A Framework to Diagnose and Improve a Contractor's Management of Project Changes

by

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Abstract

Changes are commonly required throughout construction projects. Although some changes can be beneficial, most changes are believed to adversely affect project performance. Nevertheless, the matter of change is often overlooked by construction companies and practitioners, thereby resulting in cost and schedule overruns and inefficient operations. This study presents a framework for change management (CM) improvement process, with the study consisting of (1) business case (motivation), (2) diagnostics, and (3) recommendations to overcome such issues based on a case study of a heavy civil and mining construction company based in Western Canada.

First, this study demonstrates the processes of investigating quantitative impact of changes on a construction company's profitability from a practical perspective. Despite past researchers' efforts to quantify the impact of changes, most studies have only analyzed impact on productivity, and no analysis of the impact on contractors' internal costs or profitability has been reported. Furthermore, analysis of the effects of the timing of change has been limited. This study thus presents such analyses in a statistical manner. The results generated from such an investigation can provide a valuable business case for an organization to determine whether their existing CM process requires further investigation and/or improvement. Moreover, valuable lessons learned through a practical and detailed approach are presented which can be useful for future researchers seeking to improve the reliability of similar studies.

Second, motivated by the findings from the quantitative and qualitative analyses of the impact of changes on the company's profitability, this study further investigates the company's Organizational Process Assets (OPA), Enterprise Resource Planning (ERP) and project management practice in the context of CM. The investigation is conducted based on three

different stages — planned, as-is, and to-be — in order to diagnose the current status of CM and to identify challenges and potential areas of improvement.

Lastly, based on the key issues identified through CM, this study proposes a case-specific recommendation, a Learning Management System (LMS) that uses the learning path concept adopted from a Fortune 500 company. This LMS, regardless of practice area, can be implemented for any type of organization. Particularly for the construction industry, LMS can be more effectively and efficiently implemented if consistently developed with industry-specific best practices and processes, such as Construction Industry Institute (CII) best practices and project management processes based on Project Management Body of Knowledge (PMBOK).

Although the framework presented in this thesis is based on one company's case, different companies can have different levels of CM and different systems and practices. Therefore, the proposed framework should be carefully implemented, and tailored if necessary, for each case.

Dedication

This thesis is dedicated with love and respect

to my beloved parents;

to my beloved wife; and

to my colleagues.

Acknowledgements

First and foremost, I would like to thank my supervisor, Dr. Yasser Mohamed for his support, great patience and guidance throughout the course of my study. I would also like to express my appreciation for the guidance and mentorship from Dr. A. J. Antony Chettupuzha.

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This thesis would not have been possible without the generous support from Oscar Gomez, senior project manager of the industry partner company, during the on-site investigation over ten-month period.

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Glossary of Terms

Change: Any addition, deletion, or other revision that causes an adjustment to scope, schedule, budget, resources, project governance, etc. during a construction project.

Change Management (CM): Approach to manage construction project changes.

Change Order (CO): An official modification to an original contract.

Contractor: A company that performs construction work on a contract basis; Builder

Enterprise Resource Planning (ERP): Commercial software package that enables the integration of transaction-oriented data and business processes throughout an organization to serve all departments' needs within a single system.

Margin: Percentage of gross revenue that represents profit.

Margin % Variance (MPV): Refer to 2.3.3 of this thesis.

Request for Change Order (RCO): Contractor's formal request to an owner, advising of details of the change such as schedule and cost impacts, to pursue a Change Order.

Percent Change Order (%CO): Refer to 2.3.3 of this thesis.

Profit: Amount that a business earns after subtracting its expenses from its gross revenue.

Chapter 1. Introduction

1.1 Background and Problem Statement

1.1.1 Change Management for construction companies

Throughout construction projects, changes are commonly, and inevitably, required (Alnuaimi et al. 2010), and they are believed to have a significant impact on the financial performance (Ibbs and Allen 1995). If not efficiently managed, change can be a key contributor to poor project performance.

Thus, change management (CM) practice is among the most important construction best practices (Lee et al. 2004, Zou and Lee 2006). Indeed, project change cost performance is one of the essential metrics to measure project success (Williams 2000, Eden et al. 2005).

Nevertheless, a tremendous amount of project change costs is expended each year. According to Allen (1993), between $13 and $26 billion dollars is spent on change orders (COs) for new construction projects annually in the United States. Furthermore, additional financial resources can be expended when changes lead to claims and legal disputes (Ibbs and Allen 1995).

To minimize such adverse effects of changes on project performance, project and business management teams must be able to effectively manage changes (CII 1994). In addition, quantification of the impact of changes, particularly on cost performance, would enable business management teams to diagnose project performance from business operations perspective. It can also help project teams to make informed decisions with better evaluations of the impact of changes (CII 1995).

1.1.2 Impact of changes

Approaches to quantify the impact of changes have been developed by many researchers. The impact on labour productivity is the most frequently studied topic among them, and it can be categorized into two main areas: discrete impact of changes and cumulative impact of changes (Lee 2007). The discrete approach measures the impact of an individual factor, such as overtime, overmanning, weather, or learning curve effect, whereas the cumulative approach studies the compounding effect of multiple factors and is typically known to be more difficult to measure (Ibbs 2005). However, the impact on labour productivity measured by these approaches cannot explain the true cost impact of changes, because productivity loss can be absorbed by good project management, contingencies, or other indirect costs, and therefore may not lead to profitability loss. Although studies related to the relationship between labour productivity and cost or profitability exist, they have been somewhat limited.

The impact of changes on contractor's profitability is an aspect of change that requires further studies. Although researchers and practitioners generally agree on the negative impact of changes on project cost, some argue that a contractor may increase its profit through changes (Doyle and DeStephanis 1990, Zack 1993). However, this perception has not been supported by any actual data.

1.1.3 Change Management Process

In spite of its importance, CM is often overlooked by construction companies, particularly small- to mid-size firms. In order for construction companies to have the ability to respond to changes effectively and in a timely manner, to minimize detrimental effects of changes, and to take advantage of beneficial changes, development and implementation of a CM process is essential.

The mandate of the Construction Industry Institute (CII)'s best practice for CM is to "incorporate a balanced change culture of recognition, planning, and evaluation of project changes in an organization to effectively manage project changes (CII website)". They have developed a prototype broad-based Change Management System (CMS) as a tool to assist project managers to manage change more effectively (CII 1994). Figure 1-1 is a "macro" flowchart that shows the five CM principles necessary to manage change. This flowchart can be customized for the specific circumstances of each industry, company, and/or project.

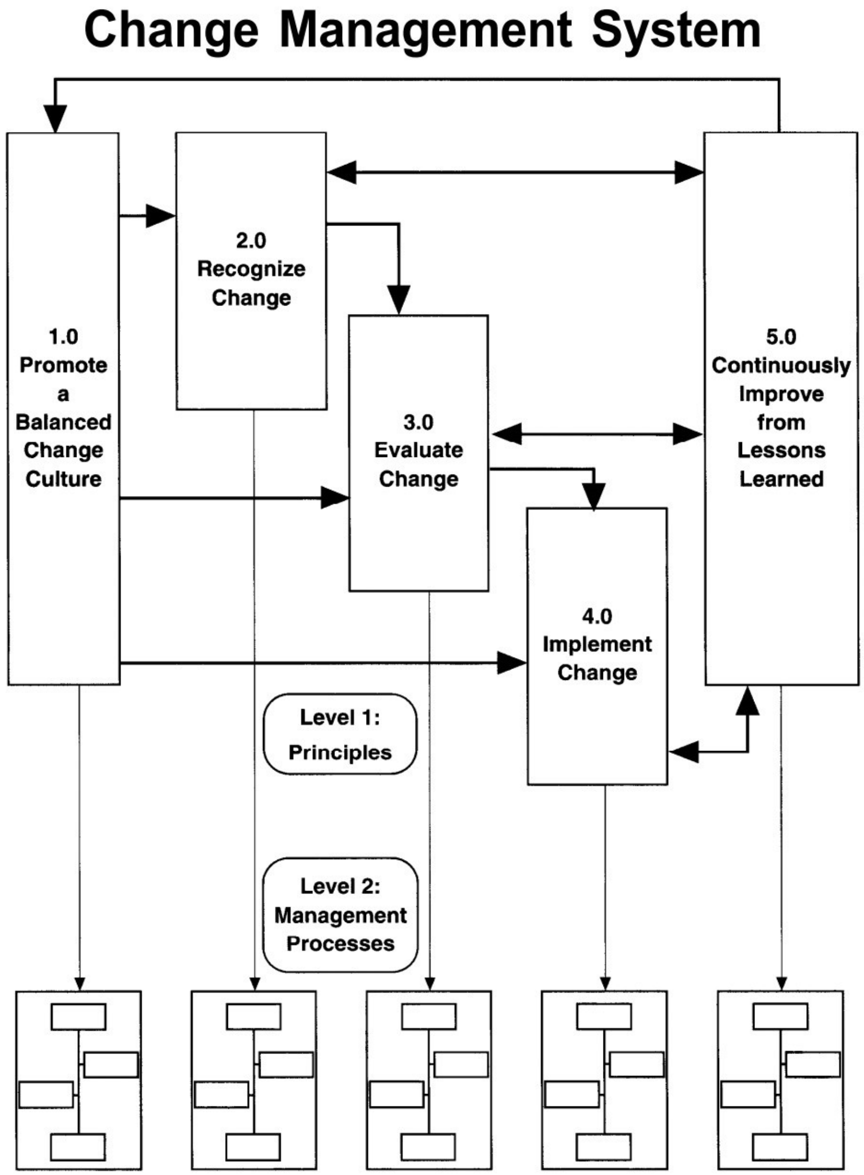

Figure 1-1. "Macro" flowchart of Change Management Principles (Adapted from CII 1994)

Oracle Corporation, a provider of one of the most popular project management software tools, together with Enterprise Resource Planning (ERP) software, presented CM best practices for engineering and construction industry in one of its white papers (Oracle 2009). Although the paper successfully presents the basic principles of proven CM process, it cannot be exhaustive or complete because each company, project, and industry is unique and therefore the process needs to be adapted.

1.1.4 Enterprise Resource Planning (ERP)

Construction companies have many internal and external resources involved in the delivery of a finished product. Such resources include the owner, consultant, contractor, subcontractor, supplier, and many other parties, depending on project size (Tambovcevs 2012). Construction companies face numerous challenges related to managing project schedules, budgets, safety, and quality to the meet requirements of these parties (Chung et al. 2008).

Computer technologies have brought many benefits to the construction industry, helping them to overcome complex challenges (Tambovcevs 2012). Enterprise Resource Planning (ERP) systems are among the most important business information technologies to have emerged in recent years (Chung et al. 2008). These commercial software packages enable the integration of transaction-oriented data and business processes throughout an organization (Markus and Tanis 2000) to serve all departments' needs within a single system (Tambovcevs 2012). The benefits of ERP include the ability to coordinate processes and information more efficiently and to improve responsiveness to customer needs by decreasing cycle time (Davenport 2000, Elarbi 2001).

Although major construction firms are to recognize the benefit of ERP systems, the high costs to implement ERP have made construction firms reluctant to invest in and adopt these systems (Chung et al. 2008). Furthermore, ERP implementation in the construction industry is still limited to areas such as accounting, costing, project control, and financing functions. Further studies and efforts are necessary in order to develop a wider range of ERP implementation to improve the efficiency of operations and management of construction (Tambovcevs 2012).

As is the case for CM, understanding the circumstances of each industry, company, and project is essential for successful implementation of ERP that meets construction companies' unique business needs (Tambovcevs 2012). In addition, identifying and analyzing success or failure factors for ERP implementation is critical.

1.1.5 Learning Management System (LMS)

In competitive business environments and project-based industries, knowledge is a vital organizational and project resource that gives market leverage and contributes to organizational innovations and project success (Egbu 1999 and 2000, Nonaka and Takeuchi 1995).

Organizations make an effort to take advantage of their knowledge resources and environments, and this approach has developed into a new concept called Knowledge Management (Moghadam and Riazi 2008).

Learning Management System (LMS) can be an effective tool to deliver such knowledge to an organization's employees effectively. LMS is a software application that automates the administration, tracking, and reporting of training events. It can also enable centralized administration and content management, self-service and self-guided services, and effective assembly and delivery of learning content (Ellis 2009).

Many construction companies have implemented LMS. However, learning contents often exist as separate pieces rather than existing as a full package with carefully planned flows of learning sequences. To fully utilize LMS's benefits and the company's existing contents, the development of an integrated and centralized learning plan with a user-friendly interface that supports self-guided learning is essential.

1.2 Scope of Research

As discussed above, CM is often overlooked by construction companies, thereby leading to inefficient operations and poor project performance. To provide a guideline to overcome such issues, this study proposes a framework of CM diagnosis and improvement process, including analysis of financial impact of changes, gap analysis of as-is practices and system, and recommendation of management and delivery system for Organizational Process Assets (OPA). However, this study is strictly based on a case from one particular company, which is a heavy civil and mining construction company in Canada, and therefore cannot account for the construction industry in general. Although this study proposes a framework of such processes for CM improvement, it would need to be customized for each industry, area, company, and type of project to properly achieve its purposes.

It should be noted that the term, Organizational Process Assets (OPA), in this thesis refers to "the plans, processes, policies, procedures, and knowledge bases specific to and used by the performing organization", based on the definition from A Guide to the Project Management

Body of Knowledge (PMBOK(c) Guide, fifth edition), published by the Project Management Institute (PMI).

1.3 Research Objectives

The major goal of this study is to diagnose the as-is status of a heavy civil and mining construction company's CM, both quantitatively and qualitatively, and to provide recommendations to fill gaps and improve companies' existing systems and practices. To reach this goal, three sub-goals are pursued.

1. To investigate the impact of changes, as well as the impact of the timing of changes, on a construction company's profitability, in order to quantitatively diagnose the company's current CM and its effectiveness and financial performance.
2. To investigate the gaps that require attention and improvement by reviewing a company's existing OPA and actual implementation, including, but not limited to, CM policies, standards, forms, procedures, resources, ERP, LMS, and project management practice.
3. To provide case-specific recommendations for the company studied. In this study, a new LMS is proposed in order to maximize the utilization of existing OPA by using the learning path concept, and to provide an effective and efficient tool for end-users and management staff.

1.4 Research Methodology

Figure 1-2 summarizes the methodology employed for this research. In order to make meaningful contributions not only to the academic body of knowledge in this area but also to the industry partner, this research begins by quantifying the financial impact of the changes on profitability based on the industry partner's construction projects executed in the last 10 years. In addition, lessons learned through a practical approach are presented as qualitative findings for future researchers and practitioners.

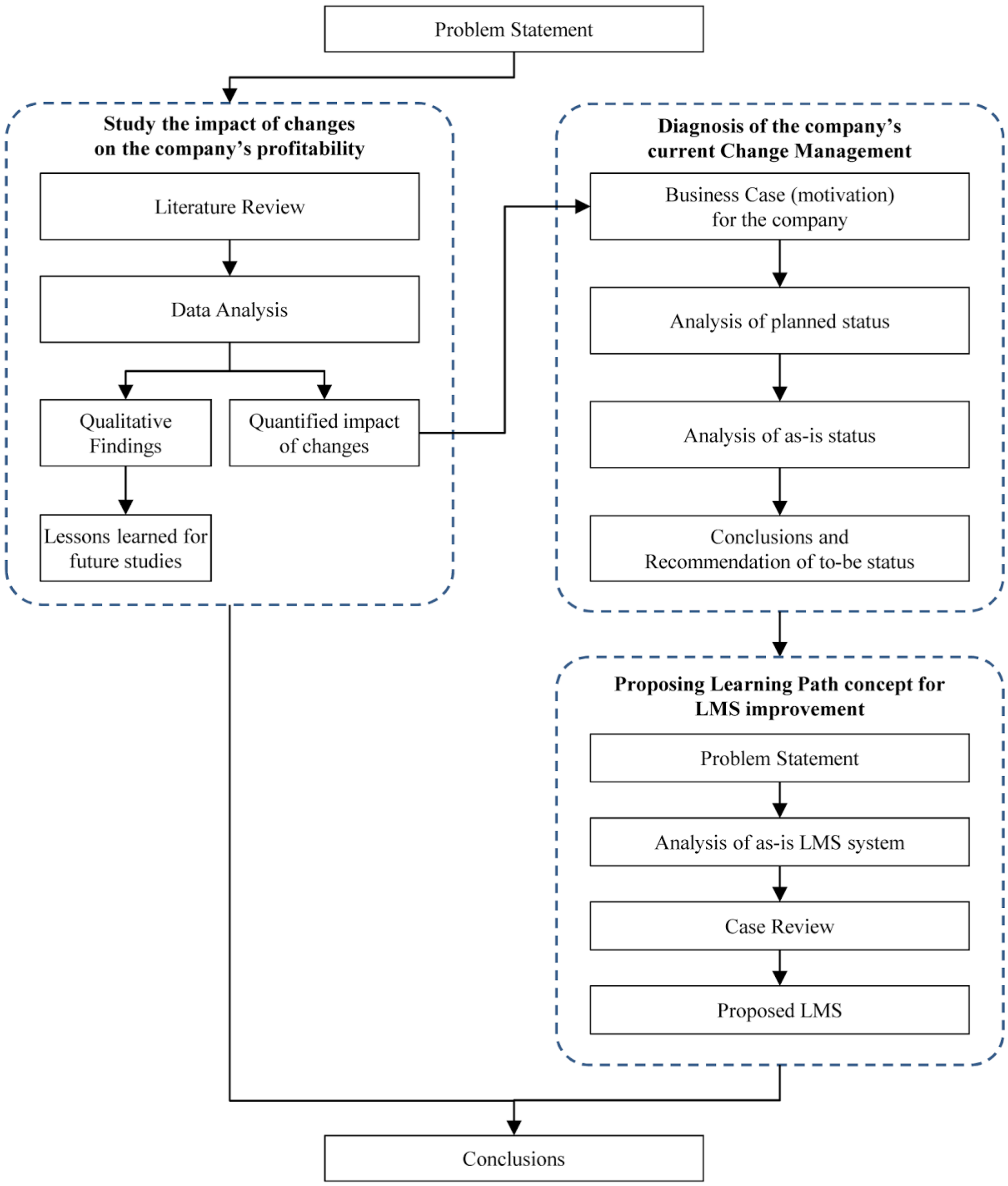

Figure 1-2. Research Methodology

The quantified financial impact of changes is then used to present the business case for the company, which would be considered as a motivation for the further investigation. This research investigates the originally-planned and as-is (actual) status of the company's CM. Based on the findings of rigorous investigation, recommendations are presented for the sub-areas of OPA, including policies, guidelines, ERP, LMS, and their actual implementations by the company's project management staff.

Based on the findings and high-level recommendations, this research presents case-specific, and more detailed, recommendations for the company. A new LMS that focuses on 're-organizing' and 're-utilizing' existing OPA is proposed as a cost- and time-effective tool. Through a case study of an international retail firm's existing LMS, this research develops and demonstrates a new LMS that can effectively re-organize and deliver existing OPA to end-users by using the learning path concept, which features flexible and customizable design.

1.5 Thesis Organization

The remainder of this thesis is organized into the following chapters.

Chapter 2 addresses the impact of changes on the company's profitability. Through rigorous data collection, analysis, and a comprehensive literature review, this chapter presents not only the findings regarding the quantified impact of changes but also valuable lessons learned for academia and industry.

Chapter 3 presents the diagnosis of the company's actual CM OPA and practices. By comparing the company's planned status, as-is status, and industry best practices, this chapter then recommends to-be status of different sub-areas of their CM.

Chapter 4 presents the further development of one of the above-mentioned sub-areas, LMS. A detailed demonstration of this LMS is also presented.

Based on the results presented in the chapters preceding it, Chapter 5 presents the conclusions drawn.

Chapter 2. Impact of changes on a contractor's profitability

2.1 Introduction

Changes are commonly, and inevitably, required throughout construction projects (Alnuaimi et al. 2010). Although some changes can be beneficial (Ibbs and Allen 1995, Lee 2007), most changes are believed to adversely affect project performance. Numerous studies to measure the effect of changes on a construction project have been conducted.

One of the most studied areas is the cumulative impact of changes on contractor's productivity. Researchers have found out that the productivity of a construction project is negatively affected when changes occur, whereas a project that is less interrupted by changes can maintain the estimated productivity (Leonard 1988, Ibbs and Allen 1995, Hanna 2001, Ibbs 2012). Ibbs (2012) also discussed the relationship between productivity and cost overrun, and found that if the actual productivity is lower than estimated productivity then cost overrun is likely to occur.

Another research area of interest is the impact of the timing of changes on productivity. Studies by Ibbs and Allen (1995), CII (1995) and Ibbs (2005) discussed that late change is more detrimental to productivity than earlier change. Front-end planning and early engagement of stakeholders are examples of best practices that are widely accepted by practitioners to minimize such negative impact of late changes. However, this area of study requires further investigation due to the limited availability of data.

It is worth noting that most studies quantify the impact of changes by measuring productivity, such as the labour productivity of contractors. However, these cannot account for the direct relationship between changes and contractor's profitability, as shown in Figure 2-1, because such productivity loss can be absorbed by contractor's margin and other indirect costs of a contract, or by better project management. Therefore, careful interpretation of the results is required when they are used by practitioners, lawyers, or other researchers. With this in mind and in the interest of clarity, the specific use of various terms in this research will be further explained later in this thesis.

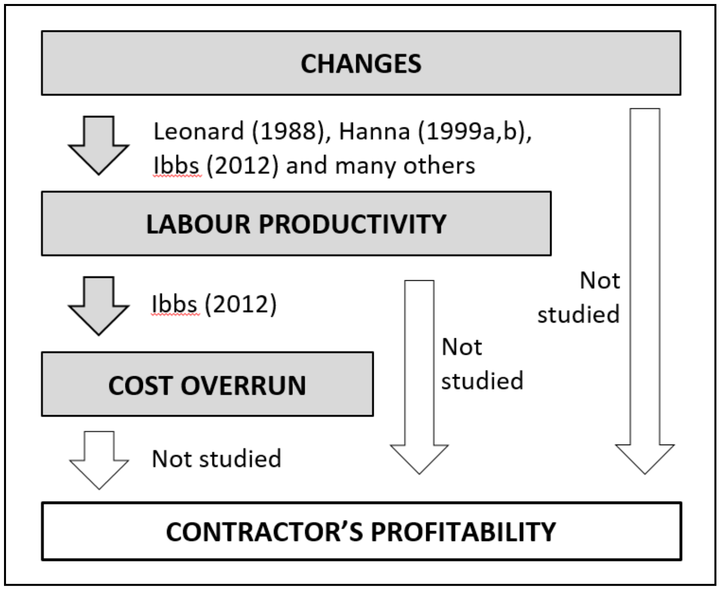

Figure 2-1. Studied areas

The impact of changes on a contractor's profitability is an aspect of change that certainly requires further study. Although researchers and practitioners generally agree on the negative impact of changes on project cost, the term "cost" in this context does not necessarily refer to the contractor's own cost. Unlike owner's cost for a construction project, which is typically an officially agreed upon contract value, the contractor's internal cost is not typically publicly known because it requires disclosure of internal cost data, which is typically confidential.

In this context, many also argue that a contractor may increase its profit through changes (Doyle and DeStephanis 1990, Zack 1993), because, once a contract is awarded, there is no competition against other contractors and the contractor is thus in a better position when pricing changes. However, this perception has not been supported by any actual data, given that construction companies are reluctant to share their financial data to support such studies

2.1.1 Study Objective

This study presents the direct relationship between accumulated changes and a contractor's final profitability by analyzing actual financial data and project documentations of a heavy civil and mining construction company in Western Canada. All project information, financial data, and documentation, including change management (CM) records and correspondence, were directly collected from the company's file system by the author of this thesis. To maximize the reliability and accuracy of the analysis and to overcome practical challenges, rigorous selection criteria are established based on the company's specific circumstances, as further described in the Research Methodology section.

Another aspect of change that this study encompasses is the relationship between the timing of changes and profitability. The selected projects are divided into two groups, more profitable projects and less profitable projects, in order to compare the different impacts of changes between two groups.

Finally, this chapter demonstrates the extent to which the reliability and accuracy of data analysis can be improved if project data are more closely investigated from a practitioner's perspective rather than depending on third party responders' judgment during data collection. Unlike most past studies, where data has often been collected through indirect ways such as questionnaires, all the data analyzed in this study is directly collected, reviewed, and analyzed for a six-month period. This chapter presents valuable lessons learned through this rigorous investigation that are believed to be useful for future researchers to improve the reliability of similar studies.

2.2 Literature Review

CM practice is known to be among the most important best practices for construction organizations (Lee et al. 2004, Zou and Lee 2006). Furthermore, project change cost performance is known to be one of the most essential metrics to measure project success (Williams 2000, Eden et al. 2005). When practitioners need to quantify the impact of changes, they rely primarily on a few traditional methods, such as total cost method and measured mile analysis, depending on available data. Although there are available quantification methods developed in academia, these methods have not been fully utilized by practitioners due to the lack of guidelines for their use (Lee 2007).

Approaches to measure the impact of changes, particularly on labour productivity, can be categorized into two main areas; discrete impact of changes and cumulative impact of changes (Lee 2007).

2.2.1 Discrete Approach

The discrete approach measures the impact of an individual change factor. Factors that have been studied by researchers include overtime, overmanning, shift work, weather, and learning curve effect.

For example, having studied work performance of 51 masonry workers, Grimm and Wagner (1974) concluded that productivity is adversely affected when humidity is less than 40%. A mathematical model that can estimate the productivity losses caused by shift work was developed by Hanna et al. (2005). According to their formula, productivity decreases when the percentage amount of total shift work man-hours exceeds roughly 5% of budgeted total man-hours. Gunduz (2003) presented statistical analyses related to the impact of overmanning, which refers to the practice of adding more workers to a jobsite than are typically required. Out of 73 tested variables, 12 variables were found to show differences between overmanned and regular projects at a 10% significance level. According to the result, projects with more changes tend to have greater overmanning. However, despite the wide application of this approach, use of a discrete approach may not be suitable when multiple factors affect a project.

2.2.2 Cumulative impact of changes

The cumulative impact of changes is known to be typically more difficult to measure (Ibbs 2005), because of its complexity and the compounding effect, often referred to as ripple effect. One of the earliest studies in this area is Leonard's study published in 1988. He investigated the project data of 90 dispute cases generated from 57 different construction projects, and identified statistical relationships between the amount of change and the loss of productivity. Among three measurements of change orders (COs) — (1) frequency, (2) average size, and (3) % change order — % change order was found to have the highest correlation with productivity loss in the regression analyses. In his study, % change order was calculated using labour hours required for COs and original work, rather than contract value. According to the result, if the cumulative amount of change exceeds 10% of contract value, labour productivity tends to be affected adversely. Despite considerable criticism, this study constitutes the pioneering attempt to study cumulative impact using a statistical analysis, and is referred to frequently in both industry and academia (Lee 2007).

Ibbs and Allen's study in 1995, published as a Construction Industry Institute (CII) report, sought to identify the cumulative impact of changes by analyzing 104 construction projects from 35 different companies, considering both owners and contractors. Unlike Leonard's data, which was collected from a construction claim servicing company using its clients' data, Ibbs and Allen used a questionnaire that mainly focused on project cost, productivity, and schedule data. A few interviews with practitioners were conducted after reviewing questionnaire responses. Their study reaffirmed that the more change is seen on a project, the more of a negative impact on labour productivity can be expected. Overall, the results from this study represented a less severe impact on labour productivity than Leonard's study, possibly because their study represents both undisputed and disputed projects whereas Leonard's presents disputed projects only.

Thomas and Oloufa (1995) presented a regression model that explains the relationship between Management Disruption Index (MDI) and Performance ratio (PF). MDI is a measure of the ability of site management to control the work environment, and PF is a measure of how efficiently the work is performed. Although their study supports the idea that increasing disruption leads to decreasing labour performance, applicability of the results may be limited due to poor definitions of the major variable MDI and disruptions, as well as to unclear classification of the two sample groups — normal projects and abnormal projects (Lee 2007).

Hanna et al. discussed the cumulative impact of change orders in two papers published in 1999 based on their analysis of data collected from mechanical and electrical contractors. Not only did they show that projects impacted by change orders suffer from productivity loss whereas projects not impacted maintain estimated productivity, but they also identified significant factors that have more impact than others by developing regression models that predict the probability and impact amount. These factors include percent change, renovation work, peak manpower, and coordination of the design issues before construction.

Ibbs (2005) analyzed a total of 162 disputed and non-disputed projects collected over nine years, beginning with those from Ibbs and Allen's earlier study published in 1995. Not only did he discuss the disruptive effect of changes on labour productivity, he also reaffirmed that late change has more negative impact on a project than early change, all other things being equal.

By combining his own data (1997, 2005) with Leonard's data (1988), Ibbs (2012) developed more comprehensive relationship models using a larger dataset containing a total of 226 projects.

In his study, the productivity index (PI), which represents final actual productivity divided by planned productivity, is used to measure impact of changes on productivity, and therefore lower PI indicates that productivity has been adversely impacted. Figure 2-2 shows that projects that have more changes tend to have lower PI. Ibbs also noted that projects with greater amounts of changes have more variable rates, which means that the predictability of productivity is affected as well with increasing changes.

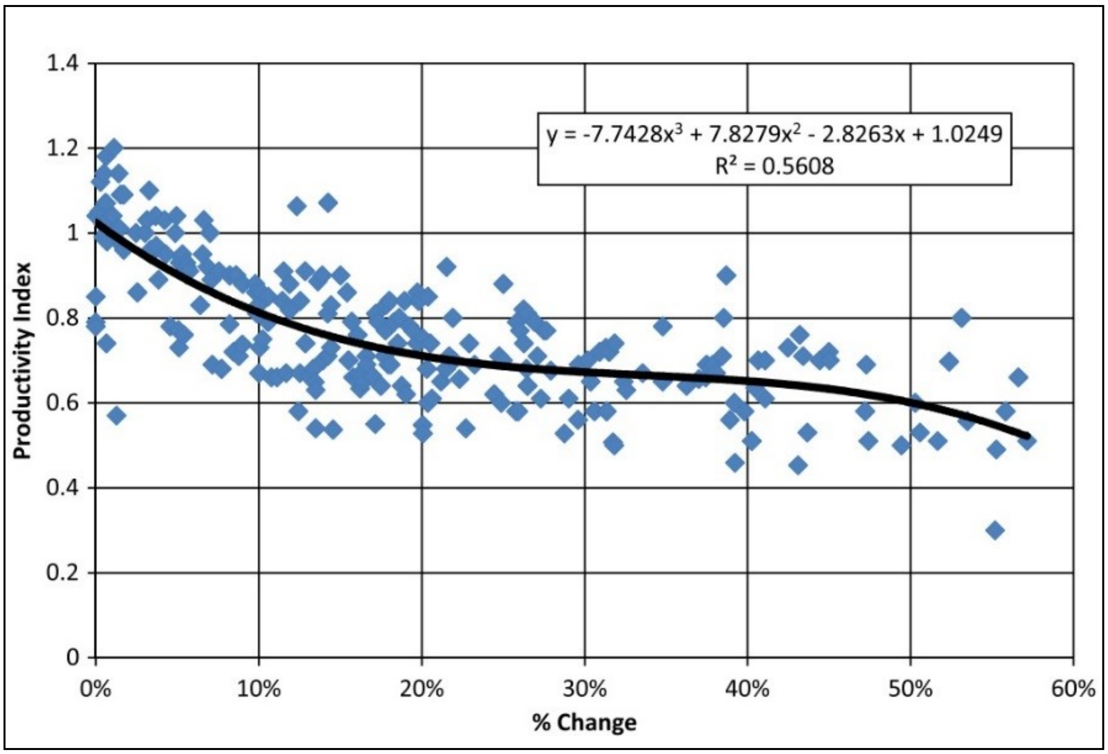

Figure 2-2. % Change versus Productivity Index (Adapted from Ibbs 2012)

In addition to the regression models developed by Hanna et al. (1999), Serag et al. (2010) developed two multiple regression models to quantify the percent increase in the contract price caused by change orders that increase the contract price from 0.01 to 5% and 5 to 15%, respectively. By analyzing sixteen roadwork construction projects in Florida, they found that (1) the timing of the change order and (2) the change order that is caused by unforeseen conditions are the most significant variables that affect the cost of a change order.

Moselhi (1998) introduced neural networks to estimate the cost and impact of change orders. In an earlier study, the neural network model had been developed based on four inputs, (1) Percentage of Change Orders (COs), (2) Number of CO, (3) Frequency of CO, (4) Average size of CO, in order to estimate percentage loss in productivity, which is the model's output. This approach was later further developed (Moselhi et al. 2005) by incorporating other researchers' models in a prototype software system. In this software, the loss of productivity is calculated by using timing impact of CO, CO intensity, work type, and type of impact.

Nguyen and Ibbs (2010) described the most acceptable methods from case law for proving and quantifying productivity loss caused by cumulative impacts, which are earned value analysis, measured mile analysis, and a combination of these two. Their paper also identified representative cases where cumulative impact claims were allowed, or denied, by courts or boards. Liability, causation, and resultant injury were three key components identified that may increase the likelihood of acceptance if proved with sufficient certainty. The idea of cumulative impact is not accepted, it is noted, when the evidence is insufficient to prove the causal linkage between changes and lost productivity.

Table 2-1 summarizes the key aspects of previously mentioned studies. It should be noted that this information is only intended to provide a general idea and comparison among different studies. Where multiple items (e.g., for input variables) are used in a study, only meaningful ones are shown. As shown in the table, most studies have analyzed the impact of changes by using labour hours and labour productivity.

A more comprehensive and detailed description and review of current research available and various methods to quantify productivity losses is found in Lee's dissertation (2007), which can be used as a useful guideline for researchers and practitioners studying the impact of changes on productivity.

Table 2-1. Past studies on cumulative impact of changes

Studies	Data source and Collection method	Sample size for analysis	Key input variable	Key output variable	Key statistical analysis methodology
Leonard (1988)	Collected from construction claim consulting company	90	• %CO (calculated using labour hours)	• % Loss of Productivity	Regression analysis
Ibbs and Allen (1995)	Questionnaire sent to CII member companies & interview	Total of 104. Varies for each testing	Varies, including… • construction change (%) based on labour hours	Varies, including… • construction productivity ratio	Regression analysis
Thomas and Oloufa (1995)	International projects	19	• Management Disruption Index (MDI)	• Performance Ratio (PR)	Regression analysis
Moselhi (1998)	Leonard (1988) data	34	• %CO (calculated using labour hours) • Number of CO • Frequency of CO • Average size of CO	• % Loss in Productivity	Neural network
Hanna et al. (1999a)	Questionnaire sent to mechanical contractors	61	• Impact Classification • Original estimated labour hours • Total estimated change hours • Number of COs • Timing of changes	• Delta (Δ) % total labour hours	Regression analysis

Studies	Data source and Collection method	Sample size for analysis	Key input variable	Key output variable	Key statistical analysis methodology
Hanna et al. (1999b)	Questionnaire sent to electrical contractors	61	• Impact classification • Project manager's number of years in construction industry • Estimate of COs as % of original estimate • Estimate of CO hours	• Delta (Δ) % total labour hours	Regression analysis
Ibbs (2005)	Unclear. Includes Ibbs and Allen (1995) data	162	• % Change (Unclear. Assumed to be based on labour hours)	• Productivity ratio	Regression analysis
Mosel et al. (2005)	Collected from construction claim consulting company (Same company with Leonard 1988)	33	• timing impact of CO • CO intensity • work type • Type of impact	• % of unproductive labour hours on original contract work	Neural network
Serag et al. (2010)	Collected from 16 different contractors who worked at different districts of Florida Department of Transportation, US	16	Varies, including… • Timing of change order • When the reason for issuing CO is unforeseen conditions	• % increase in contract price	Regression analysis
Ibbs (2012)	Leonard (1988) data and Ibbs (2005) data combined	226	• % Change (Unclear. Assumed to be based on labour hours)	• Productivity ratio	Regression analysis

2.2.3 Timing of Changes

Although many agree that late changes will have a greater negative impact on project performance, studies using statistical analysis to prove the impact of late changes have been somewhat limited. Ibbs and Allen (1995), in a CII publication, tested a hypothesis that changes which occur late in a project are less efficiently implemented than those which occur earlier. However, their study was not able to prove the hypothesis to a meaningful level of statistical significance, although linear relationships between the amount of change and its timing were observed. Ibbs (2005) is the only study to have quantified the effects of the timing of changes on productivity (Lee 2007). He rank-ordered 162 projects in three groups—early, normal, and late change—as shown Figure 2-3. By comparing the three curves corresponding to these three respective groups, Ibbs proved that projects with late changes have more detrimental effects on labour productivity.

Hanna et al. (1999a) and Serag et al. (2010) concluded that timing of changes is one of the most significant input variables for their multiple regression model. However, their models cannot explain the direct impact of timing of changes separate from other variables.

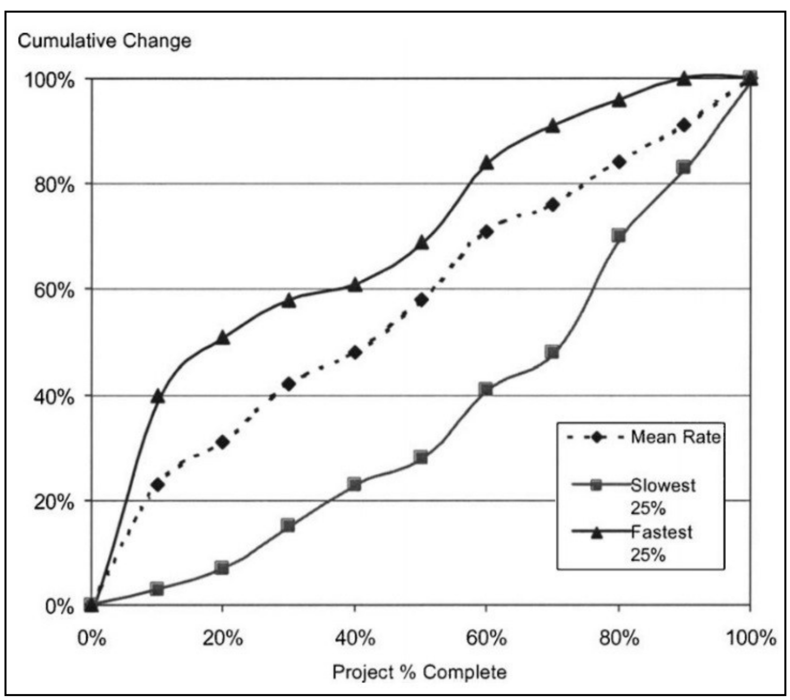

Figure 2-3. Project % Complete versus Cumulative Change (Adapted from Ibbs 2005)

2.2.4 Labour productivity versus Cost/Profitability

Studies related to the relationship between labour productivity and cost/profitability have also been limited. Ibbs (2012) found that projects with lower productivity index (PI) values tend to have more cost overruns. As is the case with the previously mentioned relationship between the amount of changes and PI, a lower PI is associated with lower predictability of final cost overrun. In his study, the term “cost” means “total cost, which includes material, general condition, construction equipment, subcontractor, and labour costs”.

The relationship between labour productivity and a construction company’s profitability has been studied by Choi et al. (2013). However, their study is limited to the relationship on the macroeconomic level only, and therefore cannot be applied to studies related to the impact of changes based on project-specific data.

2.2.5 Short-term impact of change

In a CII publication, Backes and Ibbs (1995) briefly studied the short-term impact of change on productivity by comparing change amount and productivity on a monthly basis in order to develop a predictive tool. However, due to lack of data, they were only able to present a case study of a large petrochemical project.

2.2.6 System dynamics modelling

System dynamics modelling can be an effective tool to overcome one of the limitations of cumulative impact approach, which is that it is not capable of handling multiple and/or concurrent disruptions caused by different project parties (Ibbs et al. 2007). This approach typically requires an advanced computer model to map all relationships and feedback loops in a comprehensive dynamic model (Nelson 2011), and is widely used by the defence industry (Cooper and Lee 2009). One of the key features of system dynamics modelling is its capability to provide answers to “what if” questions, such as, *what if one particular disruption had not occurred but all others had?* (Cooper 1980, Eden et al. 2005).

Park and Pena-Mora (2003) developed a dynamic CM tool to capture feedback processes caused by changes during a construction project and to minimize their impact. Their model was applied to 27 bridge construction projects in the United States, and was found to be effective when combined with other managerial efforts such as increasing coordination among projects functions and reducing process time.

An actual industry application that had been developed based on system dynamics modelling and is currently used by a large EPC company was introduced in an article from Cooper and Lee (2009) with an extensive level of detail. The company's Change Impact Assessment system simulates the dynamics of project performance from engineering phase through construction completion and enables its users to conduct "what if" impact and mitigation analyses once the as-planned project conditions have been simulated in a base case.

Despite its benefits, system dynamics modelling has not achieved popularity in construction disputes and, due to its complexity and advanced expertise required to properly understand the methodology, use of system dynamics needs to be determined carefully and with proper validation. Otherwise, it can lead to unconvincing and inaccurate results (Ibbs et al. 2007).

2.2.7 Gaps and Limitations

Most studies with a cumulative approach quantify the impact of changes by measuring the productivity of contractors. Also, as discussed in the introduction, the term "cost" in the context of most studies refers to owner's cost rather than contractor's cost. For a construction project in a traditional design-bid-build environment, a contract value, or any other addition or subtraction to it, is the amount that an owner pays a contractor, and therefore it is the owner's cost. On the other hand, contractor's cost in the construction project management context is the contract value less contractor's profit, as shown in Figure 2-4. The term "cost" as employed in most studies in this area, in fact, should be understood as an owner's cost rather than a contractor's. For example, the finding from Ibbs' study (2005), that lower productivity is associated with cost overrun, needs to be interpreted as that lower productivity is associated with owner's cost overrun or contract price increase.

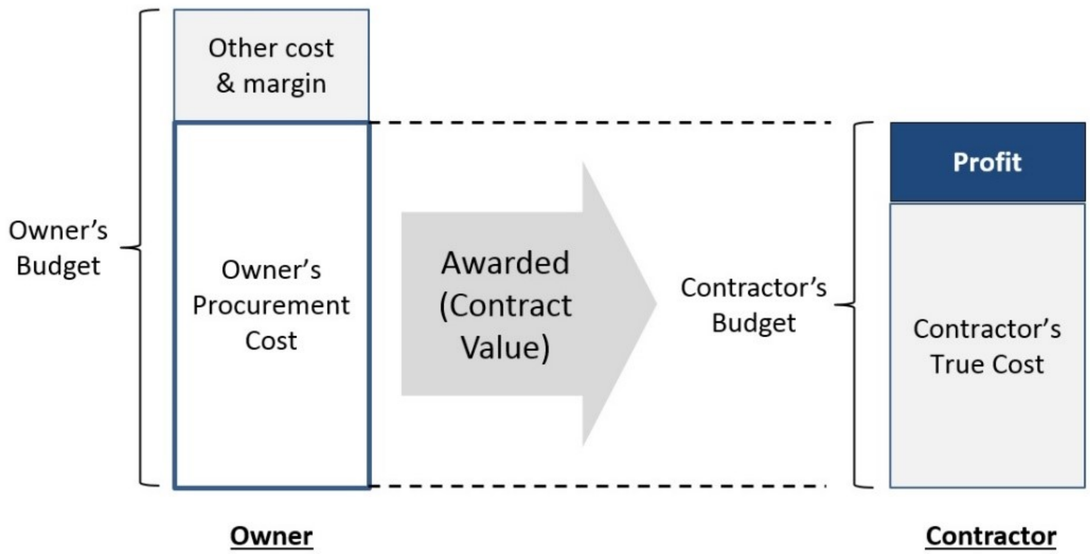

Figure 2-4. Owner's cost versus contractor's cost

Studies on cumulative impact of changes on productivity have garnered considerable discussion and criticism. One of the most common criticisms is that the cases used by a prominent study included those that had already reached the dispute stage and therefore resulted in skewed graphs towards the negative end (McEniry 2007, Ibbs 2012). Another criticism is that most studies have common limitations in that they assume that (1) the contractor's estimated work hours for original and change work are accurate, (2) the contractor did not mismanage its part of the work, and (3) most changes are caused by owners (Ibbs 2005, Lee 2007, McEniry 2007).

With the exception of Leonard (1988) and Moselhi et al. (2005), whose data were drawn from the same Canadian construction claim consulting company, most studies are believed to have collected data indirectly, e.g., through a questionnaire. Despite its many advantages, data collection using a questionnaire relies on respondents' own interpretation of the question and therefore may lack validity.

2.3 Research Methodology

For the present study, a heavy civil and mining construction company in Western Canada, hereinafter referred to as the *Company*, is investigated over the course of a six-month. All the project information and records is directly collected from the *Company*'s file system and reviewed. (To maintain confidentiality, no detailed information about the *Company* and its projects studied is revealed in this thesis.) The research begins with a total of 347 projects dating back to 2005 initially extracted from the *Company*'s project database.

Although a number of studies on the impact of changes already exist, their approach, input/output variables and limitations are quite different. Unclear use of certain terms may confuse readers, as well. Thus, the present study makes significant front-end efforts to clearly establish project selection criteria, assumptions, and definitions of terms so that the scope and boundaries of the study can be clearly explained. To avoid any misrepresentation and inconsistency of data among different projects, project teams, and CM practices, they are investigated to the level of each Request for Change Order (RCO) or Change Order (CO) document and then summarized in a consistent format. This process is iterated in order to establish a clear scope and objectives for the study. Lessons learned through these efforts are fully elaborated on in the qualitative findings as one of three main findings of this study.

Final project data selected through these processes are then quantitatively analyzed to study cumulative impact of COs on the *Company*'s profitability and impact of the timing of CO on profitability, which are the other two main quantitative findings of this study.

Figure 2-5 summarizes the overall process of the research methodology.

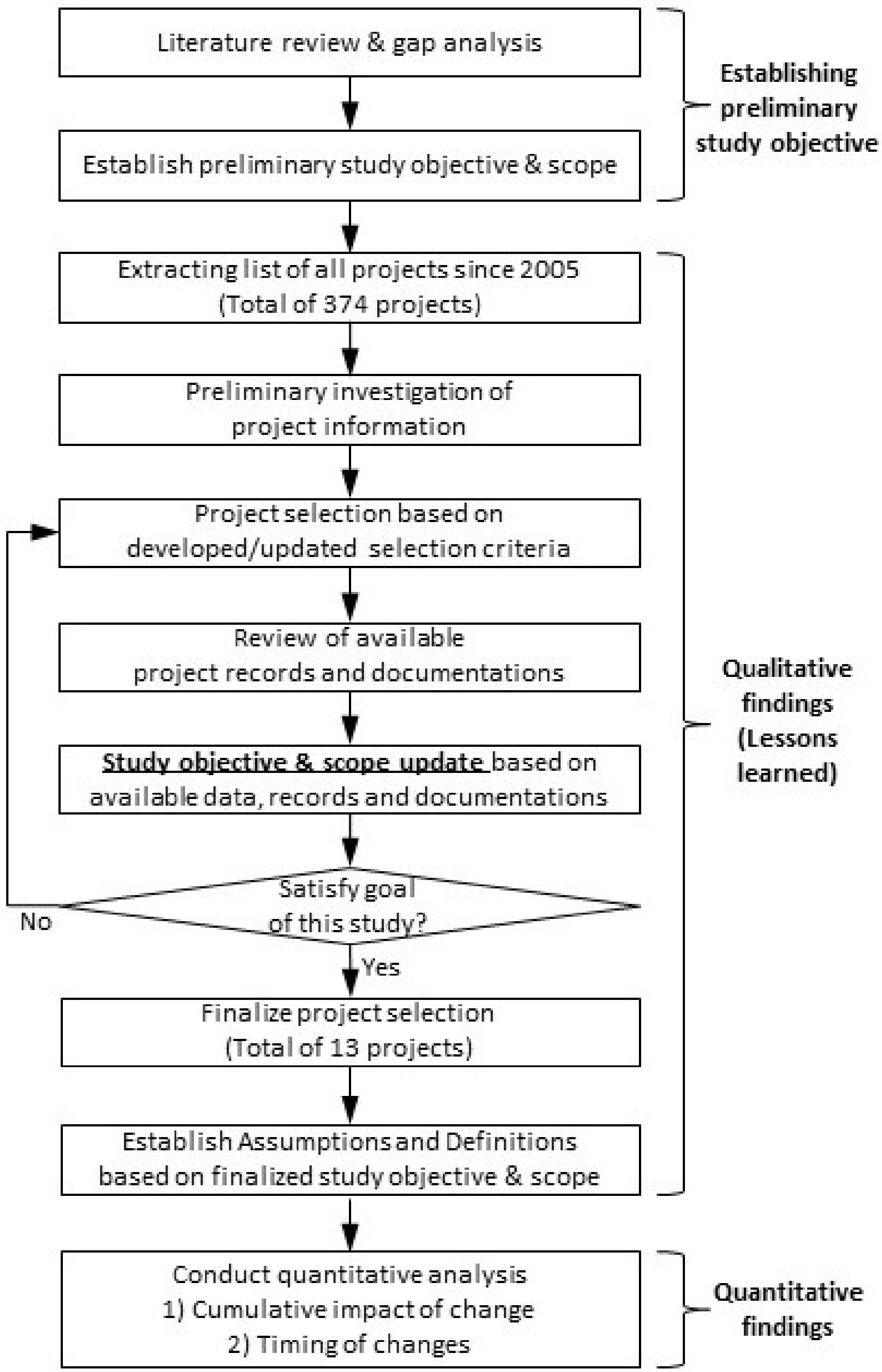

Figure 2-5. Research methodology

2.3.1 Project Selection Criteria

This study establishes project selection criteria as shown below. The rationale for each criterion is described as well, where applicable.

- A project has to have been awarded in 2005 or later: Considering the availability of project data and documentations from the *Company*'s system, only projects in the past ten years are selected.
- A project must be either lump sum or unit price contract: Many of the *Company*'s projects are found to be Time and Material (T&M) contracts, due to the nature of oil sands mining projects. According to the Project Management Institute (2013), T&M contracts are "open-ended and may be subject to a cost increase for the buyer", (in other words, the owner). Therefore, the exact quantity of work items may not be defined by the owner when a project is awarded to a contractor. Considering that in cumulative impact studies the amount of change work is always measured relatively based on the amount of original work, only lump sum or unit price contracts, where original work items and amounts are fully defined at contract awards, are selected for this study.
- A project must be a stand-alone project and should not be interrupted by other projects in adjacent areas, in terms of either actual work or project accounting: It is worth noting that most of the *Company*'s project sites are oil sands mining projects where multiple projects are actually part of a vast oil sands development site. In many cases, multiple activities, often performed by different contractors, take place simultaneously at an oil sands site. Thus, the *Company*'s activities are often affected by other contractors' operations. In some cases, a contractor is requested to utilize its workforce to assist in another contractor's work because the owner is the same for both sites, as is observed to have been the case for many of the projects considered for this study. Such projects are determined to be unsuitable for this study because the cost performances of such projects are likely to be significantly interrupted by external factors. This is a very important factor of the *Company*'s projects that differentiates this case study from past studies. Researchers are strongly advised to understand this type of project characteristic when analyzing data from different types of construction projects.

- Documents and records for a project's CM must be available for research team's detailed review: As previously mentioned, most past studies rely on data collected using questionnaires with responses solicited by industry practitioners with varying backgrounds. However, one of the key contributions of this study that sets it apart from other studies is that all the data analyzed in this study is directly collected, reviewed, and analyzed, thereby greatly increasing the reliability and accuracy. Therefore, only those projects that have detailed documents and records are selected for the final analysis. Practical challenges encountered during this process are further discussed in the Qualitative Findings section of this study.

- In addition to the criteria above, the *Company*'s own criteria to determine whether or not forecasting is required are included among the criteria. They are assumed to be guidelines by which for the *Company* to determine by means of forecasting whether or not a project is large enough to control and monitor project cost and progress against project budget.
    - Expected construction schedule of a project has to be three months or more.
    - Original contract value of a project has to be at least 2.5 million (Canadian) dollars.

2.3.2 Study Data Summary

A total of 13 projects are selected for further quantitative analysis. Table 2-2 summarizes the data from the selected projects, with their attributes.

- The value of original budget ranges between \$5.7 million and \$62 million.

- The net value of percent approved change orders (%CO) ranges between 0.0% and 65.7% of original budget value, whereas absolute value of approved %CO ranges between 0.0% and 71.7%.

- Five projects are lump-sum/fixed-price contracts, and eight are unit price contracts.

- Margin % Variance (MPV) ranges between −10.1% and 8.9%. Five projects are found to have a higher final margin % than originally estimated, and eight to have a lower final margin % than originally estimated.

Numerous practical challenges are encountered during the selection process. The project data is cleaned, and any factors that could affect the reliability and accuracy of the data are minimized or eliminated, as discussed further in the Qualitative Findings section. (It should be noted that no labour hour records were available during this case study.)

Table 2-2. Selected projects and their attributes

Project ID	Contract Type	Margin % Variance (MPV)	%CO		RCO submitted		CO approved	
			Net value	Absolute value	Quantity (ea)	Total % value*	Quantity (ea)	Total % value*
A	UP	−0.6%	16.7%	20.2%	39	29.3	38	28.4
B	LS	3.9%	0.6%	10.4%	38	14.4	17	10.4
C	UP	1.7%	43.7%	43.7%	34	77.5	12	43.7
D	LS	−4.5%	29.2%	41.2%	N/A	N/A	26	41.2
E	LS	−3.1%	22.9%	22.9%	16	38.5	12	22.9
F	UP	5.2%	10.8%	32.4%	9	39.8	4	44.5
G	UP	8.0%	9.8%	14.0%	9	15.4	6	34.2
H	UP	−8.7%	40.8%	40.8%	N/A	N/A	3	45.6
I	UP	−10.1%	65.7%	71.7%	147	113.3	18	71.7
J	UP	8.9%	0.0%	0.0%	N/A	N/A	0	0.0
K	LS	−0.3%	24.5%	24.5%	10	30.8	12	30.0
L	UP	−4.1%	23.3%	23.3%	8	10.5	8	32.8
M	LS	−4.8%	12.3%	37.5%	70	40.4	64	37.5

Note: LS =: Lump sum, UP = Unit Price

2.3.3 Assumptions and Definitions

Each of the past studies on the impact of changes has different ways of defining and measuring changes and their impacts, and therefore its application has to be carefully done when used for real world cases. The following assumptions and definitions are specifically used for this study, based on the approaches of prominent studies and the *Company*'s practices, available data, and documentation.

- How to measure changes: Consistent measurement of change is important. In keeping with one of the most prominent existing studies, where a total of 162 disputed and non-disputed projects were analyzed (Ibbs 2005), changes in this study are measured in absolute value, i.e., \$1 of additive change and \$1 of deductive change means a total of \$2 of change. Leonard's study (1988) was based on additive changes, which would lead to an underestimation of disruption due to change (Ibbs 2005, McEniry 2007)

- Change, Change Order (CO), and Request for Change Order (RCO): Any modification during a construction project can be a change. However, not all changes are approved by an owner and become COs. To be qualified as an approved CO, a change must be officially agreed upon between an owner and a contractor. In other words, a CO is an official modification to an original contract, and therefore a contractor is entitled to compensation only when the change work is approved as a CO. In this study, only approved COs are measured. An RCO, which may or may not be approved, is a contractor's formal request to an owner, advising of details of the change such as schedule and cost impacts, in order to pursue a CO. Different companies use different terms for CO and RCO, such as Extra Work Order (EWO) and Change Proposal (CP), respectively.

- Definition of "Percent Change Order (% CO)": Unlike the majority of past studies, which have used labour hours to calculate % change, this study uses approved contract value to calculate the amount of original work and change work, i.e., original contract award value and approved CO value. Thus, percent change order (%CO) can be calculated as below. (Labour hour data was not available to the researcher during this case study.)

"*%CO* = Total approved CO amount / Original contract award value"

- Profit, Margin %, and Margin % variance (MPV): Profit in this study refers to the amount that the *Company* earns after subtracting all internal costs from the total contract value. Margin % refers to the percentage value of the profit. To compare the project performance of different projects in terms of profitability, Margin % Variance (MPV) is used, which can be calculated as below. This also serves to maintain the confidentiality of the data.

  "*Margin %* = (Total contract value – Internal cost) / Total contract value"

  "*Margin % Variance (MPV)* = Final Margin % after completion – Margin % of original contract"

- Sub work packages under one contract: During the preliminary investigation, it is found that some large projects are divided into two work packages and managed separately by two different divisions of the *Company* from the tendering stage, when a project consists of different types of individual work (e.g., civil and mining). Change work is also found to be managed and tracked separately by the respective divisions. In this case, each work package of a project is treated as a stand-alone project and therefore investigated separately. Such an approach can be also observed in Leonard's study (1988), where five contracts were divided into two or more separate work packages and examined independently.

- Timing of changes: Based on the available project data and documentations, a formal issue date by an owner is used for timing of a CO. In other words, the time is marked by when a change has been formally approved through written notice. For the present study, the definition in Ibbs (2005), "when a change was formally recognized", "by either verbal or written notice, whichever is earlier," is used.

2.4 Qualitative Findings

As discussed, significant front-end efforts are made to ensure that the scope and boundaries of this study can be clearly defined. During this process, several factors believed to affect reliability and accuracy of the data are identified. These also can be treated as practical challenges which researchers and practitioners would frequently encounter during analysis of cause and impact of changes.

2.4.1 Factors affecting data reliability and accuracy

A. Different project managers have different practices: For example, some project managers of the *Company* record their unofficial RCOs even if it is not required by the owner's contract document. Some project managers tend to record a change that does not affect actual construction work as a "change", whereas some would consider this to be a revision to the original work and do not record it as a "change". This is further discussed in the next finding.

B. Some project managers fail to maintain original budget and cost baselines and therefore changes are not properly tracked: In such a case, the original budget baseline in the contract award has not been properly maintained and has later been eliminated and/or overwritten, rather than revised, by changes. This issue is consistently observed from a particular project manager in the *Company*, underscoring the need for the *Company*'s senior management team to improve its overall CM performance. It is strongly recommended that project managers maintain the original budget/cost baseline throughout the entire project cycle in order to reflect the approved changes and to properly monitor and track them apart from the original contract. It is worth noting that during the preliminary statistical analysis the projects falling in this category are found to lead to unreliable analysis results, and therefore are removed from the final results of this study.

C. Timing of a change work can vary significantly in different situations and does not necessarily indicate timing of an issued CO: When a CO is needed urgently because it can affect the schedule, the CO can be approved shortly after an RCO. In other cases, the CO is not approved immediately after the RCO if the change work is not urgent or if the owner does not agree with the requested change work. If trust exists between an owner and a contractor, a change work can be done without a CO and the CO can be approved later. In the context of this particular study, oil sands projects are often part of long-term, (e.g., five-year), agreements with the same owner, and therefore the *Company* does not always try to pursue each CO every time it encounters a change in work. The worst case from this case study, involves a CO, for which an RCO had been issued in the middle of the project, issued several months after project completion. Notably, this project (Project I in Table 2) was found to be terminated by the owner prior to project completion, due to a significant amount of changes mainly caused by estimating errors during bidding. The use of timing of change, or COs, should thus be carefully selected and clearly specified for more meaningful results from analysis of the impact of the timing of changes.

D. Not all COs affect actual work or productivity: In this particular study, two types of changes are found to have a minor impact on the *Company*'s actual work or productivity: (1) change to terms and conditions of the contract (e.g., unit price change of material, or hourly rate change of labour cost due to union agreement renewal), and (2) material quantity reconciliation of actual work done. For example, in a particular project, 20% of the COs approved are found to have been only to reconcile the quantity of earth actually moved. During the preliminary quantitative analysis, eliminating such factors from the calculation of %CO is found to drastically increase the reliability of the results, as shown in Table 2-3.

E. One project is found to be under formal dispute: One civil construction project is found to have been undergoing the formal claim stage even after project completion. This project had 25.5% of %CO, whereas its margin % variance was −16.0%. The data from this project is determined to be an outlier, and therefore is excluded from the final quantitative analysis.

F. Some COs are found to be caused by estimating errors by the *Company*: As previously mentioned, one of the criticisms of studies on cumulative impact is their assumption that the contractor's estimates are accurate. In this study, for instance, one project is identified in which 70% of COs approved actually had estimating errors. Through numerous COs, the project ended up with roughly −10% of MPV.

G. Different owners have different requirements for their CM: For example, some owners tend to group multiple RCOs into one CO based on timing, type, or other reasons, whereas others tend to issue one CO for each submitted RCO, as shown in Table 2-2. Some owners do not even require RCOs in their contract.

H. Number of COs and frequency of COs are not suitable input variables when studying impact of changes. These attributes have been used by several researchers to study the relationship between the amount of changes and the impact. However, the present study finds that blindly using the number of COs and/or frequency of COs, i.e., number of COs within a certain time period, as input variables in the analysis can yield misleading results because of the findings discussed above. Table 2-2 summarizes the total number of RCOs and a total number of COs for each project selected from the *Company*. In most cases, the number of COs is less than the number of RCOs, because not all RCOs which have been submitted by the *Company* are approved by the owner. However, in the case of Project I, the number of COs is found to be significantly lower than the number of RCOs. Through a detailed review of project documentations, it is found that the owner of the project tends to group multiple RCOs into one CO. The significantly higher number of RCOs was caused by the project manager, who tends to break down RCOs into smaller items for project management purposes, as well as in an effort to recover the loss caused by errors in original estimating, as previously discussed.

Overall, as discussed in the project selection criteria section, understanding the characteristics of a construction company's major project types, site environment, and industry sector is critical when analyzing and quantifying the impact of changes, especially for practical purposes, e.g., when preparing claims. Furthermore, it is believed to provide more substantive results that will increase acceptance by reviewers, e.g., courts. For the purpose of academic research, analyzing projects independently based on project types will result in more reliable results, although it obviously requires significantly more effort.

The extent to which the results of the data analysis can be improved through the use of a detailed and practical approach is also demonstrated in this research. For instance, during the preliminary quantitative analysis using a regression model, removing the factors A, B, D and E is found to increase the R-square value from 0.06 to 0.57. (See Figure 2-6 for the regression model before removing all the factors, and compare to Figure 2-7, the final model where those factors are eliminated.)

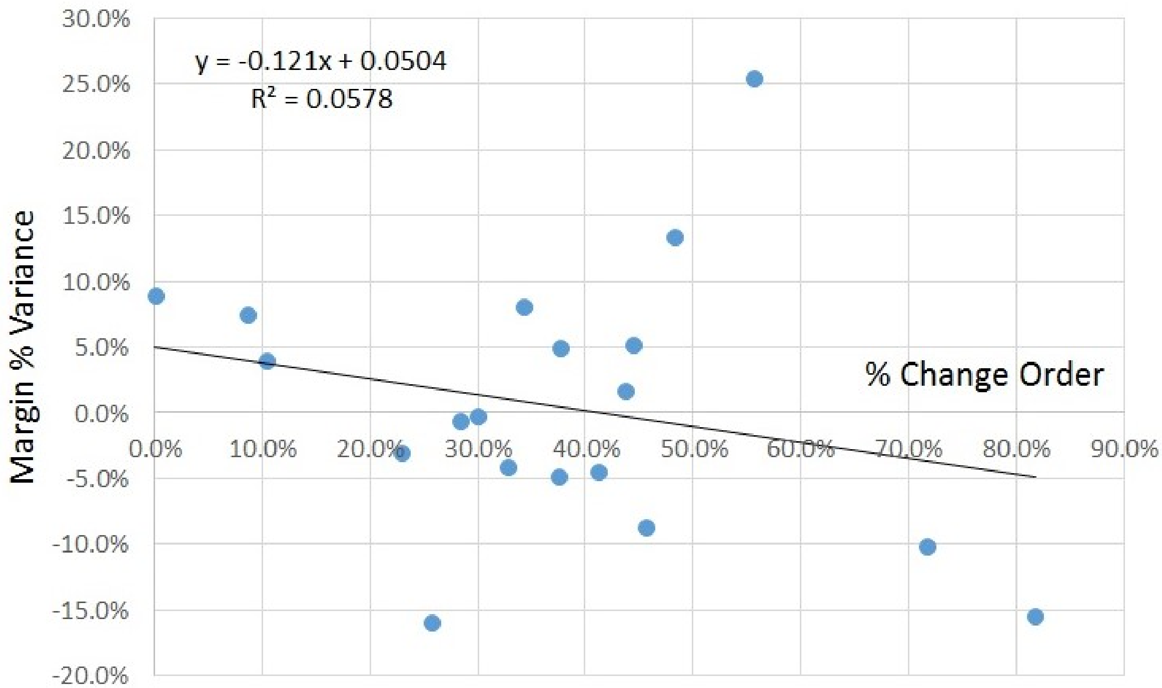

Figure 2-6. %CO versus MPV (Preliminary model)

Table 2-3 provides regression models generated from different combinations of the factors and their R-square values. Starting from a total of 19 projects originally selected for preliminary analysis, Table 3 demonstrates the extent to which the regression model has been improved by eliminating the factors. The model in the top-left cell is the initial result from the 19 projects, and the model in the bottom-right cell is the final model from the 13 projects. All 19 projects in the first row have been analyzed, whereas, in the second row, the projects affected by factors A, B, and E are removed from the analysis. All COs in the first column are included in the %CO calculation, whereas in the second column, COs affected by factor D are removed from %CO calculation.

Table 2-3. Regression models from different combinations of factors

	All Change Orders			Change Orders, excluding factor D		
	Sample Size	Regression model	R^2	Sample Size	Regression model	R^2
All projects	19	$y = -0.121x + 0.0504$	0.06	19	$y = -0.123x + 0.0473$	0.07
Projects, excluding factor A, B and E	14	$y = -0.1824x + 0.0435$	0.19	13	$y = -0.2469x + 0.066$	0.57

As noted in the literature review, past studies have often relied on input from third parties, such as questionnaire, when collecting data, and therefore consistency and quality of data cannot be guaranteed. One of the datasets widely used in a number of prominent studies was collected using questionnaires completed by industry practitioners, and later combined with older data in a separate study. Although the dataset can be a representative sample involving different project sizes, industry sectors, and delivery systems, the quality of data can be affected by inconsistent interpretation of questions by respondents from different backgrounds. Inconsistent project CM and documentations are also key factors that affect the result, as presented in this study.

As demonstrated in these qualitative findings, a detailed approach based on understanding of practical aspects of construction projects and changes would significantly increase the reliability of similar studies.

2.5 Quantitative Findings

The quantitative data analysis of this study involves two hypotheses relating to the impact of changes:

1. The more COs occur in a project, the more negative the impact on contractor profitability will be.
2. COs that occur late in a project have greater negative impact on profitability than changes that occur early in a project.

2.5.1 Cumulative impact of changes on profitability

The regression model shown in Figure 2-7 summarizes the relationship between % change order (%CO) and Margin % Variance (MPV). It clearly shows that an increasing amount of COs is associated with lower profitability.

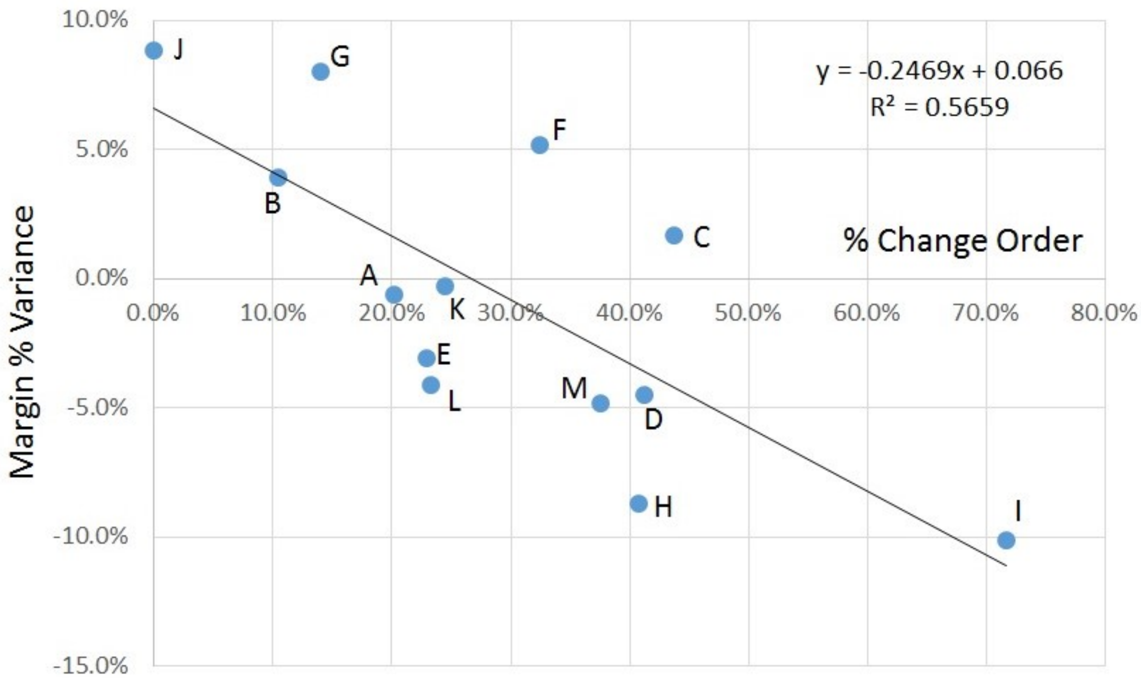

Figure 2-7. %CO versus MPV (final model)

Projects with no CO are found to result in approximately 7.5% of margin variance, which means the final actual margin % ends up 7.5% higher than the originally estimated margin % at the time of the project being awarded. Then the regression line slopes downward, meaning MPV starts decreasing as the amount of changes increases. Projects with approximately 26% of %CO are found to have zero MPV, meaning that the final actual profitability is equal to the originally estimated margin %.

Once the %CO exceeds that point, the MPV becomes a negative value and the trend continues. This trend is similar to those observed in the regression models characterizing the relationship between changes and productivity generated in past studies, including the graph by Ibbs (2012) presented in Figure 2-2. Although as stated in the introduction of this chapter lower productivity may not always be associated with lower profitability, it is reasonable to assume that lower productivity can lead to lower profitability.

To summarize, although in some CO cases contractors may generate more profit than originally estimated, the analysis result clearly shows that increasing the amount of changes adversely affects contractor profitability.

It is also noteworthy that two data points, G and F, are two separately contracted sub-projects of a larger civil project awarded by the same owner. The two sub-projects having been managed by one project management team of the *Company* as one group project, the circumstance is believed to have been favourable to the *Company*. These two points would move downward along the *y*-axis (↓) close to the regression line if the *Company* had not benefited from such circumstance, signalling an even stronger relationship arising in the regression line. Again, the result from this type of study can be vastly improved through detailed approach.

Comparisons (1) between more profitable projects and less profitable projects and (2) between lump sum and unit price contracts are not presented in this thesis because their sample sizes are too small and therefore believed to be not meaningful.

2.5.2 Timing of Change Orders

Using project records and CO documentations, the relationship between timing of changes and *Company* profitability is studied. Selected projects are divided into two groups, (1) more profitable projects and (2) less profitable projects. The first group consists of projects where the final margin % has ended up being equal to or greater than the originally estimated margin %, i.e., the MPV is equal to or greater than zero. The second group includes those where the final margin % has ended up being less than originally estimated margin %, i.e., the MPV is less than zero.

For the purpose of relative comparison among multiple projects, the final %CO amount of each project is normalized to 100%. Then, the normalized amounts of %COs are analyzed based on the timing of changes orders. Figure 2-8 presents the relative amount of changes issued before and after 50% project completion for profitable projects, less profitable projects, and the mean value of all projects.

- The horizontal axis represents the timing of COs issued, expressed in project % complete, and the vertical one represents the accumulated CO amount in a normalized term.
- The timing of each CO is based on its actual issue date by owners.
- The project % complete is based on the actual start and end date of construction. Therefore, project 0% complete refers to its actual start-date and 100% complete refers to the actual end-date of construction.
- To simplify the graphs, any COs issued before construction start, i.e., between contract award and actual construction start, are assumed to be issued at 0% complete, and the COs issued after construction complete are assumed to be issued at 100% complete.

It should be noted that, out of the 13 selected projects, two projects are excluded in this analysis. One project was stopped in the middle of the project due to severe weather condition and restarted a few months later. The other project had no COs.

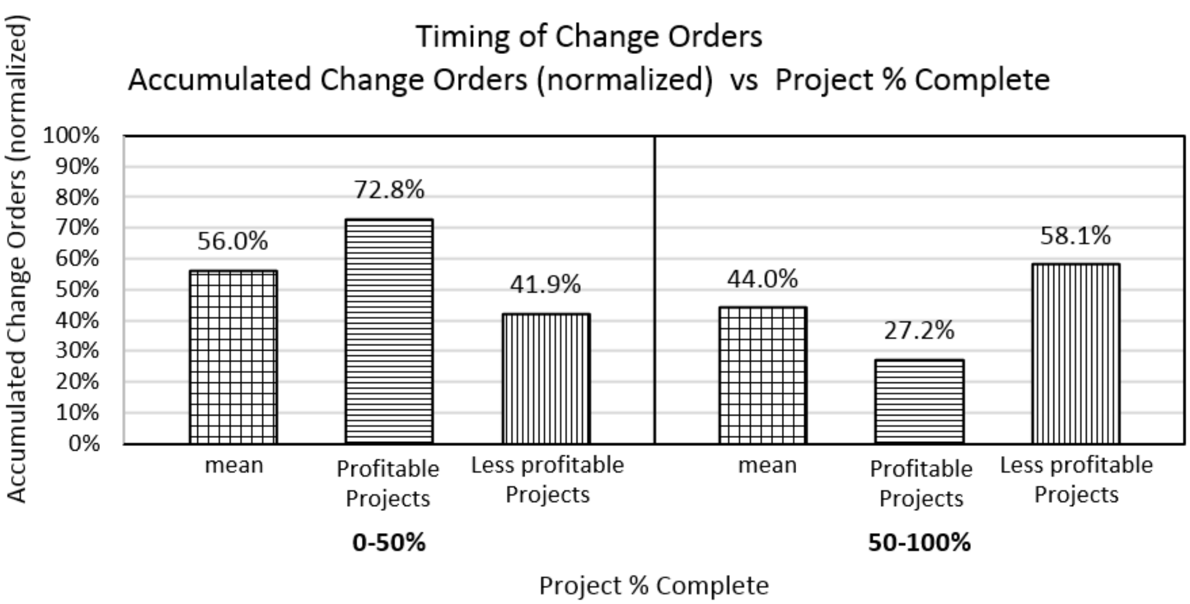

Figure 2-8. Timing of change orders before and after 50% project complete

When considering all eleven projects, 56% of COs are found to have been issued before 50% project complete, and the remaining 44% issued after 50% project complete.

However, less profitable projects are found to have more COs after 50% project complete compared to more profitable projects, meaning that less profitable projects have more COs even when past 50% complete, whereas nearly 73% of COs occur before 50% complete in more profitable projects.

Figure 2-9 presents the trend of normalized cumulative amount of COs at every 10% increment of project completeness. The middle line represents the mean rate of changes for all 11 projects. The upper line represents the mean rate from more profitable projects, whereas the lower line represents less profitable projects. This approach was used by Ibbs (2005), which is the only study that has attempted to quantify the effects of the timing of changes on productivity.

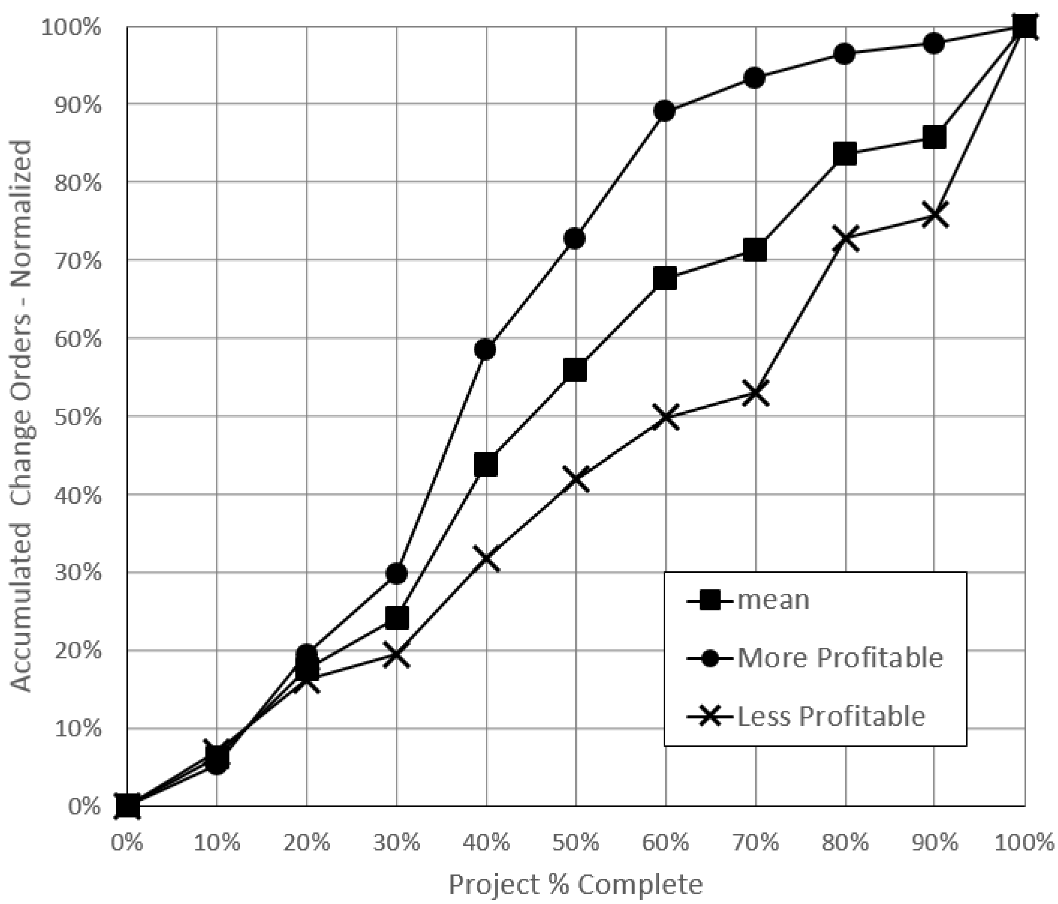

Figure 2-9. Timing of change orders

Almost 90% of COs are found to have been issued by 60% project complete in more profitable projects, whereas only 50% of COs have been issued by 60% project complete in the less profitable projects. It is clear that less profitable projects have more COs in the later stages of the project when compared to more profitable projects.

It is reasonable to assume that it is due to the fact that contractors are likely to have more time to recover from adverse effect of changes, such as productivity loss, if changes occur early rather than late in the project. Conversely, late changes can be more disruptive. However, it is worth noting that, as previously discussed in the Qualitative Findings section, there are other possible causes of late changes, especially when only approved COs are counted, rather than any changes regardless of their approval being counted, to measure the amount of changes. If a CO is not urgently needed, a project manager can wait until later to minimize their administrative work. Approval of a CO can be delayed by an owner, especially when the owner does not agree with the content of the CO. Some owners tend to group multiple RCOs into one CO. Or, in some cases change works are even caused by the contractor's own estimating error, as observed in an actual project of the *Company*. In other words, late changes may not always be causal factors for poor project performance, but in some cases may in fact be indicators of other hidden causes. Therefore, interpretation of this result must be carefully conducted.

2.6 Summary and Conclusions

Despite past researchers' efforts to quantify impact of changes, most studies have only analyzed impact on productivity, and no statistical analysis of impact on contractors' internal cost/profitability has been reported. Furthermore, analysis of the effects of the timing of changes has been limited. This chapter thus presents such analyses in a statistical manner.

Significant front-end efforts are made prior to quantitative analysis so that the scope and boundaries of the study can be clearly defined and compared with past studies on similar topics. Those factors that have been found to affect the reliability and accuracy of data and therefore ought to be excluded are also identified. These are presented in the methodology and qualitative findings of this study. Key lessons learned for future studies are as follows:

1. Not all COs affect actual work or productivity,

2. Not all changes are caused by owners (e.g., contractor's estimating error),
3. The number of COs and frequency of COs are not suitable measurements of changes, and
4. Understanding the characteristics of different industries is important and therefore project data must be closely investigated when analyzing impact of changes.

The relationship between accumulated amount of COs after project completion and the *Company*'s final profitability is studied in the first part of the quantitative analysis using a regression model. It is found that although contractors may generate more profit than originally estimated through some COs, the analysis result clearly shows that increasing amount of COs adversely affects the contractor's profitability. It is worth noting that this trend is consistent with the results from past studies where the relationship between increasing changes and productivity loss has been discussed. Although productivity loss may not directly lead to profitability loss, because such loss can be absorbed by the contractor's margin, other indirect costs, or better project management, it is reasonable to assume that it will in most cases.

The second part of quantitative analysis discusses the relationship between timing of COs and the *Company*'s profitability. By comparing more profitable projects with less profitable ones, this chapter shows that COs occurring late have a more adverse effect on the *Company*'s profitability, which is consistent with findings of Ibbs (2005). Although Ibbs quantified the impact on productivity, it is reasonable to assume that productivity loss generally leads to profitability loss, as is the case for the first part of quantitative analysis.

2.7 Contributions

This chapter presents the first study that statistically analyzes the cumulative impact of COs on a contractor's profitability. It is also the first study that presents the relationship between timing of COs and profitability. Although contractor's internal costs are also investigated during this study, for the purpose of confidentiality the findings are not presented in this chapter.

This study reaffirms that the number and frequency of COs are not suitable input variables when analyzing the impact of changes, as previously suggested by Leonard (1988).

This study supports, to some extent, one of the major criticisms of past cumulative studies, which are based on assumptions that contractor's estimated work hours for original and change work are accurate, and that most changes are caused by owners. Also, it should be noted that changes are not always causal factors for poor project performance, but instead are indicators of other hidden causes.

Unlike most past studies, where data has often been collected through indirect means such as questionnaire, all the data analyzed in this study was directly collected, reviewed, and analyzed, an approach which is shown to greatly increase the reliability of data and results. Through such a practical approach, this chapter presents lessons learned that are useful for future researchers to improve the reliability of similar studies.

2.8 Limitations

Quantitative analysis of this study is based on a somewhat limited number of project samples, (a total of 13), despite 347 samples having been initially extracted from the *Company*'s financial system in the early stages of the research. This is due to the fact that one of the main goals of this study is to increase the reliability and accuracy of results by eliminating factors that affect data quality and consistency. The majority of project samples are excluded from the quantitative analysis due to their being Time and Material contracts, which are common in the oil sands mining industry. If companies in the building industry were to be studied, it would significantly increase the project sample size because many of their projects are Lump Sum contracts. Also, if changes, or COs, are managed and recorded properly and consistently among different project managers or companies, this would also increase the samples size.

Due to the small sample size and the lack of directly comparable studies, the regression model developed in this study for cumulative impact of changes cannot be properly validated, although general trends of findings are similar to past studies on productivity. If more data are collected in future studies, this would certainly increase the validity of this approach.

This study is based on only one company's case, which is a heavy civil and mining construction company, and therefore cannot represent the overall construction industry. However, such an industry-specific approach would result in more realistic analysis and would increase the chances of acceptance by practitioners or courts if used for similar industries.

Acknowledgements

The author would like to thank the industry partner of the University of Alberta research team, and its senior project manager who provided the research team with invaluable input throughout this research.

Notation

- CO: Change Order
- RCO: Request for Change Order
- %CO: Percent Change Order, based on contract value
- MPV: Margin % Variance

Chapter 3. Diagnosis of Current Change Management Organizational Process Assets and Practices

3.1 Problem Statement

As discussed in Chapter 2, it is found that increasing the amount of changes adversely affects the profitability of construction projects. Therefore, considering that changes are commonly, and inevitably, required throughout most construction projects (Alnuaimi et al. 2010), improvement of change management (CM) can contribute to more successful project performance. The findings presented in Chapter 2 can serve as motivation for construction companies to further investigate their existing Organizational Process Assets (OPA) and as-is practices, identify gaps, and improve their CM. This chapter focuses on diagnosing the *Company*'s CM OPA and practices, and identifying areas of possible improvement.

In this study, it is found that the *Company* has been directing significant effort and investment toward developing and improving its CM OPA, which include policies, guidelines, manuals, an Enterprise Resource Planning (ERP) system, and in-class and online training. However, due to various reasons presented in this chapter, the originally expected benefits have not been fully achieved, which leads to poor Return on Investment (ROI) from the *Company*'s management perspective.

This chapter presents a detailed diagnosis of as-is CM OPA and practices, and identifies areas of potential improvement. In other words, this chapter focuses on an investigation of as-is, or a comparison between planned and as-is where applicable, and recommends to-be status.

3.1.1 Definitions and abbreviations

3.1.1.1 Organizational Process Assets (OPA)

Our working definition of "Organizational Process Assets (OPA)", a term used throughout this study, is adapted from the Project Management Institute (PMI) A Guide to the Project Management Body of Knowledge (PMBOK(c) Guide, fifth edition), one of the most widely accepted guidelines for project management professionals. The purpose of this adapted definition and those that follow is to provide more consistent understanding of this thesis not only by academia but also by industry. According to PMBOK's definition, OPA are "the plans, processes, policies, procedures, and knowledge bases specific to and used by the performing organization". OPA can be grouped into two categories, (1) processes and procedures, and (2) corporate knowledge base. For the purpose of this study, OPA is assumed to include training such as in-class training and online courses.

3.1.1.1.1 Processes and Procedures

Processes and procedures include, but are not limited to, organizational standards such as policies, processes and procedures, templates, guidelines, and work instructions.

3.1.1.1.2 Corporate Knowledge Base

Corporate knowledge base includes, but is not limited to, historical information, project records and documents, financial databases, and lessons learned. For the purpose of this study, the use of OPA is limited to processes and procedures and does not include corporate knowledge base.

3.1.1.2 Planned versus As-is versus To-be

To clarify the comparisons between three different statuses of CM OPA and practices, the following terms are frequently used in this chapter, and throughout this thesis:

- Planned: Originally planned/expected by the *Company*
- As-is: Actual/current
- To-be: Proposed/recommended by this study for future state

3.1.1.3 Change, Change Order (CO) and Request for Change Order (RCO)

Refer to Section 2.3.3 Assumptions and Definitions.

3.2 Investigation Methodology

This chapter aims to provide realistic and practical findings and recommendations for industry practice. To achieve the goal, OPA are proactively collected from the *Company*, rather than depending on materials passively provided by the *Company*. In addition, interviews with the *Company*'s project team and financial staff, participation and review of actual in-class and online training sessions, and several progress meetings are conducted as part of the investigation. In cases where more than one version of a document is obtained (e.g., updated policies with different revision dates), all versions are reviewed to identify the changes between different versions and investigate the reasons for these changes. More importantly, corporate knowledge base (e.g., actual project records and data), including those used in Chapter 2, is carefully reviewed to investigate actual practices of project management staff and financial staff.

Findings from the review of existing OPA and as-is practices are presented in the following sections. A full list of OPA reviewed is available in Appendix A. A list of the *Company*'s employees interviewed is also presented in Appendix B, although their names are omitted in the interest of confidentiality.

3.2 Overview of Planned Change Management Organizational Process Assets and Practices

As described in greater detail in Appendix A, the *Company* has developed the following OPA for its CM. They cover not only general CM knowledge but also company-specific knowledge and Enterprise Resource Planning (ERP)-related tasks. The *Company*'s OPA can be grouped into eight categories as follows:

- CM policy
- Change type matrix
- CM guidelines
- CM standard forms
- CM online training (as part of project management training)
- ERP CM module user manuals
- ERP CM module work instructions
- ERP CM module in-class training

3.2.1 Change Management Policy

The *Company*'s CM policy is designed "to provide standardized processes and procedures for managing and administering changes to external client contracts in a timely manner." Five standard procedures and their process flowcharts are provided in the policy, as shown below.

1. Change Notice (CN)
2. Request for Change Order (RCO)
3. Request for Change Order (RCO) (Type 3)
4. Change Order (CO)
5. When RCO or CN rejected by client

A sample flowchart image for change Notice (CN) is shown in Figure 3-1. The figure is partially omitted in this study for confidentiality purpose.

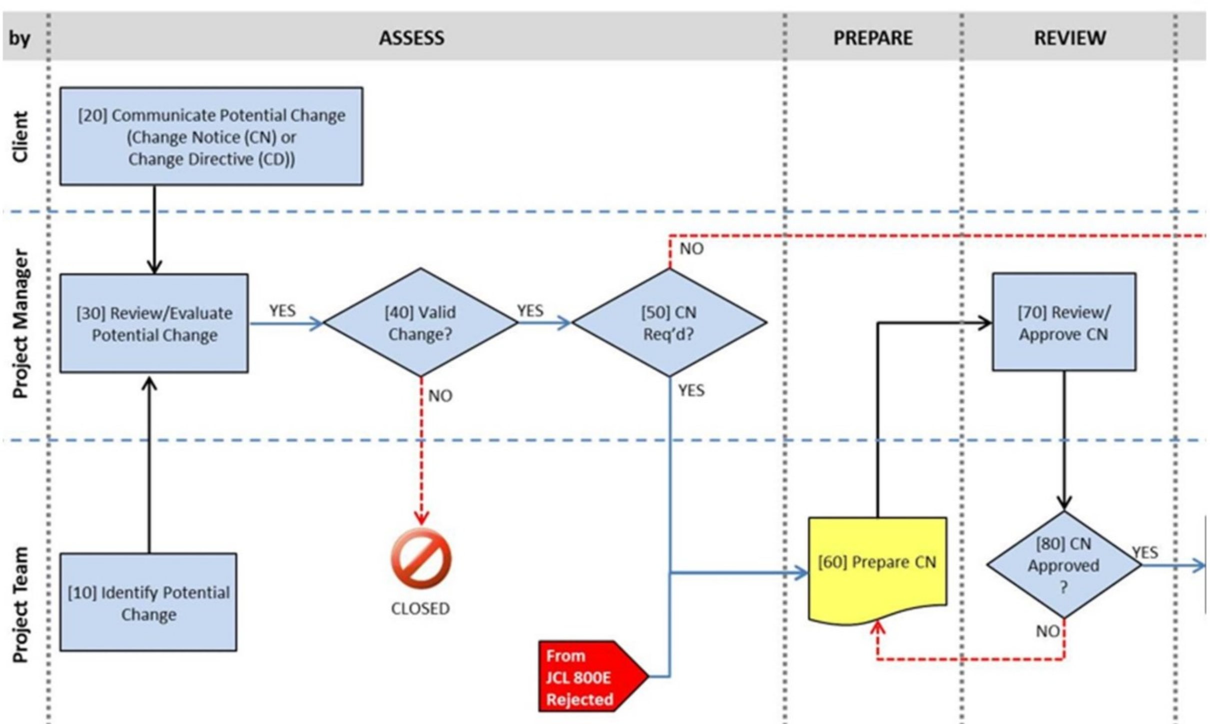

Figure 3-1. Example of standard process flowchart (adapted from the case company's CM policy)

The standardized procedures and process flowcharts cover the process from issuing Change Notice to acceptance of Change Order (CO) by the client. The flowcharts clearly show detailed processes and procedures for different cases (based on yes/no decisions or scenarios) and which staff/team is responsible for each activity. In addition to the standardized work process, a Delegation of Authority Guideline (DOAG), which outlines commitment value thresholds for the applicable role/level of authorization required to sign/execute documents on behalf of the *Company*, is also clearly specified where necessary.

3.2.2 Change Type Matrix

The *Company* uses a change matrix that categorizes changes into three different types, as described below.

- Type 1: An executed CO is required before proceeding with the Change work – "No CO, No Work"
- Type 2: Work has already started or may proceed prior to receipt of a CO (e.g., Contractually Obligated to Proceed)
- Type 3: RCO review and approval required for change to contract terms and conditions, change in rate schedules, and/or contract acceleration extension

3.2.3 Change Management Standard Forms

The *Company*'s policy includes four standard forms; (1) Change Order, (2) Change Notice, (3) Request for Change Order, and (4) Change Log. Items 1 to 3 are provided in Microsoft word format, and Item 4 is in Microsoft Excel format. These forms are also referred to in the *Company*'s ERP CM User Manual, which covers standardized paper-to-ERP tasks. The *Company* currently does not use automated or electronic forms.

3.2.4 Change Management Online Training

As part of its mandatory project management e-training for all project management staff, a section for CM is provided within the *Company*'s e-training module. Not only does the training provide general knowledge of CM for project management staff, it also provides the company-specific knowledge in a concise form, including most of the items described in this section.

3.2.5 ERP change management module user manuals

ERP plays an important role in the *Company*'s daily operations. They have recently added a CM module to their ERP in order to further leverage the various integrated and automated functionalities of ERP for effective CM. A total of seven menus are adopted within the CM modules: three menus for data entry, one menu for searching data using various filters, and three menus for generating CM reports.

During the *Company*'s implementation stage of the ERP CM module, the following benefits and impacts are expected.

"Change management module will:

- *be consistent with the company's change management standardized procedures and processes,*
- *support the tracking of changes (from Change Notice to Change Order) impacts to the revised budget,*
- *eliminate the duplicate entry between project managers' own Change Logs and existing standard Forecast spreadsheet,*
- *provide greater visibility into the changes and functions as a communication tool between the project managers and project accountants on change management status and updates,*
- *enable immediate tacking cost account structure that the company's financial group is currently using, and therefore allow consist reporting and unit rate analysis,*
- *eliminate the existing standard Change Log spreadsheet,*
- *support automated reporting for change management, and*

- *enable project managers to start to familiarize themselves with ERP through the input of change management records."*

3.2.6 ERP change management module work instructions

As previously mentioned, a total of nine menus are adopted within the ERP CM module. The *Company* has developed step-by-step instructions within the menus on how to perform CM-related tasks. The instructions also provide background information on why these steps are required and how they affect the overall project management of a job.

3.2.7 ERP change management module in-class training

The *Company*'s CM in-class training provides face-to-face training that covers most of the previously-mentioned items but within a more interactive environment. One training session spans approximately seven hours. A simplified version of this in-class training has been provided to the author of this thesis for this study.

3.3 Key findings from As-is Organizational Process Assets and Practices for Change Management

3.3.1 Organizational Process Assets Management

To successfully manage engineering and construction projects, a set of relevant processes, tools, techniques, methodologies, resources, and procedures are required (Kouprine et al. 2010). Maintaining a framework for organizing the documents associated with a project management system can be beneficial for engineering and construction companies. Kouprine et al. (2010) presents such framework and also suggests ways of improving these documents. The hierarchy of stakeholder documents associated with the preparation of project management documentation is presented in Figure 3-2. In the figure, the vertical flow indicates the sequence of document preparation, whereas the horizontal flow indicates the input of organizational documents into the project documents. If the overall framework is not properly established, project documents can end up being prepared by each functional group without taking into consideration the inter-relationships with other functional groups.

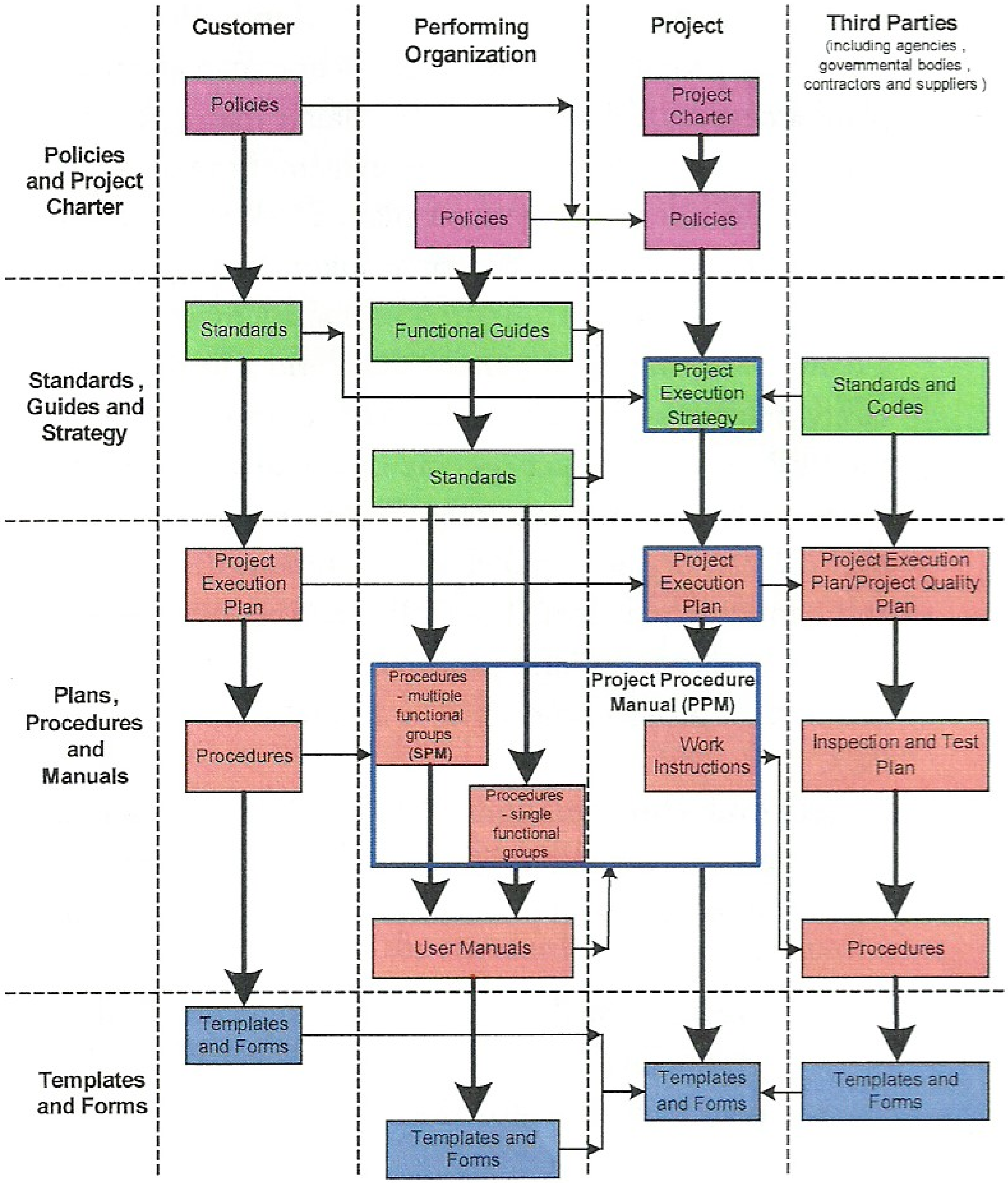

Figure 3-2. Preparation of Project Management Documentation (Adapted from Kouprine et al. 2010)

A similar approach can be used for general management of OPA. If OPA can be provided to their end-users under a well-organized framework and hierarchy, they can be more effectively and consistently delivered to their end-users. In other words, the expected benefits of the time and cost investment to create and utilize such OPA can be more successfully achieved within a well-organized framework, resulting in greater ROI for the *Company*.

As-is status of OPA management for the *Company*'s CM is investigated and analyzed using such an approach. Despite the *Company*'s significant efforts to develop and maintain a wide range of OPA to assist its project management staff and effectively implement ERP CM, it is found that the benefits that had been originally expected have not been fully achieved, mainly due to the following reasons:

- Low visibility of OPA to end-users and content managers (i.e., posted at a less desirable location on the intranet, or in some cases not posted at all).
- Lack of organized flow and centralized point of access (e.g. navigation menu on intranet) for OPA.
- OPA prepared by each functional group without taking into consideration the inter-relationships with other functional groups.
- OPA being passive to end-users (mainly because of the reasons above): Existence of OPA may not be known by end-users until "discovered" by them.
- OPA outdated or under-revision.
- Inconsistent naming of documents, which causes confusion (i.e., "Guideline", "User manual", "Work instructions", "Business Reference Guide", etc.).
- Inconsistency between CM policy and ERP CM module: Implementation of ERP CM module is carried out one year later than the latest CM policy, and therefore the latest CM policy does not reflect the current work process of ERP.
- Limitations of ERP CM module (e.g., not sufficient/flexible enough to replace traditional change logs).

- Insufficient ERP training for project management staff. For example, the materials to learn "how to interpret ERP reports" have not been officially released to end-users, although they had been developed during the implementation of the ERP CM module.
- Low acceptance of ERP by project management staff (e.g., not beneficial for project management staff, steep learning curve, training still on-going).
- Data in practice is often entered in the ERP system by project accountants and controllers although it is expected to be entered by project management staff in the field (e.g., project managers or coordinators). It is found that this practice is the result mainly of concerns of data inaccuracy, inconsistency, and ERP unfamiliarity of field staff.

3.3.2 Standard Change Management (CM) process vs ERP CM process

As previously discussed in the introduction of this thesis, ERP implementation in construction is still limited to areas such as accounting, costing, project control, and financing functions. Although the case company has been attempting to expand its use of ERP to CM in order to leverage the benefits of various integrated and automated functionalities of ERP, it is observed that actual use of the ERP CM module by project management staff, particularly by field staff, is somewhat limited. In addition to the reasons already mentioned in the previous section, noticeable gaps are observed from the direct comparison between standard CM process as described in the CM policy and the statuses entered/updated in the ERP CM module. For instance, when a change detail is first created in the *Company*'s ERP CM module, its status is set to "Submitted" by default until it has been officially approved. However, in the standard process, and more importantly in reality, many other actions and status changes can occur between the initiation of a change and the approval of the change. Because of ERP's limitation that it cannot reflect such details in the established module, project management staff may be reluctant to use the ERP CM module and instead elect to use their own forms or outdated standard forms. Figure 3-3 presents the visualized comparison between the process of the *Company*'s standard policy and its ERP CM module. Note that the procedures shown in Figure 3-3 are simplified in order to maintain confidentiality.

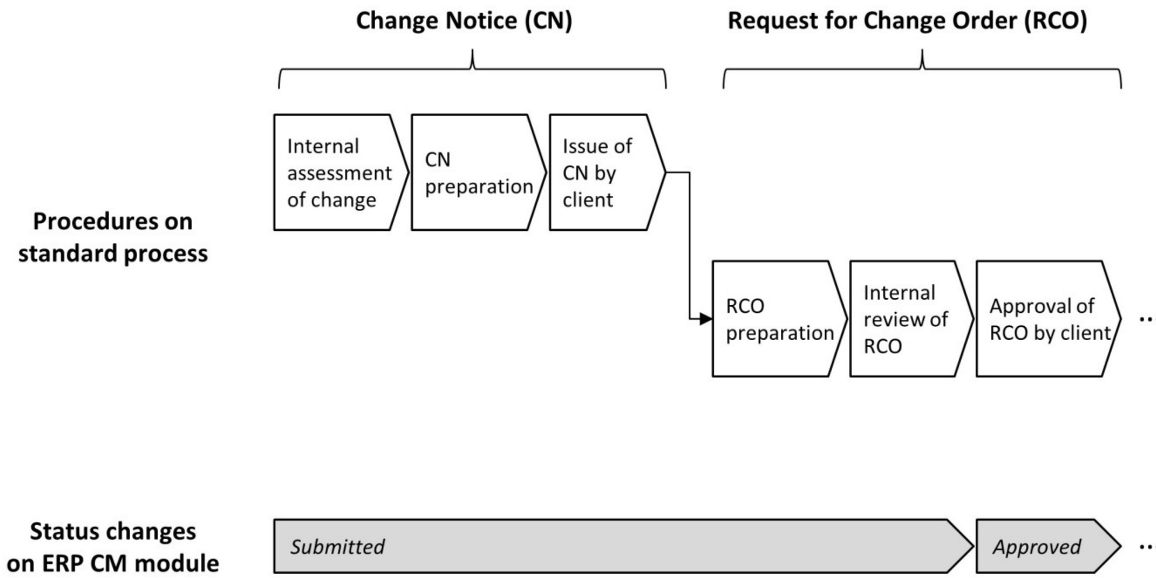

Figure 3-3. Visualized comparison between procedures on the company's standard process and status changes on ERP CM module

3.3.3 Other issues from Project Management staff's actual Change Management practices

Four major issues are observed with regard to the *Company*'s project management staff's CM practices. (It should be noted that some of these issues overlap with the qualitative findings presented in Section 2.4.) First, project managers of the *Company* have inconsistent CM practices. For example, some project managers of the *Company* record an unofficial RCO even if it is not required in the owner's contract. Some project managers record a change that does not affect actual construction work (e.g., change of labour unit rate) as a "change", whereas others consider such a change to be merely a revision to the original contract and do not record it as a "change". This issue is further discussed in the next finding.

Second, some project managers fail to maintain original budget and cost baselines and therefore changes are not properly tracked. In this case, the original budget baseline at a contract award is not properly maintained, and instead is eliminated and/or overwritten later, rather than being revised, by changes as shown in Figure 3-4. This issue is consistently observed from a particular project manager, and therefore can be used as an indication tool for the *Company*'s senior management team to improve its overall CM performance.

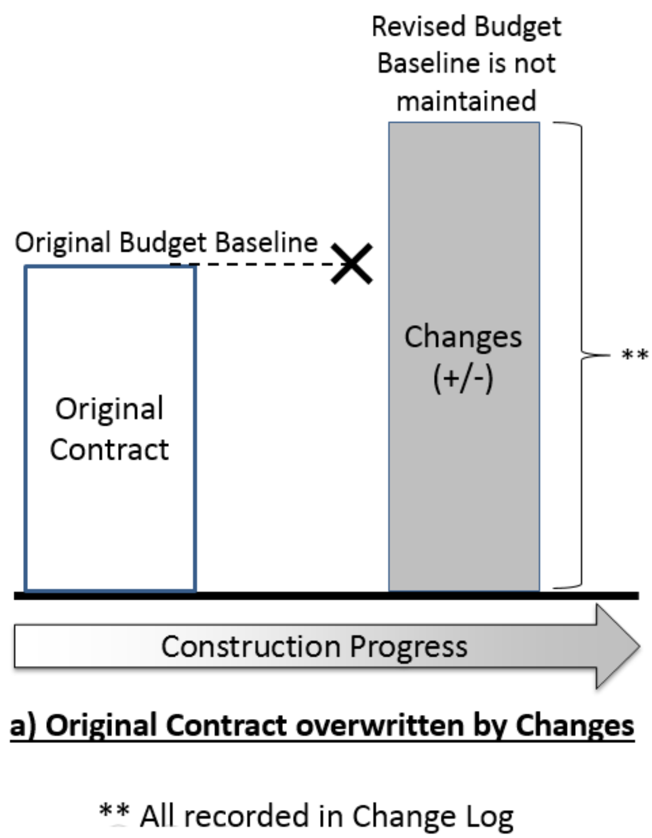

Figure 3-4. As-is practice of a project manager - Original contract overwritten by changes

It is strongly recommended that project managers maintain the original budget/cost baseline throughout the project lifecycle to reflect the approved changes and properly monitor and track them apart from the original contract, as shown in Figure 3-5.

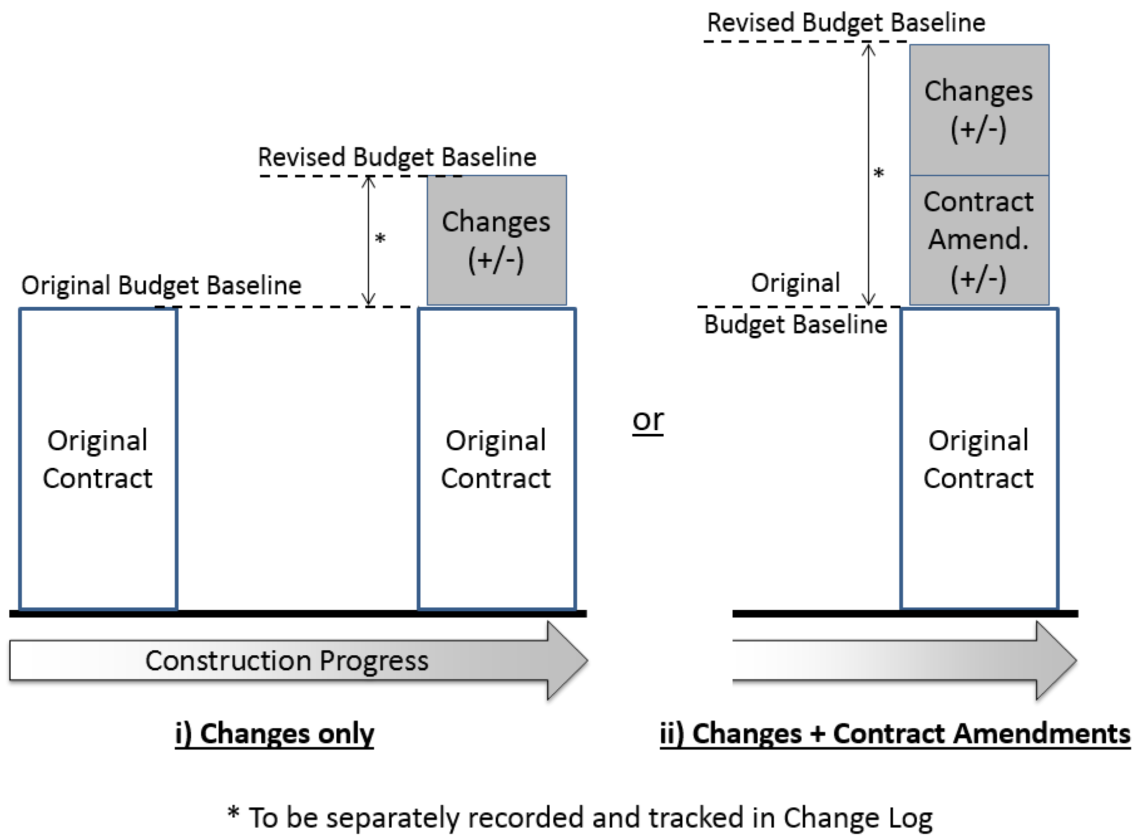

Figure 3-5. To-be practice

Third, changes to contract conditions are not always properly documented. It is found that, in the case company's practice, changes in unit rate or other conditions in a contract and lump sum addition to an original contract are not recorded as official COs. Despite these unrecorded changes having been identified and included during the cumulative impact analysis (Chapter 2 of this thesis) because the cost baseline had been established and maintained throughout the project, it is recommended that project managers record any contract amendments and COs separately from the original contract in order to properly track the changes.

Lastly, inconsistencies between project managers' own CM documents and the ERP CM module are frequently observed. Currently, in addition to project managers' own CM documents, such as Change Logs and Change Order Logs, project management staff and project accounting staff also need to update the information on the ERP CM module. However, it is observed that changes are not recorded consistently among project management and accounting staff. As discussed in the previous section, this is believed to be due to project managers' reluctance to use

ERP module because of the gaps between the two different environments: project managers' actual CM practices and ERP CM. This issue also causes inconsistency and inaccuracy of the *Company*'s financial data, because the accounting and financial data heavily depend on data entered into the ERP.

3.4 Conclusions and Recommendations

As discussed in the key findings related to the *Company*'s OPA management, the lack of organized flow and centralized point of access to OPA is one of the key factors that contributes to the failure of OPA as well as to its low visibility to end-users and content managers. In addition, this leads to weak inter-relationships of OPA among the functional groups.

Figure 3-6 summarizes the as-is status of the *Company*'s OPA that the *Company* has developed for its CM knowledge. Based on a thorough investigation, a recommended flow of knowledge for the *Company*'s CM is established in the horizontal axis. Each item, or group of items, is then laid out based on inter-relationships between items (e.g., prerequisite relationship) and their types (e.g., policy, form, training, etc.).

It is worth noting that this flow is designed entirely based on the contents of each document and the training practices of the *Company*, and therefore is to be considered case-specific. However, the summary presented in the figure can be an effective tool for management teams for any type of organization seeking to diagnose the as-is status of their OPA management and identify gaps that need to be addressed.

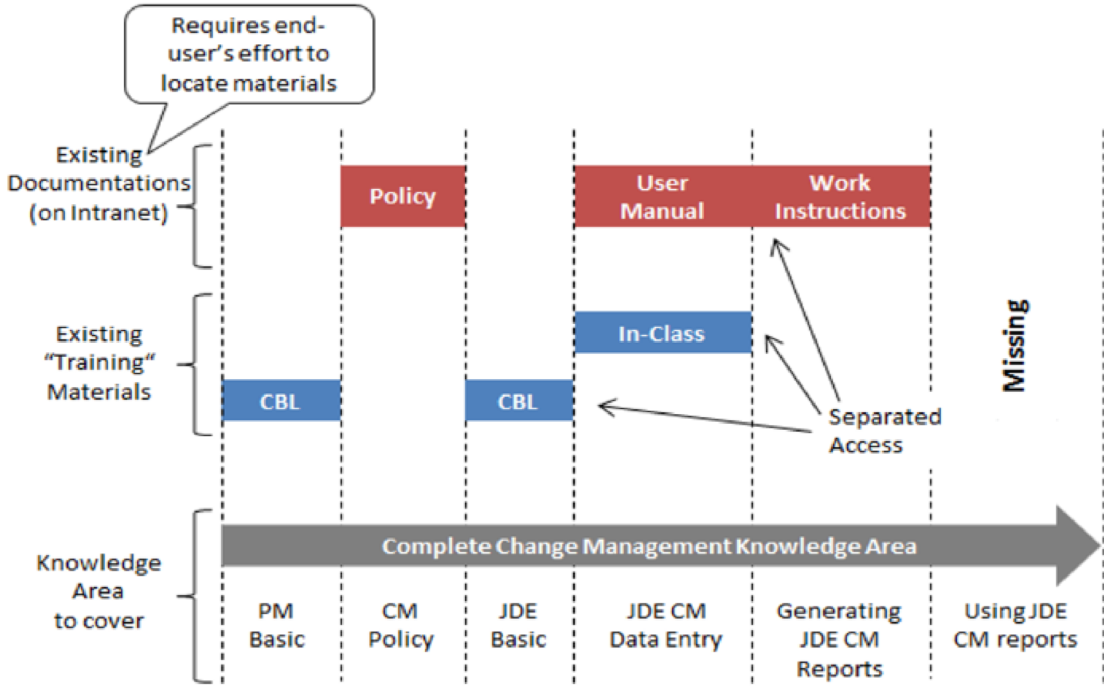

Figure 3-6. As-is status of existing OPA

Based on the analysis of visualized as-is status, it is found that the lack of flow and weak inter-relationships between the *Company*'s OPA are the key issues that require the management team's attention.

In conclusion, it is recommended that a framework and hierarchy be established to re-utilize and re-organize existing OPA as the most fundamental and effective solution to the *Company*'s overall CM challenges. This recommendation is expected to not only improve, if not solve, the key issues discussed in this study, but also to potentially improve the efficiency of the *Company*'s overall business operations across different functional groups with minimal effort.

The to-be status of the *Company*'s CM knowledge flow recommended by this study is presented in Figure 3-7. Again, it should be noted that the to-be status is case-specific, although the overall approach can be implemented for any type of organization. The key notion underlying this recommendation is that it attempts to improve the as-is status by focusing on 're-utilizing' and 're-organizing', but reducing the need for new OPA. In other words, one of the main benefits of this recommendation is that it minimizes additional time and cost investment.

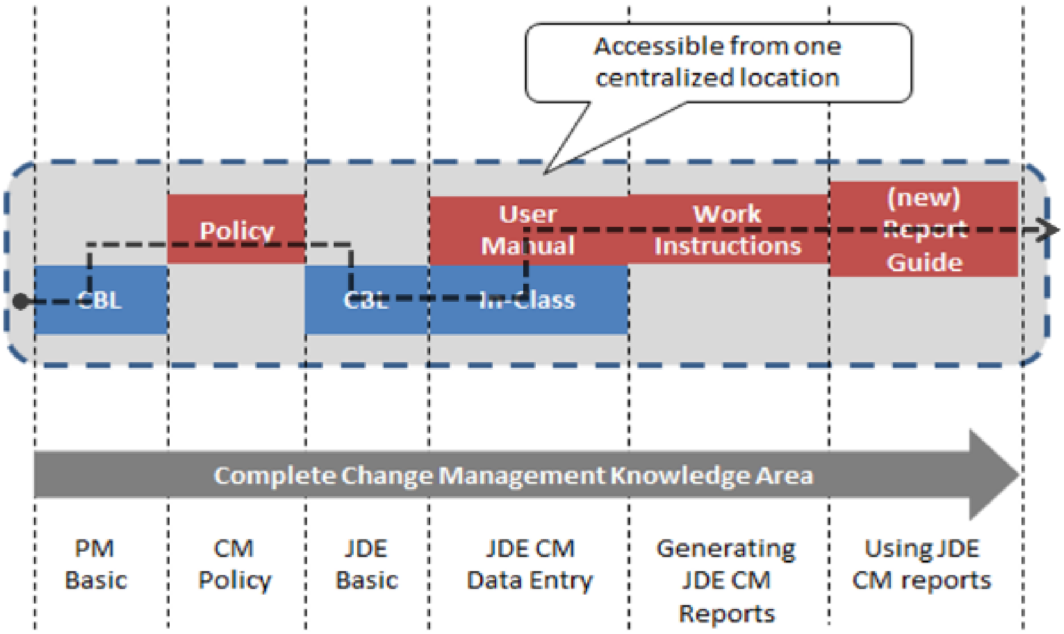

Figure 3-7. To-be status of change management knowledge flow

In the following chapter, we attempt to realize this conceptual recommendation by developing a Learning Management System (LMS) built based on a web-based interface using the learning path concept.

Chapter 4. Developing a Learning Management System (LMS) that maximizes utilization of existing resources using the learning path concept

4.1 Introduction

This chapter attempts to provide a case-specific recommendation that can help overcome the key issues discussed in Chapter 3 of this thesis. The key issues identified with regard to the *Company*'s Organizational Process Assets (OPA) and practices in the change management (CM) area can be summarized as follows:

- Low usability and Return on Investment (ROI) of existing OPA
  - Lack of organized flow and centralized point of access for OPA
  - Low visibility of OPA to end-users and content managers
- Inconsistent practices among project managers

Despite the *Company*'s significant efforts to develop and maintain a wide range of OPA to assist its project managers and effectively implement Enterprise Resource Planning (ERP) CM modules, it is found that the benefits that had been originally planned and expected have not been fully achieved, this mainly due to the above-mentioned reasons.

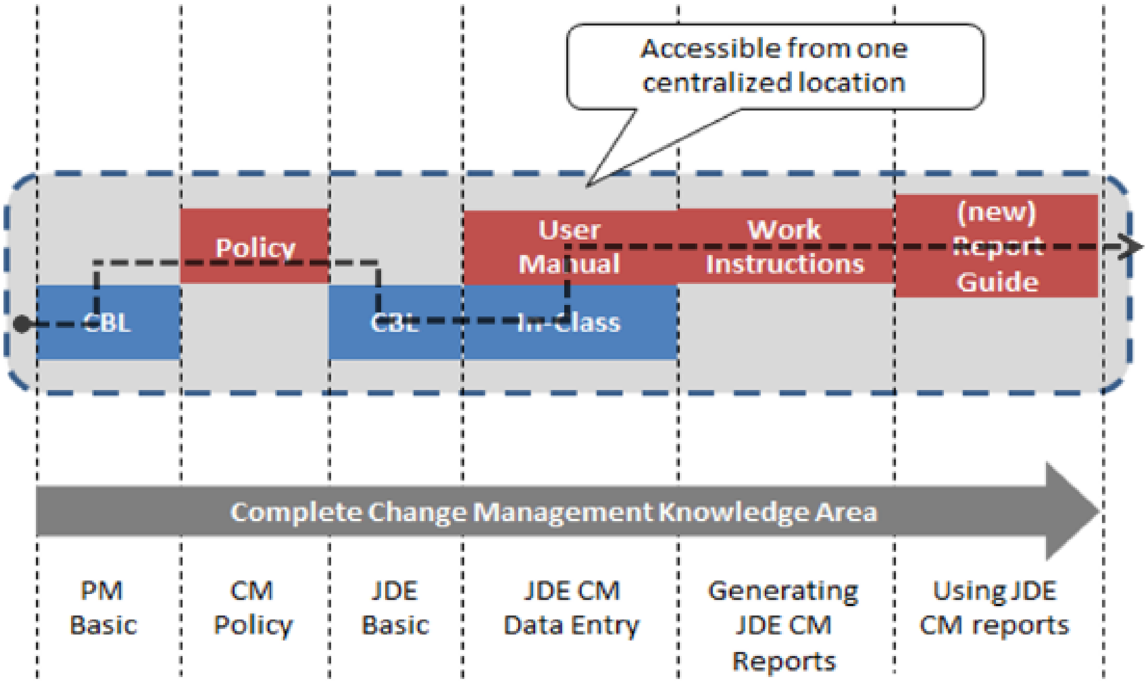

Figure 4-1. To-be status of change management knowledge flow

Chapter 4 further develops the key recommendations discussed in Chapter 3 (see Figure 4-1) to improve the *Company*'s CM by focusing on 're-utilizing' and 're-organizing', but reducing the need for new OPA. This study recommends a framework and hierarchy not only to improve the *Company*'s CM but also to improve the efficiency of the *Company*'s overall business operations across different functional groups with minimal effort and investment. The main objectives of this recommendation are to:

- re-utilize all the existing OPA that the *Company* has already developed through a significant investment of time and cost,
- identify missing OPA in order to fill gaps in the practical knowledge base,
- facilitate accessibility and visibility of OPA by providing one centralized access point and consistent learning/training flows,
- actively deliver OPA to end-users by providing a dashboard where employees can check their completion status of assets,

- provide the management team with efficient reporting tools that can answer various questions, and
- help content managers or company management staff to manage OPA more efficiently by enabling visualization of all the individual OPA and different learning paths that connect those individual OPA.

4.2 Literature Review

4.2.1 Knowledge Management

Knowledge is a vital organizational and project resource that gives market leverage and contributes to organizational innovations and project success (Egbu 1999 and 2000, Nonaka and Takeuchi 1995). It is generally agreed that Knowledge Management (KM) is the body of knowledge that deals with the management of both personal and organisational knowledge (Nonaka and Takeuchi 1995, APQC 1996, Skyrme 1997, Davenport and Prusak 1998).

Although there are many knowledge management tools on the market, there is no perfect tool for the construction industry (Kazi 2005). It is because each organization is unique from each other and the construction industry is characterised as a project-based business that delivers one-of-a-kind products (Kazi 2005). Furthermore, Tupenaite et al. (2008) addressed that the workforce in construction companies prefer to utilise knowledge in their tasks, based on previous experience and advice passed down from mentors, rather than on written standard procedures or records.

A knowledge map is a consciously designed communication medium using graphical presentation of text, models, numbers, or symbols between makers and users (Wexler, 2001), and it can be used to effectively plan the implementation of a KM strategy (Lee et al. 2004). Tserng and Lin (2005) presented an application of KM in the construction phase of construction projects by using a Web-based portal. In their application, the knowledge map identifies key knowledge areas that are most strategic and critical to the project, and deals with the assistance for users to find the needed knowledge effectively (Tserng and Lin 2005).

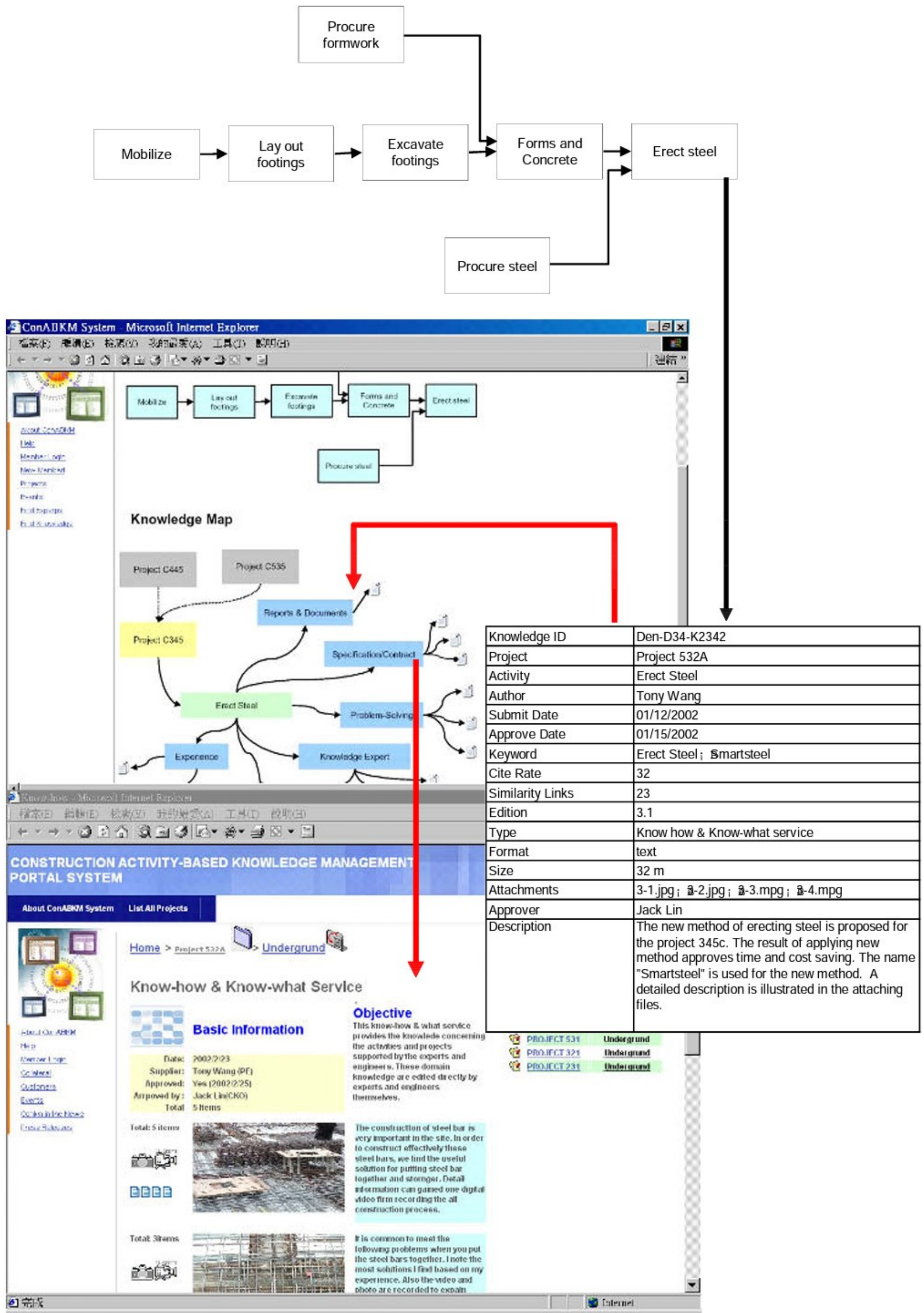

Figure 4-2. An example of a knowledge attribute of an activity unit with the help of a knowledge map

Orange et al. (2005) addressed the problem of fragmentation within the construction industry through the processes of knowledge management and organisational learning. Fragmentation is known to be a critical barrier to change since it is seen as a major factor in the poor communications between parties working together on construction projects (Latham 1994, Egan 1998). The Cross Organisational Learning Approach (COLA) process was also presented by Orange et al. (2005) to facilitate the sharing of knowledge by all partners of construction projects. Through a lifecycle of a project, knowledge is generated, such as a form of lesson learned. COLA process provides the means of externalizing and storing such knowledge, which may be lost and after the completion of a project.

4.2.2 Learning Management System

Learning Management System (LMS) is a tool to deliver such knowledge to an organization's employees. Nowadays, LMSs have become mainstream in higher education and widely used to support teaching and learning initiatives (Coates et al. 2005, McGill and Klobas 2009, Weaver et al. 2008). Using centralized administration and content management, self-service and self-guided services, and effective assembly and delivery of learning content (Ellis 2009), a LMS can be an effective tool that connects the outputs from KM with end-users.

There were nearly 600 LMSs commercially available in 2013 (Little 2015). Little (2015) discussed buying strategies and practical benefits of LMSs with two case studies of global organizations' LMS usage. Centralization of knowledge within the organization, provision of effective and productive training for new employees, and enabling consistent learning contents around the world were presented as major benefits of LMSs.

Back et al. (2016) investigated medical students′ utilization of and problems with a learning management system and its e-learning tools as well as their expectations on future developments. Interactivity of tools and their conceptual integration into face-to-face teaching were discussed as important aspects in the perception of a LMS. Furthermore, they concluded that more effort should be put on the provision of fact-oriented contents than on a sophisticated design.

Walker et al. (2016) studied LMS usage, particularly from the perspectives of university instructors. Overcoming the resistance to change, e.g., LMS adoption and diffusion, faculty training, time allotment for faculty to get the needed training, and programs to enhance the quality of content were recommended for LMS, particularly for online teaching.

4.3 Concept Development

4.3.1 Case Study

The training system developed and used by a Fortune 500 company, (ranked in the top 100), is reviewed for the case study. This retail company generated more than US$40 billion revenue in 2015 from more than 1,000 stores and offers a unique training system for its more than 100,000 employees across North America.

To deliver effective and consistent training to employees with different job positions in various locations, the retail company provides customized training on their intranet that suits each employee's job position. The intranet homepage of an employee is automatically customized based on the employee's position and location, and they can access the training materials through a dashboard on the homepage. On the dashboard, the employee is advised to follow recommended "learning paths" that are required for their position. In addition, a report that shows a full list of not-completed training modules for each employee can be generated for easy tracking of employee training.

Another benefit of this system is that it uses the concept of learning path not only to cover the whole knowledge area but also to eliminate redundant work developing and maintaining overlapping materials. Also, by using the learning path concept, it can provide recommended learning sequences for each knowledge area. The basic concept of this learning path is illustrated in Figure 4-3. This approach is being effectively used by the retail company to deliver consistent, and also customized, training to more than 100,000 employees in multiple locations, and also to help overcome the challenge of high employee turnover rate, which is typical of most retail companies.

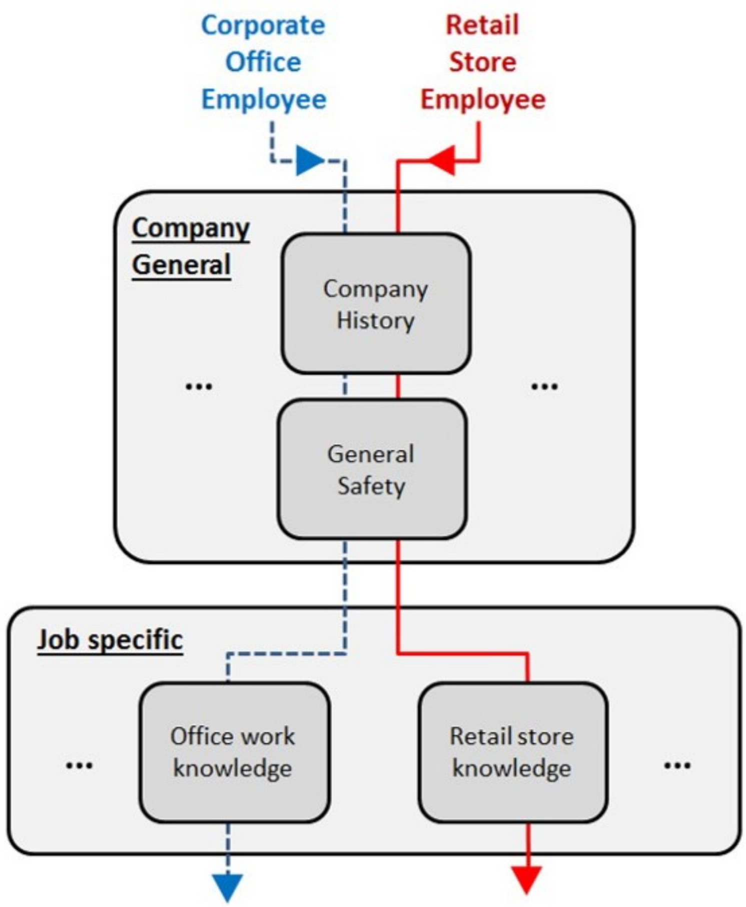

Figure 4-3. Learning path concept

4.3.2 Concept Development

As mentioned, one key objective of this study is to provide a framework that can 're-utilize' and 're-organize' the existing OPA but minimize the need for new OPA. The linking of OPA using learning paths can be an effective algorithm for establishing such a framework. As discussed in the introduction of this chapter, this study determines that the learning path concept can be broadened to improve not only the *Company*'s CM but also its overall business operations across different functional groups. The steps to developing learning paths are described below with diagrams that visualize each step. Note that the diagrams are for demonstration purposes only.

First, identify and list all existing OPA (e.g., policies, manuals, guidelines, training programs, etc.) that have been developed or retained.

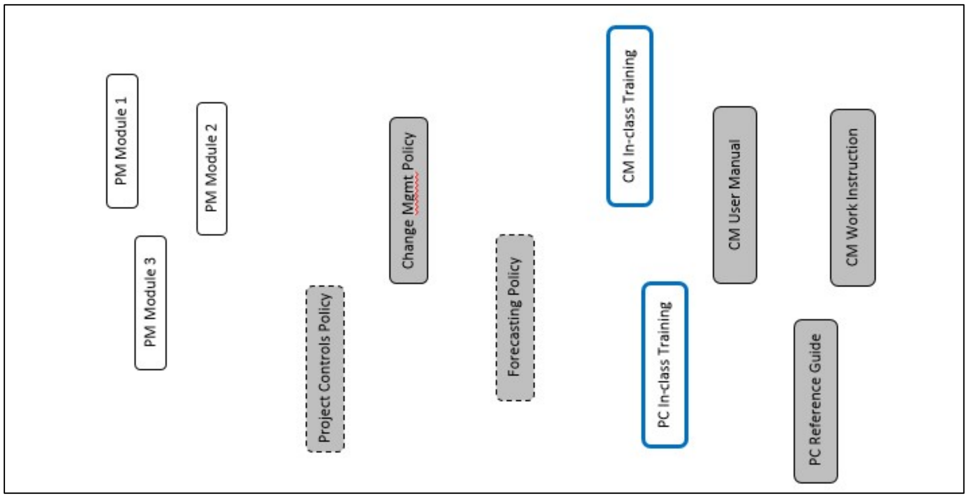

Figure 4-4-a. Step 1 - Identify existing OPA

Second, group OPA based on knowledge areas. (e.g., Change Management General, ERP Change Management, etc.)

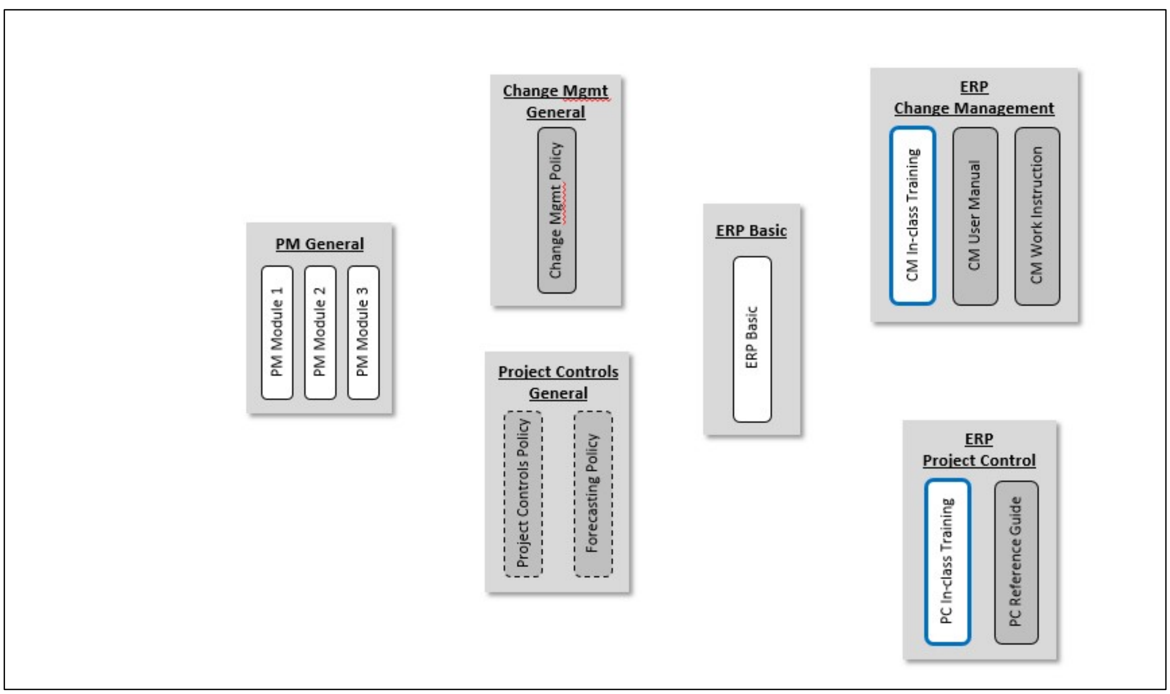

Figure 4-4-b. Step 2 - Group OPA based on knowledge areas

Third, establish high-level knowledge groups (e.g., Project management general, CM, Enterprise Resource Planning) based on the existing OPA and industry best practices.

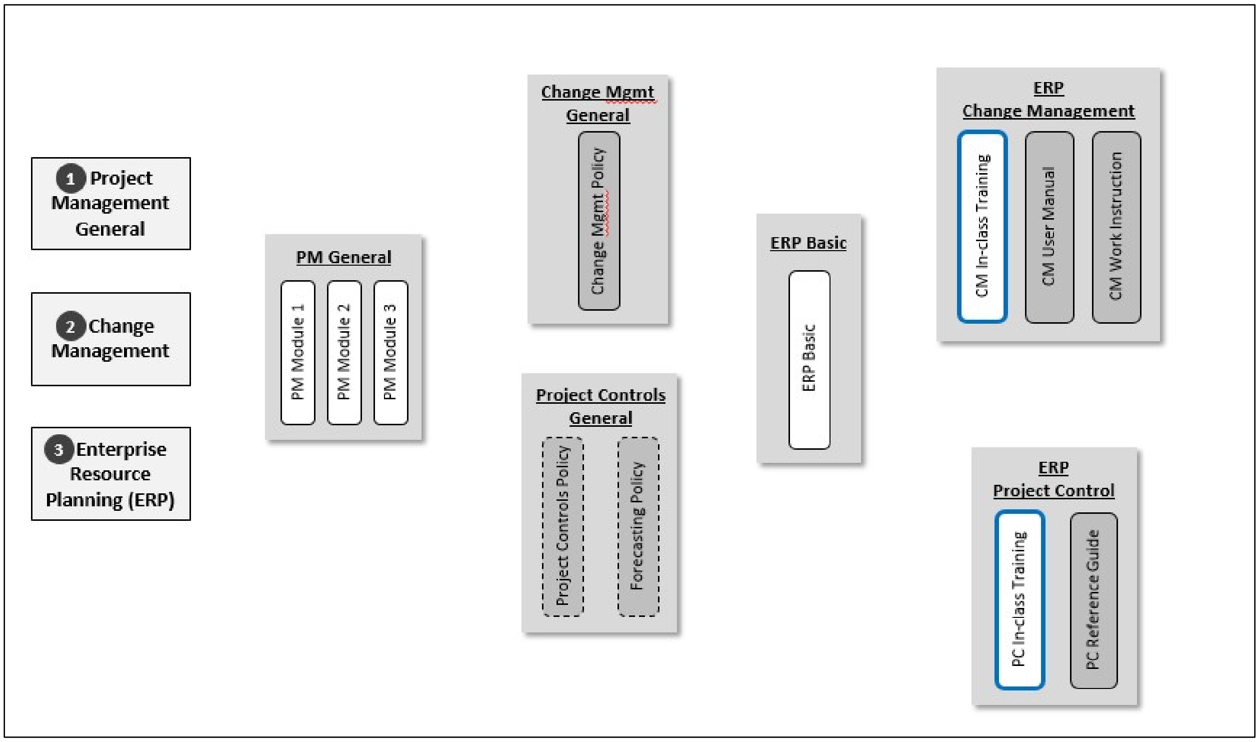

Figure 4-4-c. Step 3 - Establish high-level knowledge group

Lastly, create learning paths by linking individual OPA based on recommended learning sequences (e.g., pre-requisites)

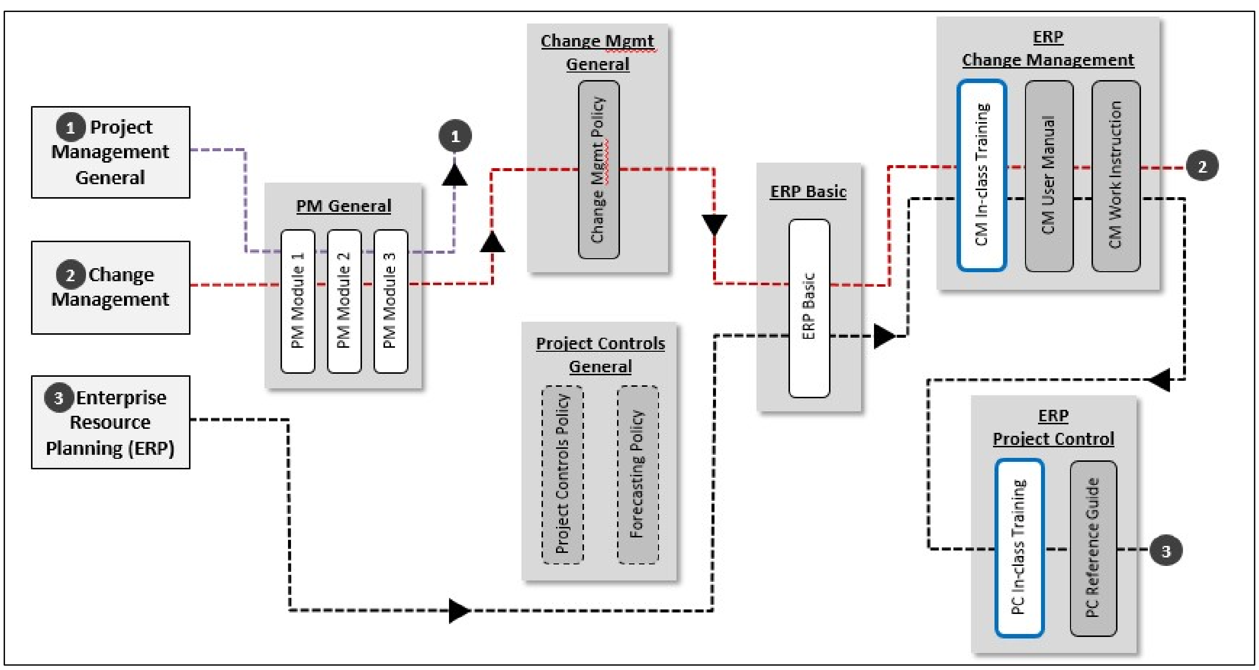

Figure 4-4-d. Step 4 - Create learning paths by linking individual OPA

The last diagram shows an example of a completed learning path diagram. This process for learning path diagram development can assist an organization in visualize all its OPA, their inter-relationships, the hierarchy of assets and knowledge groups, ideal learning sequences, and any missing assets or knowledge groups. For example, the unlinked sub knowledge area, “Project Control General”, indicates that a new knowledge group needs to be added in order to cover the unlinked asset and complete the system. With the addition of a new knowledge group “Project Control”, a new learning path can be designed by linking PM general, Project Control General, ERP Basic, and ERP Project Control.

The main benefit of this learning path diagram is its ability to provide a visualized overview of all OPA, such as policies, manuals, training, and standard forms. The ultimate goal of this diagram is to deliver the assets to end-users, such as project managers, more effectively and to achieve more consistent project management practices with better controls.

4.4 Learning Management System (LMS) Development

4.4.1 End-user Interface

Many organizations today have a unified infrastructure that supports an environment for employees to gather and share information (McCall and Almeida 2001). Intranet is a common type of infrastructure often implemented in a web-based environment that can be accessed using a web browser. This section presents an end-user interface for the Learning Management System (LMS) developed in this study. The concept presented in the previous section is used as a key algorithm to implement the LMS in an intranet-based environment.

4.4.1.1 Dashboard

A homepage of an intranet can be customized for each employee based on their role and group. This study proposes a dashboard that can be inserted into the homepage. Figure 4-5 presents an example of an LMS dashboard which can summarize an employee’s learning progress. On this dashboard, an employee can visually check the overall progress of their learning and identify incomplete paths. Each item in a row represents a learning path. *% complete* represents the percentage of completion on a learning path, which will be further explained later in this chapter.

Upcoming Due Date shows the closest upcoming due date of each learning path so that end-users can plan their learning accordingly.

Figure 4-5. Employee LMS dashboard

The main goal of this dashboard is to provide employees with a centralized access point to all the OPA of their organization. It is important to note that the dashboard is intended not only to cover training materials but also OPA, such as policies and standards. The main benefits of the dashboard include:

- providing a centralized access point to all OPA,
- providing to the end-user a quick summary of learning completion rate,
- helping end-users and management team to identify weak areas, and
- providing active notification when a new OPA has been added.

4.4.1.2 Learning Path

Once the end-user has clicked a learning path on the dashboard, they are directed to a learning path page. Figure 4-6 presents a full demonstration of a learning path page for “2. Change Management” as an example.

This demonstration is based on the idea presented in Section 4.3.2. On this page, an end-user can view all the necessary OPA that they need to review/complete in order to complete a learning path. Each asset is presented with its completion status, due date, when it was last updated, and the identity of the person who updated the item.

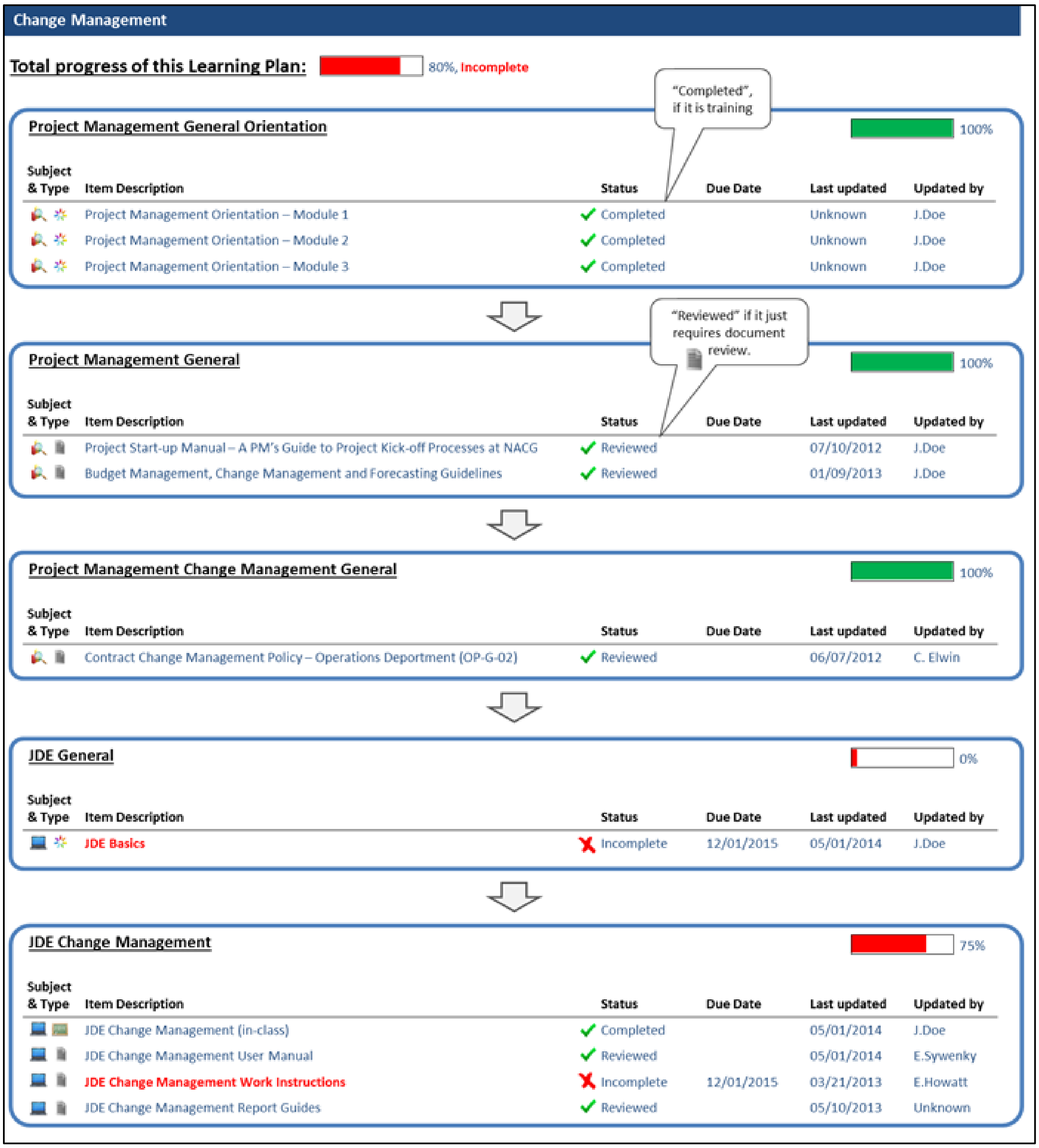

Figure 4-6. Demonstration of a learning path page for change management.

4.4.2 Compliance Report

From the *Company*'s management perspective, the overview of OPA completion is one of the most useful functions that LMS can provide. Based on the investigation of the case company's existing LMS and compliance reporting system, the following issues are identified:

- Each training module is individually tracked due to the lack of consistent training flow.
- Although employee training completion results are collected in a database system, the system does not support automated reporting. Currently, their training compliance report is periodically generated by a training coordinator using a manual process in Microsoft Excel.
- The existing training compliance reporting system only covers the training materials that are included in the *Company*'s training matrix. Other relevant OPA, such as policies and standard work procedures, are not tracked by this system.

Based on the issues above, a newly designed compliance reporting system is also recommended that uses the learning path concept. Its purpose would be mainly to track training compliance more efficiently by using the "paths", which are key elements of the learning path concept. Each path connects not only training materials but also other relevant OPA to ensure employees are guided toward completing all the necessary knowledge areas. Thus, employee compliance in various knowledge areas can be tracked by simply calculating the completion rate of each path, as shown Figure 4-7. We can consider the learning paths in Figure 4-7 as "flattened" representations of the original paths in Figure 4-4-d. Also, it should be noted that the learning path concept allows for overlapping items on different paths, and therefore they can be calculated from any path that passes through them. A full image concept diagram showing the completion/competency calculation is available in Appendix C. The degree of compliance calculated using this algorithm is used for the dashboard presented in Section 4.4.1.1 to provide the summary of compliance.

Examples of compliance reports that can be generated from this approach include, but are not limited to:

- a compliance summary of knowledge areas or topics at any level,

- a compliance summary based on a company's departments, job positions, or job sites, and
- a compliance summary of each individual employee.

Using these reports, a company's management staff or end-users can find answers to questions such as:

- "Which project manager is the most knowledgeable about Change Management?"
- "What is the overall compliance rate of the Project Management knowledge area?"
- "Which job site needs immediate attention in terms of training compliance?"
- "Which knowledge area is my weak area?"

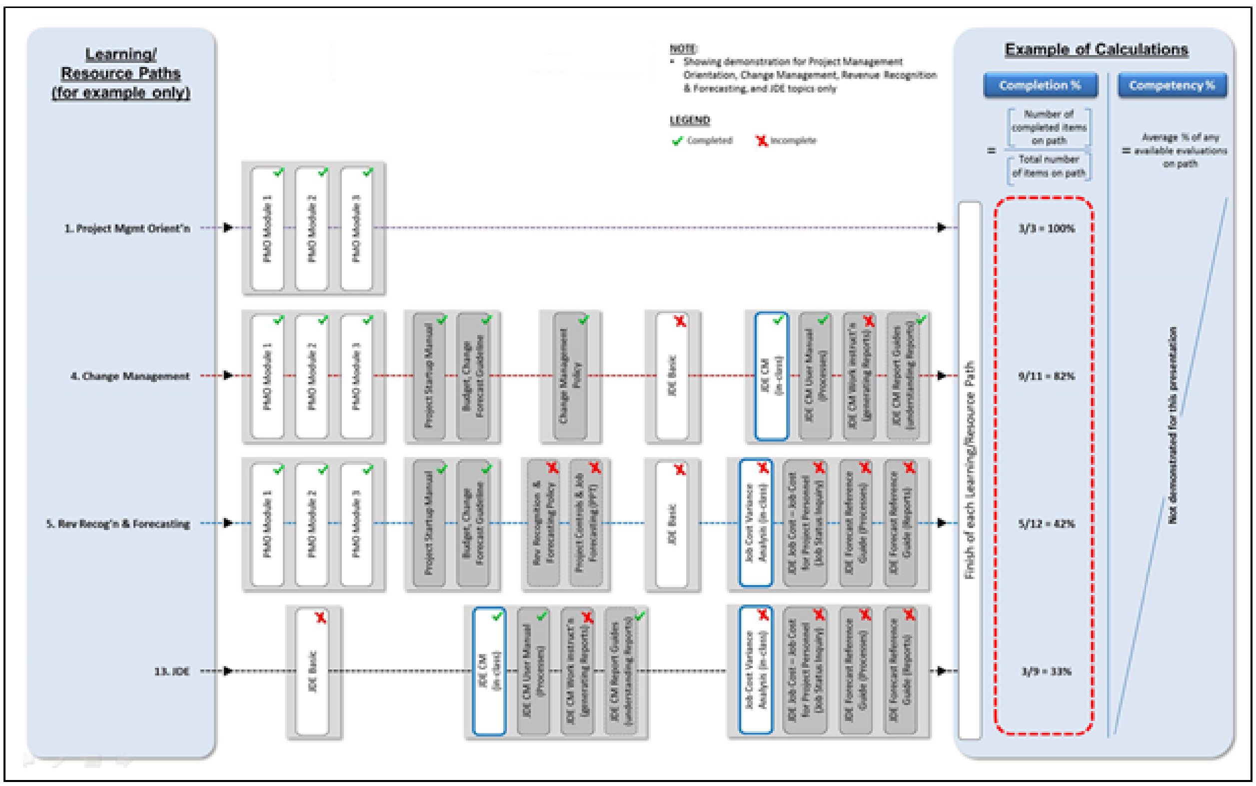

Figure 4-7. Algorithm to calculate completion and competency

4.5 Conclusions

This chapter presents an LMS by which for the *Company* to overcome its existing challenges identified during the investigation of the *Company*'s CM operational process assets (OPA) and practices. The challenges include:

- low usability and ROI of existing OPA,
- lack of organized flow and centralized point of access for OPA,
- low visibility of OPA to end-users and content managers, and
- inconsistent practices among project managers.

The learning path concept is introduced through a case study of a Fortune 500 company in order to develop the concept of the LMS. The main objectives of the LMS developed are to:

- re-utilize all the existing OPA that the *Company* has developed at a significant investment of time and cost,
- identify missing OPA in order to complete the practical knowledge base,
- facilitate accessibility and visibility to OPA by providing one centralized access point and consistent learning/training flows,
- actively deliver them to end-users by providing a dashboard where employees can check their completion status of resources,
- provide the management team with efficient reporting tools that can answer various questions, and
- help content managers or company management staff to manage OPA more efficiently by enabling visualization of all the individual resources and learning paths that connect different resources.

It is worth noting that, given that the major motivation underlying the LMS proposed in this study is to reutilize and rediscover existing OPA, the LMS can help the *Company* to maximize its ROI.

Chapter 5. Conclusions

5.1 Conclusions

Unless efficiently managed, changes during construction projects can result in poor project performance. Nevertheless, change is often overlooked by companies and practitioners, resulting in inefficient operations and poor project performance. The main goal of this thesis is to provide a framework for change management (CM) improvement, including analysis of the financial impact of changes, gap analysis of as-is practices and systems, and recommendations for resource management and delivery in order to overcome detrimental impact of changes.

The key conclusions of this study are as follows:

First, this study demonstrates the processes of investigating quantitative impact of changes on a construction company's profitability from a practical perspective. The results generated from such investigation can provide a valuable business case for an organization to determine whether their existing CM requires further investigation and/or improvement. In the first part of the quantitative analysis using a regression model, it is found that, although some Change Orders (COs) may generate more profit than originally estimated by contractors, as a general rule increasing the amount of COs adversely affects the contractor's profitability. The second part of the quantitative analysis discusses the relationship between the timing of COs and the company's profitability. Selected projects are divided into two groups: (1) more profitable projects, where the final profit % has ended up being equal to or greater than the originally estimated profit %, and (2) less profitable projects, where the final profit % has ended up being lower than originally estimated. By comparing these two groups, this study finds that COs occurring late have a more adverse effect on the company's profitability. In addition, this study identifies several factors that are found to affect the reliability and accuracy of data and analysis. Researchers in future studies are strongly advised to consider these findings as key lessons learned.

Second, the findings from the quantitative and qualitative analyses lead to further investigation of the company's as-is CM system and practices. This study thus demonstrates a detailed and practical approach to diagnose as-is system and practices and identify gaps and room for improvement. Key deficiencies of the case company's existing CM practice identified in this case study can be summarized as follows: (1) lack of organized flow and centralized point of access to Organizational Process Assets (OPA), (2) failure to effectively utilize and deliver existing OPA to end-users, and (3) lack of inter-relationships among the OPA from different functional groups. Based on these findings, a framework and hierarchy to re-utilize and re-organize the existing OPA and deliver to end-users is recommended as a fundamental solution for the company's CM and potentially for overall business operations as well.

Based on the recommendation, this study proposes a Learning Management System (LMS) for the company to address the previously mentioned gaps. The learning path concept is introduced through a case study of a Fortune 500 company in order to develop the algorithm of the LMS. One of the key benefits of this concept is that it can reduce the need for new materials and systems by re-utilizing and re-organizing existing OPA, thereby maximizing Return on Investment (ROI). It also helps content managers or company management staff to manage OPA more efficiently by enabling visualization of all the individual OPA and the learning paths that connect different OPA. Compliance reporting is another benefit of this LMS, which can answer many frequently asked questions from a management perspective.

5.2 Contributions

The major contributions of this thesis can be summarized as follows:

This thesis provides a framework by which for the construction industry to (1) analyze the quantitative and qualitative impact of changes on profitability, (2) diagnose as-is CM system and practices, and (3) propose a case-specific solution, in this case study, an LMS. In other words, this framework presents a practical flow of (a) business case development (motivation), (b) diagnosis, and (c) recommendations.

This thesis constitutes the first study that statistically analyzes the cumulative impact of COs on a contractor's profitability. It is also the first study that presents the relationship between the timing of COs and profitability.

- This study reaffirms that the number and frequency of COs are not suitable measurements when analyzing the impact of changes, as previously suggested by Leonard (1988). However, it should be noted that, unlike the Leonard's study, this study demonstrates it through direct review of project documentations, records, and project managers' practices.

- This study supports, to some extent, one of the major criticisms of past cumulative studies, i.e., that they are based on the assumptions that contractor's estimated work hours for original and change work are accurate and that most changes are caused by owners. It is worth noting that changes are not always causal factors for poor project performance. Instead, they can be indicators of other hidden causes.
- Unlike most past studies, where data has been collected through indirect means such as questionnaire, all the data analyzed in this study is directly collected, reviewed, and analyzed, an approach which greatly increases the reliability of data and results. Through this practical approach, this study presents valuable lessons learned that are useful for future researchers to improve the reliability of similar studies.
- Results generated from the approach presented in this thesis can provide a valuable business case for an organization to determine whether their existing CM practice is worth further investigation and/or improvement.

This thesis presents a detailed and practical approach to diagnose the as-is status of a construction company's CM system and practices. Although each company is likely to have its own system and practices, thorough investigation of as-is status, gap analysis based on comparison to industry best practices, and visualization of analysis constitute a useful guideline for construction companies seeking to diagnose their CM.

This thesis presents an LMS using learning path concept adopted from a Fortune 500 retail company. Particularly for the construction industry, LMS can be more effectively and efficiently implemented if consistently developed with industry-specific best practices and processes, such as Construction Industry Institute (CII) best practices and project management processes based on the Project Management Body of Knowledge (PMBOK).

5.3 Limitations and Future Work

The framework presented in this thesis is based on the case of a particular heavy civil and mining construction company in Western Canada. Different companies can have differing levels of CM, differing systems, and differing practices. Therefore, the proposed framework should be carefully implemented, and tailored if necessary, for each case.

Quantitative analysis of the impact of changes is also based on the company's case only and on a somewhat limited number of project samples. Among hundreds of project samples, only a small number of projects could be selected once consideration of factors that affect data quality and consistency had led to the elimination of many projects. Furthermore, the majority of project samples had to be excluded from the analysis because they were Time and Material contracts, which are common in the oil sands mining industry. If companies in the building construction sector were to be studied, it would significantly increase the project sample size because many building projects are Lump Sum contracts. Furthermore, if changes or COs are managed and recorded properly and consistently among different project managers or companies, it would significantly increase the sample size as well.

Recommended future works are summarized as follows:

- Any comparable studies on the impact of changes on profitability would increase the reliability of analysis, and increase the chances of acceptance by practitioners or courts. As previously mentioned, studies from the building construction sector would significantly increase the sample size because many of their projects are Lump Sum contracts and have comparatively clearer scopes and more definable project site footprints. However, it is worth noting that project data can be unreliable and misleading if not properly cleaned and investigated with a detailed and practical approach.
- As previously discussed, an LMS can be more effective and efficient if consistently combined with industry-specific best practices and processes, such as CII's best practices and project management processes based on the Project Management Body of Knowledge (PMBOK). Further development of such a framework is highly recommended.

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Appendix A. List of the industry partner company's Organizational Process Assets (OPA) reviewed

Change Management

- Online training modules (PMO)
- Contract Change Management Policy, June 7, 2012
- (Old) Change Management Policy, Aug 12, 2008
- Change Matrix (Type 1, 2, & 3)
- Project Start-up Manual, Jul 10, 2012
- Contract Execution & Job setup policy, Dec 1, 2010
- Budget Management, Change Management and Forecasting Guidelines, Sep 21, 2012

JD Edwards Enterprise One – General

The company currently uses JD Edwards Enterprise One (JDE) for their Enterprise Resource Planning (ERP).

- JDE Change Management User Manual
- JDE Work Instructions (WIs);
    - Change Log (CL) report
    - CL by Request for Change Order report
    - CL by Change Order report
- JDE Change Management, training material (ppt, 6.5 hr format), reviewed with the industry partner company's trainer
- JDE for Operations (training, ppt)
- JDE basics (Online training)

Job Cost & Forecast (JC&F) Project - Phase II (2012-2013)

The company's project team tasked in 2012 to implement JDE Change Management and Forecast modules

- Project charter
- Process maps
- Authorization for Expenditure (AFE)

- Requirements Document
- Project Implementation Plan
- Change requests
- As-Built Design Document
- Budget Management, Change Management and Forecasting Guidelines, Jan 9, 2013
- Organizational Change Management document, including JC&F Benefits/Impact Analysis
- Business Acceptance Sign-off document

Forecast

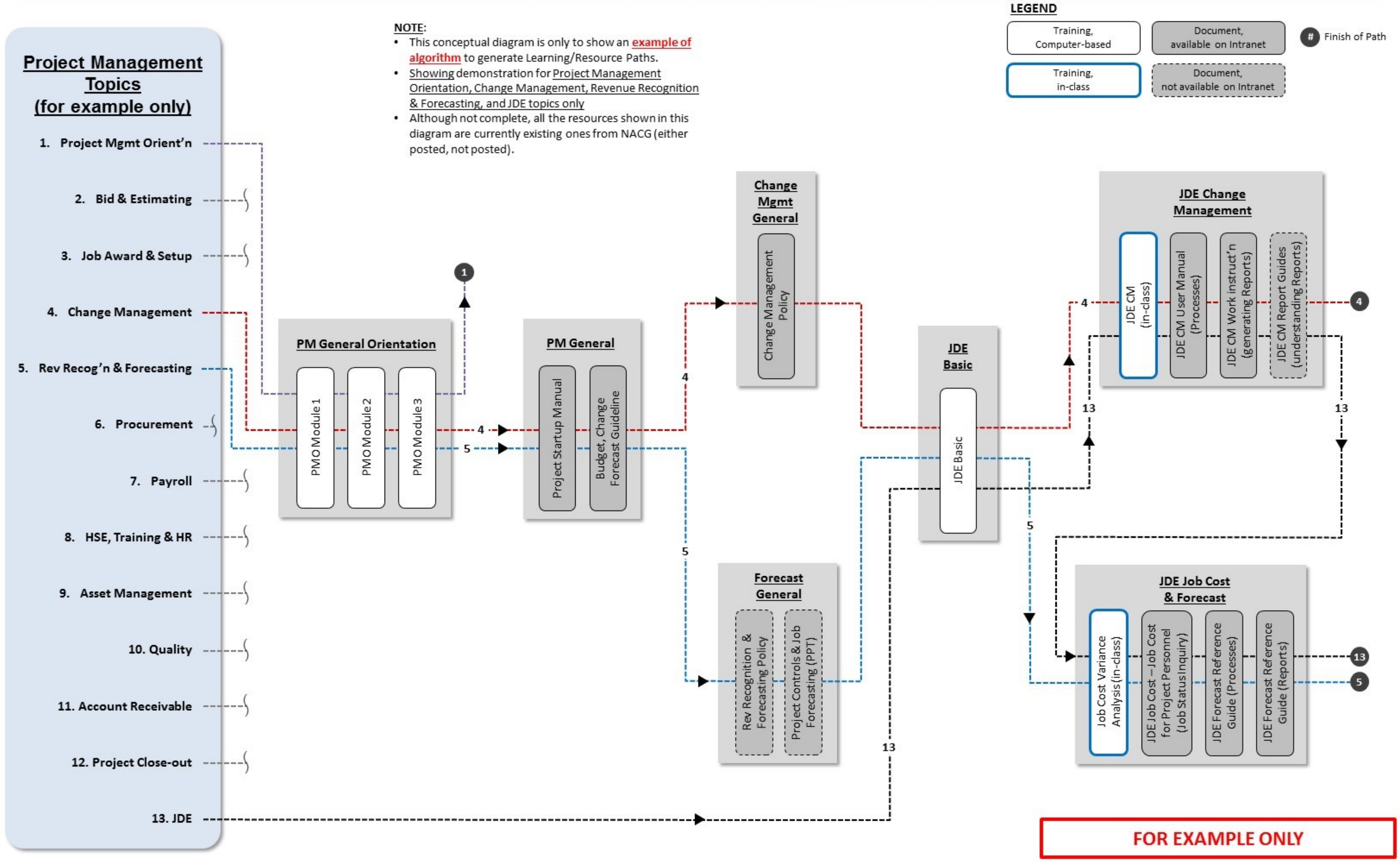
- Forecasting Training Session (Job cost variance)
- Project Controls & Job Forecasting Initiative – Phase 1 Project Managers
- Project Controls & Job Forecasting Initiative – Phase 1 Introductory Course
- Project Controls & Job Forecasting Initiative – Phase 2 Change Management
  (four items above are training modules in PowerPoint format. Not dated)
- JDE Work Instructions (WIs)
  - Progress Entry
  - Job Cost for Project Personnel
  - Job Cost and Forecast report
  - Change Management Financial report
  - Financial Summary report
  - Estimate at Completion entry
  - Comments entry
- Job Cost & Forecasting Project – Information session of project personnel, Aug 27-28, 2012
- Job Cost & Forecast Worksheet, Mar 2013
- JDE Job Cost Inquiry – PM's manual, July 2010

Appendix B. Employees of the industry partner company interviewed and their roles

Position	Remarks
Project manager A	• Main contact person of the industry partner company • Provided overall guide for this research • Provided feedback on the company's change management
Project manager B	• Provided comments during progress meetings • Attended ERP change management training session
Financial accountant	• Provided feedback on the company's change management • Attended ERP Change Management training session • Provided introduction to the company's financial system
Financial analyst	• Provided feedback on the company's change management • Attended ERP Change Management training session
Project accountant A	• Provided feedback on the company's change management • Attended ERP Change Management training session
Project accountant B	• Organized ERP Change Management training session • Provided feedback on the company's ERP change management
Estimating Manager	• Provided comments during progress meetings • Provided information about ERP Change Management module implementation project
Operations Controller	• Provided comments during progress meetings • Provided project listings • Provided introduction to the company's financial system

Appendix C. Completion/competency calculation algorithm

Algorithm for designing Learning/Resource Paths



Algorithm for calculating Completion and/or Competency