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MATRIX-BASED CHANGE MANAGEMENT: A CASE STUDY IN A CONSTRUCTION PROJECT

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Keywords: change management, construction project, scheduling

1 INTRODUCTION

This research focuses on the matrix-based approach to manage the changes occurred in a construction project. The difficulty of managing the changes in a project can be attributed to the complex interdependency among different entities in a project. Then, 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 our approach of change management, we focus on three aspects: (1) modelling of systems' dependency, (2) characterization of change options, and (3) estimation of change impact.

Given a construction project, the major project entities are first identified, such as the project asks, the responsible workers, and the required machines. Then, the dependencies involved in these entities are captured via design structure matrix (DSM) and/or domain mapping matrix (DMM). When a scenario of emerging changes takes place, the management issue is how to deploy the changes so that the propagation impact can be minimized. In this context, we want to characterize the possible options to deploy the emerging changes. Then, by estimating the impact of a specific change scenario, we can select an appropriate change option for it.

Different matrices can be used to capture different dependencies within and across domains (Danilovic & Browning, 2007; Eppinger & Salminen 2001). For example, a Task DSM can be used to capture the precedence relationships among different project tasks. A worker-task DMM can be used to capture the responsibility of workers on different tasks. Similarly, a task-machine DMM can be used to capture which machines are required for certain tasks. In literature, matrix-based models have been used to manage and control the propagation of changes, such as Ollinger and Stahovich (2004), Clarkson et al. (2004) and Chen et al. (2007).

In this research, we aim to systematically manage the changes on the schedule of a construction project. In practice, changes on a construction schedule are common due to unexpected instances (e.g., absence of workers, poor weather, machine breakdown, etc). When changes are required, there can be more than one option to modify the schedule. This research is intended to investigate how we can choose an appropriate change option to better control the change propagation. In this context, the purpose of this paper is to demonstrate how different change options can affect the revised schedule in a construction project.

2 CHARACTERIZATION OF A CONSTRUCTION PROJECT

The construction project is about the installation of pipelines for a wastewater treatment plant. To manage this project, the manager has defined a schedule in a table format, and it is partially shown in Figure 1. The left side of the table shows the identities of the workers involved in the project, while the top part shows the dates of the project's duration. Then, this schedule table shows the responsible tasks of each worker on every working day. For instance, by reading the row of Plumber F, we know that Plumber F is responsible for Task 3 starting from the week of November 15.

To characterize the project's information for change management, we define three domains: tasks, workers and machines. Then, four dependency matrices are defined for change management, and they are listed below.

- Task-task precedence matrix ($TT = [tt_{ij}]$): capture the precedence relationships of tasks on the schedule. If $tt_{ij} = 1$, the task of the jth column must be done before to start working on the task

of the *i*th row. Figure 2a shows the task-task precedence matrix of this project.

- Task-worker responsibility matrix ($TW = [tw_{ij}]$): capture the responsibility of the workers towards their assigned tasks. If $tw_{ij} = 2$ (or 1), the worker of the *j*th column has the supervisory (or low-rank) responsibility towards the task of the *i*th row. Figure 2b shows the task-worker responsibility matrix of this project.
- Machine-worker operation matrix ($MW = [mw_{ij}]$): capture the ability of the workers to operate a list of machines. If $mw_{ij} = 2$ (or 1), the worker of the *j*th column has a senior (or junior) skill level to operate the machine of the *i*th row. Figure 2c shows the machine-worker operation matrix of this project.
- Machine-task requirement matrix ($MT = [mt_{ij}]$): capture the required machines of the specific tasks. If $mt_{ij} = 1$, the machine of the *i*th row is required by the task of the *j*th column. Figure 2d shows the machine-task requirement matrix of this project.

	Nov. 1, 2009							Nov. 8, 2009							Nov. 15, 2009							Nov. 22, 2009							Nov.29,2009						
Worker name	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S
Plumber A					1	1			1	1	1							3	3	3			3	3	3	3	3			3	3	3	3	3	
Plumber B					1	1			1	1	1							3	3	3			3	3	3	3	3			3	3	3	3	3	
Plumber C					1	1			1	1	1							3	3	3			3	3	3	3	3			3	3	3	3	3	
Plumber D					1	1			1	1	1							3	3	3			3	3	3	3	3			3	3	3	3	3	
Plumber E					1	1			1	1	1							3	3	3			3	3	3	3	3			3	3	4	4	4	
Plumber F																		3	3	3			3	3	3	3	3			3	3	4	4	4	
Plumber G																		3	3	3			3	3	3	3	3			7	7	7	7	7	
Plumber H																		3	3	3			3	3	3	3	3			7	7	7	7	7	
Plumber I																		3	3	3			3	3	3	3	3			7	7	7	7	7	
Plumber J																		3	3	3			3	3	3	3	3			7	7	7	7	7	
Plumber K																														7	7	7	7	7	
Plumber L																														7	7	7	7	7	
Plumber M																														7	7	7	7	7	
Plumber N																														7	7	7	7	7	
Plumber O																														7	7	7	7	7	
Welder A												2	2			2	2	2	6	6			6	6	6		10			10	10	10	10	10	
Welder B																2							6								10	10	10		
Welder C																														3	3	3	3	3	

Figure 1. Part of the construction project schedule

3 PROPOSAL OF THE CHANGE MANAGEMENT APPROACH

In this research, we initially study the changes pertaining to the absence of a worker. That is, if a particular worker is absent for a specified period of time, we will want to investigate how to revise the schedule in Figure 1 by re-allocating the existing workers to minimize the impact from the change. The impact, in this context, is examined in two aspects: re-organization effort and project delay. The re-organization effort is referred to the scope of modifications implemented on the revised schedule, and we intend to minimize this for less risk of errors and miscommunications. The project delay is referred to the expected extension of the project due to the undesired change (i.e., an absent worker).

In our approach of change management, given a change scenario specifying the absence conditions of a worker, we first estimate the potential impact of changes by using the matrices defined in Figure 2. For instance, if the absent worker has high responsibility for several tasks (checked in the task-worker responsibility matrix) that affect many other downstream tasks (checked in the task-task precedence matrix), this change scenario is expected to have large impact on the project schedule.

Given the estimation of change impact, we propose two change options (A and B) as possible strategies for change management. In Option A, we do NOT specifically find the replacements for the absent worker, and this option should be applied for the low-impact changes. For instance, if we miss a low-skill worker for two days at the later phase of the project, we do not need to purposely find a replacement worker in this case. In contrast, Option B requires some dedicated replacements for the absent worker, and it should be applied for the high-impact changes. Compared with Option A, Option B should yield the revised schedule with more re-organization effort (due to dedicated replacements) but less project delay (due to flexible and proactive arrangement of available resources).

In sum, the change management approach has a three-step procedure. By knowing an absent worker for a specified period of time, we first assess the impact of this change scenario. Based on the assessment of the impact, we then select the change option (A or B) to guide the revision strategy. Based on the selected change option, we finally revise the original construction schedule to accommodate the change scenario in terms of the absent worker.

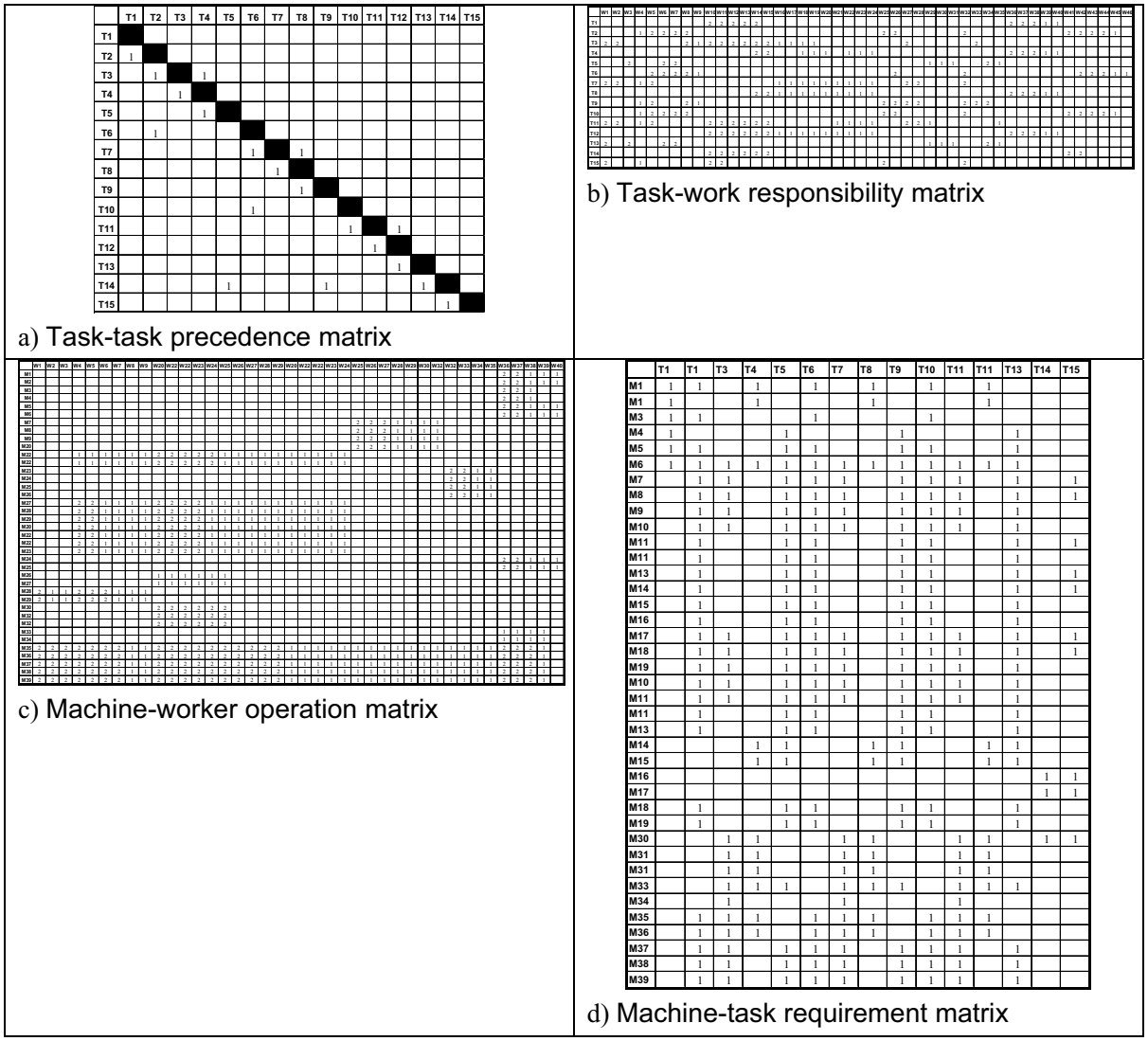


Figure 2. Matrix-based characterization of a construction project

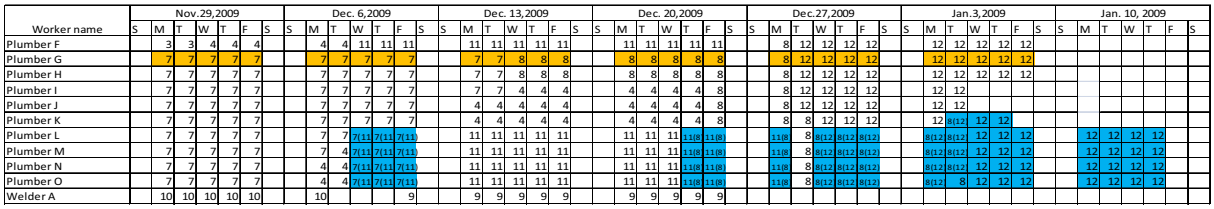
4 PRELIMINARY CASE STUDY

At the preliminary stage of the research, we want to examine whether the above change management approach can be applied to effectively revise the schedule of the construction project. Thus, we set up two cases. The first case simulates the high change impact, and we expect to check the suitability of using Option B. The second case suggests the low change impact, and we expect to check the suitability of using Option A. Comparison study in each case will also be conducted.

4.1 Scenario of high change impact

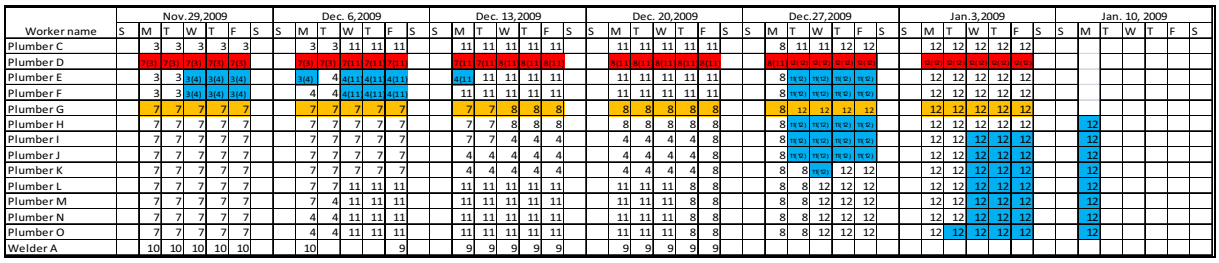
This scenario states that Plumber G will resign since November 30. The incomplete tasks of Plumber G are shaded in Figure 3. When applying Option A, the incomplete tasks (i.e., Tasks 7, 8, 12) are to be done by the remaining workers who are originally assigned to these tasks. Changes are invoked at a later time. The revised schedule is shown in Figure 3, and the modified parts are shaded for Plumbers K, L, M, N and O. As seen, since Task 11 cannot start until Task 7 is almost finished, Plumbers L, M, N and O are asked to help complete Task 7 instead of starting Task 11 in the week of December 6. This kind of changes also propagates to other tasks. Due to the absent worker, Task 12 is eventually delayed by four days.

When applying Option B, a worker needs to be re-assigned to replace Plumber G immediately. In this case, we re-assign Plumber D to work on the incomplete tasks of Plumber G, and this revision is shaded in Figure 4. The original tasks of Plumber D are then distributed to other workers. Such modified results are shaded in Figure 4, which also indicates that Task 12 is delayed by one day.



Worker name	Nov.29,2009							Dec. 6,2009							Dec. 13,2009							Dec. 20,2009							Dec.27,2009							Jan.3,2009							Jan. 10, 2009						
	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S
Plumber F		3	3	4	4	4			4	4	11	11	11			11	11	11	11	11			11	11	11	11	11			8	12	12	12	12			12	12	12	12	12								
Plumber G		7	7	7	7	7			7	7	7	7	7			7	7	8	8	8			8	8	8	8	8			8	12	12	12	12			12	12	12	12	12								
Plumber H		7	7	7	7	7			7	7	7	7	7			7	7	8	8	8			8	8	8	8	8			8	12	12	12	12			12	12	12	12	12								
Plumber I		7	7	7	7	7			7	7	7	7	7			7	7	4	4	4			4	4	4	4	8			8	12	12	12	12			12	12											
Plumber J		7	7	7	7	7			7	7	7	7	7			4	4	4	4	4			4	4	4	4	8			8	12	12	12	12			12	12											
Plumber K		7	7	7	7	7			7	7	7	7	7			4	4	4	4	4			4	4	4	4	8			8	8	12	12	12			12	8(12	12	12									
Plumber L		7	7	7	7	7			7	7	7(11	7(11	7(11			11	11	11	11	11			11	11	11	11(8	11(8			11(8	8	8(12	8(12	8(12			8(12	8(12	12	12	12			12	12	12	12		
Plumber M		7	7	7	7	7			7	4	7(11	7(11	7(11			11	11	11	11	11			11	11	11	11(8	11(8			11(8	8	8(12	8(12	8(12			8(12	8(12	12	12	12			12	12	12	12		
Plumber N		7	7	7	7	7			4	4	7(11	7(11	7(11			11	11	11	11	11			11	11	11	11(8	11(8			11(8	8	8(12	8(12	8(12			8(12	8(12	12	12	12			12	12	12	12		
Plumber O		7	7	7	7	7			4	4	7(11	7(11	7(11			11	11	11	11	11			11	11	11	11(8	11(8			11(8	8	8(12	8(12	8(12			8(12	8	12	12	12			12	12	12	12		
Welder A		10	10	10	10	10			10				9			9	9	9	9	9			9	9	9	9	9																					

Figure 3. Revised schedule according to Option A



Worker name	Nov.29,2009							Dec. 6,2009							Dec. 13,2009							Dec. 20,2009							Dec.27,2009							Jan.3,2009							Jan. 10, 2009						
	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S
Plumber C		3	3	3	3	3			3	3	11	11	11			11	11	11	11	11			11	11	11	11	11			8	11	11	12	12			12	12	12	12	12								
Plumber D		7(3)	7(3)	7(3)	7(3)	7(3)			7(3)	7(3)	7(11	7(11	7(11			7(11	7(11	8(11	8(11	8(11			8(11	8(11	8(11	8(11	8(11			8(11	8(12)	8(12)	8(12)	8(12)			8(12	8(12)	8(12)	8(12)	8(12)								
Plumber E		3	3	3(4)	3(4)	3(4)			3(4)	4	4(11	4(11	4(11			4(11	11	11	11	11			11	11	11	11	11			8	8(12)	8(12)	8(12)	8(12)			12	12	12	12	12								
Plumber F		3	3	3(4)	3(4)	3(4)			4	4	4(11	4(11	4(11			11	11	11	11	11			11	11	11	11	11			8	8(12)	8(12)	8(12)	8(12)			12	12	12	12	12								
Plumber G		7	7	7	7	7			7	7	7	7	7			7	7	8	8	8			8	8	8	8	8			8	12	12	12	12			12	12	12	12	12								
Plumber H		7	7	7	7	7			7	7	7	7	7			7	7	8	8	8			8	8	8	8	8			8	8(12)	8(12)	8(12)	8(12)			12	12	12	12	12			12					
Plumber I		7	7	7	7	7			7	7	7	7	7			7	7	4	4	4			4	4	4	4	8			8	8(12)	8(12)	8(12)	8(12)			12	12	12	12	12			12					
Plumber J		7	7	7	7	7			7	7	7	7	7			4	4	4	4	4			4	4	4	4	8			8	8(12)	8(12)	8(12)	8(12)			12	12	12	12	12			12					
Plumber K		7	7	7	7	7			7	7	7	7	7			4	4	4	4	4			4	4	4	4	8			8	8	12	12				12	12	12	12	12			12					
Plumber L		7	7	7	7	7			7	7	11	11	11			11	11	11	11	11			11	11	11	8	8			8	8	12	12	12			12	12	12	12	12			12					
Plumber M		7	7	7	7	7			7	4	11	11	11			11	11	11	11	11			11	11	11	8	8			8	8	12	12	12			12	12	12	12	12			12					
Plumber N		7	7	7	7	7			4	4	11	11	11			11	11	11	11	11			11	11	11	8	8			8	8	12	12	12			12	12	12	12	12			12					
Plumber O		7	7	7	7	7			4	4	11	11	11			11	11	11	11	11			11	11	11	8	8			8	8	12	12	12			12	12	12	12	12			12					
Welder A		10	10	10	10	10			10				9			9	9	9	9	9			9	9	9	9	9																					

Figure 4. Revised schedule according to Option B

To compare the two revised schedules in Figures 3 and 4, we check two factors. Firstly, we check the number of days that the final task delays. This factor reflects the delay of the project's duration. Secondly, we check the number of modified entries (i.e., the number of shaded boxes in the revised schedules except for the absent worker), which capture the re-organization effort in view of changing the original tasks of the workers in the revised schedule. Table 1 summarizes the results of the two change options. Since Option A does not apply an immediate replacement for the absent worker, it tends to yield a longer project's delay but less re-organization effort (indicated in the number of modified entries). The case results in Table 1 reflect this kind of property in change management. The trade-off relationship between the project's delay and the re-organization effort requires some detailed analysis to support the selection of change options (A or B).

Table 1. Comparison of two options in the high-impact scenario

	Option A	Option B
Number of days that the final task delays	4 Days	1 Days
Number of modified entries	75 Entries	95 Entries

4.2 Scenario of low change impact

This change scenario focuses on the welding part of the project. Particularly, Welder A will take a leave from December 1 to 14. The absent days of Welder A are shaded in Figure 5, which shows that Welder A cannot work on Tasks 10 and 9 during that period of time. When applying Option A, Welders B and C work extra to cover the Task 10 that is left by Welder A. In addition, Welders A and B work extra to cover the Task 9. The revised schedule is shown in Figure 5, and the modified parts are shaded accordingly.

When applying Option B, Welder C is selected to replace Welder A immediately. To share the original workload of Welder C, Welders A (at a later time) and B need to work extra to cover the incomplete tasks. The revised schedule according to Option B is shown in Figure 6, in which the replacement and modified parts are shaded.

Worker name	Nov.29,2009						Dec. 6,2009						Dec. 13,2009						Dec. 20,2009						Dec.27,2009					
	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S
Plumber O	7	7	7	7	7			4	4	11	11	11			11	11	11	11	11			11	11	11	8	8			8	8	12	12	12	
Welder A	10	10	10	10	10			10				9			9	9	9	9	9			9	9	9	9	9			9	9				
Welder B		10	10	10	10			10	10	10		9			9	9	9	9	9			9	9	9	9	9			9					
Welder C	3	3	3	3	3			3	3	10		9			7	7	9	9	9			9	9	9	9	9			11	11	11			
Welder D								7	7	7	7	7			7	7	9	9					5	5	11	11			11	11	11		13	
Welder E									5	5	5	5			5	5	5	5	5			5							11	11	11		13	

Figure 5. Revised schedule according to Option A

Worker name	Nov.29,2009						Dec. 6,2009						Dec. 13,2009						Dec. 20,2009						Dec.27,2009					
	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S
Plumber O	7	7	7	7	7			4	4	11	11	11			11	11	11	11	11			11	11	11	8	8			8	8	12	12	12	
Welder A	10	10	10	10	10			10				9			9	9	9	9	9			9	9	9	9	9			9					
Welder B		10	10	10	3			3	3	3		9			9	9	7(9)	9	9			9	9	9	9	9			9	9				
Welder C	3	10(3)	10(3)	10(3)	10(3)			10(3)	3	3		9(9)			9(7)	9(7)	7(9)	9	9			9	9	9	9	9			11	11	11			
Welder D								7	7	7	7	7			7	7	9	9					5	5	11	11			11	11	11		13	
Welder E									5	5	5	5			5	5	5	5	5			5							11	11	11		13	

Figure 6. Revised schedule according to Option B

By comparing Figures 5 and 6, the final tasks (i.e., Tasks 12 and 13) are not delayed since the initial changes from Welder A are relatively moderate. Thus, these initial changes can be somehow "absorbed" without further propagating to the final tasks. Since Option B requires the replacement of Welder A immediately, more re-organization efforts on the schedule are incurred in this case. Table 2 summarizes the results of the two change options. As Option A has less number of modified entries, it is considered that Option A is a better change option to address this change scenario.

Table 2. Comparison of two options in low-impact scenario

	Option A	Option B
Number of days that the final task delays	0 Days	0 Days
Number of modified entries	8 Entries	18 Entries

5 DISCUSSION AND CLOSING REMARKS

When comparing Options A and B as two different strategies for change management, we can find that Option B is more flexible than Option A since Option B proactively invokes replacements to address initial changes. In contrast, Option A reactively allows the initial changes to be propagated to the end of each affected task. However, the proactive modifications in Option B often lead to more re-organization effort (i.e., larger number of modified entries). As such, there likely exists a trade-off relationship between the project's delay and the re-organization effort. That is, if we allow more re-organization efforts (i.e., more flexibility in schedule revision), we can have a better means to reduce the project's delay. The case in Section 4.1 has demonstrated this trade-off relationship.

This paper reports our preliminary results on the management of changes in a project's schedule. Apparently, a project's schedule is constructed based on many elements and factors that are interrelated in a complicated manner. Thus, modifications of one part of the schedule can easily lead to intractable propagation of changes. The paper shows that different options (as change strategies) can be applied in different change scenarios. This demonstration leads to one key issue, i.e., how to select the change strategy at the early stage of the change management process subject to a known change scenario. The ongoing research work includes the characterization of change options, the quantified estimation of initial change impact and the systematic mechanism to revise the project's schedule.

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Matrix-Based Change Management: A Case Study in a Construction Project

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MANAGING COMPLEXITY
BY MODELLING DEPENDENCIES

Index

- Introduction
- Characterization of a construction project
- Proposal of the change management approach
- Preliminary case study
  - Scenario of high change impact
  - Scenario of low change impact
- Summary and future works

Introduction

- Why change management in a construction project?
  - There exists complex interdependency among different entities in a project.
  - When changes take place, they can intractably propagate to other parts of the project, leading to some undesirable impact such as long duration delay and over budget
- Three aspects of change management
  - Modelling of systems' dependency
  - Characterization of change options
  - Estimation of change impact
- Paper's purposes
  - Systematically manage the changes on the schedule of a construction project
  - Demonstrate how different change options can affect the revised schedule in a construction project

MANAGING COMPLEXITY
BY MODELLING DEPENDENCIES

Characterization of the Construction Project (1)

- Construction: installation of pipelines for a wastewater treatment plant
- Table format of a construction project
  - Left side: worker's identities
  - Table entry: task number

Worker name	Nov. 1, 2009							Nov. 8, 2009							Nov. 15, 2009							Nov. 22, 2009							Nov.29,2009						
	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S
Plumber A					1	1			1	1	1							3	3	3			3	3	3	3	3			3	3	3	3	3	
Plumber B					1	1			1	1	1							3	3	3			3	3	3	3	3			3	3	3	3	3	
Plumber C					1	1			1	1	1							3	3	3			3	3	3	3	3			3	3	3	3	3	
Plumber D					1	1			1	1	1							3	3	3			3	3	3	3	3			3	3	3	3	3	
Plumber E					1	1			1	1	1							3	3	3			3	3	3	3	3			3	3	4	4	4	
Plumber F																		3	3	3			3	3	3	3	3			3	3	4	4	4	
Plumber G																		3	3	3			3	3	3	3	3			7	7	7	7	7	
Plumber H																		3	3	3			3	3	3	3	3			7	7	7	7	7	
Plumber I																		3	3	3			3	3	3	3	3			7	7	7	7	7	
Plumber J																		3	3	3			3	3	3	3	3			7	7	7	7	7	
Plumber K																														7	7	7	7	7	
Plumber L																														7	7	7	7	7	
Plumber M																														7	7	7	7	7	
Plumber N																														7	7	7	7	7	
Plumber O																														7	7	7	7	7	
Welder A												2	2			2	2	2	6	6			6	6	6		10			10	10	10	10	10	
Welder B																2							6								10	10	10		
Welder C																														3	3	3	3	3	

- Three-domain characterization
  - Tasks
  - Workers
  - Machines

Characterization of the Construction Project (2)

- Task-task precedence matrix ($TT = [tt_{ij}]$): capture the precedence relationships of tasks on the schedule.
- If $tt_{ij} = 1$, the task of the jth column must be done before to start working on the task of the ith row.

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15
T1															
T2	1														
T3		1		1											
T4			1												
T5				1											
T6		1													
T7						1		1							
T8							1								
T9								1							
T10						1									
T11										1		1			
T12											1				
T13												1			
T14					1				1				1		
T15														1	

Characterization of the Construction Project (3)

- Task-worker responsibility matrix ($TW = [tw_{ij}]$): capture the responsibility of the workers towards their assigned tasks.
- If $tw_{ij} = 2$ (or 1), the worker of the jth column has the supervisory (or low-rank) responsibility towards the task of the ith row.

	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26	W27	W28	W29	W30	W31	W32	W33	W34	W35	W36	W37	W38	W39	W40	W41	W42	W43	W44	W45	W46
T1										2	2	2	2	2																						2	2	2	1	1						
T2				1	2	2	2	2																2	2							2									2	2	2	2	1	
T3	2	2						2	1	2	2	2	2	2	2	1	1	1	1							2							2														
T4														2	2			1	1	1		1	1	1												2	2	2	1	1						
T5			2			2	2																					1	1	1			2	1												
T6					2	2	2	2	1																2							2										2	2	2	1	1
T7	2	2		1	2											1	1	1	1	1	1	1	1	1			2	2				2														
T8														2	2	1	1	1	1	1	1	1	1	1												2	2	2	1	1						
T9				1	2			2	1																2	2	2	2				2	2	2												
T10				1	2	2	2	2																	2	2						2									2	2	2	2	1	
T11	2	2		1	2					2	2	2	2	2	2						1	1	1	1			2	2	1						1											
T12										2	2	2	2	2	2	1	1	1	1	1	1	1	1	1												2	2	2	1	1						
T13	2		2			2	2																						1	1	1			2	1											
T14										2	2	2	2	2	2																										2	2				
T15	2			1						2	2														2							2														

Characterization of the Construction Project (4)

- Machine-worker operation matrix ($MW = [mw_{ij}]$): capture the ability of the workers to operate a list of machines.
- If mw_{ij} = 2 (or 1), the worker of the jth column has a senior (or junior) skill level to operate the machine of the ith row.

	W1	W2	W3	W4	W5	W6	W7	W8	W9	W20	W22	W22	W23	W24	W25	W26	W27	W28	W29	W20	W22	W22	W23	W24	W25	W26	W27	W28	W29	W30	W32	W32	W33	W34	W35	W36	W37	W38	W39	W40
M1																																				2	2	1	1	1
M2																																				2	2	1	1	1
M3																																				2	2	1		
M4																																				2	2	1		
M5																																				2	2	1	1	1
M6																																				2	2	1	1	1
M7																								2	2	2	1	1	1											
M8																								2	2	2	1	1	1											
M9																								2	2	2	1	1	1											
M20																								2	2	2	1	1	1											
M22				1	1	1	1	1	1	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1																
M22				1	1	1	1	1	1	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1																
M23																																2	2	1	1					
M24																																2	2	1	1					
M25																																2	2	1	1					
M26																																2	2	1	1					
M27				2	2	1	1	1	1	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1																
M28				2	2	1	1	1	1	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1																
M29				2	2	1	1	1	1	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1																
M20				2	2	1	1	1	1	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1																
M22				2	2	1	1	1	1	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1																
M22				2	2	1	1	1	1	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1																
M23				2	2	1	1	1	1	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1																
M24																																				2	2	1	1	1
M25																																				2	2	1	1	1
M26										1	1	1	1	1	1																								
M27										1	1	1	1	1	1																								
M28	2	1	1	2	2	2	1	1	1																														
M29	2	1	1	2	2	2	1	1	1																														
M30										2	2	2	2	2																									
M32										2	2	2	2	2																									
M32										2	2	2	2	2																									
M33																																				1	1	1	1	
M34																																				1	1	1	1	
M35	2	2	2	2	2	2	2	1	1	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	1	
M36	2	2	2	2	2	2	2	1	1	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	1	
M37	2	2	2	2	2	2	2	1	1	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	1	
M38	2	2	2	2	2	2	2	1	1	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	1	
M39	2	2	2	2	2	2	2	1	1	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	1	

Characterization of the Construction Project (5)

- Machine-task requirement matrix ($MT = [mt_{ij}]$): capture the required machines of the specific tasks.
- If mt_{ij} = 1, the machine of the ith row is required by the task of the jth column.

	T1	T1	T3	T4	T5	T6	T7	T8	T9	T10	T11	T11	T13	T14	T15
M1	1	1		1		1		1		1		1			
M1	1			1				1				1			
M3	1	1				1				1					
M4	1				1				1				1		
M5	1	1			1	1			1	1			1		
M6	1	1	1	1	1	1	1	1	1	1	1	1	1		
M7		1	1		1	1	1		1	1	1		1		1
M8		1	1		1	1	1		1	1	1		1		1
M9		1	1		1	1	1		1	1	1		1		
M10		1	1		1	1	1		1	1	1		1		
M11		1			1	1			1	1			1		1
M11		1			1	1			1	1			1		
M13		1			1	1			1	1			1		1
M14		1			1	1			1	1			1		1
M15		1			1	1			1	1			1		
M16		1			1	1			1	1			1		
M17		1	1		1	1	1		1	1	1		1		1
M18		1	1		1	1	1		1	1	1		1		1
M19		1	1		1	1	1		1	1	1		1		
M10		1	1		1	1	1		1	1	1		1		
M11		1	1		1	1	1		1	1	1		1		
M11		1			1	1			1	1			1		
M13		1			1	1			1	1			1		
M14				1	1			1	1			1	1		
M15				1	1			1	1			1	1		
M16														1	1
M17														1	1
M18		1			1	1			1	1			1		
M19		1			1	1			1	1			1		
M30			1	1			1	1			1	1		1	1
M31			1	1			1	1			1	1			
M31			1	1			1	1			1	1			
M33			1	1	1		1	1	1		1	1	1		
M34			1				1				1				
M35		1	1	1		1	1	1		1	1	1			
M36		1	1	1		1	1	1		1	1	1			
M37		1	1		1	1	1		1	1	1		1		
M38		1	1		1	1	1		1	1	1		1		
M39		1	1		1	1	1		1	1	1		1		

Proposal of the Change Management Approach (1)

- Change scenario: if a particular worker is absent for a specified period of time, we will want to investigate how to revise the schedule.
- Assumptions on changes
  - Re-allocate the existing workers only
  - Minimize the impact from the change
- Two aspects of change impact:
  - **Re-organization effort**: scope of modifications implemented on the revised schedule → related to risk of errors and miscommunications
  - **Project delay**: expected extensions of the project due to the absent worker
- Two change options (A and B)
  - Option A: do not specifically find the replacements for the absent worker → used for the low-impact changes
  - Option B: require some dedicated replacements for the absent worker → used for the high-impact changes

MANAGING COMPLEXITY
BY MODELLING DEPENDENCIES

Three-step Procedure for Change Management

- Assess the impact of a given change scenario
  - Use of various matrices that have captured interdependencies of a project, e.g., task-worker responsibility matrix
  - If the absent worker has high responsibility for several tasks that affect many other downstream tasks, this change scenario is expected to have large impact on the project schedule.
- Select the change option
  - Option A → less flexible but may lead to less re-organization efforts
  - Option B → more flexible to minimize the project's delay
  - Trade-off on re-organization effort and project delay
- Revise the original construction schedule to accommodate the change scenario in terms of the absent worker

Case Study – Scenario of High Change Impact (1)

- Change scenario: Plumber G will resign since November 30

Worker name	Nov.29,2009							Dec. 6,2009							Dec. 13,2009							Dec. 20,2009							Dec.27,2009							Jan.3,2009							Jan. 10, 2009						
	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S
Plumber F		3	3	4	4	4			4	4	11	11	11			11	11	11	11	11			11	11	11	11	11			8	12	12	12	12			12	12	12	12	12								
Plumber G		7	7	7	7	7			7	7	7	7	7			7	7	8	8	8			8	8	8	8	8			8	12	12	12	12			12	12	12	12	12								
Plumber H		7	7	7	7	7			7	7	7	7	7			7	7	8	8	8			8	8	8	8	8			8	12	12	12	12			12	12	12	12	12								
Plumber I		7	7	7	7	7			7	7	7	7	7			7	7	4	4	4			4	4	4	4	8			8	12	12	12	12			12	12											
Plumber J		7	7	7	7	7			7	7	7	7	7			4	4	4	4	4			4	4	4	4	8			8	12	12	12	12			12	12											
Plumber K		7	7	7	7	7			7	7	7	7	7			4	4	4	4	4			4	4	4	4	8			8	8	12	12	12			12	8(12)	12	12									
Plumber L		7	7	7	7	7			7	7	7(11)	7(11)	7(11)			11	11	11	11	11			11	11	11	11(8)	11(8)			11(8)	8	8(12)	8(12)	8(12)			8(12)	8(12)	12	12	12			12	12	12	12		
Plumber M		7	7	7	7	7			7	4	7(11)	7(11)	7(11)			11	11	11	11	11			11	11	11	11(8)	11(8)			11(8)	8	8(12)	8(12)	8(12)			8(12)	8(12)	12	12	12			12	12	12	12		
Plumber N		7	7	7	7	7			4	4	7(11)	7(11)	7(11)			11	11	11	11	11			11	11	11	11(8)	11(8)			11(8)	8	8(12)	8(12)	8(12)			8(12)	8(12)	12	12	12			12	12	12	12		
Plumber O		7	7	7	7	7			4	4	7(11)	7(11)	7(11)			11	11	11	11	11			11	11	11	11(8)	11(8)			11(8)	8	8(12)	8(12)	8(12)			8(12)	8	12	12	12			12	12	12	12		
Welder A		10	10	10	10	10			10				9			9	9	9	9	9			9	9	9	9	9																					

Revised schedule according to Option A

Worker name	Nov.29,2009							Dec. 6,2009							Dec. 13,2009							Dec. 20,2009							Dec.27,2009							Jan.3,2009							Jan. 10, 2009						
	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S
Plumber C		3	3	3	3	3			3	3	11	11	11			11	11	11	11	11			11	11	11	11	11			8	11	11	12	12			12	12	12	12	12								
Plumber D		7(3)	7(3)	7(3)	7(3)	7(3)			7(3)	7(3)	4(13)	7(13)	7(13)			7(13)	7(13)	8(13)	8(13)	8(13)			8(13)	8(13)	8(13)	8(13)	8(13)			8(13)	5(9)	5(9)	5(9)	5(9)			5(9)	5(9)	5(9)	5(9)	5(9)								
Plumber E		3	3	3(4)	3(4)	3(4)			3(4)	4	4(11)	4(11)	4(11)			4(12)	11	11	11	11			11	11	11	11	11			8	11(9)	11(9)	11(9)	11(9)			12	12	12	12	12								
Plumber F		3	3	3(4)	3(4)	3(4)			4	4	4(11)	4(11)	4(11)			11	11	11	11	11			11	11	11	11	11			8	11(9)	11(9)	11(9)	11(9)			12	12	12	12	12								
Plumber G		7	7	7	7	7			7	7	7	7	7			7	7	8	8	8			8	8	8	8	8			8	12	12	12	12			12	12	12	12	12								
Plumber H		7	7	7	7	7			7	7	7	7	7			7	7	8	8	8			8	8	8	8	8			8	11(9)	11(9)	11(9)	11(9)			12	12	12	12	12			12					
Plumber I		7	7	7	7	7			7	7	7	7	7			7	7	4	4	4			4	4	4	4	8			8	11(9)	11(9)	11(9)	11(9)			12	12	12	12	12			12					
Plumber J		7	7	7	7	7			7	7	7	7	7			4	4	4	4	4			4	4	4	4	8			8	11(9)	11(9)	11(9)	11(9)			12	12	12	12	12			12					
Plumber K		7	7	7	7	7			7	7	7	7	7			4	4	4	4	4			4	4	4	4	8			8	8	11(9)	12	12			12	12	12	12	12			12					
Plumber L		7	7	7	7	7			7	7	11	11	11			11	11	11	11	11			11	11	11	8	8			8	8	12	12	12			12	12	12	12	12			12					
Plumber M		7	7	7	7	7			7	4	11	11	11			11	11	11	11	11			11	11	11	8	8			8	8	12	12	12			12	12	12	12	12			12					
Plumber N		7	7	7	7	7			4	4	11	11	11			11	11	11	11	11			11	11	11	8	8			8	8	12	12	12			12	12	12	12	12			12					
Plumber O		7	7	7	7	7			4	4	11	11	11			11	11	11	11	11			11	11	11	8	8			8	8	12	12	12			12	12	12	12	12			12					
Welder A		10	10	10	10	10			10				9			9	9	9	9	9			9	9	9	9	9																					

Revised schedule according to Option B

Case Study – Scenario of High Change Impact (2)

- Comparison factors
  - Number of days that the final task delays → capture the project's delay
  - Number of modified entries on the revised schedule → capture the re-organization effort
- Results

	Option A	Option B
Number of days that the final task delays	4 Days	1 Days
Number of modified entries	75 Entries	95 Entries

- Trade-off relationship between the project's delay and the re-organization effort requires some detailed analysis to support the selection of the change option (A or B).

Case Study – Scenario of Low Change Impact

- Welder A will take a leave from December 1 to 14

Worker name	Nov.29,2009						Dec. 6,2009						Dec. 13,2009						Dec. 20,2009						Dec.27,2009					
	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S
Plumber O	7	7	7	7	7			4	4	11	11	11			11	11	11	11	11			11	11	11	8	8			8	8	12	12	12	
Welder A	10	10	10	10	10			10				9			9	9	9	9	9			9	9	9	9	9			9	9				
Welder B		10	10	10	10			10	10	10		9			9	9	9	9	9			9	9	9	9	9			9					
Welder C	3	3	3	3	3			3	3	10		9			7	7	9	9	9			9	9	9	9	9			11	11	11			
Welder D								7	7	7	7	7			7	7	9	9					5	5	11	11			11	11	11		13	
Welder E									5	5	5	5			5	5	5	5	5			5							11	11	11		13	

Revised schedule according to Option A

Worker name	Nov.29,2009						Dec. 6,2009						Dec. 13,2009						Dec. 20,2009						Dec.27,2009					
	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S
Plumber O	7	7	7	7	7			4	4	11	11	11			11	11	11	11	11			11	11	11	8	8			8	8	12	12	12	
Welder A	10	10	10	10	10			10				9			9	9	9	9	9			9	9	9	9	9			9					
Welder B		10	10	10	3			3	3	3		9			9	9	7(9)	9	9			9	9	9	9	9			9	9				
Welder C	3	10(3)	10(3)	10(3)	10(3)			10(3)	3	3		9(9)			9(7)	9(7)	7(9)	9	9			9	9	9	9	9			11	11	11			
Welder D								7	7	7	7	7			7	7	9	9					5	5	11	11			11	11	11		13	
Welder E									5	5	5	5			5	5	5	5	5			5							11	11	11		13	

Revised schedule according to Option B

	Option A	Option B
Number of days that the final task delays	0 Days	0 Days
Number of modified entries	8 Entries	18 Entries

Results

MANAGING COMPLEXITY
BY MODELLING DEPENDENCIES

Summary and Future Works

- Proposed a systematic approach for change management of a construction project
  - Characterization of a construction project via DSM and DMM
  - Definition of change options as different strategies for change management
  - Trade-off relationship between project's delay and re-organization effort
- Current research effort
  - Estimation of change impact → selection of change options
  - Matrix-based quantification techniques to evaluate the scope of change propagation
  - Formal comparison of the quality of the final revised schedules
  - Systematic mechanism to revise the project's schedule