones, Option A can be applied. The DCM approach applying in the cases of single replacement worker takes effectiveness when the cases with smaller affected workloads. Therefore, we consider that the DCM approach can take partially effectiveness to deal with this type of change scenario.

Then, we discuss the occurrence probability of cases of single replacement worker under the conditions of different amounts of affected workload in daily construction process. In a large construction project, the situation of finding only one replacement worker only happens in a very short time because there is high possibility to find multiple potential replacement workers in the future. It means that chance about the occurrence rate in this type of cases with smaller affected workload is far higher than this type with larger ones. Therefore, we conclude that the DCM approach takes validity in the specific case type b with smaller affected workloads, which means that it takes validity to the most of this type of cases of change scenario.

5.5.3. The specific case type c

To evaluate quality of the revised schedule in specific case type c, we firstly find that this type of specific case is to force the replacement workers who interrupt their work of the existing critical tasks to work on the non-critical outstanding tasks. As we discussed before, if the DCM approach applying in the case type 3 and 4 is implemented for the change scenario with non-critical outstanding tasks, we consider selecting Option A or Option C. If the affected workloads are larger, we should choose Option C. However, the most unusual cases that replacement workers' current tasks are critical just happen for a short time in the actual construction project. For instance, the non-critical outstanding tasks have to finish tomorrow due to future storm. But only the replacement workers who are working on the critical tasks are found. Assume that repair actions are needed to deal with this change scenario, these replacement workers have to interrupt the existing work to work on affected tasks. However, this replacement just allows for a short time because the project managers understand that the delay of affected critical tasks may cause the project delay. After the weather gets better, these workers will return to the original work. That means the specific case type c with smaller affected workload happens at most times of the construction process. Therefore, we can ignore the DCM approach used for this specific case type c with larger affected workloads.

Note: P- proportion of affected workload; M –maximum additional workload

Case No.	The DCM Approach		Verification			
	Values of Three Impact Factors	*Option Selected by Assessing Impact Factors*	*Three Options*	*The Final Delayed Days*	*The Modified Entries*	*Option Selected by Two Criteria*
The Specific cases *c. the replacement workers whose current tasks are critical to work on non-critical outstanding tasks*						
17	Non-critical tasks P=0.0053 M=1.40	A	A	0	7	*A*
			B	2	21	
			C	2	21	
18	Non-critical tasks P=0.0023 M=1.50	A	A	0	3	*A*
			B	1	3	
			C	1	3	

Table 5-11: summaries of the cases in the specific case type c

By evaluating quality of the revised schedule in the specific case type c, when smaller affected workloads exists in this case, we observe that the change option selected by the DCM approach matches the one selected based on two criteria. Option A selected by evaluating two criteria is the same option selected by the DCM approach in table 5-11. The specific cases of type c indicate that Option A will be a better choice. It means that re-allocating those replacement workers whose current tasks are critical to work on non-critical affected workload immediately is not a better choice. Here, Option A would be a better option that allows these replacement workers complete the current critical task and then work on the affected workloads. Therefore, we consider that the DCM approach can take partially effectiveness to deal with these types of cases of change scenarios with smaller affected workload.

The summary of the cases studies indicates two obvious issues. First, the Decision-based Change Management approach can be effectively used to most of the cases of change scenarios to minimize the impact of changes. Second, it can also partially be applied for some specific cases to deal with the changes when just small work is impacted by the changes. These results demonstrate that validity of the DCM approach applied in the construction practice to improve quality of the decision-making about absence of the workers.

5.6. Discussion of three change impact factors

The target of this section is to discuss validity of three change impact factors of the Decision-based Change Management (DCM) approach to choose the appropriate change option. As we discuss above, the DCM approach can be used in the case type 1, 2, 3, and

4 to get a better revised schedule while they also can be partially used in the specific cases to get a better revised one. To most of the cases, the selected change option based on the assessed level of change impact has proved that the three change impact factors can effectively assess the level of change impact.

In view of these cases, we discuss that the first change impact factor—the criticality of task can help us identify whether the tasks are critical or non-critical. It is easy to make us understand whether the outstanding tasks' delay will result to the project delay. For instance, the case type 1 and 2 show that if outstanding tasks are critical identified by factor of the criticality of task, Option C is considered to apply in the case type 1 while Option B is preferred to apply in the case type 2. While outstanding tasks are non-critical, Option C is considered to apply in the case type 3 or Option A is preferred to apply in the case type 4.

The second change impact factor- the proportion of affected workload can help us assess the level of change impact based on the amount of affected workloads. The larger amounts of affected workloads exist in this case, the higher change impact the change scenario has. Those cases of type 1, 2, 3, and 4 indicate that factor of the proportion of affected workloads can identify the amounts of affected workloads that is directly related to the project delay and the disturbance to the existing organization. For instance, factor of the proportion of affected workloads helps us identify small amounts of affected workload existed in these change scenarios in the case type 2 or 4. Under these conditions, the project delay maybe is not a big issue but re-organization effort should be focused by the project managers. Therefore, Option B or A will be considered as a better choice. When the affected workloads checked by the proportion of affected workloads increase to certain amounts, the problem about the project delay will be mainly considered. The change scenarios in these cases have high change impact because larger amounts of affected workloads easily result to the project delay. Then, the earliest and most flexible Option C should be chosen to deal with the project delay.

The third change impact factor—worker importance can assist us identify the specific cases of worker importance. Two specific cases of type a indicate validity of factor of worker importance in table 5-9. As there are very less remaining workers to work on the outstanding tasks, the outstanding tasks will easily be delayed. Then, it results in delay of the project duration. To minimize this project delay, the manager will take repair action to revise the schedule. Therefore, when factor of worker importance is higher, repair action is taken to revise the schedule.

Finally, we summarize some observations as follows. To the case type 1 and 2, we observe that Option A isn’t the best one to be implemented in such types of cases when the outstanding tasks are critical. We just require choosing Option B or C to deal with this change scenario when the change scenario in case of the critical outstanding tasks happens. Furthermore, we understand that Option B is a better choice to apply in such cases of change scenario with small proportion of affected workloads. Option C is appropriate to apply in such change scenarios with larger proportion of affected workloads.

To the case type 3 and 4, we didn't find Option B is the best option to apply in such types of cases of change scenario that the non-critical outstanding tasks are replaced by other non-critical tasks. When such change scenario happens, we just consider selecting Option A or C to revise the schedule. Moreover, we know that Option A is a better choice to apply in such cases of change scenario with small proportion of affected workloads. Option C is appropriate to apply in such change scenarios with larger proportion of affected workloads.

Validity of factor of worker importance is indicated in the specific case 13 and 14. If just using the second impact factor- the proportion of affected workloads to check these two change scenarios, we find the change scenarios have medium or low change impact. We use the third impact factor—worker importance to find out high change impact existing in this change scenario. Through comprehensive evaluation, we estimate this change scenario has high change impact. Option C should be chosen to revise the schedule in these two cases. The cases show that factor of worker importance is a primary change impact factor to be considered in such type of change scenario cases.

Chapter 6

Conclusion and Future Work

6.1 Summary and Conclusions

In this research, we have proposed a change management approach to deal with the changes during the project. The result of applying a change management approach is based on the effective data and the capability of the analysis approach to find out the attributes of interdependencies among different entities in a project. However, it isn't easy to find out the proper analysis approach and acquire reliable data in the complicated project since changes often occur in an unexpected condition. Managing such changes is difficult because of the complex interrelationship among different entities in a project. When changes happen in a project, change propagation will affect other parts of the project, resulting in the complex situation in the project.

Under this situation, the project manager often plays a critical role. The project manager should fully understand the content of the project; monitor the project process and budget. The manager should take a proper action to minimize the impact of changes when changes occur. In tradition, the manager acquires such ability due to past experience. Such experience makes the project manager understand intrinsic attributes of the complex interdependencies among the entities of the project.

However, promptly and effectively making decisions for change management is still challenging and difficult even though the project manager has a rich experience in managing changes of the complex project. The manager's experience is acquired from the daily practice. The project manager will face a challenge to make appropriate decisions for change management when the changes of the existing interrelationship among the entities occur. The manager also face the more and more complicated engineering project related to all kinds of resources, techniques, and organizations, etc. A systematic change management approach will help him deal with the changes in project managements. So far, there are not much change management tools that provide approaches to systematically cope with the changes in the project based on our best knowledge.

Our suggested approach addresses on systematically deal with changes in the project so as to appropriately control and minimize the impact of changes. Acquiring the interrelationships of the entities of the project and surveying the key factors relating to change management are the main method of this approach. In this context, we confine the scope of the thesis to the project scheduling of the construction project, which explore one change type: unexpected absence of the workers in specific.

By exploring various cases studies concerning absence of the workers in sub-project of pipeline installation, the Decision-based Change Management (DCM) approach has been proved to be used for coping with changes in the project that control and minimize the impact of changes. We investigate quality of the revised schedules while applying the DCM approach in various cases. By comparing the result of three revised schedules by evaluating two criteria (project delay & the re-organization effort), the results of most of the cases match our expectation. That is, implementing the change option selected by the DCM approach can acquire the minimum of project delay and the re-organization effort. Furthermore, it minimizes the impact of changes to deal with the changes at most of the cases.

The contribution of this thesis in the field of the schedule control of project time management is to propose an improved schedule control approach and a developed comparison method between the actual schedule and the planned one that is used for the schedule control. As not much research emphasizes on the problems of daily allocation of all kinds of resources by using the resources allocation schedule format, different steps in the proposed Decision-based Change Management Approach are derived based on professional project managers' experience and knowledge. Meanwhile, the DCM approach in this research can be used to follow and manage the engineering changes effectively that Engineering Change Management (ECM) concerns. Through discussing the complexity of the construction project, this thesis tried to demonstrate several critical change impact factors that affect the process of the project. This paper proposed a developed change management method to manage the changes, which is related to change management in project time management.

The author's contributions are:

- A new worker allocation schedule was developed. To the author's best understanding, this schedule format could provide a further advance in the research of project change management. In cases was this research contain some kinds of change scenario concerning absence of the workers. One can further develop such research for the change scenario concerning other entities of the project with the help of the development of the schedule format of resources allocation.

- Three change options are identified. The thesis has indicated that applying different change options can result to different revised schedules. The authors suggested comparing the results of applying three change scenarios to revise the schedule by evaluating two criteria, to identify validity of three change options.

- Threshold value table including threshold value of three change impacts factors used to estimate the level of change impact to the corresponding type of change scenarios is discovered. This threshold value table is very helpful for new project management practitioner to quickly judge the level of change impact in views of values of the three change impact factors of certain change scenario.

- The authors have applied the DCM approach in the change scenario cases concerning absence of the workers to improve effectiveness and efficiency of decision-making in the construction engineering which project change management addresses. The revised schedule can be created by the DCM approach to apply in practice that project time management focuses.

6.2 Future Work

This section is a conclusion of the future work for the approach suggested in this thesis. The purpose of this thesis is to apply the Decision-based Change Management (DCM) approach in the field of the construction engineering. This thesis addresses some kinds of change scenarios concerning absence of the workers happened in the construction project.

Generally, not much work has been done on the Decision-based Change Management approach for change management in the construction industry. However, there is significant practical application in the construction engineering if the DCM approach is developed in the future. In view of sub-project of pipeline installation, the authors were to develop a technique suitable to deal with the change scenario, which is related to project change management and project time management. The DCM approach was applied as the effective technique for this target. Four types of the cases are surveyed to examine the validity of the DCM approach to deal with the impact of changes. In all these cases, a number of substantive suggestions were provided to improve efficiency and effectiveness of decision-making in project change management and project time management.

To further develop the accuracy of the proposed approach to apply in practice, the future work for the suggested approach in this thesis is as follows:

- A more accurate and clear schedule format of resources allocation should be developed. This existing schedule format in the thesis is used to address the project scheduling of the construction project in the research of project change management, which are based on exploring the interdependencies between the tasks and workers. More complex interdependencies among the entities of the project in the schedule format of resources allocation should be developed. As this research contains some kinds of change scenario concerning absence of the workers, such research for the change scenarios concerning other types of change scenario (i.e. the breakdown of the machines) will further be developed with the help of similar type of the worker allocation schedule.

- Threshold values of the three change impact factors used to estimate the level of change impact should be more accurate and sensible. To reach this goal, threshold values of the three change impacts factors in threshold value table should be re-estimated on the basis of more experiments' data. Meanwhile, more key change impact factors should be surveyed in the future work. When more change impacts factors are considered, the DCM approach will help the project managers judge the level of change impact more accurately to deal with certain change scenario

- More change options should be identified. The thesis has indicated that applying different change options can result to different revised schedules. The further research should develop more specific types of change options to cope with more specific change scenarios.

- Application of the proposed approach for the sub-project in this thesis is to manually modify the schedule. To deal with the complexity of the project, a series of codes will be developed for automatic implementation of different steps of the proposed approach as one of the future extensions of this research.

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Appendix A

Cases Studies Concerning Absence of the Workers

A-1: Example of the case type 2

Change scenario: lifting worker A (W38) will be absent from Day 31 to Day 37.

Information: absence of the worker (W38) causes 7 affected workloads of Task 12.

Step 1: Selection by assessing level of change impact

a. Checking factor of task criticality: outstanding task 12 is critical. Therefore, one of two Options (C or B) is available in view of table 4-1 of threshold value table.

b. Calculating value of the proportion of affected workloads. The proportion of affected workloads is equal to 0.0053, which is smaller than 0.0117. This change scenario has medium change impact based on table 4-1.

c. Calculating value of maximum additional workload. The maximum additional workload is equal to 1.75, which is smaller than 2.14. This change scenario has medium change impact in view of table 4-1.

Totally, we assess that this change scenario has medium change impact and option B should be selected to deal with this change scenario.

Step 2: Implementation

While applying Option B to revise the schedule format, the outstanding task 12 should be done by the replacement worker (W36) through repair actions highlighted in the blocks with dark shaded areas in Figure A-1. Then, we revise the schedule by patch actions to minimize the disturbance to the existing organization at the later revision actions. Finally, the last delayed task 8 is finally 2-day delay. But the project's duration is not delayed.

Worker	Duration / Worker	Day 25	Day 26	Day 27	Day 28	Day 29	Day 30	Day 31	Day 32	Day 33	Day 34	Day 35	Day 36	Day 37	Day 38	Day 39	Day 40	Day 41	Day 42	Day 43	Day 44	Day 45	Day 46	Day 47	Day 48	Day 49	Day 50	Day 51	Day 52
W32	Gas welder A						7	7	7	7	7	7	7	7					9	9	9					9	9	9	9
W33	Gas welder B	11	11	11	11	11													9	9	9	13	13	13	13	13	13	9	9
W34	Gas welder C						5	5	5	5	5	5	5	5	5	5						13	13	13	13	13	13	13	13
W35	Gas welder D						5	5	5	5	5	5	5	5	5	5						13	13	13	13	13	13	13	13
W36	Lifting worker A	4	4	4	4	4	4	12 ~~8~~	12 ~~8~~	12 ~~8~~	12 ~~8~~	12 ~~8~~	12 ~~8~~	12 ~~8~~	8	8	8	8	8	8	8	8	8	8					
W37	Lifting worker B	4	4	4	4	4	4	8	8	8	8	8	8	8	8	8	12	12	12	12	12	8	8	8	8				
W38	Lifting worker C	4	4	4	4	4	4	12	12	12	12	12	12	12	12	12	12	12	12	12	12	8	8	8	8				
W39	Lifting worker D	4	4	4	4	4	4	12	12	12	12	12	12	12	12	12	12	12	12	12	12	8	8	8					
W40	Lifting worker E	4	4	4	4	4	4	12	12	12	12	12	12	12	12	12	12	12	12	12	12	8	8	8					
W41	Painter A																												
W42	Painter B																												
W43	Painter C																												
W44	Painter D																												
W45	Painter E																												

Figure A-1: revised schedule applying Option B in the case type 2

Step 3: Comparison

Suppose applying Option C, two replacement workers (W36, 37) are assigned to work on the affected workloads of W38 through repair actions highlighted in the blocks with dark shaded areas in Figure A-2. Then, we revise the schedule by patch actions to minimize the disturbance to the existing organization at the later revision actions. Finally, the changes lead to 1-day delay of the last affected critical task 12, causing 1-day delay of the project duration.

Worker	Duration / Worker	Day 25	Day 26	Day 27	Day 28	Day 29	Day 30	Day 31	Day 32	Day 33	Day 34	Day 35	Day 36	Day 37	Day 38	Day 39	Day 40	Day 41	Day 42	Day 43	Day 44	Day 45	Day 46	Day 47	Day 48	Day 49	Day 50	Day 51	Day 52
W32	Gas welder A						7	7	7	7	7	7	7	7					9	9	9					9	9	9	9
W33	Gas welder B	11	11	11	11	11													9	9	9	13	13	13	13	13	13	9	9
W34	Gas welder C						5	5	5	5	5	5	5	5	5	5						13	13	13	13	13	13	13	13
W35	Gas welder D						5	5	5	5	5	5	5	5	5	5						13	13	13	13	13	13	13	13
W36	Lifting worker A	4	4	4	4	4	4	12 ~~8~~	12 ~~8~~	12 ~~8~~	12 ~~8~~	8	8	8	8	8	8	8	8	8	8	8	8	8					
W37	Lifting worker B	4	4	4	4	4	4	12 ~~8~~	12 ~~8~~	12 ~~8~~	8	8	8	8	8	8	8 ~~12~~	8 ~~12~~	8 ~~12~~	12	12	12 ~~8~~	8	8	8				
W38	Lifting worker C	4	4	4	4	4	4	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12 ~~8~~	8	8	8				
W39	Lifting worker D	4	4	4	4	4	4	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12 ~~8~~	8	8					
W40	Lifting worker E	4	4	4	4	4	4	12	12	12	12	12	12	12	12	12	12	12	12	12	12	8	8	8					
W41	Painter A																												
W42	Painter B																												
W43	Painter C																												
W44	Painter D																												
W45	Painter E																												

Figure A-2: revised schedule applying Option C in the case type 2

While applying Option A, the outstanding task 12 will be done by 4 replacement workers (W37 to 40) after they complete current works through patch actions highlighted in the blocks with light shaded area in Figure A-3. Then, we revise the schedule by patch actions to minimize the disturbance to the existing organization at the later revision actions. Finally, 2-day delay of the last affected critical task 12 causes the whole project's 2 days delay.

Worker	Duration / Worker	Day 25	Day 26	Day 27	Day 28	Day 29	Day 30	Day 31	Day 32	Day 33	Day 34	Day 35	Day 36	Day 37	Day 38	Day 39	Day 40	Day 41	Day 42	Day 43	Day 44	Day 45	Day 46	Day 47	Day 48	Day 49	Day 50	Day 51	Day 52
W32	Gas welder A						7	7	7	7	7	7	7	7					9	9	9					9	9	9	9
W33	Gas welder B	11	11	11	11	11													9	9	9	13	13	13	13	13	13	9	9
W34	Gas welder C						5	5	5	5	5	5	5	5	5	5						13	13	13	13	13	13	13	13
W35	Gas welder D						5	5	5	5	5	5	5	5	5	5						13	13	13	13	13	13	13	13
W36	Lifting worker A	4	4	4	4	4	4	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8					
W37	Lifting worker B	4	4	4	4	4	4	8	8	8	8	8	8	8	8	8	12	12	12	12	12	12 ~~8~~	8	8	8				
W38	Lifting worker C	4	4	4	4	4	4	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12 ~~8~~	12 ~~8~~	8	8				
W39	Lifting worker D	4	4	4	4	4	4	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12 ~~8~~	12 ~~8~~	8					
W40	Lifting worker E	4	4	4	4	4	4	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12 ~~8~~	12 ~~8~~	8					
W41	Painter A																												
W42	Painter B																												
W43	Painter C																												
W44	Painter D																												
W45	Painter E																												

Figure A-3: revised schedule applying Option A in the case type 2

Two criteria (project delay and re-organization effort) are evaluated to examine the quality of the revised schedules. Table A-1 summarizes the results of implementation of three change options. By comparing the number of extended days pertaining to the final task(s) of the project, option B is the best choice in this case. This result matches the one acquired by applying the DCM approach. The DCM approach is considered as effectiveness to deal with this change scenario.

Criteria	Option B	Option C	Option A
Number of extended days pertaining to the final task(s) of the project	0	1	2
Number of the modified entries	14	20	14

Table A-1: results applying three change options in the case type 2

Step 4: Analysis

In view of small amounts of affected workload in this change scenario, applying option B is easier to decrease the risk of impacting more downstream tasks than applying option C. This case indicates applying option B didn't impact other later tasks except for the replacement task. But applying option C leads to the delay of other later tasks and easily results to more disturbances to the existing organization than applying option B. This situation is more obvious when this change scenario happens in small size of technical group. To the latest and least flexible option A, taking patch actions leads to more delay of the affected critical tasks than taking repair actions. Therefore, we can consider option B is the best choice to deal with this change scenario.

A-2: example of the case type 3

Change scenario: plumber L and M (W18 & 19) will be both absent from Day 19 to Day 39.

Information: absence of the workers (W18, 19) causes 42 affected workloads of task 3, 4, and 7.

Step 1: Selection by assessing level of change impact

a. Checking factor of task criticality: the outstanding task 3, 4, and 7 are non-critical. Therefore, one of two Options (C or A) is available in view of table 4-1.

b. Calculating value of the proportion of affected workloads. The proportion of affected workloads is equal to 0.0316, which is larger than 0.0112. This change scenario has high change impact in view of table 4-1 of threshold value table.

c. Calculating value of maximum additional workloads. The maximum additional workload is equal to 8.37, which is larger than 2.76. This change scenario has high change impact in view of table 4-1 of threshold value table.

Totally, we assess this change scenario has high change impact and option C should be selected to deal with this change scenario.

Step 2: Implementation

Suppose applying Option C, three replacement workers (W20, 21, and22) are assigned to work on the affected workloads of W18 and W19 through repair actions highlighted in the blocks with dark shaded areas in Figure A-4. Then, we revise the schedule by patch actions to minimize the disturbance to the existing organization at the later revision actions. Finally, the changes cause 6-day delay of the last delayed non-critical task 8 but no delay of the project duration.

Worker	Duration / Worker	Day 15	Day 16	Day 17	Day 18	Day 19	Day 20	Day 21	Day 22	Day 23	Day 24	Day 25	Day 26	Day 27	Day 28	Day 29	Day 30	Day 31	Day 32	Day 33	Day 34	Day 35	Day 36	Day 37	Day 38	Day 39	Day 40	Day 41	Day 42	Day 43	Day 44	Day 45	Day 46	Day 47	Day 48	Day 49	Day 50	Day 51	Day 52	Day 53
W10	Plumber A	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12									
W11	Plumber B	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12									
W12	Plumber C	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12									
W13	Plumber D	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12									
W14	Plumber E	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12									
W15	Plumber F	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12									
W16	Plumber G	3	3	3	3	3	3	3	3	3	3	3	3	7	7	7	7	12	12	12	12	12	12	12		12	12	12	12	12	12									
W17	Plumber H	3	3	3	3	3	3	3	3	3	3	3	3	7	7	7	7	7	7	7	7	7	7	12	12	12	12	12	12	8	8	8	8	8	8	8	8	8		
W18	Plumber I	3	3	3	3	3	3	3	3	3	3	3	3	7	7	7	7	7	7	7	7	7	7	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8	8	8	
W19	Plumber J	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	7	7	7	7	7	7	7	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8	8		
W20	Plumber K	3	3	3	3	4	3 4	3 4	3 4	3 4	3 4	4	4	4	4	4	4	4 ~~7~~	4 ~~7~~	4 ~~7~~	4 ~~7~~	4 ~~7~~	4 ~~7~~	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8		
W21	Plumber L	3	3	3	3	4	3 4	3 4	3 4	3 4	3 4	4	4	4	4	4	4	4 ~~7~~	4 ~~7~~	4 ~~7~~	4 ~~7~~	4 ~~7~~	4 ~~7~~	4 ~~7~~	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8		
W22	Plumber M	11				4	3 4	3 4	3 4	3 4	3 4	4	4	4	4	4	4	4 ~~7~~	4 ~~7~~	4 ~~7~~	4 ~~7~~	4 ~~7~~	4 ~~7~~	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8		
W23	Plumber N	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	7	7	7	7	7	7	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8		
W24	Plumber O	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	7	7	7	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8	8		
W25	Welder A	6										11	11	11	11														9	9	9	9	9	9	9	9	9	9	9	9
W26	Welder B											11	11	11	11																	13	13	13	13	13	13	13	13	13

Figure A-4: revised schedule applying Option C in the case type 3

Step 3: Comparison

While applying Option B to revise the schedule format, the affected task 3 should be done by the replacement worker (W21) through repair actions highlighted in the blocks with dark shaded areas in Figure A-5. Then, we revise the schedule by patch actions to minimize the disturbance to the existing organization at the later revision actions. Finally, the changes cause 1-day delay of the last delayed critical task 12 that causes 1-day delay of the project duration.

Worker	Duration / Worker	Day 15	Day 16	Day 17	Day 18	Day 19	Day 20	Day 21	Day 22	Day 23	Day 24	Day 25	Day 26	Day 27	Day 28	Day 29	Day 30	Day 31	Day 32	Day 33	Day 34	Day 35	Day 36	Day 37	Day 38	Day 39	Day 40	Day 41	Day 42	Day 43	Day 44	Day 45	Day 46	Day 47	Day 48	Day 49	Day 50	Day 51	Day 52	Day 53
W8	Riveter E	6	6		3	3	3	3	3	3	3																		9	9	9	9	9	9	9	9	9	9	9	9
W9	Riveter F	6	6				3	3	3	3	3																		9	9	9	9	9	9	9	9	9	9	9	9
W10	Plumber A	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12								
W11	Plumber B	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12								
W12	Plumber C	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12								
W13	Plumber D	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12								
W14	Plumber E	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12								
W15	Plumber F	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12								
W16	Plumber G	3	3	3	3	3	3	3	3	3	3	3	3	3 ~~7~~	3 ~~7~~	3 ~~7~~	3 ~~7~~	12	12	12	12	12	12	12		12	12	12	12	12	12									
W17	Plumber H	3	3	3	3	3	3	3	3	3	3	3	3	3 ~~7~~	3 ~~7~~	3 ~~7~~	3 ~~7~~	7	7	7	7	7	7	7 ~~12~~	7 ~~12~~	7 ~~12~~	7 ~~12~~	7 ~~12~~	7 ~~12~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8			
W18	Plumber I	3	3	3	3	3	3	3	3	3	3	3	3	7	7	7	7	7	7	7	7	7	7	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8			
W19	Plumber J	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	7	7	7	7	7	7	7	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8	8		
W20	Plumber K	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4 ~~7~~	4 ~~7~~	4 ~~7~~	4 ~~7~~	7	7	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8	8		
W21	Plumber L	3	3	3	3	3 4	3 4	3 4	3 4	3 4	3 4	3 4	4	4	4	4	7 4	4 ~~7~~	4 ~~7~~	4 ~~7~~	4 ~~7~~	7	7	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8	8	8		
W22	Plumber M	11				4	4	4	4	4	4	4	4	4	4	4	4	4 ~~7~~	4 ~~7~~	4 ~~7~~	4 ~~7~~	7	7	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8	8			
W23	Plumber N	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	7	7	7	7	7	7	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8	8			
W24	Plumber O	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	7	7	7	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8	8			
W25	Welder A	6										11	11	11	11														9	9	9	9	9	9	9	9	9	9	9	9
W26	Welder B											11	11	11	11																	13	13	13	13	13	13	13	13	13

Figure A-5: revised schedule applying Option B in the case type 3

While applying Option A, the affected task 3 will be done by 2 replacement workers (W16, 17) after they complete current works through patch actions highlighted in the blocks with light shaded area in Figure A-6. Then, we revise the schedule by patch actions to minimize the disturbance to the existing organization at the later revision actions. Finally, the last affected critical task 12 is 2-day delay that causes 2 days delay of the project duration.

Worker	Duration / Worker	Day 15	Day 16	Day 17	Day 18	Day 19	Day 20	Day 21	Day 22	Day 23	Day 24	Day 25	Day 26	Day 27	Day 28	Day 29	Day 30	Day 31	Day 32	Day 33
W8	Riveter E	6	6		3	3	3	3	3	3	3									
W9	Riveter F	6	6				3	3	3	3	3									
W10	Plumber A	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12
W11	Plumber B	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12
W12	Plumber C	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12
W13	Plumber D	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12
W14	Plumber E	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12
W15	Plumber F	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12
W16	Plumber G	3	3	3	3	3	3	3	3	3	3	3	3	3 ~~7~~	3 ~~7~~	3 ~~7~~	3 ~~7~~	3 ~~12~~	3 ~~12~~	3 ~~12~~
W17	Plumber H	3	3	3	3	3	3	3	3	3	3	3	3	3 ~~7~~	3 ~~7~~	3 ~~7~~	3 ~~7~~	3 ~~7~~	3 ~~7~~	3 ~~7~~
W18	Plumber I	3	3	3	3	3	3	3	3	3	3	3	3	7	7	7	7	7	7	7
W19	Plumber J	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	7	7	7	7
W20	Plumber K	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4 ~~7~~	7	7
W21	Plumber L	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4 ~~7~~	7	7
W22	Plumber M	11				4	4	4	4	4	4	4	4	4	4	4	4	4 ~~7~~	4 ~~7~~	7
W23	Plumber N	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	7	7	7
W24	Plumber O	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	7	7	7
W25	Welder A	6										11	11	11	11					
W26	Welder B											11	11	11	11					

Worker	Duration / Worker	Day 34	Day 35	Day 36	Day 37	Day 38	Day 39	Day 40	Day 41	Day 42	Day 43	Day 44	Day 45	Day 46	Day 47	Day 48	Day 49	Day 50	Day 51	Day 52
W8	Riveter E									9	9	9	9	9	9	9	9	9	9	9
W9	Riveter F									9	9	9	9	9	9	9	9	9	9	9
W10	Plumber A	12	12	12	12	12	12	12	12	12	12	12	12							
W11	Plumber B	12	12	12	12	12	12	12	12	12	12	12	12							
W12	Plumber C	12	12	12	12	12	12	12	12	12	12	12	12	12						
W13	Plumber D	12	12	12	12	12	12	12	12	12	12	12	12							
W14	Plumber E	12	12	12	12	12	12	12	12	12	12	12	12							
W15	Plumber F	12	12	12	12	12	12	12	12	12	12	12	12							
W16	Plumber G	12	12	12	12	12	12	12	12	12	12	12	12							
W17	Plumber H	3 ~~7~~	7	7	7 ~~12~~	7 ~~12~~	7 ~~12~~	7 ~~12~~	7 ~~12~~	7 ~~12~~	7 ~~8~~	8	8	8	8	8	8	8		
W18	Plumber I	7	7	7	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8	8		
W19	Plumber J	7	7	7	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8		
W20	Plumber K	7	7	7	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8	8		
W21	Plumber L	7	7	7	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8	8		
W22	Plumber M	7	7	7	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8	8		
W23	Plumber N	7	7	7	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8	8		
W24	Plumber O	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8	8		
W25	Welder A									9	9	9	9	9	9	9	9	9	9	9
W26	Welder B												13	13	13	13	13	13	13	13

Figure A-6: revised schedule applying Option A in the case type 3

Two criteria (project delay and re-organization effort) are evaluated to examine the quality of the revised schedules. Table A-2 summarizes the results of implementation of three change options. By comparing the number of extended days pertaining to the final task(s) of the project and the number of modified entries, option C is the best choice in this case. This result matches the one selected by applying the DCM approach and the DCM approach is considered as effectiveness to deal with this change scenario.

Criteria	Option C	Option B	Option A
Number of extended days pertaining to the final task(s) of the project	0	1	2
Number of the modified entries	118	112	95

Table A-2: results applying three change options in the case type 3

Step 4: Analysis

In view of large amounts of affected workload in this change scenario, flexibility is fully shown while applying option C to revise the schedule. As the most flexible change option, applying Option C can timely adjust allocation of resources and avoid the later critical tasks impacted by the delay of the former affected tasks. Option B has less flexible to deal with downstream critical tasks' delay. Furthermore, Option A is applied to seriously delay the whole project duration because the affected workloads cannot be completed on time. Therefore, we can consider option C is the best choice to deal with this change scenario.

A-3: Example of the case type 4

Change scenario: plumber L (W21) will be absent from Day 19 to Day 22 then plumber K (W20) will be absent from Day 23 to 27.

Information: absence of the workers (W20, 21) causes 9 affected workloads of task 4.

Step 1: Selection by assessing level of change impact

a. Checking factor of task criticality: affected task 4 is a non-critical task. Therefore, one of two Options (C or A) is available in table 4-1.

b. Calculating value of the proportion of affected workloads. The proportion of affected workloads is equal to 0.0068, which is smaller than 0.0112. This change scenario has low change impact in view of threshold value table.

c. Calculating value of maximum additional workloads. The maximum additional workload is equal to 2.25, which is smaller than 2.76. This change scenario has low change impact in view of table 4-1.

Totally, we assess this change scenario has low change impact. Option A should be selected to deal with this change scenario.

Step 2: Implementation

While applying Option A, the outstanding task 4 will be done by 4 replacement workers (W19 to W22) after they complete current works through patch actions highlighted in the blocks with light shaded area in Figure A-7. Then, we revise the schedule by patch actions to minimize the disturbance to the existing organization at the later revision actions. Finally, the last affected critical task 8 is 1-day delay but no project duration delay.

Worker	Duration / Worker	Day 15	Day 16	Day 17	Day 18	Day 19	Day 20	Day 21	Day 22	Day 23	Day 24	Day 25	Day 26	Day 27	Day 28	Day 29	Day 30	Day 31	Day 32	Day 33	Day 34	Day 35	Day 36	Day 37	Day 38	Day 39	Day 40	Day 41	Day 42	Day 43	Day 44	Day 45	Day 46	Day 47	Day 48	Day 49	Day 50
W10	Plumber A	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12						
W11	Plumber B	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12						
W12	Plumber C	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12						
W13	Plumber D	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12						
W14	Plumber E	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12						
W15	Plumber F	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12						
W16	Plumber G	3	3	3	3	3	3	3	3	3	3	3	3	7	7	7	7	12	12	12	12	12	12	12		12	12	12	12	12	12						
W17	Plumber H	3	3	3	3	3	3	3	3	3	3	3	3	7	7	7	7	7	7	7	7	7	7	12	12	12	12	12	12	8	8	8	8	8			
W18	Plumber I	3	3	3	3	3	3	3	3	3	3	3	3	7	7	7	7	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8	8	8			
W19	Plumber J	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4 ~~7~~	4 ~~7~~	4 ~~7~~	7	7	7	7	7	7	7	7 ~~8~~	8	8	8	8	8	8	8			
W20	Plumber K	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4 ~~7~~	4 ~~7~~	7	7	7	7	7	7	7	7 ~~8~~	8	8	8	8	8	8	8			
W21	Plumber L	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4 ~~7~~	4 ~~7~~	7	7	7	7	7	7	7	7 ~~8~~	8	8	8	8	8	8	8			
W22	Plumber M	11				4	4	4	4	4	4	4	4	4	4	4	4	4 ~~7~~	4 ~~7~~	7	7	7	7	7	7	7	7 ~~8~~	8	8	8	8	8	8	8			
W23	Plumber N	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	7	7	7	7	7	7	7	7	7	7 ~~8~~	8	8	8	8	8	8	8			
W24	Plumber O	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	7	7	7	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8	8			
W25	Welder A	6										11	11	11	11														9	9	9	9	9	9	9	9	9
W26	Welder B											11	11	11	11																	13	13	13	13	13	13
W27	Welder C				3	3	3	3	3	3	3	11	11	11																		13	13	13	13	13	13
W28	Welder D																7	7	7	7	7	7	7	7	7	7						13	13	13	13	13	13
W29	Welder E																5	5	5	5	5	5	5	5	5	5			9	9	9	13	13	13	13	13	13
W30	Welder F																5	5	5	5	5	5	5	5	5	5			9	9	9	9	9	9	9	9	9
W31	Welder G																5	5	5	5	5	5	5	5	5	5			9	9	9	9	9	9	9	9	9

Figure A-7: revised schedule applying Option A in the case type 4

Step 3: Comparison

Suppose applying Option C, two replacement workers (W17, 18) are assigned to work on the affected workloads of W20 and W21 through repair actions highlighted in the blocks with dark shaded areas in Figure A-8. Then, we revise the schedule by patch actions to minimize the disturbance to the existing organization at the later revision actions. Finally, the changes cause the 1-day delay of the last delayed critical task 12 that causes 1-day delay of the project duration.

Worker	Duration / Worker	Day 15	Day 16	Day 17	Day 18	Day 19	Day 20	Day 21	Day 22	Day 23	Day 24	Day 25	Day 26	Day 27	Day 28	Day 29	Day 30	Day 31	Day 32	Day 33	Day 34	Day 35	Day 36	Day 37	Day 38	Day 39	Day 40	Day 41	Day 42	Day 43	Day 44	Day 45	Day 46	Day 47	Day 48	Day 49
W10	Plumber A	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12					
W11	Plumber B	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12				
W12	Plumber C	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12				
W13	Plumber D	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12				
W14	Plumber E	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12					
W15	Plumber F	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12					
W16	Plumber G	3	3	3	3	3	3	3	3	3	3	3	3	3 ~~7~~	3 ~~7~~	7	7	7 ~~12~~	7 ~~12~~	7 ~~12~~	7 ~~12~~	7 ~~12~~	7 ~~12~~	12	12	12	12	12	12	12	12					
W17	Plumber H	3	3	3	3	3	4 ~~3~~	4 ~~3~~	3	4 ~~3~~	4 ~~3~~	4 ~~3~~	3	3 ~~7~~	3 ~~7~~	7	7	7	7	7	7	7	7	12	12	12	12	12	12	12 ~~8~~	12 ~~8~~	8	8			
W18	Plumber I	3	3	3	3	3	4 ~~3~~	4 ~~3~~	3	3	4 ~~3~~	4 ~~3~~	3	3 ~~7~~	3 ~~7~~	7	7	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8	8	8		
W19	Plumber J	3	3	3	3	3	3	3	3	3	3	3	3 ~~4~~	3 ~~4~~	3 ~~4~~	4	4 ~~7~~	4 ~~7~~	7	7	7	7	7	7	7	7	8	8	8	8	8	8	8	8		
W20	Plumber K	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4 ~~7~~	7	7	7	7	7	7	7	7	8	8	8	8	8	8	8	8		
W21	Plumber L	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8	8	8		
W22	Plumber M	11				4	4	4	4	4	4	4	4	4	4	4	4	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8	8			
W23	Plumber N	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8	8			
W24	Plumber O	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	7	7	7	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8	8			
W25	Welder A	6										11	11	11	11														9	9	9	9	9	9	9	9
W26	Welder B											11	11	11	11																	13	13	13	13	13
W27	Welder C				3	3	3	3	3	3	3	11	11	11																		13	13	13	13	13

Figure A-8: revised schedule applying Option C in the case type 4

While applying Option B to revise the schedule format, the affected task 4 should be done by the replacement worker (W17) through repair actions highlighted in the blocks with dark shaded areas in Figure A-9. Then, we revise the schedule by patch actions to minimize the disturbance to the existing organization at the later revision actions. Finally, the changes lead to 1-day delay of the last delayed critical task 12 that causes 1-day delay of the project duration.

Worker	Duration / Worker	Day 15	Day 16	Day 17	Day 18	Day 19	Day 20	Day 21	Day 22	Day 23	Day 24	Day 25	Day 26	Day 27	Day 28	Day 29	Day 30	Day 31	Day 32	Day 33	Day 34	Day 35	Day 36	Day 37	Day 38	Day 39	Day 40	Day 41	Day 42	Day 43	Day 44	Day 45	Day 46	Day 47	Day 48	Day 49
W10	Plumber A	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12					
W11	Plumber B	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12				
W12	Plumber C	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12				
W13	Plumber D	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12				
W14	Plumber E	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12					
W15	Plumber F	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12					
W16	Plumber G	3	3	3	3	3	3	3	3	3	3	3	3	3 ~~7~~	3 ~~7~~	3 ~~7~~	7	7 ~~12~~	7 ~~12~~	7 ~~12~~	7 ~~12~~	7 ~~12~~	7 ~~12~~	12	12	12	12	12	12	12	12					
W17	Plumber H	3	3	3	3	4 ~~3~~	4 ~~3~~	4 ~~3~~	4 ~~3~~	4 ~~3~~	4 ~~3~~	4 ~~3~~	4 ~~3~~	4 ~~7~~	7	7	7	7	7	7	7	7	7	12	12	12	12	12	12	12 ~~8~~	12 ~~8~~	8	8			
W18	Plumber I	3	3	3	3	3	3	3	3	3	3	3	3	3 ~~7~~	3 ~~7~~	7	7	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8	8	8		
W19	Plumber J	3	3	3	3	3	3	3	3	3	3	3	3 ~~4~~	3 ~~4~~	3 ~~4~~	4	4 ~~7~~	4 ~~7~~	7	7	7	7	7	7	7	7	8	8	8	8	8	8	8	8		
W20	Plumber K	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4 ~~7~~	7	7	7	7	7	7	7	7	8	8	8	8	8	8	8	8		
W21	Plumber L	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8	8	8		
W22	Plumber M	11				4	4	4	4	4	4	4	4	4	4	4	4	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8	8			
W23	Plumber N	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8	8			
W24	Plumber O	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	7	7	7	7	7	7	7 ~~8~~	7 ~~8~~	7 ~~8~~	8	8	8	8	8	8	8			
W25	Welder A	6										11	11	11	11														9	9	9	9	9	9	9	9
W26	Welder B											11	11	11	11																	13	13	13	13	13

Figure A-9: revised schedule applying Option B in the case type 4

Two criteria (project delay and re-organization effort) are evaluated to examine the quality of the revised schedules. Table A-3 summarizes the results of implementation of three change options. By comparing the number of extended days pertaining to the final task(s) of the project and the number of modified entries, option B is the best choice in this case. This result is the same as the one selected by the DCM approach and the DCM approach is considered as effectiveness to deal with this change scenario.

Criteria	**Option A**	**Option B**	**Option C**
Number of extended days pertaining to the final task(s) of the project	0	1	1
Number of the modified entries	27	40	41

Table A-3: results applying three change options in the case type 4

Step 4: Analysis

In view of small amounts of affected workload in this change scenario, applying option B or C is easier to increase the risk of impacting more downstream tasks than applying option A. This case indicates that applying option B or C easily results to more disturbances to the existing organization than option A. In this case, applying option B or C both impacts the later critical task 12. Its delay causes the project delay. To the latest and least flexible option A, taking patch actions didn't impact downstream critical tasks and didn't cause the project delay. Therefore, we can consider option A is the best choice to deal with this change scenario.

A-4: Example of the specific case type a

Change scenario: Riveter B (W5) will be absent from Day 7 to Day 14.

Information: absence of the worker (W5) causes 8 affected workloads of Task 10.

Step 1: Selection by assessing level of change impact

a. Checking factor of task criticality: the outstanding task 10 is the critical ones. Therefore, one of two Options (C or B) is available in view of table 4-1.

b. Calculating value of the proportion of affected workloads. The proportion of affected workloads is equal to 0.0060, which is smaller than 0.0117. This change scenario has medium change impact in view of threshold value table.

c. Calculating value of maximum additional workload. The maximum additional workload is equal to 4.00, which is larger than 2.14. This change scenario has high change impact in view of threshold value table.

After comprehensive evaluation, we assess this change scenario has high change impact and option C should be selected to deal with this change scenario.

Step 2: Implementation

Suppose applying Option C, two replacement workers (W8 and W9) are assigned to work on the affected workloads of W5 through repair actions highlighted in the blocks with dark shaded areas in Figure A-10. Then, we revise the schedule by patch actions to minimize the disturbance to the existing organization at the later revision actions. Finally, the changes cause no delay of the project duration.

Worker	Duration / Worker	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12	Day 13	Day 14	Day 15	Day 16	Day 17	Day 18	Day 19	Day 20	Day 21	Day 22	Day 23	Day 24
W1	Benchworker A																		3	3	3	3	3	3	3
W2	Benchworker B																				3	3	3	3	3
W3	Benchworker C																								
W4	Riveter A						10	10	10	10	10	10	10	10	10				11	11	11	11			
W5	Riveter B						10	10	10	10	10	10	10	10	10				11	11	11	11			
W6	Riveter C					2	2	2	2	2	10	10	10	10	10										
W7	Riveter D					2	2	2	2		6	6	6	6	6	6	6	6	6						
W8	Riveter E					2	2	2	2	2	10 ~~6~~	10 ~~6~~	10 ~~6~~	10 ~~6~~	6	6	6	6	6 ~~3~~	3	3	3	3	3	3
W9	Riveter F					2	2	2	2	2	10 ~~6~~	10 ~~6~~	10 ~~6~~	10 ~~6~~	6	6	6	6	6	3	3	3	3	3	3
W10	Plumber A	1	1	1	1	1					3	3	3	3	3	11	11	11	11	11	11	11	11	11	11
W11	Plumber B	1	1	1	1	1					3	3	3	3	3	11	11	11	11	11	11	11	11	11	11
W12	Plumber C	1	1	1	1	1					3	3	3	3	3	11	11	11	11	11	11	11	11	11	11
W13	Plumber D	1	1	1	1	1					3	3	3	3	3	11	11	11	11	11	11	11	11	11	11
W14	Plumber E	1	1	1	1	1					3	3	3	3	3	11	11	11	11	11	11	11	11	11	11

Figure A-10: revised schedule applying Option C in the specific case type a

Step 3: Comparison

While applying Option B to revise the schedule format, the affected task 10 should be done by the replacement worker (W9) through repair actions highlighted in the blocks with dark shaded areas in Figure A-11. Then, we revise the schedule by patch actions to minimize the disturbance to the existing organization at the later revision actions. Finally, the project's duration is not delayed but more number of modified entries than applying option C.

Worker	Duration / Worker	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12	Day 13	Day 14	Day 15	Day 16	Day 17	Day 18	Day 19	Day 20	Day 21	Day 22	Day 23	Day 24
W1	Benchworker A																		3	3	3	3	3	3	3
W2	Benchworker B																				3	3	3	3	3
W3	Benchworker C																								
W4	Riveter A						10	10	10	10	10	10	10	10	10				11	11	11	11			
W5	Riveter B						10	10	10	10	10	10	10	10	10				11	11	11	11			
W6	Riveter C					2	2	2	2	2	10	10	10	10	10										
W7	Riveter D					2	2	2	2		2 ~~6~~	2 ~~6~~	6	6	6	6	6	6	6						
W8	Riveter E					2	2	2	2	2	2 ~~6~~	6	6	6	6	6	6	6	6 ~~3~~	3	3	3	3	3	3
W9	Riveter F					2	2	10 ~~2~~	10 ~~2~~	10 ~~2~~	10 ~~6~~	10 ~~6~~	10 ~~6~~	10 ~~6~~	10 ~~6~~	6	6	6	6	3	3	3	3	3	3
W10	Plumber A	1	1	1	1	1					3	3	3	3	3	11	11	11	11	11	11	11	11	11	11
W11	Plumber B	1	1	1	1	1					3	3	3	3	3	11	11	11	11	11	11	11	11	11	11
W12	Plumber C	1	1	1	1	1					3	3	3	3	3	11	11	11	11	11	11	11	11	11	11
W13	Plumber D	1	1	1	1	1					3	3	3	3	3	11	11	11	11	11	11	11	11	11	11
W14	Plumber E	1	1	1	1	1					3	3	3	3	3	11	11	11	11	11	11	11	11	11	11

Figure A-11: revised schedule applying Option B in the specific case type a

While applying Option A, the affected Task 10 will be done by 2 replacement workers (W4, 6) through patch actions after they complete current works highlighted in the blocks with light shaded area in Figure A-12. Then, we revise the schedule by patch actions to minimize the disturbance to the existing organization at the later revision actions. Finally, 5-day delay of the last affected critical task 10 causes the whole project's 5 days delay.

Worker	Duration / Worker	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12	Day 13	Day 14	Day 15	Day 16	Day 17	Day 18	Day 19	Day 20	Day 21
W1	Benchworker A																		3	3	3	3
W2	Benchworker B																				3	3
W3	Benchworker C																					
W4	Riveter A						10	10	10	10	10	10	10	10	10	10	10	10	11	11	11	11
W5	Riveter B						10	10	10	10	10	10	10	10	10				11	11	11	11
W6	Riveter C					2	2	2	2	2	10	10	10	10	10	10	10	10	10	10		
W7	Riveter D					2	2	2	2		6	6	6	6	6							
W8	Riveter E					2	2	2	2	2	6	6	6	6	6	6	6		3	3	3	3
W9	Riveter F					2	2	2	2	2	6	6	6	6	6	6	6				3	3
W10	Plumber A	1	1	1	1	1					3	3	3	3	3	11	11	11	11	11	11	11
W11	Plumber B	1	1	1	1	1					3	3	3	3	3	11	11	11	11	11	11	11
W12	Plumber C	1	1	1	1	1					3	3	3	3	3	11	11	11	11	11	11	11
W13	Plumber D	1	1	1	1	1					3	3	3	3	3	11	11	11	11	11	11	11
W14	Plumber E	1	1	1	1	1					3	3	3	3	3	11	11	11	11	11	11	11

Figure A-12: revised schedule applying Option A in the specific case type a

Two criteria (project delay and re-organization effort) are evaluated to examine the quality of the revised schedules. Table A-4 summarizes the results of implementation of three change options. By comparing the number of extended days pertaining to the final task(s) of the project and the number of the modified entries, Option C is the best choice in this case. This result matches the one selected by applying the DCM approach. The DCM approach is considered as effectiveness to deal with this change scenario.

Criteria	Option C	Option B	Option A
Number of extended days pertaining to the final task(s) of the project	0	0	5
Number of the modified entries	13	20	8

Table A-4: results applying three change options in the specific case type a

Step 4: Analysis

This case shows validity of worker importance in estimating the level of change impact. The validity of worker importance easily occurs in small size of technical team, such as the riveter team in this case. In figure A-12 of applying option A, less remaining workers to do the replacement causes more delay of the outstanding task 10 than applying two other options. It means if revision actions aren't taken earlier, delay of the project will be serious. This change scenario has high change impact and requires other replacement workers to work on affected tasks immediately (repair action). In this case, the most flexible option C can be applied for a little later and not to impact task 2. But less flexible option B has to be applied immediately to impact task 2. Applying option B causes more disturbances to the existing organization than applying option C in this case. Therefore, we can consider option B is the best choice to deal with this change scenario.

A-5 example of the specific case type b

Change scenario: lifting worker C (W38) will be absent from Day 40 to Day 44.

Information: absence of the workers (W38) causes 5 affected workloads of task 12. Only one replacement worker is found.

Step 1: Selection by assessing level of change impact

a. Checking factor of task criticality: the outstanding task 12 is critical and only one potential replacement worker is found.

b. Calculating value of the proportion of affected workloads. The proportion of affected workloads is equal to 0.0038, which is smaller than 0.0117. This change scenario has medium change impact in view of table 4-1.

c. Calculating value of maximum additional workload. The maximum additional workload is equal to 1.00, which is smaller than 2.14. This change scenario has medium change impact in view of table 4-1.

Totally, we assess this change scenario medium change impact and Option B should be selected to deal with this change scenario.

Step 2: Implementation

While applying Option B to revise the schedule format, the affected task 12 should be done by the replacement worker (W36) through repair actions highlighted in the blocks with dark shaded areas in Figure A-13. Then, we revise the schedule by patch actions to minimize the disturbance to the existing organization at the later revision actions. Finally, the last affected non-critical task 8 is 1-day delay but no project duration delay.

Worker	Duration / Worker	Day 30	Day 31	Day 32	Day 33	Day 34	Day 35	Day 36	Day 37	Day 38	Day 39	Day 40	Day 41	Day 42	Day 43	Day 44	Day 45	Day 46	Day 47	Day 48	Day 49	Day 50	Day 51	Day 52	Day 53	Day 54	Day 55	Day 56
W32	Gas welder A	7	7	7	7	7	7	7	7					9	9	9					9	9	9	9	9			
W33	Gas welder B													9	9	9	13	13	13	13	13	13	9	9	9			
W34	Gas welder C	5	5	5	5	5	5	5	5	5	5						13	13	13	13	13	13	13	13	13	13	13	13
W35	Gas welder D	5	5	5	5	5	5	5	5	5	5						13	13	13	13	13	13	13	13	13	13	13	13
W36	Lifting worker A	4	8	8	8	8	8	8	8	8	8	12 8	12 8	12 8	12 8	12 8	8	8	8									
W37	Lifting worker B	4	8	8	8	8	8	8	8	8	8	12	12	12	12	12	8	8	8									
W38	Lifting worker C	4	12	12	12	12	12	12	12	12	12	12	12	12	12	12	8	8	8									
W39	Lifting worker D	4	12	12	12	12	12	12	12	12	12	12	12	12	12	12	8	8	8									
W40	Lifting worker E	4	12	12	12	12	12	12	12	12	12	12	12	12	12	12	8	8	8									
W41	Painter A																											
W42	Painter B																											
W43	Painter C																											
W44	Painter D																											
W45	Painter E																											

Figure A-13: revised schedule applying Option B in the specific case type b

Step 3: Comparison

While applying Option A, the affected task 12 will be done by the replacement workers (W36 to 40) after they complete current works through patch actions highlighted in the blocks with light shaded area in Figure A-14. Then, we revise the schedule by patch actions to minimize the disturbance to the existing organization at the later revision actions. Finally, the changes result to 1-day delay of the last delayed critical task 12 that further causes 1-day delay of the project duration.

Worker	Duration / Worker	Day 30	Day 31	Day 32	Day 33	Day 34	Day 35	Day 36	Day 37	Day 38	Day 39	Day 40	Day 41	Day 42	Day 43	Day 44	Day 45	Day 46	Day 47	Day 48	Day 49	Day 50	Day 51	Day 52	Day 53	Day 54	Day 55	Day 56
W32	Gas welder A	7	7	7	7	7	7	7	7					9	9	9					9	9	9	9	9			
W33	Gas welder B													9	9	9	13	13	13	13	13	13	9	9	9			
W34	Gas welder C	5	5	5	5	5	5	5	5	5	5						13	13	13	13	13	13	13	13	13	13	13	13
W35	Gas welder D	5	5	5	5	5	5	5	5	5	5						13	13	13	13	13	13	13	13	13	13	13	13
W36	Lifting worker A	4	8	8	8	8	8	8	8	8	8	8	8	8	8	8	12 8	8	8									
W37	Lifting worker B	4	8	8	8	8	8	8	8	8	8	12	12	12	12	12	12 8	8	8									
W38	Lifting worker C	4	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12 8	8	8									
W39	Lifting worker D	4	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12 8	8	8									
W40	Lifting worker E	4	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12 8	8	8									
W41	Painter A																											
W42	Painter B																											
W43	Painter C																											
W44	Painter D																											

Figure A-14: revised schedule applying Option A in the specific case type b

Two criteria (project delay and re-organization effort) are evaluated to examine the quality of the revised schedules. Table A-5 summarizes the results of implementation of two change options. By comparing the number of extended days pertaining to the final task(s) of the project and the number of the modified entries, Option B is the best choice in this case. This result matches the one selected by the DCM approach and the DCM approach is considered as effectiveness to deal with this change scenario.

Criteria	**Option B**	**Option A**
Number of extended days pertaining to the final task(s) of the project	0	1
Number of the modified entries	10	10

Table A-5: results applying the change options in the specific case type b

Step 4: Analysis

In view of only one replacement worker is found to take repair action in this change scenario, the outstanding critical task 12 requires taking repair action to minimize the project delay. As option C cannot be applied for this change scenario because of only one replacement, applying option B can decrease the project delay by taking repair action. Therefore, we can consider option B is the better choice to deal with this change scenario.

A-6: example of the specific case type c

Change scenario: lifting worker B (W37) will be absent from Day 32 to Day 38.

Information: absence of the workers (W37) causes 7 affected workloads of task 8.

Step 1: Selection by assessing level of change impact

a. Checking factor of task criticality: the outstanding task 8 is a non-critical task.

b. Calculating value of the proportion of affected workloads. The proportion of affected workloads is equal to 0.0053, which is smaller than 0.0112. This change scenario has low change impact in view of table 4-1 of threshold value table.

c. Calculating value of maximum additional workload. The maximum additional workload is equal to 1.40, which is smaller than 2.76. This change scenario has low change impact in view of table 4-1 of threshold value table.

Totally, we assess this change scenario has low change impact and option A should be selected to deal with this change scenario.

Step 2: Implementation

While applying Option A, the outstanding task 8 will be done by 5 replacement workers (W36 to 40) after they complete current works through patch actions highlighted in the blocks with light shaded area in Figure A-15. Then, we revise the schedule by patch actions to minimize the disturbance to the existing organization at the later revision actions. Finally, the last affected critical task 8 is 2-day delay but no project duration delay.

Worker	Duration / Worker	Day 27	Day 28	Day 29	Day 30	Day 31	Day 32	Day 33	Day 34	Day 35	Day 36	Day 37	Day 38	Day 39	Day 40	Day 41	Day 42	Day 43	Day 44	Day 45	Day 46	Day 47	Day 48	Day 49	Day 50	Day 51	Day 52	Day 53
W32	Gas welder A				7	7	7	7	7	7	7	7					9	9	9					9	9	9	9	9
W33	Gas welder B	11	11	11													9	9	9	13	13	13	13	13	13	9	9	9
W34	Gas welder C				5	5	5	5	5	5	5	5	5	5						13	13	13	13	13	13	13	13	13
W35	Gas welder D				5	5	5	5	5	5	5	5	5	5						13	13	13	13	13	13	13	13	13
W36	Lifting worker A	4	4	4	4	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8						
W37	Lifting worker B	4	4	4	4	8	8	8	8	8	8	8	8	8	12	12	12	12	12	8	8	8	8					
W38	Lifting worker C	4	4	4	4	12	12	12	12	12	12	12	12	12	12	12	12	12	12	8	8	8	8					
W39	Lifting worker D	4	4	4	4	12	12	12	12	12	12	12	12	12	12	12	12	12	12	8	8	8						
W40	Lifting worker E	4	4	4	4	12	12	12	12	12	12	12	12	12	12	12	12	12	12	8	8	8						
W41	Painter A																											
W42	Painter B																											
W43	Painter C																											
W44	Painter D																											
W45	Painter E																											

Figure A-15: revised schedule applying Option A in the specific case type c

Step 3: Comparison

Suppose applying Option C, two replacement workers (W39, 40) are assigned to work on the affected workloads of W37 through repair actions highlighted in the blocks with dark shaded areas in Figure A-16. Then, we revise the schedule by patch actions to minimize the disturbance to the existing organization at the later revision actions. Finally, the changes cause 2-day delay of the last delayed critical task 12, further leading to 2 days delay of the project duration.

Worker	Duration / Worker	Day 27	Day 28	Day 29	Day 30	Day 31	Day 32	Day 33	Day 34	Day 35	Day 36	Day 37	Day 38	Day 39	Day 40	Day 41	Day 42	Day 43	Day 44	Day 45	Day 46	Day 47	Day 48	Day 49	Day 50	Day 51	Day 52
W32	Gas welder A				7	7	7	7	7	7	7	7					9	9	9					9	9	9	9
W33	Gas welder B	11	11	11													9	9	9	13	13	13	13	13	13	9	9
W34	Gas welder C				5	5	5	5	5	5	5	5	5	5						13	13	13	13	13	13	13	13
W35	Gas welder D				5	5	5	5	5	5	5	5	5	5						13	13	13	13	13	13	13	13
W36	Lifting worker A	4	4	4	4	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8					
W37	Lifting worker B	4	4	4	4	8	8	8	8	8	8	8	8	8	12	12	12	12	12	12 ~~8~~	8	8	8				
W38	Lifting worker C	4	4	4	4	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12 ~~8~~	12 ~~8~~	8	8				
W39	Lifting worker D	4	4	4	4	12	8 ~~12~~	8 ~~12~~	8 ~~12~~	8 ~~12~~	12	12	12	12	12	12	12	12	12	12 ~~8~~	12 ~~8~~	8					
W40	Lifting worker E	4	4	4	4	12	8 ~~12~~	8 ~~12~~	8 ~~12~~	12	12	12	12	12	12	12	12	12	12	12 ~~8~~	12 ~~8~~	8					
W41	Painter A																										
W42	Painter B																										
W43	Painter C																										
W44	Painter D																										
W45	Painter E																										

Figure A-16: revised schedule applying Option C in the specific case type c

While applying Option B to revise the schedule format, the affected task 8 should be done by the replacement worker (W39) through repair actions highlighted in the blocks with dark shaded areas in Figure A-17. Then, we revise the schedule by patch actions to minimize the disturbance to the existing organization at the later revision actions. Finally, the changes lead to 2-day delay of the last delayed critical task 12 that further causes 1-day delay of the project duration.

Worker	Duration / Worker	Day 27	Day 28	Day 29	Day 30	Day 31	Day 32	Day 33	Day 34	Day 35	Day 36	Day 37	Day 38	Day 39	Day 40	Day 41	Day 42	Day 43	Day 44	Day 45	Day 46	Day 47	Day 48	Day 49	Day 50	Day 51	Day 52
W32	Gas welder A				7	7	7	7	7	7	7	7					9	9	9					9	9	9	9
W33	Gas welder B	11	11	11													9	9	9	13	13	13	13	13	13	9	9
W34	Gas welder C				5	5	5	5	5	5	5	5	5	5						13	13	13	13	13	13	13	13
W35	Gas welder D				5	5	5	5	5	5	5	5	5	5						13	13	13	13	13	13	13	13
W36	Lifting worker A	4	4	4	4	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8					
W37	Lifting worker B	4	4	4	4	8	8	8	8	8	8	8	8	8	12	12	12	12	12	12 ~~8~~	8	8	8				
W38	Lifting worker C	4	4	4	4	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12 ~~8~~	12 ~~8~~	8	8				
W39	Lifting worker D	4	4	4	4	12	8 ~~12~~	8 ~~12~~	8 ~~12~~	8 ~~12~~	8 ~~12~~	8 ~~12~~	8 ~~12~~	12	12	12	12	12	12	12 ~~8~~	12 ~~8~~	8					
W40	Lifting worker E	4	4	4	4	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12 ~~8~~	12 ~~8~~	8					
W41	Painter A																										
W42	Painter B																										
W43	Painter C																										
W44	Painter D																										
W45	Painter E																										

Figure A-17: revised schedule applying Option B in the specific case type c

Two criteria (project delay and re-organization effort) are evaluated to examine the quality of the revised schedules. Table A-6 summarizes the results of implementation of three change options. By comparing the number of extended days pertaining to the final task(s) of the project and the number of the modified entries, option A is the best choice in this case. Applying the DCM approach can get the same result. It is considered as effectiveness to deal with this change scenario.

Criteria	**Option A**	**Option B**	**Option C**
Number of extended days pertaining to the final task(s) of the project	0	2	2
Number of the modified entries	7	21	21

Table A-6: results applying three change options in the specific case type c

Step 4: Analysis

In view of those cases intended to take repair actions in this change scenario, applying Option B or C is easier to increase the risk of impacting more downstream tasks than applying Option A. This case indicates applying Option B or C easily results to 2 days delay of the project but Option A doesn't. When this type of change scenario happens, we still consider that Option A is the best choice to deal with this change scenario.

Appendix B:

Estimation of threshold value of three change impact factors

To effectively estimate threshold value of three change impact factors, we use the traditional quantitative methods---statistical decision-making approach (Borror 2009). Two sets of threshold value for the proportion of affected workload and maximum additional workload, depending on whether the outstanding tasks are critical or non-critical, are used to form the threshold value table shown in table 4-1.

In case of critical outstanding tasks (the case type 1 and 2), we estimate threshold value of the proportion of affected workload and maximum additional workload applied in the DCM approach based on the cases in table 5-5 and table 5-6. To minimize the impact of extreme value of the proportion of affected workload and maximum additional workload taken from 6 cases in table 5-5 and table 5-6, we estimate threshold value of two change impact factors according to median value of 6 cases of type 1 and 2. By calculating, median value of the proportion of affected workload is 0.0117 and median value of maximum additional workload is 2.14. Therefore, we can assume when the proportion of affected workload is more than 0.0117 and/or maximum additional workload is more than 2.14, we should choose Option C applied in the DCM approach for the case type 1. Otherwise, we should select Option B for the case type 2.

In case of non-critical outstanding tasks (the case type 3 and 4), we estimate threshold value of the proportion of affected workload and maximum additional workload applied in the DCM approach based on the cases in table 5-7 and table 5-8. To minimize the impact of extreme value of the proportion of affected workload and maximum additional workload from 6 cases of type 3 and 4, we assess threshold value of two change impact factors based on median value of 6 cases of type 3 and 4. By calculation, median value of proportion of affected workload is 0.0112 and median value of maximum additional workload is 2.76. Therefore, we can assume when the proportion of affected workload is more than 0.0112 and/or maximum additional workload is more than 2.76, we should choose Option C applied in the DCM approach for the case type 3. Otherwise, we should select Option A for the case type 4.

Appendix C

The worker allocation schedule in Pipeline Installation Sub-project

Worker	Duration / Worker	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12	Day 13	Day 14	Day 15
W1	Benchworker A															
W2	Benchworker B															
W3	Benchworker C															
W4	Riveter A						10	10	10	10	10	10	10	10	10	
W5	Riveter B						10	10	10	10	10	10	10	10	10	
W6	Riveter C					2	2	2	2	2	10	10	10	10	10	
W7	Riveter D					2	2	2	2		6	6	6	6	6	
W8	Riveter E					2	2	2	2	2	6	6	6	6	6	6
W9	Riveter F					2	2	2	2	2	6	6	6	6	6	6
W10	Plumber A	1	1	1	1	1					3	3	3	3	3	11
W11	Plumber B	1	1	1	1	1					3	3	3	3	3	11
W12	Plumber C	1	1	1	1	1					3	3	3	3	3	11
W13	Plumber D	1	1	1	1	1					3	3	3	3	3	11
W14	Plumber E	1	1	1	1	1					3	3	3	3	3	11
W15	Plumber F										3	3	3	3	3	11
W16	Plumber G										3	3	3	3	3	3
W17	Plumber H										3	3	3	3	3	3
W18	Plumber I										3	3	3	3	3	3
W19	Plumber J											3	3	3	3	3
W20	Plumber K											3	3	3	3	3
W21	Plumber L											3	3	3	3	3
W22	Plumber M															11
W23	Plumber N															11
W24	Plumber O															11
W25	Welder A						2	2	2	2	2	6	6	6	6	6
W26	Welder B								2					6		
W27	Welder C									10	10	10	10	10	10	
W28	Welder D									10	10	10	10			
W29	Welder E															
W30	Welder F															
W31	Welder G															
W32	Gas welder A								10	10	2				6	
W33	Gas welder B															
W34	Gas welder C															
W35	Gas welder D															
W36	Lifting worker A	1	1	1	1	1										
W37	Lifting worker B	1	1	1	1	1										
W38	Lifting worker C	1	1	1	1	1										
W39	Lifting worker D	1	1	1	1	1										
W40	Lifting worker E	1	1	1	1	1										
W41	Painter A								2	2	2		10	10	10	
W42	Painter B								2	2	2		10	10	10	6
W43	Painter C										2			10	10	6
W44	Painter D										2			10	6	6
W45	Painter E										2			10	6	6

(To be continued)

Day 16	Day 17	Day 18	Day 19	Day 20	Day 21	Day 22	Day 23	Day 24	Day 25	Day 26	Day 27	Day 28	Day 29	Day 30	Day 31	Day 32	Day 33	Day 34	Day 35	Day 36
		3	3	3	3	3	3	3	11	11	11									
				3	3	3	3	3								7	7	7	7	7
														5	5	5	5	5	5	5
		11	11	11	11											7	7	7	7	7
		11	11	11	11															
														5	5	5	5	5	5	5
														5	5	5	5	5	5	5
6		3	3	3	3	3	3	3												
6				3	3	3	3	3												
11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12
11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12
11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12
11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12
11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12
11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12
3	3	3	3	3	3	3	3	3	3	3	7	7	7	7	12	12	12	12	12	12
3	3	3	3	3	3	3	3	3	3	3	7	7	7	7	7	7	7	7	7	7
3	3	3	3	3	3	3	3	3	3	3	7	7	7	7	7	7	7	7	7	7
3	3	3	3	3	3	3	3	3	3	4	4	4	4	7	7	7	7	7	7	7
3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	7	7	7	7	7	7
3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	7	7	7	7	7	7
			4	4	4	4	4	4	4	4	4	4	4	4	7	7	7	7	7	7
11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	7	7	7	7	7	7
11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	7	7	7	7	7	7
									11	11	11	11								
									11	11	11	11								
		3	3	3	3	3	3	3	11	11	11									
														7	7	7	7	7	7	7
														5	5	5	5	5	5	5
														5	5	5	5	5	5	5
														5	5	5	5	5	5	5
														7	7	7	7	7	7	7
		3	3	3	3	3	3	3	11	11	11	11	11							
														5	5	5	5	5	5	5
														5	5	5	5	5	5	5
			4	4	4	4	4	4	4	4	4	4	4	4	8	8	8	8	8	8
			4	4	4	4	4	4	4	4	4	4	4	4	8	8	8	8	8	8
			4	4	4	4	4	4	4	4	4	4	4	4	12	12	12	12	12	12
			4	4	4	4	4	4	4	4	4	4	4	4	12	12	12	12	12	12
			4	4	4	4	4	4	4	4	4	4	4	4	12	12	12	12	12	12
6																				
6																				
6																				
6																				

(To be continued)

Day 37	Day 38	Day 39	Day 40	Day 41	Day 42	Day 43	Day 44	Day 45	Day 46	Day 47	Day 48	Day 49	Day 50	Day 51	Day 52	Day 53	Day 54	Day 55	Day 56	Day 57
								13	13	13	13	13	13	13	13	13	13	13	13	
								13	13	13	13	13	13	13	13	13	13	13	13	
5	5	5			9	9	9	13	13	13	13	13	13	9	9	9				
7					9	9	9		9	9	9	9	9	9	9	9				
								13	13	13	13	13	13	9	9	9	13	13	13	
5	5	5						13	13	13	13	13	13	9	9	9	13	13	13	
5	5	5						13	13	13	13	13	13	13	13	13	13	13	13	
					9	9	9	9	9	9	9	9	9	9	9	9				
					9	9	9	9	9	9	9	9	9	9	9	9				
12	12	12	12	12	12	12	12													14
12	12	12	12	12	12	12	12													14
12	12	12	12	12	12	12	12													14
12	12	12	12	12	12	12	12													14
12	12	12	12	12	12	12	12													14
12	12	12	12	12	12	12	12													
12		12	12	12	12	12	12													
12	12	12	12	12	12	8	8	8												
7	7	7	8	8	8	8	8	8	8											
7	7	7	8	8	8	8	8	8	8											
7	7	7	8	8	8	8	8	8	8											
7	7	7	8	8	8	8	8	8	8											
7	7	7	8	8	8	8	8	8	8											
7	7	7	8	8	8	8	8	8	8											
8	8	8	8	8	8	8	8	8	8											
					9	9	9	9	9	9	9	9	9	9	9	9				
								13	13	13	13	13	13	13	13	13	13	13	13	
								13	13	13	13	13	13	13	13	13	13	13	13	
7	7	7						13	13	13	13	13	13	13	13	13	13	13	13	
5	5	5			9	9	9	13	13	13	13	13	13	13	13	13				
5	5	5			9	9	9	9	9	9	9	9	9	9	9	9				
5	5	5			9	9	9	9	9	9	9	9	9	9	9	9				
7					9	9	9					9	9	9	9	9				
					9	9	9	13	13	13	13	13	13	9	9	9				
5	5	5						13	13	13	13	13	13	13	13	13	13	13	13	
5	5	5						13	13	13	13	13	13	13	13	13	13	13	13	
8	8	8	8	8	8	8	8	8	8											
8	8	8	12	12	12	12	12	8	8											
12	12	12	12	12	12	12	12	8	8											
12	12	12	12	12	12	12	12	8	8											
12	12	12	12	12	12	12	12	8	8											

(To be continued)

Day 58	Day 59	Day 60	Day 61	Day 62	Day 63	Day 64	Day 65	Day 66	Day 67	Day 68	Day 69	Day 70	Day 71	Day 72
			15	15	15	15	15	15	15	15	15	15	15	15
			15	15	15	15	15	15	15	15	15	15	15	15
14	14	14	15	15	15	15	15	15	15	15	15	15	15	15
14	14	14	15	15	15	15	15	15	15	15	15	15	15	15
14	14	14												
14	14	14												
14														
			15	15	15	15	15	15	15	15	15	15	15	15
			15	15	15	15	15	15	15	15	15	15	15	15
14	14	14												
14	14	14												