DEVELOPING A SPECIFICATION FOR A COMPUTER-BASED DECISION SUPPORT ENVIRONMENT FOR MANAGING CHANGE ORDERS IN CONSTRUCTION PROJECTS

by

DINESH MALINGA SOORIYAARACHCHI

B.Sc. Engineering (Honours), University of Moratuwa, 2001

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Abstract

The objective of this research is to develop a decision support environment for managing construction change orders and to visualize and interpret change order data to describe project performance as a function of change orders. The detailed conceptual development of a change management view is followed by the design of visualization techniques to represent change order data. The specified change view is expected to be implemented and integrated into the multi-view representation of a construction project. The multi-view representation of a project supports a wide range of project management functions. The change view provides a comprehensive set of properties that is sufficient to meaningfully represent the change management function of a project. Integration with other views makes it possible to link with other project data such as activity data, daily site data, records, etc. which can then use in representation of their variation against change order data. This helps project management personnel in taking their decisions.

A comprehensive literature search provides insight into various industry practices and potential impacts of change orders on project performance. A review of commercially available state-of-the-art change order management systems was done to investigate solutions currently available for the industry in managing related information. Interestingly, the available solutions do not provide sufficient facilities to interpret change order data that help describe the impacts on project performance.

The change management system specified in this thesis is expected to help streamline the change order process by capturing day-to-day information associated with change orders, generating reports and then interpreting the data to assist project personnel in their decision making. It also helps flag critical aspects that need emergency attention, such as congestion and trade interferences.
Table of Contents

ABSTRACT .......................................................................................................................... ii

TABLE OF CONTENTS ..................................................................................................... iii

LIST OF TABLES ................................................................................................................ vi

LIST OF FIGURES ............................................................................................................. vii

ACKNOWLEDGEMENT .................................................................................................... ix

CHAPTER 1: INTRODUCTION ............................................................................................ 1

1.1 BACKGROUND FOR THE RESEARCH ....................................................................... 1

1.2 RESEARCH OBJECTIVES ......................................................................................... 3

1.3 STRUCTURE OF THE THESIS ................................................................................... 4

CHAPTER 2: STATE-OF-THE-ART CHANGE ORDER MANAGEMENT ................. 5

2.1 INDUSTRY PRACTICES ............................................................................................ 5

2.1.1 Terminology ......................................................................................................... 5

2.1.2 Project Procurement Modes .................................................................................. 6

2.1.3 Change Order Process ........................................................................................ 10

2.1.4 Documentation .................................................................................................... 17

2.2 LITERATURE REVIEW ............................................................................................ 22

2.2.1 Definition of ‘Change Order’ ............................................................................... 22

2.2.2 Sources of Change Orders ................................................................................... 23

2.2.3 Categorizing Change Orders .............................................................................. 24

2.2.4 Impacts of Change Orders ................................................................................... 25

2.2.5 Change Order Management Technique .............................................................. 31

2.3 COMMERCIAL SOFTWARE SOLUTIONS ............................................................... 33

2.3.1 Primavera Expedition ......................................................................................... 34

2.3.2 Timberline Office ............................................................................................... 36
CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS ........................................... 98

5.1 OVERVIEW ...................................................................................................... 98

5.2 CONTRIBUTIONS ............................................................................................. 98

5.2.1 Literature Search ........................................................................................ 98

5.2.2 Designing the Change View ...................................................................... 99

5.2.3 Data Visualization ...................................................................................... 100

5.3 RECOMMENDATIONS AND FUTURE WORK .............................................. 100

BIBLIOGRAPHY .................................................................................................... 101
## List of Tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Change Order Properties used by Primavera Expedition 9.0</td>
<td>36</td>
</tr>
<tr>
<td>3.1</td>
<td>Properties of the PCO List</td>
<td>66</td>
</tr>
<tr>
<td>3.2</td>
<td>Properties of Project Participants</td>
<td>71</td>
</tr>
<tr>
<td>3.3</td>
<td>Properties of Change Proposal</td>
<td>72</td>
</tr>
<tr>
<td>3.4</td>
<td>Properties of Change Order Associations</td>
<td>75</td>
</tr>
<tr>
<td>3.5</td>
<td>CO Associations with Other Project Views</td>
<td>77</td>
</tr>
<tr>
<td>3.6</td>
<td>Properties of CO List</td>
<td>79</td>
</tr>
</tbody>
</table>

List of Figures

Figure 2.1 General Contracting Procurement .........................................................7
Figure 2.2 Design - Build Procurement .................................................................8
Figure 2.3 Construction Management Procurement ...........................................8
Figure 2.4 Construction Management with GMP Procurement ......................9
Figure 2.5 Simplified Change Order Process Flow Chart ..................................11
Figure 2.6 Primavera 9.0 - Change Management - Cost/Contract Control Aspects ....34
Figure 2.7 Primavera 9.0 - Change Management - Graphic Mode ...................35
Figure 2.8 Timberline Office - Change Management ...........................................37
Figure 2.9 Meridian Project Systems Prolog Manager, Potential Change Orders ......38
Figure 2.10 Meridian Project Systems Prolog Manager, Change Order Request ....39
Figure 2.11 Change Management Framework in Meridian Prolog Manager .........40
Figure 2.12 Change Order Template created using Microsoft Excel ............41
Figure 3.1 PCO Identification Phase ..............................................................51
Figure 3.2 PCO Evaluation Phase ..................................................................52
Figure 3.3 PCO Negotiation Phase .................................................................53
Figure 3.4 PCO Approval & Execution Phase ..................................................54
Figure 3.5 Steps of a typical Change Order Process ......................................60
Figure 3.6 Entity Relationship Diagram for Change View .............................64
Figure 3.7 PCO List - User Interface ..............................................................66
Figure 3.8 User Interface used to Enter PCO data ............................................70
Figure 3.9 Change Proposal Properties User Interface ..................................74
Figure 3.10 RFI Log User Interface ...............................................................76
Figure 3.11 Record List User Interface ...........................................................76
Figure 3.12 Associations Tree view User Interface .........................................78
Figure 3.13 User Interface of the CO List ......................................................80
Figure 3.14 User Interface used to enter CO data .........................................81
Figure 4.1 Distribution of Change Orders over Time (Daily Basis) .............87
Figure 4.2 Distribution of the Value of Change Orders over Time(Weekly Basis) ....89
Figure 4.3  Distribution of Change Orders over Physical Locations & Time.............91
Figure 4.4  Distribution of Change Orders over Trades..................................92
Figure 4.5  Distribution of Change Orders over Time & Trades..........................93
Figure 4.6  Impact on Total Project Cost by Change Order................................94
Figure 4.7  Distribution Change Order amounts over Trades............................95
Figure 4.8  Processing Change Orders..............................................................97
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1 Introduction

1.1 Background for the Research

Changes to the base contract are a fact of life in any construction project. An excessive number of changes during the construction phase can lead to major disruptions of planned schedules, work methods, productivity and overall project performance. The construction industry has a unique mechanism of handling these changes; by means of change orders. A change order is the formal vehicle for making a change in the scope of work of the previously approved contract. Without the mechanism of change orders, most projects could not be completed in a timely and efficient way. Nevertheless, handling changes fairly is still considered as one of the most contentious areas in the construction process (Civitello 2002). Owner and contractor seldom agree on the cost and schedule impact of a change. Design professionals and other consultants often add to the dispute. Effective management of the change order process is key to making change orders an effective tool for providing benefits to both owner and contractor.

Change order management is an integral part of the construction management process. A sizeable construction project might encounter thousands of change orders during its execution phase. These changes need to be properly documented and the impact of an individual change order on project performance analysed as soon as it occurs. This is often a challenge to project management staff due to the complex information management involved in the process. Incomplete information and multiple change orders occurring at the same time adds to the complexity. Inefficiency in managing change orders could lead to significant economic losses to the owner. Delayed project delivery, cost overruns, claims and legal disputes could eventually lead to project failure (Ibbs and Allan 1995).

The change order process is a complex one. A particular change order can involve several trades and designers. It may have to interact with other on-going work at the site. These interactions can affect project performance at different levels. A change may have an impact
on immediate project milestones as well as project delivery date. Changes can originate in various ways. No standardized, industry wide process exists on how to deal with changes, irrespective of their origin (Krone 1992). Owners hesitate to approve and pay for changes, fearing possible economic losses. On the other hand contractors do everything possible to get paid for all work done. Change orders often lead to intense disputes among the parties involved in the construction process. Given these facts, careful management of change orders is obviously a critical factor for the success of a construction project.

Developing an orderly and well-defined procedure for processing change orders and setting it up before the work begins is an essential prerequisite to the effective management of changes (McCally 1997). As noted previously, there is no universally accepted procedure for dealing with change orders (Krone 1992). Experienced owners have their own procedures that have been developed over time and firmly established in their organizations. An inexperienced owner may ask the contractor to develop a procedure and submit it for the owner’s review, or else an expert could be hired to setup a system. Irrespective of the way it is setup, there should be a mechanism in place to handle the vast information flow associated with change order management in a timely manner. A totally paper based information management system may not be efficient enough to take up this challenge, especially for larger projects. When adopted properly, today’s information technology tools can be immensely powerful in generating, processing, organising, transferring and retrieving information. But it would still be a challenge to attract project professionals to use a computer based system unless they are fully confident that the system is capable of handling all the necessary processes involving change orders in a way that does not conflict with other project management functions.

One possible solution to the foregoing is to develop a customized change management system for each project. Project participants can give their feedback during the system development phase in order to make sure it is well suited for the project environment. Another alternative is to implement a change order management system developed for construction projects in general. This generalized system should be sufficiently flexible to accommodate modification, in order to be compatible with existing project management functions and owner imposed systems. State-of-the-art project management systems have
attempted to provide a solution for this problem and have achieved different levels of success as described in Chapter 2 of this thesis.

The research described in this thesis is focused on designing a computer based solution for managing change orders in construction projects. The scope of the research is different from the contents of most of the commercially available solutions in that it is focused on capturing the story of construction and assessing its impacts on performance, as well as assisting in managing the change process. Research work, both completed and in-progress at the University of British Columbia under the supervision of Prof. Alan D. Russell, which focuses on developing a generalized, comprehensive and integrated multi-view representation of a construction project, provides a background to this research. The outcome of this research is expected to contribute to the development of the change view as part of a multi-view representation of a construction project. The focus is on a detailed conceptual development of a change management view with an emphasis on representation and interpretation of change management data. The implementation of what is proposed is beyond the scope of this thesis.

1.2 Research Objectives

The objectives of the research described in this thesis are to:

(1) Discuss the importance of change order management and describe the state-of-the-art of change order management as presented in the literature and commercially available systems;

(2) Design a computer based decision support environment to manage the change order process; and

(3) Assist in telling the as-built story of a construction project, focusing on change order management and its linkages with other aspects of the project through visual and other means.
1.3 Structure of the Thesis

Chapter 2 presents existing literature on managing construction change and its impact on project performance. Current industry practices are discussed in order to gain an insight into the practical problems faced by project teams in dealing with change orders. Different methods of handling changes, their merits and de-merits are identified. The literature reviewed explores both formal research work and other views written based on the personal experiences of practitioners. Finally, several popular state-of-the-art commercial software solutions are explored, and their strengths and weaknesses highlighted.

Chapter 3 explains the comprehensive representation of a change order management process. Factors to consider, scope to achieve and challenges are discussed. Presented in this chapter is a generalized flow of steps in the change order process that reflects the basics of many different practices prevalent in the construction industry. Finally, this chapter introduces the change order management system that is being developed as a part of the research.

Modes of examining and interpreting change order data are presented in Chapter 4. Visualization techniques available to better understand the implications of change information are discussed. Different ways of representing change data are explored and graphically represented.

Chapter 5 presents conclusions of the research as well as recommendations for future work.
2 State-of-the-Art Change Order Management

This chapter presents a background to the current knowledge areas surrounding construction change order management. The chapter is comprised of 3 sections. First, current industry practices are discussed in detail while identifying similarities and inconsistencies among them. Then, previous research contributions are discussed through an extensive literature review. In the last section, popular state-of-the-art commercial software solutions are reviewed.

2.1 Industry Practices

This section starts with introducing terminology used in the change order process. Then the change order process is detailed, followed by a description of the documents used in the process.

2.1.1 Terminology

Generally accepted terminology used in the construction industry is presented here. It is noted that there is not an absolute consensus on terminology used, and the design of any general procedure should allow for the use of synonyms.

*Change Order* –
A change order is considered as a modification or deviation from the original scope of work of a project as defined by the contract. With a change in work scope, there is usually an increase or decrease in cost and there can also be a change in the time taken to perform the work (O’Brien 1988).

*Potential Change Order* –
When a potential for a change in the scope of work is identified, a Potential Change Order (PCO) is developed. In some processes, this is referred to as a Contemplated Change Order (CCO) or a Contemplated Change Notice (CCN). PCO follows the change order process...
from its identification, through negotiation process and finally to the approved change order. It is cross-referenced to requests for information (RFI), site instructions (SI), change proposal, change estimate, change order and other related documents.

*Change Directive* –
A change directive is a type of a change order. It is initiated by the owner or his agent at his sole discretion, clearly stating the required scope change. The primary purpose of the change directive is to allow expeditious pursuit of the work, even if time and cost consequences have not been resolved.

*Request for Proposal* –
Once the requirement for a change is identified, the owner sends a request for proposal (RFP) to the contractor asking him to submit a proposal plan for performing the changed work.

*Change Proposal* –
A change proposal corresponds to the contractor’s submission of the proposal plan to perform the work related to the potential change order. It also includes the amount and the schedule adjustment claimed.

### 2.1.2 Project Procurement Modes

The change order process varies from one procurement mode to the other in terms of process flow and responsibilities of project personnel. It is helpful to understand the mechanism of different procurement modes before looking into the change order process under each of these modes. Several different procurement modes widely used in the construction industry and their effects on the change order process are briefly described in this section.

**General Contracting (Traditional)** – Figure 2.1 represents typical general contracting relationships. In this procurement mode, the owner contracts directly with the general contractor and the architect. The architect is responsible for administering the contract between the owner and the general contractor (GC), functioning as the owner’s agent. It is
the contractor's responsibility to enter into contracts with sub-trades and administer them. The owner looks only to the general contractor regarding satisfactory performance of the project. Subcontractors always have to go through the general contractor for resolution of any difficulties. The owner may appoint a Project Manager (PM) as his representative for the project. When a GC perspective is considered, two types of change orders are involved. A prime contract change order deals with changes made to the contract with the owner. Subcontract change orders handle the changes in contracts with various subcontractors. But the owner has only to deal with the GC regarding change orders.

**Design-Build** – As shown in Figure 2.2, in a design-build contract arrangement, the owner singularly contracts with the design-build firm. The design-build company can have contractual relationships with sub-trades. Although it is easier for the owner to deal with one contract entity, inspection of work and evaluation of changes become a complicated operation (Civitello 2002). The owner has to be confident of the competence of the design-build company.
Construction Management — Figure 2.3 depicts a construction management arrangement. The construction manager (CM) contracts directly with the owner to provide professional management services. Although there is direct communication between the CM and trades, there is no contractual relationship between them. Instead, the owner enters into separate contracts with each trade contractor. The CM is not liable for the performance or non-performance of trade contractors. The owner or his representative project manager or the CM has to administer change orders borne by all trade contractors. A typical change order may involve several trade contractors.
The construction management procurement mode allows the owner to fast track the construction sequence. Certain portions of the work can be bid and construction commenced before finalizing the entire facility design. Although the owner can benefit from early project delivery, additional costs can occur due to subsequent changes made to previously completed designs. These additional costs take the form of change orders submitted by trade contractors.

**Construction Management with a Guaranteed Maximum Price (GMP) (or CM-at-Risk)**

This is a variation of the construction management contract arrangement (Figure 2.4). The CM is responsible for completing the project for a sum equal to or less than the guaranteed maximum price. The initial GMP may be decided with only a percentage of drawings completed and subject to adjustments based upon changes in scope. Here, the CM directly contracts with trade contractors and is responsible for their performance similar to the general contracting arrangement. Thus the CM is exposed to risk while the owner benefits from the CM’s input for the facility design and fast-tracking (Civitello 2002).

![Diagram: Construction Management with GMP Procurement](image)

**Figure 2.4: Construction Management with GMP Procurement**

The change order process described in the next section assumes a traditional general contracting organizational structure with the owner represented by a project manager (PM) for administering the construction work. The architect is confined to producing/amending designs and administering the contract.
2.1.3 Change Order Process

A change order can arise due to different reasons. Once the potential for a change is recognized, the PCO enters into a process which varies greatly depending on the procedures set out by the owner (O’Brien 1988). Most governmental organizations and quasi-public agencies have set a cumbersome and lengthy approval process mandated by rules and regulations, while private owners use the conditions set forth in the contract to control the procedure to follow.

Although the change order process varies from one owner to the other, the basic concepts behind it are the same. Upon recognition of a PCO, the architect details the scope of the change which is reviewed separately by the contractor and the PM. After a negotiation process to arrive at a price, the potential change order is submitted for the owner’s approval.

Civitello (2002) pointed out the six ‘P’s of describing the change order process from a contractor’s point of view;

Prospecting (Discovery) – Clear identification of items of work that are beyond the scope of the original contract.

Preparing – Preparing a potential change order file once a potential change is identified. It includes information of discovery and all related records.

Pricing – Evaluating the impact due to the change and estimating the price to claim

Presenting – Preparing the change order proposal

Performing – Carrying out the scope of work specified in the change order

Payment – Getting paid for the work done

Pathways to a Change Order

Change orders originate in a variety of ways. The process leading up to the approval greatly depends on how and by whom the change order is originated. The process is shorter when it is a direct order from the owner (Change Directive) as opposed to a case where the change is initialized through requests for information (RFI). In the latter case the process is longer and often involves a negotiation process between the owner and the contractor. The flowchart in Fig. 2.5 shows only the basic steps in a typical change management process.
Owner requested scope change

Issue change directive to contractor

Defective plans/specifications
Unforeseen field condition

RFI exchange among project participants

PM identifies potential change and starts logging information

A/E reviews change situation and issues drawings/specification

PM issues request for proposal to the contractor

Contractor obtains quotations from subcontractors

Contractor submits change proposal to the PM

PM evaluates the change proposal

Contractor & Owner negotiate for the price and schedule adjustment

If negotiation successful, Owner approves change

Execution of work

Figure 2.5: Simplified Change Order Process Flow Chart
Typical causes of change orders as identified by O’Brien (1988) are:

- **Unforeseen Field Conditions**: When the existing field conditions don’t match with what is detailed in contract documents, a change order is used to modify the specified scope of work;

- **Defective Plans and Specifications**: If it is discovered that construction cannot proceed according to plans and specifications due to insufficient or erroneous details, the contractor requests corrections from the owner. This leads to a change in the scope of work;

In both the above situations, a Request for Information (RFI) is sent to the Architect/Engineer (A/E) regarding ambiguous or defective drawings and specifications. All the RFIs and clarifications received from the contractor and the related responses by the A/E and other affected parties are documented. Generally, an exchange of several RFIs and answers (resolution comments) takes place among contractor, trades, architect, consultants, owner and other parties. All these RFIs are entered into a RFI log to track the development of the case. An RFI procedure is central to the control system that identifies potential change orders (O’Brien 1988).

Once the A/E decides that there is a defect or error in the design/specification, suitable clarifications and solutions are issued along with a corrected design and related specifications. The PM contemplates the potential change order and tracks the development of the issue. The owner or his agent issues a request for a proposal (RFP) to the contractor. After the contractor submits the change proposal for the scope of work involved, the PM evaluates it. This usually leads to a negotiation process between the owner and the contractor to finalize the scope of work, price of the work and schedule adjustment.

- **Owner directed Scope Changes**: When the owner decides to change the scope of work after the award of the contract, the change is accommodated through a change directive. The change should be within the general scope of the original contract for it
to be accepted by the contractor, otherwise, the terms of the contract may no longer apply.

Whenever the owner decides to make a change in the original scope of work, a change directive is issued to the contractor. Once the A/E issues the relevant drawings/specifications, a request for proposal is issued to the contractor. Then the contractor prepares a change proposal, which is reviewed by the PM and the architect. A negotiation process often follows to come up with an agreement on a price and/or time extension for the work involved.

- Value Engineering Proposals: Contractors are welcome to bring forward value engineering change proposals (VECP) in order to achieve cost savings. The savings are shared by both the contractor and the owner. Value engineering proposals may also come from other parties, such as the trades or Architect/Engineer.

The process starts with the contractor writing to the PM and the architect stating the scope of the proposed change, estimated design cost, potential saving and estimated schedule impact. The PM and the architect evaluate the Value Engineering proposal and make recommendations to the owner. If the owner approves the proposal, the rest of the process is similar to an owner directed change order.

- Force Majeure: Delays due to forces that are beyond the control of the contractor are generally allowed for a contract time modification. The most common reasons are strikes and bad weather (O’Brien 1988). Most of the time, there will not be any change in contract price nor in the scope of work. Only the contract time is extended by approving a change order.

- Acceleration: When owner decides to expedite the construction to achieve an earlier completion date or to regain the lost time, changes in the scope of work are often required.

Tasks of different parties in the change order process are identified as follows:
Project Manager (Owner’s Representative)

Immediately upon the discovery of a potential change, the PM records the event by opening a change order file and initiating a potential change order (PCO). A sequential PCO code number is given to the potential change and steps in the process that ensues are logged. By means of a PCO log, the PM documents the development of the change order starting from the initialization phase through A/E responses, request for proposals, negotiations and finally to the approved change order. The PCO log is updated regularly and kept available for review by the contracting parties. The unique PCO number assigned to each potential change is useful for tracking purposes. This PCO number is referenced in each revised or new drawing, sketch and specification.

The project manager’s tasks in the change order process include (O’Brien 1988),

- To verify whether the proposed change is actually a change in contract scope and not covered by the scope of work covered by the original contract and previous modifications
- To verify that the change is necessary and desirable
- To determine what revisions are necessary to be made to contract documents
- To verify whether the A/E concurs with the proposed change in the design
- To estimate cost of work of the proposed change
- To estimate schedule impact of proposed change
- To notify the owner of possible or definite costs and project effects
- To analyse quotations submitted by the contractor for proposed work comparing them with previously forwarded estimates.

Architect/ Engineer

The A/E participates in the change order process as the owner’s design professional in reviewing and approving revised drawings and specifications. Common tasks of the architect include (note: it is possible that the architect also fulfills the owner’s PM) (O’Brien 1988);

- Review and approve shop drawings
- Review and recommend/approve change orders
- Prepare change order designs
- Issue documentation (eg.: transmittals)
- Make site inspections.

**Contractor**

Once a PCO is initiated, the contractor receives a request for proposal from the owner, for which a reply is usually required within a specified number of days. Then the contractor submits a change proposal giving the amount and the schedule impact claimed. The contractor’s tasks are (O’Brien 1988);

- Identify extra work and analyse impacts on construction performance due to the change
- Request and collect quotations from suppliers and sub-contractors
- Compile all cost components including direct cost, indirect cost and impact costs
- Evaluate schedule impact
- Submit the proposal with a detailed cost and schedule impact analysis.

The change proposal may be submitted in the form of a detailed cost estimate including trade man-hours, material costs and impact costs. The contractor usually relies on quotes submitted by sub contractors in preparing the cost proposal (Civitello 2002).

**Negotiation Process and Pricing**

Submission of a quotation by the contractor is usually followed by a negotiation process between the owner and the contractor. The purpose of the negotiation is to come up with an agreed-upon price for the scope of work involved for the change. If a revision to the schedule is required, it is also negotiated to establish a new date of substantial completion.

The purpose of pricing a change order is to give the owner a substantive description and detail of the extra costs to be incurred due to a contract change (Levin 1998). There are two types of pricing. Forward pricing establishes a firm fixed price before the work is done, so the owner knows exactly how much a change will cost. This allows the work to be incorporated into the contract with a firm price and schedule and resolves any issue of risk typically born by the owner. Post pricing is used during performance of the work and
payment is based on actual resource usage of the contractor. This method is useful when the nature and the extent of the changed or added work are unknown.

Detailed records of the negotiations should be kept, including dates of all meetings cancelled or rescheduled. Meeting minutes are dated and contain the names of all participants, issues discussed and agreements reached. The method and schedule of payment are also firmly established.

Schedule Impact Evaluation
Change orders are evaluated in terms of specific impacts they have on the progress of the project. Contractors are required to present a detailed time impact analysis and establish a value for the time in their change order proposal.

The contractor is usually required to give a timely notice to the owner, regarding the intent to request a time extension. Otherwise, the owner may deny an extension of time. Nevertheless, owners are usually reluctant to give time extensions (O’Brien 1988). It is essential to demonstrate convincingly that additional project time is required by a specific change.

Final Approval
If the negotiation process ends successfully, the PM will prepare the change order. Change orders are numbered chronologically and a change log is maintained to show all the changes approved for each contract.

The whole process might take several days to several months for the change order to be finally approved. It gets longer when the change proposal cannot be readily agreed upon.

Alternative Pathways
The process leading up to the approval of a change order is not always the same as described above. Depending on several factors the process may be more streamlined and involves only a few steps on its way to approval or denial. These factors include:
- Procedures established by owner’s organization: For example, if the owner is the government, all the government regulations have to be complied with during the change order process.
- Relative magnitude of the change: Different pathways could be established for change orders of different magnitudes. Minor change orders, which may be defined by the owner relative to the contract price, go through a simpler and straightforward approval process.
- Contract clauses: Change order process is determined by clauses in the contract. – i.e. The contract can be used to specify in detail how to deal with changes.

**Subcontractor Change Orders**

Subcontractors are the most affected party by change orders as they do most of the work on construction projects (O’Brien 1988). Subcontractor’s claims against prime contractors for the changes in scope of work are usually passed onto the owner without significant amendments. The change order process is more cumbersome for subcontractors due to the added processing time and that it has to go through the prime contractor (O’Brien 1988). In case of a change directive, the prime contractor passes them to the subcontractor and returns change order claims from the subcontractor to the owner.

### 2.1.4 Documentation

Various types of records are used in the change order process. Some of the important documents and their contents are described in this section.

*Request for Information (RFI)*

An RFI could be prepared by the contractor requesting the A/E to clarify ambiguities in plans and specifications. RFIs are issued frequently during the shop drawing phase of a construction process requesting clarifications on defective/ambiguous designs. These RFIs often lead to change orders. It is essential to respond to RFIs in timely manner. Response time and total number of RFIs can provide supportive evidence for a contractor’s claim.
(O’Brien 1988). The RFI log tracks each RFI for initiation date, description, date sent, date returned and resolution comments.

If the contractor either discovers conflicts, omissions or errors in contract documents or has any questions concerning interpretations or clarifications of the contract documents, then, before proceeding with the work affected, the contractor will immediately notify the project manager in writing in the form of a RFI. There could be several thousand RFIs generated in a particular project. They are numbered consecutively for easier tracing.

An RFI log includes the following data fields (O’Brien 1988):

- Attention To: Person accountable for responding to the RFI
- Drawing No.: Drawings applicable to the RFI, if any
- Specification No.: The specification sections that covers the RFI
- Information Needed: The request made in detail
- From Contractor: Date the RFI is received from the contractor
- Requested by: Person requesting the information
- Response Required by: Date the response is required
- To Review: Date The RFI is sent for review
- Reviewer: Person doing the review
- From Reviewer: Date RFI is returned by the reviewer
- To Contractor: The date the RFI is returned to the contractor
- Reply: Information sent to the contractor as the answer
- PCO No.: Related Potential Change Orders, if any.

**Potential Change Order (PCO)**

A potential change order is initiated by the Project Manager to identify the existence of an issue or circumstance which may result in a change order. A PCO follows the change order process from the request for a price quote from the contractor, through negotiations, and finally to the approved change order. It is cross-referenced with RFIs, the change estimate and the change order log. A log of all PCOs is maintained as a PCO log by the PM.
Data fields in the PCO log are (O’Brien 1988):

- Specification No.: Specification sections applicable to the PCO
- Drawing: Drawings relevant to the PCO, if any
- Initiated by: The party or person, who initiated the change order process
- Reason for Change: Major reason why the change is proposed/requested
- Requested By: The person requesting the change
- Request Date: The date the request is being made
- Trades involved: Subtrades affected by the PCO
- Quotation: Cost and the time as quoted by Contractor
- Change Estimate: Time extension and cost as estimated by the PM
- Change Negotiate: Time extension and Cost as negotiated
- Status: Status of the Change order process

Whether it is approved, cancelled or still pending

**Change Order Proposal**

This is a proposal prepared by the contractor and submitted to the project manager detailing the scope of work, total cost and schedule impact due to a change. It includes (O’Brien 1988);

- Summary of cost components and change order total cost
- Analysis of schedule impact and time extension claimed
- Required change order approval date and consequences of failing to approve by the required date

**Change Order Log**

A change order log is prepared by the PM to list all the change orders approved for a particular contract. The following information is logged (O’Brien 1988):

- PCO No.: The potential change order number that initiated the change order
- Amount: Total amount of the change order
- Days: Number of days allotted for the change
- To Contractor: Date the change order is sent to the contractor for signature
- Signed On: Date the contractor signed the change order
- To Owner: Date the change order is sent to the owner
- Executed: Date the owner signed the change order
- Work Started: Date the work was started

**Change Request**

A change Request can be initiated by the Project Manager, Architect, a Consultant as well as Contractor. Information provided would include;

- Description of the change
- Brief justification
- Affected contract drawings and specifications
- Anticipated effect on project cost and time, if any

**Value Engineering Proposal**

The contractor may suggest a better design solution than the one mentioned in the contract documents. These may reduce cost, give better quality/functionality or accelerate the schedule. The information provided includes;

- A detailed description of the difference between the existing contract requirements and the proposal.
- A comparative cost analysis of the proposed changes versus the existing requirements.
- Range of potential savings
- Estimated schedule impact

**Field Order/ Site Instruction**

Field Orders (FO) and Site Instructions (SI) are directives issued by the PM to the contractor to initiate changes in the work, typically resulting from;

- Coordination impacts on other contracts
- Design revisions
- Identification of unsafe situations and practices
- Clarification of contract requirement
- Identification of non-conforming work
Field order typically refers to the directive issued to perform a minor change that does not change project amount or time (AIA 1997) and a site instruction may involve a project change and hence lead to a change order. But the use of these terminologies in the industry and in the literature does not always conform to this differentiation. Therefore, the following description of FO/SI does not recognize the difference between FO and SI.

The contractor is instructed to notify the project manager within a specified number of days, whether the FO/SI would result in a change to project cost or time of performance.

Information provided in a field order includes (O’Brien 1988):

- Issued By: Person preparing the FO/SI
- Specification No.: The specification sections applicable to the FO/SI
- Instructions: Instruction given to the contractor in order to respond the FO/SI, such as
  - Confirm in writing
  - Follow instructions given
  - Take urgent actions

- Description: Description of the work required to be done
- Inspected On: Date the work related to field order is inspected
- Inspected By: Person who do the inspection of work

Other Documents

Other documents generated relating to change order process

E.g.: Meeting Minutes, Extra Work Orders, Correspondence
2.2 Literature Review

There is a significant amount of information in the literature related to change orders and their impacts on construction projects. Some of the literature discusses outcomes of research work (Leonard 1988, Krone 1990, Semple 1996, Ibbs et al 2003), while others are based on personal experience and are explanatory in nature (Dellon 1986, McCally 1997, Bridgers 2002, Revay 2003). Textbooks written as Guidance for professionals (O’Brien 1988, Cushman and Butler 1994, Civitello 2002) and technical handbooks provide a useful reference on existing industry practices (Rowland 1981, JLCPEER 2002). The following topics have been widely discussed in the of literature;

- Defining the “Change Order”
- Sources of change orders
- Change Order Categories
- Impacts of change orders on project performance
- Change order management techniques
- Change Order Cost Elements
- Dispute Resolution

Information found in the literature regarding the above topics is presented in the following sub-sections of this chapter.

2.2.1 Definition of ‘Change Order’

Although addressed previously in section 2.1.1, per completeness the definition of change order is elaborated upon here.

In generally accepted terminology, a change order is an agreement between contractual parties in a construction project to make a physical change in an originally agreed upon product. The change may be in contract price, time taken to construct, scope or quality of the final product. A more precise definition is often required by project personnel to avoid
disputes. The Standard General Conditions of the Construction Contract (1997 Edition) prepared by the American Institute of Architects (AIA) define a change order as; “A written instrument prepared by the Architect and signed by the Owner, Contractor and Architect, stating their agreement upon the following:

1. A change in the work
2. The amount of the adjustment in the Contract Sum; and
3. The Extent of the adjustment in the Contract Time.”

The Canadian Construction Documents Committee defines a change order in its Stipulated Price Contract (CCDC2 1994) as; “A Change Order is a written amendment to the Contract prepared by the Consultant and signed by the owner and the Contractor stating their agreement upon: a change in the work, the method of adjustment or the amount of the adjustment in the Contract Price, if any, and the extent of the adjustment in the Contract Time, if any”. These two definitions are widely accepted and used in most of the standard form contracts in North America.

2.2.2 Sources of Change Orders

Various factors hinder construction personnel from carrying out the construction work according to initial plans. These include unforeseen factors, factors beyond the control of the contractual parties, as well as intentional changes made during the construction phase of the project. The following factors are the most common reasons for change orders (Cushman and Butler 1994) (O’Brien 1988):

- Differing Field Conditions – Conditions in the field do not match with the contract documents. Examples include:
  - Failure to make the site available at the time and in the condition required by the contract
  - Subsurface physical conditions such as geological configuration, water levels, or suitability of soils that differ from those promised or implied by the contract documents. It also includes man-made site conditions from previous or concurrent construction activities.
• Errors or omissions in contract documents – Work cannot be done according to plans and specifications. Examples include:
  - Details in drawings do not match those in specifications or vice versa
  - Inadequate level of detail in drawings and specifications
  - Specified method of construction in the contract has become obsolete
• Interference with the contractor’s method or sequence of work – The contractor is not allowed to start/continue work as specified in the contract. Examples include:
  - Delay in obtaining city permits or environmental permits
  - Failure to obtain permission from neighbouring land owners for access
• Changes requested by the owner – Additions, enhancements or alterations directed by the owner. Examples include:
  - Extend one or more components of the project
  - Request the installation of better appliances
• Disruptions caused due to owner’s negligence and inefficiency. Examples include:
  - Delayed approval of contractor submissions
  - Defects or delays in owner-furnished items
  - Failure to coordinate work of third parties
  - Failure to grant, or delay in granting legitimate time extensions
  - Unreasonable or mistaken inspection
• Accident or damage – Damages beyond the control of any of the parties.
• Force majeure – Time delay due to forces beyond the control of the project team
  - Fire, flood, strikes, war, severe weather etc.
• Acceleration – Owner requesting the work to be completed at an earlier date requiring the contractor to implement methods of acceleration, usually at a higher cost.

2.2.3 Categorizing Change Orders

Various bases of categorizing change orders have been proposed in the literature. One of the useful categorizations is described in this section.
Civitello (2002) identified 3 categories of change orders depending how they are originated.

1. Owner Acknowledged
2. Constructive Change Orders
3. Consequential Change Orders

Owner’s change directives and change requests are the most simple and straightforward in managing change orders. These originate when the owner recognizes a need to make changes in plans and specifications and decides to accept responsibility for the change. Disputes may still arise regarding the cost of work actually performed and regarding impact or interference costs.

Constructive Change Orders originate when the contractor is required to perform work different from that stipulated under the contract due to the acts of owner and his representatives. Constructive acceleration, defective designs, defective inspection, interference and disruption are some examples. A contractor should be quick to recognize events leading to a constructive change order and should start documenting it.

Consequential change orders are not readily apparent or recognized by the owner and therefore a frequent subject of lengthy disputes, which can result in claims. Extra costs due to interferences and impacts are considered consequential costs.

2.2.4 Impacts of Change Orders

Changes made to original scope during the course of construction work impact the performance of any construction project (Leonard 1988, Coffman 1997, Hanna et al 2002a). Many research works have been carried out to examine how change orders impact the performance and to establish qualitative and/or quantitative relationships.

Change orders could affect construction in various ways;

i. Impact on productivity of labour force
ii. Affect the quality of work
iii. Cost impacts (overruns)
iv. Schedule delays

**Loss of Labour Productivity**

Impact on labour productivity is the most contentious area of change order impacts (Moselhi *et al.* 1991). It is also the most difficult impact to quantify (Hanna *et al.* 1999b). Considerable research work has been carried out that not only proves that the labour productivity of original scope of work is negatively affected by the amount of change work performed on a project, but also formulated models to quantify the impact (Coffman 1997).

Leonard (1988) carried out an extensive study to assess the effect of change orders on productivity. The study, which examined 90 cases drawn from construction projects derived the conclusion that change orders that disrupt and delay progress of work adversely affect productivity of the labour force. The main reasons are; stop-and-go operations, out of sequence work, de-motivation of work force and loss in benefiting from the learning curve. The study further revealed that change orders have a ripple effect on productivity of unchanged activities due to the interdependency of construction operations.

Quantitative examination of the impacts of change orders on productivity showed a significant direct correlation between the labour component of change orders and the loss of productivity (Moselhi *et al.* 1991). Based on the results of the study, Moselhi *et al.* (1991) developed a regression model for direct estimation of productivity losses due to change orders.

During the period of time the work related to the change order is performed, the work area can become more congested than it would have been under the original scope (Thomas and Napolitan 1995). Another factor that seriously affects the work is when it has to be done out of sequence. When a crew that has developed momentum in their work task is then told to stop and change their work, they will be demoralized and slow in recovering momentum (Construction Industry Institute 1990). Out of sequence work occurs when disruption force the construction to be performed in a different sequence to what has been originally planned.
There is a good chance that the revised schedule becomes illogical and uneconomical compared to the original schedule (Leonard 1988). In some instances, disruption and out-of-sequence work due to change orders hinders work crews from benefiting from the learning curve effect because they were prevented from keeping on repetitive tasks (Leonard 1988). As a result of changes, the level of complexity of the work may also be changed requiring more work hours per unit of work. All these factors give rise to productivity losses of labour.

According to the assessment of Thomas and Napolitan (1995), the loss of labour efficiency when changes are being performed is 30% on average. Various researchers have attempted to develop models to quantitatively assess/estimate the productivity loss due to change orders. Leonard’s (1988) model estimates percentage loss of productivity at the micro level taking into account labour hours spent on changed work compared to that of original work. Moselhi et al. (1991) followed a similar approach to develop a regression model for the direct estimation of productivity losses due to change orders. The model, which provides adjustment factors for different types of work, Electrical/Mechanical and Civil/Architecture, is based on the finding that “Total labour-hours spent carrying out changed work, expressed as a percentage of total labour-hours spent on original contract work, directly correlates with percentage loss of productivity on contract work.”

Thomas and Napolitan (1995) developed multivariate regression models to quantify the impacts of changes on field-labour efficiency. The models address the issue of causation; why changes negatively impact labour performance. Changes themselves do not lead to productivity losses. Instead, a change activates other disruptive influences. The model recognizes this high correlation between changes and various types of disruptions, rework and weather events. Because disruption is the root cause of loss of efficiency, and change work is related to an increased occurrence of disruption, changes and disruption are also correlated.

Studies done at the University of Wisconsin-Madison under the supervision of Awad S. Hanna have made a significant research contribution (Hanna et al. 1998, Hanna et al. 1999a, Hanna et al. 1999b, Hanna et al. 1999c, Hanna et al. 2000, Hanna et al. 2002a, Hanna et al.
2002b, Gunduz 2002) on the impact of change orders on labour efficiency of electrical and mechanical construction. Based on data collected from actual projects, statistical models were developed to estimate the actual amount of labour efficiency lost due to change orders. These models can be used by owners and contractors to estimate a baseline measure of lost labour productivity.

Their studies identified 3 quantifiable productivity-related problems caused by change orders (Hanna et al. 1999b).

1. Trade stacking – congestion that occur when change orders force operations to be performed concurrently instead in an orderly sequence as per the original work plan.
2. Schedule compression – change directed acceleration of work that can cause out-of-sequence work, excessive overtime, overmanning and multiple shift work.
3. Poor sequence of work – altered sequence of work forced by changes which is usually not as logical and smooth as the originally planned sequence.

Those studies further identified that even though there are other factors that impact labour efficiency such as effects on worker morale, they are difficult to qualify.

Not all change orders impact labour productivity the same way. Size of change orders, relative size of project, timing of change orders, complexity of change orders and effectiveness of on-site management have a significant effect on the impacts caused by change orders.

Regression analysis was used in Hanna’s research to formulate mathematical models to estimate labour inefficiency of electrical construction projects and mechanical construction projects. Changes frequently have ripple effects. Any disruption made to a task in a sequence will impact the subsequent tasks even if the change order itself does not involve these tasks. There is no clear understanding of all of the complicated relationships involved and it is difficult to isolate factors to quantify those (Hanna et al. 2000). The delta approach (Hanna et al. 2000) is aimed at representing the cumulative impact of change orders taking the ripple effect into consideration. A linear regression relationship has been developed to determine a value of delta, which indicates labour efficiency and is defined as the difference between the
actual labour hours expended to complete the project and the estimated base hours plus change order hours. For projects where change orders are the main reason for loss of efficiency, delta is attributable to the cumulative impact of change orders, or the so-called ripple effect.

Apart from the above mentioned significant research contributions, other researchers have also contributed using different approaches. For example, Kuprenas and Songer (1997) suggested the use of influence diagrams as a quantitative modeling tool to estimate the impacts of construction changes and change orders.

Although these studies present slightly different views on how change orders impact labour productivity and how to go about quantifying them, all of them conclude that the loss of labour productivity due to changes is an important area of concern in the construction industry. The results of these studies help resolve some disagreements among construction industry practitioners whether change orders actually have negative effects on labour productivity.

**Schedule Impacts**

Change order caused schedule impacts may not be confined to critical path activities. It may be possible to successfully incorporate the change work into the schedule. But a reduction on the float of non-critical activities is likely to occur. Float represents scheduling flexibility available to handle unforeseen situations, including changes. Ownership of float is a subject of controversy as both the owner and the contractor want to make use of available float as they wish. Many contracts do not identify ownership of float (Veenendaal 1998). Whenever an issue arises regarding the use of float, the contractor will claim the float ownership, saying that float is a management tool and the contractor must be allowed to manage his work. The owner will make his argument by saying that changes are obvious in any construction project, hence the float should be considered available to help absorb schedule delays due to changes. Float is a shared commodity and should be specified as such in the contract (Douglas 2003). The owner should be permitted some use of float for change orders. On the other hand, the owner should not use float to the point that the entire project becomes totally
critical (O’Brien 1988). Cost and/or schedule adjustment is necessary if either of them use a disproportionate share of the float (CII 1990).

In assessing the impacts caused by change orders, it is important to determine at what point in the network (CPM) a particular change order impacted the field work. The time of issue of the site instruction to proceed with the work is critical in assessing the impact. If the time of issue is later than the late start date of the affected activity, the change order has probably caused a delay in the project completion date (O’Brien 1988).

The impact of change orders on the project schedule can be analysed to determine whether the project duration has been affected. For this analysis the baseline (as-planned) schedule is used to compare all adjustments due to changes. A revised schedule is prepared by incorporating changes to the baseline schedule, including all preparatory time, new work activities and affected activities. The preparatory time includes total time spent on estimating, material and equipment procurement, reviews and owner approval. This estimated time frame is added to the schedule as a new activity. A critical path comparison table (Veenendaal 1998) can be used to compare the outcomes of all change orders. This table allows each activity on the critical path to be compared against each change order to determine the impact on the schedule. By analysing the updated schedule in conjunction with the comparison table, the effect of change orders on the baseline schedule can be identified. This approach helps to determine the excusable schedule due to change orders.

Cost Impacts
The cost impact of a change order can be several fold. To effectively manage changes it is important to establish the associated increase (or decrease) in project cost in a realistic and quantitative way (Hester and Kuprenas 1987). This is another source of dispute between the owner and the contractor to determine what costs are compensable. Owners want to pay only the direct and immediate costs associated with a change while contractors often demand additional compensation for reduced productivity, administrative costs (including home office overhead) and other consequential damages (Hester and Kuprenas 1987).
Several different attempts of classifying change order cost elements can be found in the literature. Civitello (2002) pointed out three basic cost elements that the contractor is entitled to recover.

1. Direct costs: labour, materials, site supervision
2. Indirect costs: home office overhead, off-site supervision, opportunity costs
3. Consequential costs (damages): interference and disruption, project delay costs, acceleration costs.

The contractor should address all of these cost categories in the change order proposal. Direct costs are readily justifiable as a change orders cost item because of the clear cause-effect relationship. It is less obvious as to what indirect and consequential costs are attributable to the modified work. Proper documentation and accurate, verifiable records is the key to identify and recognize these cost items as specific change order expenses (Civitello 2002).

2.2.5 Change Order Management Technique

Because changes are almost inevitable on construction projects, the effective management of the change order process should be given a high priority by all project participants. Project participants should be well prepared to identify changes, evaluate potential impacts, approve or reject changes and incorporate approved changes into the project. Early identification of a change and efficient processing is vital to minimize the impacts on project performance. Proper documentation and record keeping is the key to proving the impacts of changes and avoiding disputes (Duff 2002). Developing an orderly and well defined procedure for processing change orders prior to the start of a construction project is essential to the effective management of changes (McCally 1997). For active change management, change control systems require a systematic methodology that quickly and clearly identifies the origin of a potential change, records its communication and tracks processing (Baar and Jacobson 2004).

McCally (1997) identified 9 characteristics of an effective Change Order Management System.
1. A clearly defined change order processing procedure – formally document the processing procedure by issuing a flow diagram and narrative description of the process.

2. Supervision of the processing procedure – monitor document flows through various steps in the process.

3. Clear instructions regarding the scope changes – clearly stating in the request for proposal all the information necessary to deal with the change.

4. Timely issuance of a request for proposal (RFP) to the contractor (by owner) – as soon as the need for a change is known, RFP should be prepared and issued to the contractor.

5. Prompt response by the contractor to the RFP – review RFP information and start developing the price proposal.

6. Timely review of the contractor’s proposal (by owner).

7. Timely issuance of the work authorization (by owner) – promptly issue a work order once the change proposal is reviewed and found acceptable.

8. Timely performance of the changed work (by contractor) – add change work to the schedule so that it is properly integrated into the overall network plan.

9. Prompt payment for the change order work (by owner) – changed work is paid for in a manner consistent with the payment cycle for all other work.

Krone (1990) formulated a change order process which promotes efficient administrative performance and confronts daily demands arising from the changes. A large number of construction case studies were used to investigate the administrative process of change orders and to analyse cause-effect relationships of the change order process. He developed an innovative technique based on network models to formulate and analyse the change order process and its ripple effect.

Park and Pena-Mora (2003) introduced a model-based approach to change management. The dynamic project model presented focuses on capturing feedback processes caused by construction changes and minimizing their impact. Love et al. (2002) followed a similar approach to analyse the change process and describe how its dynamics can impact the project
management system. This approach considers a project management system as a dynamic system, which is subject to both attended and unattended dynamics. It tries to understand how a particular dynamic can hinder the performance of the project management system and determines the responsive actions required.

Barron and Fischer (2001) at the Center of Integrated Facility Engineering (CIFE), Stanford University, studied the potential benefits of internet-based project control systems by modeling and analysing a business process model of the change order process. The research aimed at evaluating the potential quantitative and qualitative benefits an integrated internet-based change management system would offer compared to a traditional paper-based system. A case study was used to develop the business process model that illustrated typical problems found with paper-based systems. The research concluded that the total effort put on processing change orders can be reduced by nearly 75%, mainly by preventing data duplication and re-entry across multiple systems, documents and project participants. It also revealed that 97% of information used for all the change order processing activities can be taken from previous experiences dealing with change orders. By doing this, change order processing durations can be reduced from a typical 1 month to 1 week. This research is important in that it provided a framework consisting of several structural levels of detail to model the business process for change management in a consistent and logical way. The model can be used to describe and compare different business processes across companies and projects.

2.3 Commercial Software Solutions

There are numerous state-of-the-art project management software solution providers available to the construction industry today. They provide both off-the-shelf software systems and fully or partially customized solutions to suit user requirements. Most of the time change management functions can be found integrated with other project management functions. In this section, the three software systems that dominate the current market are overviewed. They correspond to the systems offered by Primavera, Timberline and Meridian Project Systems.
2.3.1 Primavera Expedition

Primavera Expedition is a project control software solution for construction professionals. It provides an integrated solution for project communication, information management and cost/contract control (Primavera Systems 2002). According to ENR 2003 Technology study (McGraw Hill 2003), Expedition is the most widely used project management/contract control software in the world.

Expedition handles change order management in a separate change management module using two simultaneous views, one for the change order process and the other for cost/contract control. The change process view shows important dates along the process, document references and status details, while the cost/contract control view (Fig. 2.6) details what changes are made to the contract in terms of both cost and time impacts.

Figure 2.6: Primavera Expedition 9.0 – Change Management – Cost/contract control aspects
(Source: http://www.primavera.com/solutions/ec_expedition.html)
Instant updating of change order information enables users to realise cost and schedule impacts of any change on the project and immediately identify which contractors are affected, if new material and/or equipment are needed and whether a schedule delay is expected. Expedition creates a budget for new work, material and equipment needed. It facilitates communicating potential change information with the project team and developing multiple requests for proposals to be sent to all affected subcontractors. Its multi-user database streamlines the communication process distributing meeting minutes, RFIs, design changes etc. without any delays. Change management workflow is user customizable to some extent adding flexibility to the system. It has the capability to analyse ripple effects of a change on several contracts. Impacts of changes and document status can be viewed in a graphical mode (Fig. 2.7).

![Figure 2.7: Primavera Expedition 9.0 – Graphical Mode](http://www.primavera.com/solutions/ec_expedition.html)

The table 2.1 shows the abstractions extracted from the Primavera change management module.
<table>
<thead>
<tr>
<th>Change Management Process</th>
<th>Cost Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Title</td>
<td>Date Initiated</td>
</tr>
<tr>
<td>Party Contracted with</td>
<td>Status</td>
</tr>
<tr>
<td>Contract No.</td>
<td>Commitment in Dispute</td>
</tr>
<tr>
<td>Document No.</td>
<td>Estimated Budget</td>
</tr>
<tr>
<td>Spec Reference</td>
<td>Estimated Commitments</td>
</tr>
<tr>
<td>Drawing Reference</td>
<td>Quoted Budget</td>
</tr>
<tr>
<td>Response Date</td>
<td>Quoted Commitments</td>
</tr>
<tr>
<td>Approved Date</td>
<td>Negotiated Budget</td>
</tr>
<tr>
<td>Required Date</td>
<td>Negotiated Commitments</td>
</tr>
<tr>
<td>Change Issue</td>
<td>Reason Code</td>
</tr>
<tr>
<td>Approval Status</td>
<td>Scope</td>
</tr>
<tr>
<td>Activity</td>
<td>Final Budget</td>
</tr>
</tbody>
</table>

Table 2.1: Change Order Properties used by Primavera Expedition 9.0

2.3.2 Timberline Office

Timberline Office is best known for its estimation capabilities. But it has a modular design with accounting, reporting, procurement, project management and production management modules in addition to its estimating module. Timberline is the industry’s leading software for accounting/job costing and estimation (McGraw Hill 2003). Timberline can be used to automate the change order process. Once all the information is recorded, it can be tied with the contract, subcontracts, purchase orders and budgets. It can be used to track changes to the original contract and prepare change estimates, purchase orders, meeting minutes, RFIs and other project related documents.

The software’s modular design makes change order management more convenient because of the integration capability with the accounting module which contains contract and job cost data and with the project management module which provides change order process information.
2.3.3 Meridian Prolog Manager

Meridian project systems is the fastest growing construction management software solution provider (McGraw Hill 2003). Prolog Manager provides extensive functionality to control the change order process. Change order management features come under the cost control module and are presented under four views; Potential change orders, Change order requests, Prime contract change orders and subcontract change orders. The potential change order (PCO) is the foundation of the change management system. The PCO list view is the gateway to the system, which shows PCO codes, date of initiation, brief description, category (basis of costing) and reason. Further details provide contract information, references to related records, requested schedule adjustment and all the cost detail of the PCO (Fig. 2.9).
## Potential Change Orders

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
<th>Category</th>
<th>Reason</th>
<th>Field Condition</th>
<th>Requested Days</th>
<th>Approved Days</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>002</td>
<td>7/22/2000 Run wall w/ hat-channel @ starwell</td>
<td>Time &amp; Material</td>
<td>Field Condition</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>007</td>
<td>7/30/2000 Whiskey manure</td>
<td>Contingency</td>
<td>Field Condition</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>014</td>
<td>7/17/2000 Duct control</td>
<td>Contingency</td>
<td>Field Condition</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>016</td>
<td>7/22/2000 Re-route SD &amp; EI</td>
<td>Lump Sum</td>
<td>Field Condition</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>017</td>
<td>7/22/2000 Leveling dies at fascia stool</td>
<td>Lump Sum</td>
<td>Field Condition</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>021</td>
<td>7/25/2000 Remove unsatisfactory slope</td>
<td>Time &amp; Material</td>
<td>Field Condition</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>022</td>
<td>7/29/2000 Bailing at penthouse roof</td>
<td>Time &amp; Material</td>
<td>Field Condition</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>023</td>
<td>7/31/2000 AC leveling guides</td>
<td>Time &amp; Material</td>
<td>Field Condition</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>029</td>
<td>8/13/2000 AC leveling Curbs</td>
<td>Time &amp; Material</td>
<td>Field Condition</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>032</td>
<td>9/1/2000 Fire caulking</td>
<td>Lump Sum</td>
<td>Owner Directive</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>040</td>
<td>7/12/2000 A08 interior door @ starwell</td>
<td>Lump Sum</td>
<td>Owner Directive</td>
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<tr>
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<td>Lump Sum</td>
<td>Owner Directive</td>
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<tr>
<td>053</td>
<td>7/18/2000 Concrete batch plant strike</td>
<td>Strike</td>
<td>Owner Directive</td>
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<td></td>
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<tr>
<td>005</td>
<td>7/16/2000 Steel support at dumbwaiter cage</td>
<td>Owner Directive</td>
<td>Owner Directive</td>
<td></td>
<td></td>
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<tr>
<td>017</td>
<td>7/30/2000 Mansard</td>
<td>Lump Sum</td>
<td>Owner Directive</td>
<td></td>
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<tr>
<td>021</td>
<td>7/25/2000 Reroute SD &amp; DI</td>
<td>Lump Sum</td>
<td>Owner Directive</td>
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<td>023</td>
<td>7/31/2000 AC leveling guides</td>
<td>Lump Sum</td>
<td>Owner Directive</td>
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<tr>
<td>029</td>
<td>8/13/2000 AC leveling Curbs</td>
<td>Lump Sum</td>
<td>Owner Directive</td>
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<tr>
<td>032</td>
<td>9/1/2000 Fire caulking</td>
<td>Lump Sum</td>
<td>Owner Directive</td>
<td></td>
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<tr>
<td>040</td>
<td>7/12/2000 A08 interior door @ starwell</td>
<td>Lump Sum</td>
<td>Owner Directive</td>
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<tr>
<td>049</td>
<td>8/19/2000 Art glass revision</td>
<td>Lump Sum</td>
<td>Owner Directive</td>
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</tbody>
</table>

### Figure 2.9: Meridian Project Systems Prolog Manager, Potential Change Orders

(Source: www.mps.com/products/prolog/PM)
The change order request function allows the contractor to roll up several PCOs into a single change order for submission to the owner. This simplifies the change order process and makes it more effective in carrying out negotiations. The change order request view (Fig. 2.10) shows contact information, claimed amount and time, important dates for tracking purposes and notes.

Figure 2.10: Meridian Project Systems Prolog Manager, Change Order Requests
(Source: www.mps.com/products/prolog/PM)

Subcontract change orders and prime contract change orders are viewed separately showing all the details of cost and time adjustment and important dates and references. Change orders are integrated directly into the budget, so that budget updates can be viewed instantly. The tree view shown in Fig. 2.11 illustrates how change management is structured in Prolog Manager.
Figure 2.11 Change Management Framework in Meridian Prolog Manager
2.3.4 Other Software solutions

Internet-based project management solutions are becoming popular in the construction industry. Constructware and AutoDesk Buzzsaw are two of the most widely used solutions of this kind. They provide change order functions integrated into their online software systems. This enables real time sharing of information and documents among users at remote locations.

Apart from the above-mentioned leading software solution providers, several other companies have made their software available to the industry and most of that software has change management functions built in. Contract Manager.cs by Explorer Software inc., BuildLinks, Corecon, Projectmates, and e-Builder are some of the examples.

Some owners and contractors opt for simpler change order management processes which use templates designed and built using spreadsheet packages such as Microsoft Excel (Moucon 2000) (Fig.2.12). Although such an approach does not provide much in the way of integration capabilities across different project management functions, it has the benefit of allowing the use to customize the change order view to their particular needs.

Figure 2.12: Change Order Template created using Microsoft Excel
(Source: Office of the State Architect of the State of Ohio, USA www.gsd.das.state.oh.us/sao/saoforms.htm)
Many contractors still rely on their well established, carefully maintained, paper-based systems to manage change orders (Arsalan et al 2002) and restrain from implementing computer-based systems. Paper-based solutions work effectively as long as the information flow is at a manageable level and the project participants are not pressurized to go for a computer based system. Although implementation costs may be high, computer based systems have proved to be more efficient and economical over paper based systems (Sulankivi et al 2002).

Current commercial solutions offer significant opportunities to record numerous detail related to day-to-day change management process. Various types of documents/reports can be generated using the templates available in them. These software system providers usually have thousands of users in their customer base and regularly receive user feedback which helps them improve their software. Therefore, these commercial systems are elegant in terms of their user friendliness. Further, powerful search engines are embedded in them for random keyword searching making the data readily accessible. These features make the commercial software solutions best suited for day-to-day tasks associated with getting on with the job of building the project. But these commercial solutions lack the ability to establish relationships between change management data and other different project functions such as records, daily site data, schedule, etc. This makes it impossible for them to make associations among different project data and explain the impacts on overall project performance. None of the commercial solutions described in this section are capable of explaining the project performance (in terms of productivity, cost, time, etc.) as a function of the impact of change orders encountered in the project nor they are capable of triggering any performance related aspects that need to be addressed (such as congestion, trade interferences etc.).

Shortcomings of currently available change management systems discussed above, provide the opportunity to develop a system that has the integration capability to link with other project data and produce useful information that explains project performance against change orders encountered.
3 System Analysis and Design

3.1 Introduction

Managing change orders is one of the most challenging tasks faced by project personnel in any construction project. It is a time consuming and costly process which often leads to loss of productivity (Assem 2000), poor project quality (Carippa 2000), prolonged project delivery and at times failure of a project. Efficient management of information and timely communication would significantly enhance the effectiveness of the change order management process. Field surveys have shown that change order management practices used by many construction companies are not optimized either in terms of information management or time consumption (Semple 1997). Implementation of a computer based change order management system could significantly enhance the effectiveness of managing change orders saving both time and cost (Krone 1993, Barron and Fischer 2001).

Many construction companies still use paper based documentation management systems, where information generating, organizing, processing and retrieving are time consuming compared to computer based systems (Barron and Fischer 2001). This becomes more cumbersome in large projects where thousands of change orders can be encountered. Several commercially available software systems provide support for handling change orders. As discussed in Chapter 2, they do not reflect the true complexity of the actual change order process and can be inadequate in fulfilling the requirements of many project personnel. Therefore, often times construction companies and project managers have opted to develop their own systems for managing change orders. These are mostly spreadsheet based stand-alone applications, and hence are not integrated with other project management functions.

The primary objective of this research effort is to develop a specification for a computer based process management and decision support environment for managing change orders in construction projects as part of a layer of an integrated environment that supports a diverse range of construction management functions. Such a process will facilitate the real time management of change order information and assist in other functions related to claim
preparation, explaining performance to date, etc. As part of the effort to ensure a comprehensive representation of the change order process, meaningful abstractions are developed to describe the different aspects of the change view of a project.

The scope of the research is different from the contents of most of the commercially available solutions, in that it is not only focused on capturing the story of construction, but also assists in assessing the impacts on project performance. This is achieved through integration of a diverse range of project management functions. The change order management process developed here is an integral part of a research system called REPCON. REPCON is based on the framework for computer-integrated construction described by Russell and Froese (1997) and extended by Russell and Chevallier (1998), Udaipurwala and Russell (1999) and Russell and Udaipurwala (2001), which focuses on developing a generalized, comprehensive and integrated multi-view representation of a construction project. It captures the primary dimensions of a project relevant to its planning and control as well as post project analysis. Meaningful abstractions are being developed to describe different aspects of:

(i) Physical View (what is being built and site context);
(ii) Process View (how, when, where and by whom it will be built);
(iii) Cost View (how much it will cost the various participants);
(iv) As-built View (what happened, why and actions taken);
(v) Quality View (compliance requirements and achievements for input and output products);
(vi) Change View (changes in scope, why and consequences for other views)
(vii) Organizational/Contractual View (the construction team, contractual obligations & entitlements, insurance, bonding, warranties, and evaluation of participant performance);
(viii) Environmental View (natural and man-made environments that accompany the project); and
(ix) Risk View (potential risk events that could be encountered, mitigation measures, and outcomes).
Some of these modules have being implemented in the research system, REPCON, while others are in the research/design stage, such as the Change View described herein.

It is important to represent changes in a separate view as they are inevitable in any construction project and managing them is regarded as a major project management function (Douglas 2003). The change view helps project personnel to coordinate and manage information related to the change order process, carry out reasoning and searches on information related to changes and visualize of information pertaining to issues of interest.

3.2 System Environment

3.2.1 Scope

In terms of contributing to the development of a change view, the scope of work set for this thesis embraces the following:

- Establish a generalized flow of change order processes that reflects the basics of the range of different practices prevalent in the construction industry. As a part of this define the terminology being used;
- Identify the modules and components (building blocks) of a construction change management system and establish linkages among them;
- Identify a rich set of abstractions sufficient to capture the story of scope changes in a construction project;
- Determine how the change management process can be integrated with the REPCON research system as its Change View, so that fullest advantage of existing resources can be utilized to strengthen the change view;
- Document a comprehensive set of specifications necessary to implement the design;
- Design user interfaces and navigational structure for the change management system; and,
- Examine modes of interpreting change order data (e.g. visualization techniques).
3.2.2 Expected Benefits of the System

The change order management process presented here is designed to be used by project personnel during the execution phase of a project to efficiently organize and manage the immense amount of information related to change orders. It enables them to have informative and timely communication between related parties, organize various types of documents and retrieve them easily, perform quick searches for information and share information more effectively and efficiently. It provides a complete story of the project in terms of changes during the post-award phase. This is helpful in resolving claims, visualizing the effect of changes on project performance, post-project analysis and managing knowledge and learning.

3.2.3 Challenges in Electronic Representation

The construction process in general is challenging when it comes to electronic representation, because it is a custom business and each project is unique. The way projects are managed varies from one organization to the other and from one geographical location to another. The change order process is no different. Terminology, supporting management and approval processes, documents involved and information flow are different from one organization to the other, one project to the other and even in the same project it may differ from one change order to the other (O’Brien 1988). Change management is one of the most difficult and challenging tasks faced by project personnel (Revay 2003). In a field study of documentation practices in construction projects, Jiang (2002) observed Change Management to be one of the most complex parts of site documentation practice.

In developing a computer based system that is expected to be used in different contexts, many factors have to be taken into consideration. Major challenges in designing a comprehensive process and supporting system are seen to include the following.

1. The system has to be flexible enough to allow different parties of the construction process to use it. The owner or his representative and Construction Manager/General
Contractor are expected to be direct users of the system. Designing an information management system compatible with different perspectives is always a challenging task as each party’s requirements are different.

2. The system should be capable of managing information under different types of contracting. The main types of construction contracting such as general contracting, construction management contracting and turn-key (Design-Build) contracts are considered. Contractual relationships between parties are different in different types of contracts. Hence, the change order approval process can differ from one contract type to the other.

3. There is an absence of an industry standard procedure for managing change orders. Although the issuance of a change order is regarded as the standard method of dealing with a change made to a construction contract, either in terms of scope of work or project duration, there is no generally accepted industry standard procedure. Hence, the procedure for generating and approving changes varies from one project to the other depending on the agreement reached between parties or on conditions imposed by the owner.

4. Inconsistent vocabulary is used in the industry. Terminology used for different documents, processes and project elements differs from one place to the other. The same term is sometimes used to identify different things in different scenarios. Therefore it is important to define precisely the vocabulary used.

5. Multiple project participants may be involved in the same change order. There may be a number of contractors/sub-contractors/designers/suppliers involved in the change. For example, if the change is regarding a concrete retaining wall; excavation, formwork, reinforcing, concreting, anchoring and seepage control are handled by different contractors/sub-contractors who have separate contractual agreements with the owner/general contractor and input is required from both the geotechnical and structural specialists. In such a situation, the system should be able to handle many-
to-one information management (i.e. many participants to one change order) and treat each contract separately in the same change order situation.

3.3 Analysis of Change Order Process

The construction change order process is analysed in the light of the literature available through text books, research reports and guide books identified as part of the literature review in Chapter 2. We seek a flexible set of procedures that represents the change order process in general. Various procedures followed by different organizations under different contexts are described by Civitello (2002) and O’Brien (1988) in their popular change order guide books. These texts and several industry manuals (Rowland 1981, USEPA 1983, JLCPEER 2002) and technical reports (e.g. MacAskill 1985) are referenced in developing a generalized change management process.

3.3.1 Users of the System

Various parties are involved in the change order management process and play different roles and hold different responsibilities. But not all the parties would actively use the change order management system. The General Contractor, in the case of a traditional general contracting type of contract or the Construction Manager, in the case of a construction management contract will be the direct user of a change order management system put into place in a construction project. Other project participants (e.g. Project Architect) will make use of the reports of varying information content generated by the system.

In a general contracting type of a contract, the General Contractor (GC) plays the central role of the change order management process. The GC maintains the potential change list, requests quotations and proposals from sub-contractors and evaluates them, compiles the change order proposals to be submitted for the owner’s approval, and keeps track of all the records associated with the change. The Construction Manager (CM) plays a similar role in a construction management type of contract. The CM tracks the development of potential
changes, prepares request for proposals to be sent to trade contractors, evaluates submitted proposals and keeps track of all the records. Although contractual relationships are different, the roles of GC and CM are basically similar when it comes to the change order management process. The change order process presented in this thesis is designed to suit both a GC and a CM type of procurement mode.

3.3.2 Phases of Change Order Process

In this section, the change order management process is analysed and different change situations are identified. For the purpose of this analysis, the change order process is broken down into four phases.

1. Identification Phase
2. Evaluation Phase
3. Negotiation Phase
4. Approval and Execution Phase

Identification Phase
During the identification phase, signs of a potential change are identified by one or more project participants and are communicated to all affected parties. The construction Manager(CM)/ General Contractor(GC) collects all related records and starts documenting the evolution of the potential change. A preliminary evaluation is done to assess the feasibility of the change in terms of constructability and financing availability. If the estimated impacts are intolerable, potential change will not be implemented. It is also important to consider whether the construction work related to the change has already been executed in the field. This is the situation in most of the changes initiated by extra work orders and field orders.

If the potential change is considered to be a minor change, in most cases it does not require extensive evaluation or price negotiation. It is directly given approval/denial by the owner. The owner can define a ‘minor change’, which is sometimes referred to an ‘internal low cost change’, at his own discretion, depending on a criterion set out prior to project start.
**Evaluation Phase**

Once a potential change is identified, the scope of work is defined and the impacts of the change are evaluated. This includes both cost impacts and schedule impacts. Contractors respond to a ‘request for proposal’ by submitting change proposals detailing their price and time impact estimates for the work involved. This proposal is compared with an in-house estimate by the CM/GC, in order to help evaluate it. If these proposals are agreeable to all parties, the PCO is forwarded to the owner or his agent for approval.

**Negotiation Phase**

If the contractor’s valuation for the work (cost and/or time) is contested, the owner and the contractor will have to try and negotiate an equitable amount. This can involve a series of meetings and the exchange of correspondence among the concerned parties. Contractors may be asked to revise their proposals several times during the process of negotiation. If the negotiations fail to come up with an agreeable solution to all parties, the change may be abandoned or, a change directive is given. If the work has already being executed, contractors can seek arbitration or litigation measures to get compensated.

**Approval and Execution Phase**

Once an agreement is reached from the negotiations, the potential change is approved by the owner as a change order. Contract documents are amended accordingly and designs are finalised before issuing field orders to execute the work involved. The project schedule should also be amended if necessary.

Not all PCOs go through all of these four phases. One or more phases may be by-passed in some cases. But most of the significant changes follow all four phases described above before being finally approved as a change order. Different processes involved during these four phases are represented in the process flow diagrams in figures 3-1 to 3-4. The change order process represents a generic industry practice identified through the literature, elements of which are reflected in individual firm procedure. These process diagrams are used to identify properties of the change order management system discussed in this chapter.
Problem Identified

Identify the potential for a change

Sources
CD – Change Directive from the owner
RFI – Request for Information issued to clarify an error/ambiguity in plan and/or specification
SI/FO – Site Instruction and/or Field Orders issued leading to out of scope work
EW – Extra work identified by the contractor
VEP – Value Engineering Proposal made by contractor

Case Initiated

CM/GC - Initiate a PCO and start tracking its development

Problem Communicated

CM/GC
‘Notice of Change’ sent to all affected parties

Preliminary Review

CM/GC – Schedule & Budget impact
Constructability
Owner – Affect on project’s general scope
Economic viability of the project
Availability of financing
Architect – Feasibility of design changes
Regulatory conformance

Figure 3.1: PCO Identification Phase
PCO Evaluated

Owner - Evaluate financing options
Architect - Describe the scope of PCO
Prepare new and amended designs
Send for design amendments in other design disciplines (e.g. mechanical)
CM/GC - Prepare 'request for proposal'

CM/GC
'Request for Proposal' sent to all affected trades

Proposal Prepared

Trades
Obtain quotations and proposals from sub-trades/suppliers
Prepare Change Proposal (Cost estimate & Schedule Impact Analysis)

Proposal Reviewed

CM/GC
Evaluate Change Proposals submitted by trades
Compare cost proposal with Cost Engineer's estimate
Review 'schedule impact analysis'

Change proposal disputed?

NO

Proceed to Approval Phase

YES

Proceed to Negotiation Phase

Figure 3.2: PCO Evaluation Phase
Prepare for Negotiation

**CM/GC**
- Call for negotiation meetings
- Coordinate correspondence
- Compile all available records related to the PCO

---

**Negotiation**

Trades - Negotiate for the scope of work, price & time
CM/GC - Evaluate revised proposals submitted by trades
Owner - Actively participate in negotiating a price and a time allowance for the change
Architect - Review work scoping

---

**Re-Evaluation**

- **YES**
  - Architect - Refine the scope of work
  - CM/GC - Identify affected trades and send ‘Request for proposal’
  - Trades - Submit revised change proposals
- **NO**

---

**Negotiations failed?**

- **YES**
  - Cancel PCO
  - Consider other actions (arbitration, litigation) if necessary.
- **NO**

---

Proceed to Approval phase

---

Figure 3.3: PCO Negotiation Phase
3.4 System Design Considerations

3.4.1 Design Requirements

Facilitating Different Change Scenarios
The change order management system should have the flexibility of handling different scenarios of construction change situations. The following factors are considered in designing the system components:

- By the time the change order process is commenced, the construction work related to the change may have already started or may even have been completed. This is common in most extra work order (or extra work claim) generated changes. In such situations, daily site data are important in
establishing the case. The change order process focuses on determining cost and time implications of the work done by different trades.

- In other cases, where a change is proposed, the change order management process focuses on determining the feasibility of the change and negotiating the work scope and a price for it. Properties of system components should facilitate both of these scenarios.

- Owner initiated changes (change directives) follow a different path from the beginning. Once the work scope is clearly defined and the designs are completed, it is directly approved as a change order. Negotiations are required only to come up with a price for the work and possible time impact on project schedule.

- The negotiation process may or may not involve the submission of a number of revised proposals by trades. Scope and impacts of change are re-evaluated in each proposal. The system should facilitate representing important information on each proposal and development of the negotiation process.

- If negotiations fail, the potential change is cancelled. The affected parties can take further steps of dispute resolution, such as arbitration and litigation. Detailing the proceeding of these steps is considered to be beyond scope of the system designed here.

**Capability to handle different change orders**

The system should be capable of handling both complex and simple change orders. A complex change order could involve many participants, relate to many physical components and activities and go through a rigorous negotiation process during an extended time period. On the other hand, a change order could be as simple as an owner directed modification of a component specification for which the contractor’s cost estimate is not contested.

**Option to choose level of detail**

Different users may prefer to maintain different levels of detail in their system. While it is emphasised that the user cannot achieve all of the potential benefits that a comprehensive system can offer if they opt out of providing values for some of the properties of entities, the
option to choose the level of detail the user wants to input to the system has to be given. Users have the option to ignore some non-essential data fields if they decide it is convenient for them to do so. This not only makes the system flexible for different users, but also prevents the system from becoming inoperative due to missing information.

**Searches on data**
Searching across change view data files, associated records, process information and links to other views has to be facilitated.

**Linking to other views**
Establishing appropriate associations between the change view and other views of the multi-view representation is critical for the effective functioning of the system. Relevant links to other views should be identified and facilitated in the design of the system.

**Graphical representation of data**
Useful visualization formats for representing important change view data should be developed.

### 3.4.2 Design of Abstractions

Effectiveness of capturing the change order data of a construction project significantly depends on the selection of abstractions that represent them. Documents that carry information pertaining to the change view have associations pointing towards the change view. These associations can be understood as content abstractions and are sometimes not stated explicitly in text format making it necessary to be interpreted using suitable headings. The abstractions have to be in support of time, cost, scope, quality, links to other views, and communication and coordination amongst project participants.

A set of abstractions that is sufficient to best describe the story behind the change order process and its impacts are described below. For each attribute, its characteristics and operations performed on them are identified.
The following were considered in specifying the abstractions used:

- The attribute name should not be ambiguous. The name should be self explanatory and precisely definable. But the name of an attribute might have different meanings to different users under different contexts. A comprehensive set of terminology definition should be included in the system manual/help for the benefit of users.
- Each attribute should provide a meaningful representation of the change order process. An attribute should be either useful in providing information on the current status of a change or helpful in carrying out reasoning and searches.
- Values of attributes can either be hard-coded (pre-defined) or user-defined. Attributes that should have hard-coded values have to be carefully selected and those values have to be determined in a way that reflects values assigned in practice.
- Properties of the attributes, such as their type (linguistic, numeric, Boolean etc.) and character length have to be specified clearly.
- Attributes need to be clear as to the nature of relationships. i.e. one-to-one; one-to-many; many-to-many etc.
- Attribute properties need to allow items to be aggregated. E.g. Multiple PCO's to become a single CO.

3.4.3 Design of System Components

Gateways to the System

The change order process described here is built up on two fundamental building blocks, which can also be considered as gateways to the system.

1. Potential Change Order (PCO) List
2. Change Order (CO) List

A change item could either be originated as a potential change order or as a change directive from the owner. In the former case, once the change item is identified as a PCO, it is entered into the PCO list and tracked using its unique PCO number. Once approved as a change
order, it is entered into the CO list. In the case of a change directive, the change item is
given a CO number and directly entered into the CO list. A corresponding PCO item is also
created and added to the PCO list, so that PCO list contains all the change items of the
project. This is convenient for tracking purposes.

The potential change order list provides a list of all change situations for the project, whether
approved as change orders, rejected subsequently or still under process. The potential change
order list is used as the tool to create intersections between other project views and the
change view. The change order list is a subset of the PCO list and consists of potential
changes that have been formally approved as change orders.

Major Steps of the Change Order Management Process

System components and their properties are identified by analysing a typical change order
process that is flexible enough to represent different industry practices. In light of the generic
process represented in figures 3-1 to 3-4 and considering the different change scenarios
described above, major steps of a change order management system along with a logical
sequence are identified. These are shown in Figure 3-5: This figure is used as the basis to
formulate the change order management system described in following sections.

The steps of the process are described below;

1. Once a source of a potential change is recognised, the need for a change or a situation
leading to a change is discovered. The source may be one or more RFIs concerning an
error in a design drawing, which reveals a need for a change in scope of work. It can
also be an extra work order (or extra work claim) a contractor has submitted for a
work performed.

2. If the change is initiated by the owner by way of a change directive, a change order
item is created and added to the change order list of the project. A PCO item is also
entered to the PCO list. Scope of the work and designs are finalised by the architect.
GC/CM negotiates with affected trade/trades for a price for work scope and for a
possible schedule adjustment.
3. If the source is not a change directive, the change cannot be considered a change order at the outset. It is logged as a potential change and a unique code is assigned for identification. The PCO list of the project is updated with the new PCO.

4. All of the records related to the potential change are compiled as evidence to establish a case for the change. Daily site data provide strong proof if the work related to the change has already been executed.
Discover the need/situation of a change

Owner initiated change (CD)?

NO

YES

1. Initiate a PCO item and assign a unique code
2. Initiate both a PCO item and a CO item and assign unique codes

3. Compile all related records and daily site data
4. Identify affected parties (Trades, Designers, Consultants etc.)
5. Establish associations with other project functions (views)
6. Revise drawings and prepare new drawings & issue them to affected parties

7. Describe the scope of PCO
   Prepare design changes & deliver them to affected parties
8. Obtain quotes/proposals from trades
9. Negotiate for Price & Time Impact
10. Prepare & submit change proposals

CO – Change Order
PCO – Potential Change Order
RFI – Request for Information
EW – Extra Work
CD – Change Directive
SI – Site Instruction
FO – Field Order
VEP – Value Engineering Proposal

Figure 3.5: Steps of a Typical Change Order Process (continued in next page)
Evaluation of change proposals

Does the change proposal need to be disputed?

- If yes, proceed to negotiations for:
  - Scope of work
  - Price
  - Time impact

- If no, proceed to change PCO status to 'Approved' & initiate a CO item

- After approval, approve drawings/specifications and issue SI to execute work
5. All affected parties to the change are identified. This not only includes affected trades, but also related designers, consultant engineers, suppliers etc. These parties should be informed about the change once the PCO is recognized.

6. Associations with all other project views are identified and linked with the PCO. Physical components and drawings in the Physical View, activities in the Process View, records and daily site data in the As-built View and, contracts and project participants in Organizational/Contractual View are useful associations. More information about the PCO becomes available further into the change order process which helps refine these associations.

7. It is the duty of the architect to analyse available PCO information and elaborate on its scope. Revisions to the drawings and specifications as well as new designs required are prepared and sent to affected parties.

8. CM/GC prepares the request for proposal (RFP) and sends it to affected trades. It provides a description of the scope of work and requests to submit a cost proposal. Usually, trades are given a deadline to submit their change proposals.

9. When preparing change proposals, trades often rely on proposals and quotes from their sub-trades and suppliers. Change proposal includes work methods and cost breakdown. If the work is expected to affect the project duration, a schedule impact analysis can also be submitted.

10. Once the change proposals are received from trades, they are analysed by the CM/GC. Independent cost estimation prepared by a cost engineer consultant may be used to evaluate the cost proposal. If the owner agrees to the cost and time impact proposals submitted by the trades, then the PCO is approved.

11. If the change proposals are contested, the parties have to negotiate to achieve a solution. Negotiation typically involves re-evaluation of scope of work, costs and time impact. There can be several rounds of negotiations. In each round, work scope is refined, affected parties assessed and revised proposals are requested from affected trades. If the negotiations fail to achieve a solution, the PCO is cancelled. Trades then submit claims for the work already done. Arbitration or litigation measures may be required to resolve these claims.

12. If an agreeable solution is reached, owner approves the change.
13. Once the PCO is given approval by the owner, a new change order is initiated and an item is added to the project's change order list. All the information related to the PCO transfers to the CO. New and revised designs are finalised, schedule is revised showing new activities generated by the change, pay items are modified to reflect the change and new schedule of values are prepared.

14. Shop drawings are approved and necessary site instructions are issued to execute construction work. This step is not required if the change order is related to already completed work.

3.4.4 Identification of Fundamental Components and their Properties

In this sub-section, fundamental components of the change order management system and their properties are identified, in keeping with the process described in the previous sub-section. Some of the data can be accessed by way of associations to different project views, such as process view, physical view and as-built view. All these project views have already been implemented in the REPCON research system. The change view presented here makes use of those implemented project views to access data.

Figure 3.6 represents the components of the change view, their attributes and how components are inter-linked.
Figure 3.6: Entity Relationship Diagram for Change View
3.5 System Specifications and Interface Design

3.5.1 Components Description

Potential Change Order (PCO) List
The PCO list is a comprehensive list of all changes encountered in the project, as all the potential changes that occur on the project, irrespective of whether they are subsequently approved or not, are entered into it. A benefit of having all the changes in a single list is the ability to use it to link the change view with other project views. Whenever an entity in another view needs to be linked with related changes, the PCO list can be triggered to select relevant item(s) to make associations. It should be noted that some of the items listed here are only proposals made by different project participants and are not physically implemented due to cancellation at a later date. Hence the status of a change item is an important attribute that should accompany the change item whenever it is linked with other views.

The PCO list shows several selected properties of PCOs.
1. PCO Number
2. Description
3. Date Initiated
4. Primary Source Document
5. Initiated By
6. Primary Cause of PCO
7. Status/ Date of Status Change
8. Corresponding CO Number (For approved PCOs)

These attributes can be considered sufficient to recognize each PCO and have been gleaned from the change order process identified in Figures 3-1 to 3-4 as well as from all of the literature reviewed and other systems examined. Further explanation of these properties is provided in the following table. Figure 3.7 shows a screenshot of the PCO list user interface. The user interface shown in Figure 3.8 is used to enter the PCO data.
Figure 3.7: PCO List – User Interface

Table 3.1: Properties of the PCO List

<table>
<thead>
<tr>
<th>Property</th>
<th>Description</th>
<th>Rationale</th>
<th>Type of Field</th>
<th>Length of Field</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCO No.</td>
<td>The PCO code is automatically assigned by the system in chronological order when a new PCO item is added to the list. It consists of the prefix, 'PCO' and a numeric code of length 5.</td>
<td>PCO No. is the unique identification number of change items in the project's change list and the main property that helps associate changes to other project views.</td>
<td>Alphanumeric</td>
<td>9</td>
<td>PCO-00209</td>
</tr>
<tr>
<td>Description</td>
<td>An extended description provided by user to describe the PCO item. Format and content are to be decided by the user.</td>
<td>Extended description is important to identify the PCO and its work scope.</td>
<td>Alphanumeric</td>
<td>250</td>
<td>Performance of all work necessary to repair and stabilize the cut slopes damaged by the slide caused by the heavy rainfall on Sep24</td>
</tr>
<tr>
<td>Field</td>
<td>Description</td>
<td>Date Initiated</td>
<td>9</td>
<td>25SEP04</td>
<td></td>
</tr>
<tr>
<td>------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>----------------</td>
<td>-----</td>
<td>--------</td>
<td></td>
</tr>
<tr>
<td>Date Initiated</td>
<td>The date on which the source of the potential change item was initiated, generated, received or identified. It is up to the user to select the most convenient date that best describes the timing of discovery of the issue leading to the change item.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initiated by</td>
<td>The project participant who initiated the process leading to the potential change. The name of the organization is selected from a list of project participants contained in the organizational/Contractual view. In case of multiple initiating parties, the primary party is selected.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary Source</td>
<td>Source is the method by which the change item is initiated. Multiple choices are provided to select from.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Source</td>
<td>Source of the PCO item is a major determinant of the procedure that follows it. It can also be considered as the</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Initiator directly links with the source of the PCO.
<table>
<thead>
<tr>
<th>Primary Cause</th>
<th>The primary reason leading to the potential change. There may be several apparent reasons for the change, but only the primary reason (in the user’s opinion) is selected from the provided list.</th>
</tr>
</thead>
</table>
|              | • Plan & specification issue  
|              | • Site condition issue  
|              | • Interference/disruption issue  
|              | • Accident/damage issue  
|              | • Contract scoping issue  |

*Extra work claim*  
*Owner change directive*  
*Request for information (RFI)*  
*Site Instruction/ Field Order*  
*Value engineering proposal*  
*Other*

If a single document can be identified as the primary source, it is accessed from the records list in the As-built view.

*category under which the PCO item falls. This is important in grouping change items.*

<table>
<thead>
<tr>
<th>Primary Cause</th>
<th>The primary reason leading to the potential change. There may be several apparent reasons for the change, but only the primary reason (in the user’s opinion) is selected from the provided list.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Project personnel are interested to know why the changes have originated. This is another determinant of the PCO procedure to be followed.</td>
</tr>
</tbody>
</table>

| Alphanumeric | 30 | Accident/Damage Issue |
| Status/Date of Status change | Status indicates what has happened or is happening to the PCO item. The value of this attribute is dynamic and should be updated when it changes. The status can be selected from;  
- In Process – PCO is still in process  
- Approved – PCO is approved as a change order  
- Cancelled – PCO is either rejected by the owner or is abandoned due to changed conditions. | As many potential changes are subsequently cancelled by the owner, the status of them at any given time is important. Whenever a change item is associated with another view, the status should also accompany it to make it clear whether the change item is approved, in process or cancelled. | Linguistic  
10  
18DEC04 |

| CO No. | Corresponding CO code is entered when the PCO gets approved. | CO code provides a link to further details of the change order. | Alphanumeric  
8  
CO-00101 |
### General Information

<table>
<thead>
<tr>
<th>PCO No.</th>
<th>Initiated by</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCO-00209</td>
<td>C001 Construction Manager</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date Initiated</th>
<th>Primary Source</th>
<th>Record</th>
</tr>
</thead>
<tbody>
<tr>
<td>25SEP04</td>
<td>Site Instruction/Field On</td>
<td>51-00492</td>
</tr>
</tbody>
</table>

### Description

Performance of all work necessary to repair and stabilize the cut slopes damaged by the slide caused by the heavy rainfall on Sep. 24, 2004

### Primary Cause

Accident/Damage Issue

### Affected Project Participants

<table>
<thead>
<tr>
<th>Res. Code</th>
<th>Participant Class</th>
<th>Resp. Abbrev.</th>
<th>Name</th>
<th>Contact Person</th>
</tr>
</thead>
<tbody>
<tr>
<td>T008</td>
<td>Trade Contractor</td>
<td>EXCAV/SHORE</td>
<td>Mega Excavators Ltd</td>
<td>Steve Hamlot</td>
</tr>
</tbody>
</table>

### Change Proposals

<table>
<thead>
<tr>
<th>Trade</th>
<th>Work/Material Description</th>
<th>Date Proj.</th>
<th>Date Proj. Method</th>
<th>Total Amo</th>
</tr>
</thead>
<tbody>
<tr>
<td>T008</td>
<td>Clearing the site to remove...</td>
<td>26SEP04</td>
<td>27SEP04</td>
<td>Lump Sum</td>
</tr>
</tbody>
</table>

### Associations

- RFI Log
- Meetings
- Contracts
- Records
- Daily Site Data
- Other Associations

### Status

- In Process: 16DEC04
- Approved
- Cancelled

---

Figure 3.8: User interface used to enter PCO data
Affected Participants

All the participants assumed to be affected by the change are listed here with their responsibility codes. Project participant class (e.g. Engineers & Consultants, Trade Contractors, Suppliers etc) and contact person details are also provided (Fig. 3.8). These properties are accessed from the Organizational/Contractual view of the existing REPCON system and imported to Change View. This provides a short list of all the participants involved in the change order process and is helpful in selecting parties to correspond with in matters dealing with the change.

<table>
<thead>
<tr>
<th>Property</th>
<th>Type of Field</th>
<th>Length of Field</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Responsibility Code</td>
<td>Alphanumeric</td>
<td>4</td>
<td>T008</td>
</tr>
<tr>
<td>Project Participant Class</td>
<td>Linguistic</td>
<td>50</td>
<td>Trade Contractor</td>
</tr>
<tr>
<td>Resp.Abbrev.</td>
<td>Linguistic</td>
<td>12</td>
<td>EXCAV/SHORE</td>
</tr>
<tr>
<td>Name</td>
<td>Linguistic</td>
<td>90</td>
<td>Mega Excavators Ltd</td>
</tr>
<tr>
<td>Contact Person</td>
<td>Linguistic</td>
<td>50</td>
<td>Steve Hamlot</td>
</tr>
</tbody>
</table>

Table 3.2: Properties of Project Participants

Change Proposal

During the negotiation phase, change proposals and quotations submitted by each trade/supplier are evaluated. Proposal requested date and submitted date are important to determine any delay. Amount and time values submitted by trades are compared with independently prepared A/E estimates. Details of change proposal and quotations submitted by each contractor and supplier are entered in a separate user interface (Figure 3.9).

The description of properties for a change proposal is provided in the following table.
Table 3.3: Properties of Change Proposal

<table>
<thead>
<tr>
<th>Property</th>
<th>Description</th>
<th>Type of Field</th>
<th>Length of Field</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trade</td>
<td>Responsibility code and name of the trade (Accessed from Organizational/Contractual view)</td>
<td>Alphanumeric</td>
<td>4 + 30</td>
<td>T008 Mega Excavators Ltd</td>
</tr>
<tr>
<td>Work/Material Description</td>
<td>Brief description of the work involved and/or material quoted for</td>
<td>Alphanumeric</td>
<td>250</td>
<td>Clearing the site to remove slide soil and construct shoring to stabilize the slopes.</td>
</tr>
<tr>
<td>Date Proposal Requested</td>
<td>Date on which a change proposal is requested from the trade</td>
<td>Date</td>
<td>7</td>
<td>26SEP04</td>
</tr>
<tr>
<td>Date Proposal Submitted</td>
<td>Date on which the proposal is submitted by the trade</td>
<td>Date</td>
<td>7</td>
<td>27SEP04</td>
</tr>
<tr>
<td>Method of Pricing</td>
<td>Basis of pricing used by the trade to price the work. Select from: Lump Sum</td>
<td>Linguistic</td>
<td>20</td>
<td>Lump Sum</td>
</tr>
<tr>
<td><strong>Unit Price</strong></td>
<td><strong>Time &amp; Material</strong></td>
<td><strong>Other</strong></td>
<td><strong>Total Amount Quoted</strong></td>
<td><strong>A/E Estimated Amount</strong></td>
</tr>
<tr>
<td>----------------</td>
<td>---------------------</td>
<td>-----------</td>
<td>-------------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td><strong>Total Amount Quoted</strong></td>
<td>Total price of the change proposal made by the trade</td>
<td>Alphanumeric</td>
<td>10</td>
<td>$27,300</td>
</tr>
<tr>
<td><strong>A/E Estimated Amount</strong></td>
<td>Total amount of the independent estimate prepared by Engineer/Architect</td>
<td>Alphanumeric</td>
<td>10</td>
<td>$22,800</td>
</tr>
<tr>
<td><strong>Activity(s) Affected</strong></td>
<td>Activity/activities for which a time adjustment is claimed. Activity(s) is selected from the activity list with the code.</td>
<td>Linguistic</td>
<td>100</td>
<td>010010 Bulk Excavation &amp; Earth Anchoring</td>
</tr>
<tr>
<td><strong>Time Adjustment Requested</strong></td>
<td>Time impact requested by the trade to be made to total contract duration</td>
<td>Alphanumeric</td>
<td>12</td>
<td>2.5 Days</td>
</tr>
<tr>
<td><strong>A/E Estimated Time Impact</strong></td>
<td>Time impact assessed by the A/E</td>
<td>Alphanumeric</td>
<td>12</td>
<td>1.5 Days</td>
</tr>
</tbody>
</table>
Associations

Other information related to PCOs is imported from existing views of the REPCON research system by making associations. List view interfaces are used in between the change view and other views to list the associated properties. This makes it easier for the system user to access related items. Figures 3.10 and 3.11 shows several of these list view interfaces. RFI logs, records, meetings and daily site data accessed from the as-built view are useful in tracking the development of the PCO. Association with Organizational/Contractual view to access contract details is useful to see the details of the contracts and clauses related to a change situation. All other association, such as related PCBS components, activities, pay items etc. are made using a tree view as shown in Figure 3.12.
The lists with which associations can be forged are;

<table>
<thead>
<tr>
<th>List Associated</th>
<th>Description</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFI Logs</td>
<td>Sent and received RFIs are imported from the as-built view and grouped together.</td>
<td>RFI log is the best source to track the development of most PCOs. Grouping the related RFIs together helps access them easily when required.</td>
</tr>
<tr>
<td>Records (As-built View)</td>
<td>Lists all the types of records related to the PCO and its management process.</td>
<td>Convenient in retrieving all related records and their properties.</td>
</tr>
<tr>
<td>Meetings (As-built View)</td>
<td>Negotiation meeting details are logged in the as-built view. Those related to the PCO are associated and grouped together.</td>
<td></td>
</tr>
<tr>
<td>Daily Site Data (As-built View)</td>
<td>Daily site data such as weather condition, site condition, problems encountered are logged in the as-built view. Related daily site data are identified and associated with the PCO item.</td>
<td>Daily site data can be crucial for making decisions regarding contested change orders.</td>
</tr>
<tr>
<td>Contracts</td>
<td>For the parties with contractual relationship, the contract is selected from the contract list imported from the Organizational/Contractual view. Contract code is shown.</td>
<td>Association with Organizational/Contractual view to access contract details is useful to see the details of the contracts and clauses related to a change situation.</td>
</tr>
</tbody>
</table>

Table 3.4: Properties of Change Order Associations
Fig. 3.10: RFI Log User Interface

Fig. 3.11: Records List User Interface
Table 3.5: CO Associations with Other Project Views

<table>
<thead>
<tr>
<th>Association</th>
<th>Description</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCBS (Physical View)</td>
<td>PCBS items affected by the change, are selected from PCBS.</td>
<td>Affected PCBS should be modified by recording change item information under its change component.</td>
</tr>
<tr>
<td>Activity (Process View)</td>
<td>Existing activities that are expected to be changed are selected from the activity list.</td>
<td>Activities required to be reviewed are identified. This is useful to revise the schedule.</td>
</tr>
<tr>
<td>Drawing (Physical View – Drawing control)</td>
<td>Both the shop drawings and detailed drawings that are associated with the change are selected from the drawing list.</td>
<td>All the drawings that need to be revised can be easily identified.</td>
</tr>
<tr>
<td>Specification (Physical View)</td>
<td>Related specification sections are selected from the available list of specifications.</td>
<td>All the specifications needed to be revised are identified.</td>
</tr>
<tr>
<td>Quality (Quality View)</td>
<td>Related quality items are selected from list provided in the quality view and associated.</td>
<td>Change work should be carried out in conformance with the quality plan</td>
</tr>
<tr>
<td>Pay Item (Cost View)</td>
<td>Related pay items are identified in the cost view and associated.</td>
<td>Pay items need to be revised as a result of the change</td>
</tr>
<tr>
<td>----------------------</td>
<td>---------------------------------------------------------------</td>
<td>---------------------------------------------------</td>
</tr>
<tr>
<td>Problem Code</td>
<td>Related linguistic items are selected from a hard-coded set of problem codes.</td>
<td>Change item can be linked with other problems related to it.</td>
</tr>
<tr>
<td>Keyword</td>
<td>Related items are selected from a hard-coded keyword list.</td>
<td>Linking the change item with keyword makes the system-wide searching function effective.</td>
</tr>
</tbody>
</table>

Figure 3.12: Associations Tree View User Interface
Change Order (CO) List

Once a PCO is approved as a change order, a change order item is added to the CO list. All the attribute properties of the PCO can then be considered properties of the CO as well. Additional required data will have to be recorded by the user. CO list provides a list of all approved changes. It shows the following attributes.

1. CO Number
2. Corresponding PCO Number
3. Description
4. Date Approved
5. Date Design Finalised
6. Date Work Started
7. Date Work Completed
8. Total Amount Approved
9. Schedule Impact Adjustment

The following table provides description of the properties represented in the CO list.

<table>
<thead>
<tr>
<th>Property</th>
<th>Description</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO Number</td>
<td>CO number is assigned by the system in chronological order.</td>
<td>Unique code assigned to COs helps identify the change item</td>
</tr>
<tr>
<td>PCO Number</td>
<td>The corresponding PCO numbers associated with the CO item.</td>
<td>PCO is essentially required for every CO, so that CO list becomes a subset of PCO list. CO inherits properties from the corresponding PCO.</td>
</tr>
<tr>
<td>Description</td>
<td>Extended description of the change. If a corresponding PCO exists, the same description is imported.</td>
<td>Description helps identify the change order item and provides a brief scope of work.</td>
</tr>
<tr>
<td><strong>Date approved</strong></td>
<td>Date on which the change order is approved by the owner.</td>
<td>Approval date represents the status change of the change item.</td>
</tr>
<tr>
<td>------------------</td>
<td>------------------------------------------------------</td>
<td>-------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Date design finalised</strong></td>
<td>All the designs and approvals are finalised on this date.</td>
<td>Design finalised date is important in evaluating timeline of the process.</td>
</tr>
<tr>
<td><strong>Date work started</strong></td>
<td>Work associated with the change is started on this date.</td>
<td>Important date to track the impact of changes.</td>
</tr>
<tr>
<td><strong>Date Work Finished</strong></td>
<td>Date on which the work associated with the CO is completed.</td>
<td>Important date to track the impact of changes.</td>
</tr>
<tr>
<td><strong>Total amount</strong></td>
<td>Total amount approved by the owner for the change order. This is the cost to the owner.</td>
<td>This figure is useful in determining the magnitude of the change order relative to overall project cost.</td>
</tr>
<tr>
<td><strong>Time Impact Adjustment</strong></td>
<td>Adjustment made to the total duration of the project, if any.</td>
<td>This also represents the magnitude of the change order and its impact.</td>
</tr>
</tbody>
</table>

Figure 3.13 shows the user interface used to represent the CO list. Interface shown in Figure 3.14 is used to enter change order data.

![Figure 3.13: User interface of the CO List](image-url)
3.6 Discussion

The change order management system specified in this chapter has unique objectives over other available systems and it functions differently in several ways. Change management data in the system specified here is able to associate with the data from other project management functions. This is made possible by implementing the specified system and integrating it into the existing REPCON research system as its change view. Other project management views already implemented in REPCON provide comprehensive project management functionality and facilitate integration of information. The ability to associate change order data with other project data makes it possible to extract useful meaning from the data and generate insights on how change orders impact project performance. It also helps identify how the change order concentration in time, location, trades can impacts on project performance.

Commercially available systems have the capability to efficiently manage the day-to-day tasks associated with change orders during a construction project. They facilitate various data types, and help project participants generate and distribute various related documents. The approach taken in this research is not only to capture the story behind the change order
management, but also to meaningfully represent the impacts of changes on project performance. The project performance is explained in terms of time, cost, productivity etc. as a function of the impact of a single change order or a collection of change orders, during a time interval, at a specific location, by a specific organization, etc.
4 Visualization of Change Order Data

4.1 Benefits of Data Visualization

As discussed in previous chapters, construction change orders have both direct and indirect effects on project performance. Project participants are eager to find out how, when and to what extent, change orders have impacted the outcome of the project. If a project encounters a large number of change orders, analysing the data related to them can be a complex task. In such a situation, graphical visualization techniques provide a useful mean of gaining insights from the data. Graphical representation of variations among selected parameters could produce meaningful interpretations of the data to assist in explaining reasons for performance to date. These explanations can assist in resolving difficult claim situations. Visual means of data representation also help project participants during the execution phase of the project. They can be used to explain impacts of changes on the project and help trigger aspects that need to be addressed (e.g. trade interferences, congestion etc.). An analysis of change order data can also be done as a part of the post project analysis. This helps project team members learn from project experiences, and can assist in the claims phase of a project, should it arise.

In this chapter, various modes of interpreting change order data are explored. How one can gain important insights by using these visualization techniques is also discussed.

4.2 Identification of Parameters

One of the challenges in representing and interpreting change order data is the selection of a suitable set of parameters that can meaningfully represent project performance. A number of attribute properties are collected by a typical change management system. Care should be taken to make sure that the properties selected provide reliable and complete data. The following parameters are selected considering the above aspects and are expected to provide a meaningful explanation of change order data of a project.
Work start and end dates:
Here we focus on the date on which the work related to a change order physically started executing in the field and the date the work completed. The period between these start and end dates of work execution best represents the time duration that the change order had an impact on on-site work performance. The impacts can be due to congestion, obstructions, breaking learning curves, and rhythm of work crews etc.

Date of initiation (discovery) and date of approval:
Date of initiation can be somewhat ambiguous. It means the date on which a potential for a change is first identified. Different project participants may attach different meaning to this date. Some may consider the date on which the primary source document is issued as the initiation date, while some others might consider the date of the physical event that led to the change as the date of initiation. The date on which GC/CM recognised the change/potential change may also be taken as the initiation date. The period of time between the date of initiation and the date of approval can be considered as the change order approval time. It is an indicator of how quickly the owner responded to the change order. Higher response times adversely affect the performance of all the related parties due to idling, low productivity, low morale etc.

Number of change orders:
The number of change orders encountered in the project is a measure of the impact the change orders had on the project. It is not a direct measure of the impact as not all the change orders have similar impact on a project’s performance. But still it is useful to visualize the composition of the total number of change orders over different aspects of the project, such as:

- Time
- Trades
- Physical locations the work is carried out
- Reason for the change (Primary cause)
- Primary source (e.g. CD, RFI, SI/FO, EW etc.)
- Affected disciplines (e.g. electrical, mechanical etc.)
A 3-D data visualisation facility can provide an additional explanation to the data. For example, the distribution of the number of change orders over time and physical locations provides an insight into possible congestion related issues.

**Change order amount and time impact:**
Total amount of the change order and its impact on total project duration are direct measures of the impact caused by a change order. Using these two parameters, composition of the cost and time impacts caused by different trades can be clearly identified.

### 4.3 Challenges in Graphical Representation

Although graphical representations can be helpful for many project participants to look into the explanation of the change order data, it can also be misleading for many reasons. To minimize these problems, selected parameters should be clearly defined, assumptions behind the representations should be identified and possibilities of misrepresenting data should be identified. It is a challenge to identify and minimize possible misrepresentations. Some of the factors one should consider in deciding on graphical formats are discussed in this section.

Whenever the number of change orders is used to represent the impact on performance, it is assumed that each change order carries the same weightage towards the impact. But, in reality this is not true. One method of overcoming this is to represent the value of change orders in place on the change order count. Here it is assumed that the impact of a change order is proportional to its value, which again is not necessarily true.

The period of time during which the change order work is carried out can be easily calculated by counting the number of days between the date work started and the date work completed. If this duration is used as a parameter to represent the period of change order impact, it is assumed that the work is evenly distributed among the counted number of days. But, practically there may be discontinuities and the work may have been physically performed on only a few number of days. This situation can lead to a misrepresentation of data. If the
duration of execution is several weeks longer, the impact may be better represented by clustering change orders on a weekly basis instead of a daily basis. In this case it is assumed that the work is carried out in selected weeks and the change order work has impacts on the project’s overall performance. This assumption is reflective of most actual situations.

Due to the possibility of one-to-many relationships between change orders and trades, locations, etc., a clear definition of what is represented should be provided whenever these parameters are represented. For example when the distribution of total number of change orders over different trades is represented, one possible assumption is that all trades involved in each change order have an equal share of the work involved. Then, the cumulative value of change orders does not equate to the total number of change orders in the project. A more useful method of representing the same data would be to calculate the proportional work load for each trade in every change order and use it as a weighting. The basis of calculating their weightings can then be the proportional contribution to total value of change order.

4.4 Modes of Graphical Representation

4.4.1 Distribution of change orders over time

Distribution of all the change orders of a project over the project duration is a useful representation to identify periods of time excessively impacted by change orders. The time frame for a change order is taken as the period during which the work related to the change order is being executed in the field. A 2-D graph is drawn to show number of change orders vs. time (Fig. 4.1). The graph represents the number of change orders being executed in the field on any given day.

This graph helps to visualize the distribution of change order work over time. Periods of times with higher number of change orders taking place can be easily identified and marked as highly impacted time periods. The major shortcoming of the graph is that it treats each and every change order as having a similar impact. Hence it only provides an indirect measure of the impact of change orders on project performance.
Number of COs under Execution

01/01/2003
08/01/2003
15/01/2003
22/01/2003
29/01/2003
05/02/2003
12/02/2003
19/02/2003
26/02/2003
05/03/2003
12/03/2003
19/03/2003
26/03/2003
02/04/2003
09/04/2003
16/04/2003
23/04/2003
30/04/2003
07/05/2003
14/05/2003
21/05/2003
28/05/2003
04/06/2003
11/06/2003
18/06/2003
25/06/2003
02/07/2003
09/07/2003
16/07/2003
23/07/2003
30/07/2003
06/08/2003
13/08/2003
20/08/2003
27/08/2003
03/09/2003
10/09/2003
17/09/2003
24/09/2003
01/10/2003
08/10/2003
15/10/2003
22/10/2003
29/10/2003

Figure 4.1: Distribution of Change Orders over Time (Daily Basis)
Alternatively, the value of change orders can be considered in place of the number of change orders and instead of considering daily data, COs can be clustered into fixed time intervals, such as weeks. Assuming the change order work is distributed evenly over their period of execution, the value of the ‘change order work per week’ can be calculated - i.e. For a given week,

\[
\text{CO work per week} = \frac{\text{Total value of all COs executed during the week}}{\text{Sum of execution times in weeks}}
\]

A graph showing the distribution of ‘CO value per week’ against time is a better representation of magnitude of change order impact over the time (Fig. 4.2).
4.4.2 Distribution of change orders in both time and space

This is a 3D representation that shows how change orders are distributed over both time and physical locations of the construction site (Fig. 4.3). This graph tells where the change order work has been carried out in different weeks. If an activity time-space diagram is superimposed on this graph so that the activities scheduled to be carried out at different locations are shown along with change order work carried out simultaneously, it helps to identify the potential for congestion on different parts of the site.

Similar to the graph 4.1, each and every change order is treated the same in terms of their impact making the graph an indirect representation of the impact. But, similar to the previous case, ‘CO value per week’ can be considered in place of number of COs to make it a better representation of the impact.

4.4.3 Distribution of change orders among different trades

A 2D graph (Fig. 4.4) drawn to show the number of change orders against different trades involved, is useful in identifying the most and the least affected trades. Extending it into a 3rd dimension over time (Fig. 4.5) shows possible interaction effects on project performance.

4.4.4 Impact on project cost and total duration

A graph showing how the total project cost is changed with the approval of each new change order is depicted in figure 4.6. A cumulative curve that represents how the project cost arrived at the final value is also included in figure 4.6.

This graph can be stretched in the 3rd dimension to distribute the costs among different trades (Fig. 4.7).
Figure 4.3: Distribution of Change Orders over Physical Locations & Time
Figure 4.4: Distribution of Change Orders over Trades
Figure 4.5: Distribution of Change Orders over Time & Trades
Figure 4.7: Distribution of Change Order amounts over the Trades
4.4.5 Change order processing time

Change order processing time is an important factor in determining to what extent a particular change order impacts project performance. It is important to define the processing time carefully. Change order processing time is calculated as the time between the date of initiation (discovery) and date of approval. A graph showing processing time of each change order is presented in figure 4.8.

This graph can also be stretched in the 3rd dimension to show how each trades is affected by the change order processing time.
Figure 4.8: Processing Time of Change Orders

![Diagram showing processing times for different change orders (CO #)]
5 Conclusions and Recommendations

5.1 Overview

This thesis focuses on developing a conceptual design for the change management view as a part of the multi-view representation of a construction project. The multi-view representation of a project facilitates integration of a diverse range of construction project management functions such as productivity analysis, change management, quality management, etc. The change view provides a comprehensive set of properties that can meaningfully represent the change management functions of a project. The concepts developed for the change view is expected to be implemented and integrated in the REPCON research system, but the implementation is beyond the scope of the thesis. Rather, emphasis has been placed on developing a holistic approach to change management and representation and interpretation of change management data.

5.2 Contributions

5.2.1 Literature Search

The importance of effective change order management and the potential impact on project performance due to change orders are explored through a thorough literature survey. The literature search helped identify different industry practices for the change order process and different terminology being used. A generally accepted set of terminology is defined and a generic flow of processes that reflects industry practices was formulated, while noting that there is little consensus in the construction industry on both the terminology and the process. Project procurement mode is identified as one of the main determinants on how the change order process of a given project is arranged. A set of documents used in the change order process and the data fields contained in them are identified. This information is used in designing the specification for the change order system presented in this thesis.
Review of academic research conducted mostly in North America provided insights into the impacts of change orders on construction performance. Impact on labour productivity, affect on the quality of work and cost and time impacts of change orders are discussed in light of published research findings. Several academic researches into improving change order management techniques are also explored. An extensive bibliography is provided which covers both academic research and industry practices.

Several commercially available state-of-the-art systems that facilitate change order management are overviewed with an emphasis on how they capture change order data. Their capabilities and shortcoming are also discussed.

### 5.2.2 Designing the Change View

The main focus of the research was on developing a specification for a change management system that, while providing facilities to capture day-to-day information associated with change orders, assists project participants make good decisions by generating insights on how change orders impact overall project performance. Integration with other project management functions makes it possible to link with related information, which can then use in representation of their variations against change order data. The system specified here is assumed to be integrated into the REPCON research system making it possible to import data related to activities, PCBS components, trades, records, etc.

The system is expected to be controlled by a construction manager in a project procured as a construction management contract or by a general contractor in a traditional general contracting project. The review of industry practices and commercial software was used to formulate a generalized flow of change order processes, which was then used as the basis of the change management system designed. A rich set of abstractions sufficient to capture the change order data is specified with their properties. User interfaces and the navigational structure that links them, help visualize how the system will operate once implemented.
5.2.3 Data Visualization

Different modes of interpreting change order data are presented emphasizing the assumptions behind them. Challenges in representing change order data in a meaningful way are discussed. Distribution of change orders and their values over time, space and over different trades are presented using graphical means. This visual means are expected to provide valuable information for project participants in making project related decisions. They also help flag critical aspects such as congestion and trade interferences.

5.3 Recommendations and Future Work

The specification for a change management system presented in this thesis can be refined in many aspects. Integration with other functions can be further extended to include cost related data, contract data, risk management data, method statements, etc. This would help management personnel to explain the impact of change orders on several other project related aspects and/or to figure out relationships between change orders and these other aspects. RFI and SI/FO data are closely related to change order management. An improved means of capturing these data should be explored along with a way of associating them with the change view. A report generating system should be developed and incorporated including graphical reports. Standards and knowledge management aspects related to the change orders should be further developed. Further modes of data visualization should be explored. Process related data such as response time, approval time and procurement data can be represented to interpret their impacts. Data imported from other functions, such as quality related data, risk related data, daily site data, etc. can also be represented against change order data to gain further insight into the impact of change orders.

Implementation of the specified system and integrating it with REPCON research system will enable the prototype system to be tested on an actual project. It should be tested under both construction management and general contracting delivery modes in order to validate the concepts developed.
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