Measuring and Classifying Construction Field Rework: A Pilot Study

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May 2003

Presented to:

Construction Owners Association of Alberta (COAA)
Field Rework Committee

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Available on Website

The Field Rework Data Collection System (database), Executive Summary, and full report, *Measuring and Classifying Construction Field Rework: A Pilot Study*, are all available on the following websites:

http://www.coaa.ab.ca
http://www.construction.ualberta.ca/papers.html

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ACKNOWLEDGEMENTS

Many individuals participated in this project. This study is a result of the collective efforts of the Field Rework Measurement Subcommittee and the Pilot Study Steering Committee of the Construction Owners Association of Alberta. Special acknowledgement is given to the following people for their continuous guidance and support throughout the pilot study:

Don McLeod (Co-Chair of Field Rework Committee)	SNC Lavalin
Hans Wolf (Chair of Measurement Sub-committee)	Graham Industrial
Daniel Meek	TransCanada Pipeline
Glen Warren	Ledcor Industrial
John Hull	
Rod Wales	North American Enterprises

Additionally we would like to express our appreciation to Don McLeod (Co-Chair of Field Rework Committee) who provided many forms of assistance, but best of all always kept us in good spirits through the completion of this pilot study. We also appreciate the invaluable support provided by the Syncrude Aurora 2 project team throughout the data collection period. Their support in terms of providing access to the data and resources, and their full cooperation and knowledge sharing were key to the success of this study. Anthony Van Tol, a Ph.D. Candidate at the University of Alberta, was involved in the early part of this study; his contributions are gratefully acknowledged.

Special thanks are directed to NSERC and the Consortium of Alberta Construction Companies, COAA, Aurora 2 Project Group, and the Construction Research Institute of Canada, for their financial support.

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LIST OF ABBREVIATIONS

AFE	Authorization For Expenditure
CCA	Cost Control Appropriation
CEP	Construction Execution Plan
CFRI	Construction Field Rework Index
CII	Construction Industry Institute
COAA	Construction Owners Association Of Alberta
Convero™	AMEC's Proprietary Project Management System
CPM	Critical Path Method
CPP	Canada Pension Plan
CWP	Construction Work Package
DBM	Design Basis Memorandum
EDS	Engineering Design Specification
EI	Employment Insurance
EPC	Engineering, Procurement, and Construction
EWBS	Engineering Work Breakdown Structure
EWP	Engineering Work Package
FRDCS	Field Rework Data Collection System
IFC	Issued-For-Construction
OPEX	Operation Expense
PCN	Project Change Notice
PDRI	Project Definition Rating Index
PEP	Project Execution Plan
PRRT	Project Rework Reduction Tool
PMI	Project Management Institute
QPMS	The Quality Performance Management System
TIC	Total Installed Cost
WBS	Work Breakdown Structure
WCB	Workers' Compensation Board

1.0 INTRODUCTION

1.1 Problem Statement

The Alberta Construction Industry is currently experiencing rapid growth, particularly in the industrial sector. Several mega-projects are currently underway. With tight schedules and multiple parties involved, cost and schedule overruns are often difficult to avoid. A significant contributing factor to these overruns is rework.

The Construction Owners Association of Alberta (COAA) defines rework as the "total direct cost of redoing work in the field regardless of initiating cause" (Construction Owners Association of Alberta 2001). The Construction Industry Institute (CII) defines rework as "activities in the field that have to be done more than once in the field or activities which remove work previously installed as part of the project" (Rogge et al. 2001). In the past, numerous studies have been undertaken with respect to rework. The direct correlation between cost and schedule growth and rework has been determined (Love 2002), leading to the desire to reduce the amount of rework on individual projects and in the industry as a whole. The COAA has therefore established a goal of developing industry Best Practices for reducing and preventing construction field rework. The Field Rework Committee was subsequently established to facilitate the development of these Best Practices. Before rework can be reduced and prevented, however it must first be quantified, measured, and its root causes identified. The Field Rework Measurement Subcommittee was created and charged with this mandate.

Despite the fact that numerous studies have been conducted on rework, there is still no industry-wide standard for measuring and classifying rework as it occurs in the field. Currently, different organizations track rework using different indices, making it difficult to compare the amount of rework on an industry-wide level. Furthermore, an industry-wide method of classifying the causes of rework is required, before the most significant causes can be identified and subsequently remedied.

1.2 Objectives of Pilot Study

The overall objective of the COAA Field Rework Committee is to develop industry Best Practices for reducing and preventing construction field rework. As a first step, a methodology was required to measure and quantify field rework, and to identify the most significant causes of rework. A pilot study was commissioned with the University of Alberta to develop and test such a methodology, which consists of developing the following:

1. An industry standard index for quantifying field rework.
2. An industry standard classification system for identifying the causes of field rework.

The intent of the pilot study is to develop and test a methodology for collecting this information, which will help identify the significant issues related to such measures. The methodology developed can be used on subsequent projects to collect data over time and to establish industry standards and statistics on field rework. This report describes the pilot study, indices, and methodology developed; presents the findings from the case study project; and describes lessons learned for the sake of future studies.

2.0 PILOT STUDY

2.1 Description of the Project

The Syncrude Aurora 2 Project in Fort McMurray, Alberta was selected for use as a case study. The Aurora 2 project is a mega-project, performed under an engineering, procurement, and construction (EPC) arrangement. It consists of a mining expansion to process 58 million t/a of ore to provide 38 million bbl/yr of feedstock for a related upgrader expansion project (UE-1). The project is a cost reimbursable project, which is part of an Alliance contract consisting of AMEC E&C Services Limited (design/engineering), TIC Canada (structural/mechanical), Chemco Electrical Contractors Limited (electrical), North American Enterprises Limited (civil) and Syncrude Canada Limited (owner). All parties involved are working together under an agreement of full disclosure of information.

The selection of the Aurora 2 Project in particular was primarily based on the suitability of the project type, which is reflective of major industrial projects in Alberta, and on the availability and willingness of the Aurora project group to participate and provide in-kind funding for the pilot study.

2.2 Objectives of the Pilot Study

The intent of the pilot study was to help to develop and refine a research methodology for collecting and quantifying field rework data, before a full-scale study is undertaken involving numerous projects. The specific goals of the pilot study were as follows:

- To develop a definition for construction field rework.
- To develop a standard rework index for quantifying the amount of field rework done on a project.
- To develop a standard methodology for identifying rework in the field and for measuring or quantifying the amount of rework on the basis of cost, schedule, and other impacts.
- To develop a realistic classification of the major factors and sub-factors causing rework, and to develop a standard definition of each factor.
- To develop a standard methodology for quantifying the impact of each cause on the rework amount.
- To develop a methodology of assessing the impact of rework from a given activity on other affected activities in the project.
- To develop a standard methodology of tracing the cause(s) that led to rework, from the original source.

Since the pilot study is being conducted on a mega-project performed under an EPC arrangement, the results of this study are geared towards similar types of projects.

2.3 Research Methodology on the Aurora 2 Project

The data collection period for the pilot study was from April 29th, 2002 to December 19th, 2002. The following steps were taken in conducting the pilot study:

- A list of rework causes and standard definitions against which to categorize causes of rework in the field were developed.
- Previous research on measuring field rework was reviewed, particularly that conducted by the Construction Industry Institute. A number of organizations involved in mega projects in Alberta were consulted, to gather ideas on their rework tracking practices.
- A preliminary data collection strategy and data collection forms were developed.
- The field rework tracking process on the Aurora project was examined. The researchers worked closely with field supervision on the Aurora 2 project in order to track rework items as they occurred. Significant rework items were examined in greater detail to collect the relevant information which consisted of:
  - (1) Direct field cost associated with rework (workforce and supervision hours, material quantities, equipment hours, subcontract amounts, supplier and vendor costs).
  - (2) Schedule impacts and the subsequent impact of the rework item on other activities in the project.
  - (3) Root causes of rework, and parties involved.
- The data collected was compiled on a monthly basis. Field management personnel were consulted to obtain their feedback on the causes of the rework items.
- The methodologies developed were refined and modified, as required. This process involved periodic review meetings with site management and the COAA pilot study advisory committee.
- Upon conclusion of the data collection on the Syncrude Aurora 2 project, the data were analyzed and the report prepared.

3.0 LITERATURE AND INDUSTRY REVIEW

A comprehensive literature review was conducted to investigate previous research efforts on measuring field rework. Furthermore, several local organizations involved in tracking rework on mega-projects performed under EPC arrangements were consulted. The results of these reviews are described in this section.

3.1 Rework Definition

There are various interpretations of rework in construction management literature, including quality deviations, non-conformance, defects, and quality failures, although these definitions vary, according to Love (2002). He identifies two main definitions of rework: "the process by which an item is made to conform to the original requirement by completion or correction" (Ashford 1992) and "doing something at least one extra time due to non-conformance to requirements" (Construction Industry Development Agency 1995). Love et al. (2000) define rework as "the unnecessary effort of redoing a process or activity that was incorrectly implemented the first time".

Rogge et al. (2001) define field rework as "activities in the field that have to be done more than once in the field or activities which remove work previously installed as part of the project". The COAA defines rework as the "total direct cost of redoing work in the field regardless of initiating cause" (Construction Owners Association of Alberta 2001) They also state that field rework does not constitute change orders (for new work), off-site fabricator errors, or off-site modular fabrication errors.

3.2 Rework Indices

Several indices related to rework measurement were reviewed. These indices are listed in Table 3.1 and are described in the following sections.

Table 3.1. Rework Indices Reviewed

Doc.	Description	Source
FRI	Field Rework Index	CII
PDRI	Project Definition Rating Index	CII
PRRT	Project Rework Reduction Tool	COAA
QPMS	The Quality Performance Management System	CII

3.3 The Field Rework Index - FRI

The FRI is a tool developed by Research Team 153 of the CII (Rogge et al. 2001) to provide an early warning if a project is headed towards high levels of field rework. The FRI is intended for use before the start of construction.

To develop the FRI, a list of possible predictors of field rework was first developed and tested with data taken from completed construction projects. This information was obtained via a questionnaire survey of a number of industrial projects. The database, consisting of rework measurements, subjective ratings, and project variables identified as potentially related to field rework, was then developed based on the findings of the industry questionnaire survey.

An analysis was carried out to determine how these variables related to field rework. The Field Rework Index (FRI) resulted from statistical analysis of the database. The research team was able to determine that significant relationships existed between field rework and certain project variables and parameters studied. Table 3.2 is a list of the project variables (14) related to field rework and ranked in descending order.

Table 3.2. Variables with Statistically Significant Relationships with Field Rework

FRI Variable	**Relationship**
Owner alignment	Strongest
Design rework	↓
Constructability commitment	
Interdisciplinary design coordination	
Degree of project execution planning	
Design firm's qualifications	Weakening
Field verification	↓
Expected craft worker availability	
Expected construction overtime	
Engineering overtime	
Design leadership changes	
Design schedule compression	Weakest
Supplier pre-qualification	
Supplier information	

Source: Rogge et al. (2001)

Table 3.3 presents the summary statistics from the project database from which the FRI is derived. The FRI questionnaire and rework danger chart are given in Appendix A.

Table 3.3. FRI Database Summary Statistics

FRI Score	% of Projects with "High" or "Very High" Rework	% of Projects with "Low" or "Very Low" Rework	Rework Rating Average 1=Very Low 5=Very High	Mean Measured Rework (%)
>45	65% (13/20)	25% (5/20)	3.6 = High	6.8% (16 projects)
30-45	32% (24/74)	42% (31/74)	2.8 = Medium	5.0% (53 projects)
<30	2% (1/43)	86% (37/43)	1.8 = Low	2.5% (34 projects)

Source: Rogge et al. (2001)

The results of the regression analysis concluded that it was not possible to predict a percentage of field rework via the FRI, but, rather, the FRI proved to be a simple tool providing early warning for field rework and cost growth.

3.4 The Project Definition Rating Index – PDRI

The PDRI (Gibson and Dumont 1996) is a tool for measuring the degree of scope development. There are two versions of the tool: one for industrial projects and one for building projects. The PDRI for Industrial Projects was created by the Construction Industry Institute's (CII) Front End Planning Research Team. It is intended to be an evaluation tool for the analysis of scope definition at any point prior to the time a project is considered for authorization to perform detailed design and construction. The PDRI allows a project team to quickly analyze the scope definition package and predict factors that may impact project risk.

“The PDRI for industrial projects consists of 70 elements in a weighted checklist format. The 70 elements are divided into three main sections and 15 categories. A complete list of the sections, categories, and elements are given in Appendix B. In addition, all elements are described in a 34 page detailed checklist format (Gibson and Dumont 1996). These descriptions provide industry planners with a common and definitive understanding of what constitutes the complete definition of each element” (Gibson 2002).

A low (i.e. good) PDRI score represents a well-defined project definition package and high (i.e. bad) score represents a poorly defined project definition package, which should be re-examined prior to project authorization (Gibson 2002).

The PDRI can be used as (Gibson 2002):

- “A checklist that a project team can use for determining the necessary steps to follow in defining the project scope”.
- “A listing of standardized scope definition terminology throughout the construction industry”.
- “An industry standard for rating the completeness of the project scope definition to facilitate risk assessment and prediction of escalation, potential for disputes, etc”.
- “A means to monitor progress at various stages during the pre-project planning effort”.
- “A tool that aids in communication between owners and design contractors by highlighting poorly defined areas in a scope definition package”.
- “A means for project team participants to reconcile differences using a common basis for project evaluation”.
- “A training tool for companies and individuals throughout the industry”.
- “A benchmarking tool for companies to use in evaluating the completion of scope definition versus the performance of past projects, both within their company and externally, in order to predict the probability of success on future projects”.

Gibson (2002) concluded that "the PDRI alone will not ensure successful projects but, if combined with sound business planning, team alignment, and good project execution, it can greatly improve the probability of meeting or exceeding project objectives".

3.5 PRRT- COAA's Project Rework Reduction Tool

The PRRT is a management tool developed by the COAA to rate project performance against known rework-causing issues (East 2002). The PRRT was founded upon efforts undertaken by the CII with their PDRI (Gibson and Dumont 1996) and FRI (Rogge et al. 2001) tools as well as by efforts from the Building Research Centre's work on their COMPASS tool (Building Research Establishment Limited 2000).

"The tool is designed to rate performance against known and significant rework causing factors at any point in the project time line. The ratings can be interpreted within the 5 sections of the COAA fishbone classification, but an overall average rating may be used for trend analysis and benchmarking similar projects" (COAA 2002).

The PRRT can be used to carry out project "health checks" by making evaluations, rating key field rework causing factors, and by suggesting practical solutions to improve future ratings. The tool functions through the project ratings given by a user in response to a multiple-choice questionnaire. The questionnaire itself consists of 30 to 80 questions. The number and type of questions in the questionnaire vary due to the project's position in the project life cycle. The PRRT has been developed with five different questionnaire formats that are applied at different times in the project life cycle.

The questions and responses from the questionnaire are mathematically weighted in order to calculate a periodic rating. A high periodic rating is indicative of a low propensity for rework. The calculated periodic percentage ratings can also be observed visually through the "Dashboard" and "Tile Diagram" representations, which allow analysis by overall project or by principal rework cause (COAA 2002).

3.6 QPMS - The Quality Performance Management System

The CII developed the QPMS tool to give management the information necessary to identify quality improvement opportunities. QPMS tracks the cost of quality and provides a cost breakdown identifying the cost of rework by its primary cause (CII 1990). To date, QPMS is the most comprehensive system developed by CII to track rework (Rogge et al. 2001).

The criteria that define QPMS's role and function are (CII 1990):

- "Be capable of tracking quality-related costs involved in the design and construction of engineering projects and answer the following four questions:"
    - "What quality management activities and deviation categories were involved?"

    - "When were the quality management activities and deviation costs incurred?"
    - "Why did the deviation occur (i.e. the root causes)?"
    - "How did the rework relate to the quality management?"
- "Provide valuable cost of quality information to establish baselines and identify opportunities for improvement, without providing either too much or too little detail."
- "Be adaptable to various types and aspects of design and construction projects."
- "Be easily implemented by owners, designers, and contractors."
- "Be cost effective."
- "Be compatible with existing cost systems used by management."

Rework is categorized by major cause, and the cause is coupled with the time of detection (phase) of the management action. This assumes four phases (design, procurement, construction, and start-up) and a normal project execution. Twenty-six (26) possible deviation categories were identified with some potential categories being logically eliminated. Table 3.4 shows these categories (CII 1990).

Table 3.4. QPMS: Major Causes of Rework by Project Phase

Primary Cause Party and Type	**When Detected (Phase)**			
	Design	Procurement	Construction	Start-up
Owner Change	X	X	X	X
Designer Error/Omission	X	X	X	X
Designer Change	X	X	X	X
Vendor Error/Omission	X	X	X	X
Vendor Change	X	X	X	X
Constructor Error/Omission			X	X
Constructor Change			X	
Transported Error		X	X	X

Source: CII (1990)

A detailed discussion regarding QPMS (i.e. potential benefits, level of familiarity, and industry response) can be found in Rogge et al. (2001).

3.7 Classification of Rework Causes

Two different methods of rework cause classification have been identified from the literature. Firstly, Burati et al. (1992) used the deviation categories listed in Table 3.5 to identify the causes of rework from nine fast-tracked industrial construction projects.

Secondly, Love et al. (1997) proposed a rework classification system from preliminary study findings of two construction projects: residential development and industrial development. They classified rework into three principle groups: (1) People, (2) Design, and (3) Construction, as illustrated in Figure 3.1. They demonstrated that a number of causes were encountered for each group. The majority of rework causes are common causes, which can be attributed to the system (process). They further conclude that some causes are interrelated due to complexity of construction operations.

Later, Love and Li (2000) used Burati et al.'s (1992) classification to quantify the causes and costs of rework on the same two construction projects. The data collected for this research were limited to the construction phase of the project. Rework was classified in three categories: client-initiated changes, non-variations, and defects. The study also made an attempt to count non-productive time or non-contributory work, which refers to the loss of time due to waiting, being idle, traveling, and re-doing work.

Table 3.5 Deviation Categories Causing Rework

Deviation Category	**Description**
Construction Change	Change in the method of construction: usually to enhance the constructability
Construction Error	Results of erroneous construction methods
Construction Omissions	Omission of some construction activity or task
Design Error	Error made during design
Design omission	Omission made during design
Design Change/Construction	Changes in design made at the request of the field or constructional personnel
Design Change/ Field	Changes due to Field conditions, a deviation could not have been foreseen by the designer
Design change/ Owner	Design change initiated by owner (Scope definition)
Design Change/ process	Design change in the process, initiated by owner/designer
Design Change/ fabrication	Design change initiated or requested by fabricator or supplier
Design change/ improvement	Design revision, modification, and improvements
Design Change/ Unknown	Redesign due to an error
Operability Change	Change made to improve operability
Fabrication Change	Change made during fabrication
Fabrication Error	Error made during fabrication
Fabrication Omission	Omission made during fabrication
Transportation Change	Change made to method of transportation
Transportation Error	Error made in method of transportation
Transportation Omission	Omission made in transportation

Source: Burati et al. (1992)

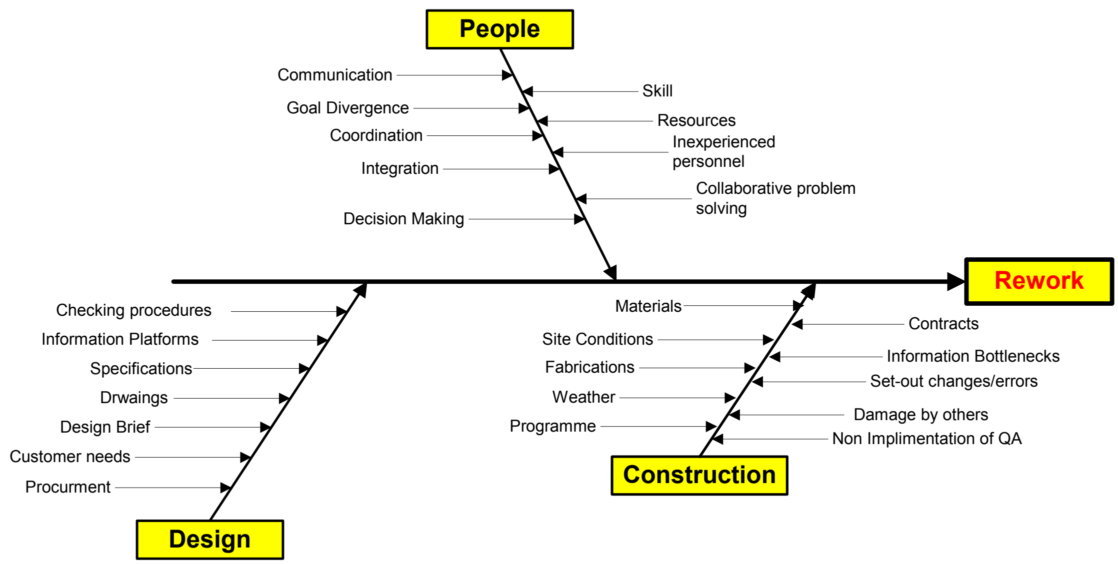

Figure 3.1. Generic Cause-and-Effect Rework Diagram Derived From Qualitative Data
Source: Love et al. (1997)

3.8 Rework Measurement System

The measurement of rework allows a company to see if they are meeting their rework targets. If the rework is found to be unacceptably high, the company can use the information to initiate activities to reduce rework on current and future projects. Providing directions for future improvement is one of the benefits of a measurement system (Rogge et al. 2001). Rogge et al. (2001) identified that the industrial sector of the North American construction industry utilizes QPMS to track their field rework, and that several other companies use some adaptation of QPMS. They also found that other companies have very good internal proprietary tracking systems for field rework. In contrast, Love et al. (2002) found that in the Australian construction industry, rework costs are very rarely, if ever, measured.

According to Love et al. (1999) "the cost of quality is one type of measurement that can provide the user with information about rework and activities designed for its prevention. It is a measurement that could be considered after-the-fact, because it occurs after the action has occurred. Thus, the measurement of rework should be used as a mechanism to learn from the past to improve on the future. That is, measurement becomes a proactive management activity on a new project". This study also indicated that rework measurement should address not only the magnitude and cause of rework, but also the non-productive time (i.e. standby and reallocation time) and its severity, as well as the cost of rework to the specific parties involved.

3.9 Cost of Rework

Several attempts can be found in the recent literature to identify the cost of rework in the construction industry. Josephson and Hammarlund (1999) reported that the cost of rework on residential, industrial, and commercial building projects ranged from 2% to 6% of their contract values. Similarly, Love and Li (2000), in their study of rework costs for a residential and industrial building, found the cost of rework to be 3.15% and 2.40% of the contract value, respectively. In addition, Love and Li (2000) found that when a contractor implemented a quality assurance system in conjunction with an effective continuous improvement strategy, rework costs were found to be less than 1% of the contract value.

Love (2002) found two key research works that indicated the cost of quality deviations in civil and heavy industrial engineering projects. First, the study by Burati et al. (1992) on nine major engineering projects indicates that, for all nine projects, quality deviations accounted for an average of 12.4% of the contract value. Second, a significantly lower figure was reported by Abdul-Rahman (1995), who found non-conformance costs (excluding material wastage and head office overheads) on a highway project to be 5% of the contract value. Abdul-Rahman (1995) made the point that the non-conformance costs may be significantly higher on projects where poor quality management is found.

In a recent study to identify the influence of project types and procurement methods on rework costs for building construction projects, Love (2002) obtained direct and indirect rework costs from 161 Australian construction projects via a questionnaire survey. He found that rework contributed to 52% of a project's cost growth, and that 26% of the variance in cost growth was attributable to changes due to direct rework.

According to Love et al. (1999) "The costs of rework between each country should not be considered to be authoritative, but merely indicative, as levels and interpretations of quality will differ between each country. Local practices, industry culture, and contractual agreements may also have a significant influence on the incidence and cost of rework in any situation and locality".

3.10 Review of Industry Practices

In our review of industry practices, we found that almost all companies have a rework tracking system, although there does appear to be variation in these systems and no apparent industry-wide standard. Some methods focus on tracking direct field workforce hours (i.e. the proportion of general foreman's time, foreman's time, and crew's time), but do not focus on tracking costs associated with rework as a method of quantification. Many methods, however, recognize the value in classifying rework in order to identify the most significant source(s) of rework.

Frequently, field indirect costs are not taken into consideration, as they are too variable between companies (e.g. indirect costs generally include the superintendent's time, and tools and equipment, although scaffolding may or may not be considered as an indirect cost). In some cases, companies track equipment and material costs separately from the workforce hours for rework. In general, companies believe that a percentage of workforce hours (to the total direct field workforce hours) is a better measure, since equipment and material costs can vary depending on the type of activity.

Also, using the TIC (Total Installed Cost, i.e. construction phase cost) as a denominator can be misleading since proportions of labour to equipment costs can vary depending on the type of project, as some may be more labour intensive than others. Also, TIC includes field indirect costs, and may or may not include mechanical completion, turnover, and commissioning.

The following index (Equation 3.1) is commonly used by some organizations to quantify field rework:

$$\frac{\text{Workforce Hours for Rework}}{\text{Total Direct Field Workforce Hours}} = \%\,\text{Rework} \qquad [3.1]$$

Additionally, some organizations produce variance documents to identify discipline(s) in area(s) of projects that experience the greatest variance and rework. Some organizations also track schedule impacts as the number of workforce hours added to the schedule (either through an extended schedule or by an increase in workforce levels).

The CII's Benchmark and Metrics program (2003) proposes the following index to measure the amount of field rework or Benchmarking:

$$\text{Total field rework factor} = \frac{\text{Total direct cost of field rework}}{\text{Actual construction phase cost}} \qquad [3.2]$$

A framework for a rework-tracking system, as proposed by the CII field rework research team (Rogge et al. 2001), is given in Appendix C.

In general, organizations categorize rework into engineering driven (e.g. drawing changes, design errors, constructability issues, changes in scope), customer driven (mostly due to changes requested by operators; i.e. after construction complete), manufacturing and supply (e.g. poor quality of manufactured equipment), and construction (errors in field) classes. In addition, some organizations track rework through account (discipline) and craft (piping, structural, etc). Table 3.6 shows the common categories and methods dealing with rework as used in industry for EPC contracts, both in cost reimbursable and fixed price contracts.

Table 3.6. Industry Methods of Categorizing and Dealing with Rework for EPC Contracts

Category of Rework	Cost Reimbursable Contracts	Fixed Price Contracts
Engineering	Trend Program	Scope Changes
Manufacturing	Trend Program & Back Charge	Scope Change & Back Charge
Construction	Performance Factor	Performance Factor
Customer	Trend Program	Scope Change

3.11 Summary

Previous studies indicate the existence of various definitions of rework (Ashford 1992, CIDA 1995, Love et al. 2000, Rogge et al. 2001, COAA 2001), however, none of these definitions address the issue of identifying construction field rework when it occurs in the field. Previous studies also indicate that the cost of rework can range anywhere from 2-12% of the contract values. However, a variety of methods have been utilized to calculate these percentages. The numerators and denominators used for the calculations vary across companies, and across countries. Two different methods of rework cause classification were identified, although neither of them address the issue of identifying the root causes of rework, which are extremely important in minimizing and preventing this problem.

Accordingly, the need for a precise definition of "Construction Field Rework" and an industry-wide standard for measuring and classifying construction filed rework, was identified. The following section describes the proposed definition of construction field rework, the constructs of an industry standard index for quantifying field rework, and an industry standard system for classifying the causes of rework.

4.0 PROPOSED METHODOLOGY FOR FIELD REWORK DATA COLLECTION AND ANALYSIS

4.1 Proposed Field Rework Definition

This pilot study started with the COAA definition of field rework, as this work builds on efforts started by the COAA that were based on this definition. As the study progressed, researchers identified the need for a more detailed definition of rework to clearly indicate what is and what is not considered rework from the owner's or from an industry-wide perspective.

Accordingly, we have adopted and modified the CII's (2002) definition, and defined field rework as:

> *Activities in the field that have to be done more than once in the field, or activities which remove work previously installed as part of the project regardless of source, where no change order has been issued and no change of scope has been identified by the owner.*

Furthermore, field rework is not:

- Project scope changes.
- Design changes or errors that do not affect field construction activities.
- Additional or missing scope due to designer or constructor errors (but rework does include the cost associated with redoing portions of work that incorporate or interface with additional or missing scope).
- Off-site fabricator errors that are corrected off site.
- Off-site modular fabrication errors that are corrected off site.
- On-site fabrication errors that do not affect direct field activities (i.e. that are corrected without disrupting the flow of construction activities).

Project scope is "the work that must be done to deliver a product with the specified features and functions" (PMI 2000). Any change to the project scope (scope changes) should not be considered as field rework. These "changes may require expanding the scope or may allow shrinking it. Most change requests are the result of: (1) An external event (e.g. a change in a government regulation); (2) An error or omission in defining the scope of the product (e.g. failure to include a required feature in the design of a telecommunications system); (3) An error or omission in defining the scope of the project (e.g. using a bill of materials instead of a work breakdown structure); and (4) A value-adding change (e.g. an environmental remediation project is able to reduce costs by taking advantage of technology that was not available when the scope was originally defined)" (PMI 2000).

Rework costs are tracked once the rework is identified, and from that point to where the activity is back to the condition or state it was in when the rework commenced. This includes the standby/relocation time spent once rework is identified, the time needed to carry out the rework, and the time needed to gear up in order to carry on with the original scope of the activity. The sequences of events that constitute rework are shown in Figure 4.1.

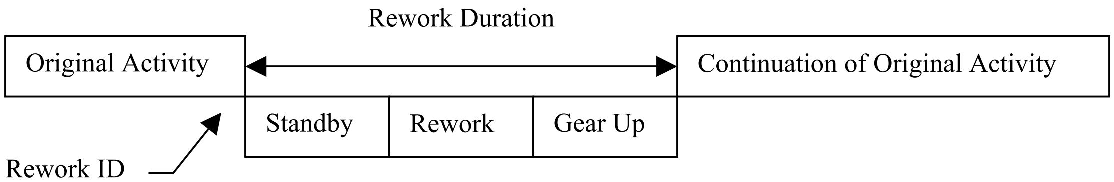

Figure 4.1. Components of Rework

4.2 Proposed Construction Field Rework Index

An established field rework measurement system is necessary for a project to see whether it meets the targets set or not and/or to provide a basis for future improvements. The following index is used in the pilot study to measure rework:

$$\text{CFRI} = \frac{\text{TOTAL DIRECT PLUS INDIRECT COST OF REWORK PERFORMED IN THE FIELD}}{\text{TOTAL FIELD CONSTRUCTION PHASE COST}}$$

$$\text{CFRI} = \frac{D_r \times I_f}{\left[D_t + I + P + O\right]} \qquad [4.1]$$

Where,

D_r = Total direct field cost of rework

$$D_r = \sum_1^n l_{r_i} + e_{r_i} + m_{r_i} + s_{r_i} + v_{r_i} \qquad [4.2]$$

l_r = Direct field labour and supervision cost of rework

e_r = Direct equipment cost of rework

m_r = Material cost of rework

s_r = Subcontract cost of rework

v_r = Vendor and suppliers cost of rework

i = rework event

n = Number of rework events

$$I_f = \frac{D_t + I}{D_t} = \text{Field indirect markup factor} \qquad [4.3]$$

D_t = Direct field construction phase cost

I = Indirect field construction phase cost

P = Profit fees($)

O = Overhead fees($)

The numerator is defined as the direct field rework cost plus the indirect field rework cost. The direct field rework cost is a combination of the following, which can be attributed directly to the corresponding scope of work: (1) direct field labour and supervision-l_r, (2) materials-m_r, (3) construction equipment-e_r, (4) field contracts (subcontracts) - s_r, and (5) vendors and suppliers' cost-v_r. The total direct plus indirect cost of rework is calculated using a mark-up factor (Equation 4.2) that is applied to the direct field cost (equation 4.1) in order to account for the indirect field cost. Field and/or office re-engineering costs associated with rework are not considered a direct field cost, but are included in the indirect field costs. The denominator consists of the total construction phase cost, which is a combination of: (1) direct field costs, (2) indirect field costs, (3) contractor overheads, and (4) contractor profit (See Appendix D for cost inclusions details). The denominator includes the costs associated with the original scope of work plus both those costs associated with changes in scope and the costs associated with rework. The total construction phase cost excludes original design and engineering costs, but includes field engineering and re-engineering during construction. The mark-up factor is a ratio between direct plus indirect field construction cost and direct field construction cost.

In the case where s_r is back-charged to the subcontractor, it should be accounted for in both numerator and denominator for cost plus contracts. For lump sum contracts, the option exists to include back-charged costs of rework in the numerator, but not modify denominator if cost of contract does not change. Following table shows the data sources used in this study to obtain the hourly and unit rates direct field cost of rework.

Table 4.1. Hourly and unit rates for direct field costs

Labour and Field Supervision	Union Labour rates: • Local 488 (Pipefitters) • Local 1460 (Millwrights/Boilermakers) • Local 424 (Electrical) • Local 955 (Operating Engineers) • Local 92 (Labourers) • Local 720 (Iron Workers)
Materials	Supplier quotations
Equipment	Equipment Rental Rates Guide 2002 (Alberta Roadbuilders Heavy Construction Association)
Subcontracts	Subcontractor quotations
Vendor	Vendor quotations

4.3 Proposed Rework Classification System

The classification system proposed in this research for categorizing the causes of rework is based on the fishbone classification system developed by the COAA. The COAA used the Cause & Effect (CE) diagram (also known as fishbone diagram due to its shape) to explore all the potential or actual causes of rework. The fishbone consists of five broad areas of rework and four possible causes in each of the five broad areas of rework. As the study progressed, the COAA's original fishbone was modified with the COAA Field Rework Committee approval in order to overcome some of the anomalies identified by the researchers. Figure 4.2 shows the fishbone diagram at the conclusion of the pilot study. Previous versions of the fishbone diagram are shown in Appendix F.

Furthermore, our efforts have generated a third level of classification for rework causes (see Appendix F for details). It was decided that the third level provides the best degree of classification detail before its complexity exceeds its effectiveness. The third level factors for the Engineering and Reviews category were reconciled with those developed by the Engineering and Reviews Rework Subcommittee.

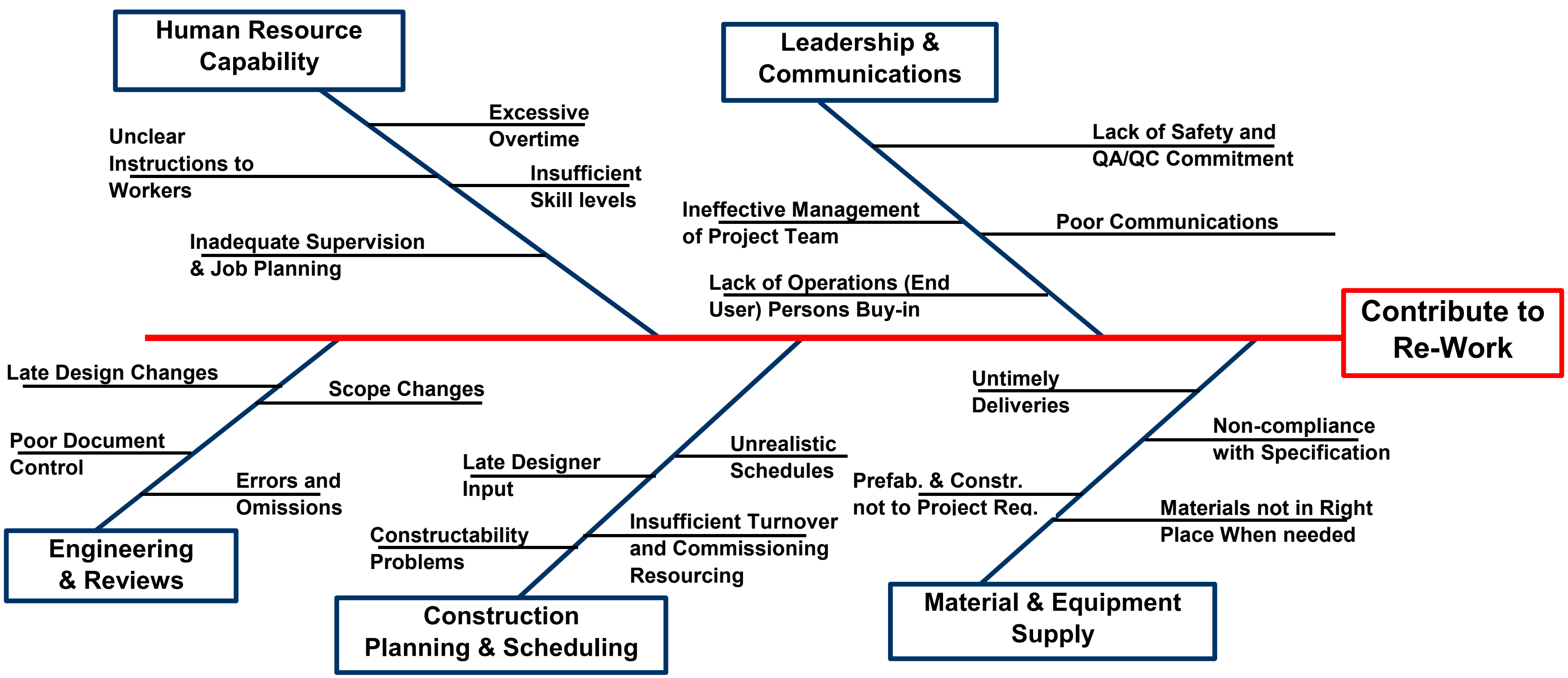

Figure 4.2. COAA's Fishbone Rework Cause Classification (last updated October 2002)

4.4 Multiple Causes of Rework

In some causes, there are several root causes that lead to a rework incidence. A standard approach is proposed for attributing multiple root causes to a rework item and apportioning these causes to the resulting rework item. This approach is based on the Analytic Hierarchical Process, or AHP (Saaty 1980), with the purpose of developing a ratio scale of relative priorities among multiple root causes of rework. The relative weight of each cause of a particular incidence is based on a pairwise comparison of each. The relative importance of Cause A to Cause B in contributing to the occurrence of a rework incidence is assigned by the user according to Table 4.2.

Table 4.2. Linguistic measures of importance

Intensity of Importance	Description
1	Equally important
3	Weakly more important
5	Strongly more important
7	Demonstrably or very strongly more important
9	Absolutely more important
2,4,6,8	Intermediate values

For example, assume a rework incidence has three root causes A, B, and C. The user assesses that A is strongly more important than B and therefore selects "5" to insert in the position (A, B) where the row of A meets the column of B in the matrix shown below.

Root Cause	A	B	C
A	1	5	3
B	1/5	1	3/5
C	1/3	5/3	1

It is noteworthy that the percentage is assigned to the cause, and not to the level of factors. For example, root cause A can be "Engineering & Reviews", "Errors & Omissions", or "Inadequate Discipline Coordination". Every cause is equally important when compared with itself, so where the row of A and column of A meet in position (A, A), the values is 1. Thus the main diagonal of a matrix must consist of 1's. The appropriate reciprocal 1/5 is inserted where the column of A meets the row of B, i.e. position (B, A), for the reverse comparison of B with A. The same procedure can be followed for the comparison between Cause A and C. In the case of n multiple rework causes, in doing pairwise comparison we need only n-1 pairwise comparison judgments. From them, all other judgments can be deduced simply by using the following kind of relation: A = 5 B and A = 3C. It should follow that 5B = 3C or B=3/5 C .The numbers 2,4,6,8 and their reciprocals are used to facilitate compromise between slightly differing judgments.

Once all the pairwise comparisons are completed, divide the elements of each column by the sum of that column (i.e. the column is normalized). The sum of the row is then divided by the number of elements in the row. This is the process of averaging over the normalized columns. The values obtained can be used to apportion multiple causes to the resulting rework item. A detailed working example of this analysis is given in Appendix G.

Alternatively, if the user does not need to use this approach, multiple causes can be apportioned subjectively to add up to 100% as shown below.

Cause	Percentage
A	70
B	20
C	10
Total	**100**

4.5 Field Rework Data Collection Methodology

The field rework tracking process shown in Figure 4.3 is used in the pilot study to monitor field rework events. The field rework event tracking process starts when an incidence is identified in the field, which involves redoing something in the field.

Site personnel usually identify these incidences are: (1) Workforce, (2) Foreman, (3) Field technical personnel, (4) Field engineer, and/or (5) Quality control personnel. Depending on the incidence, they report it to the respective authority (e.g. Field engineer, Quality control, Field technical) in order to obtain the instructions. The instructions will mainly fall into two categories, either to redo the work or accept it as is. If the relevant authority decides to redo it, they will have to issue instructions on the processes and appoint a time for accomplishing the rework. Necessary resources are assigned accordingly, and the rework is then carried out.

Rework event information is collected by observing the event, time sheets, and/or interviewing the construction personnel. Firstly, event information obtained from the field is reported in "Field Rework Data Collection Form" (see Appendix E for sample data collection forms and a worked example). Secondly, this information is transferred to the "Rework Event Information Sheets" given in the same Appendix E, in order to obtain the direct cost of the rework event. Finally, as shown in the Section 4.2, event data are aggregated according to the Equation 4.2 and the CFRI is then constructed using Equation 4.1.

Root causes of the rework event were identified by interviewing relevant parties involved in the rework event. Once the causes were identified, researchers classified those causes according to the methodology described in Section 4.3 and Section 4.4.

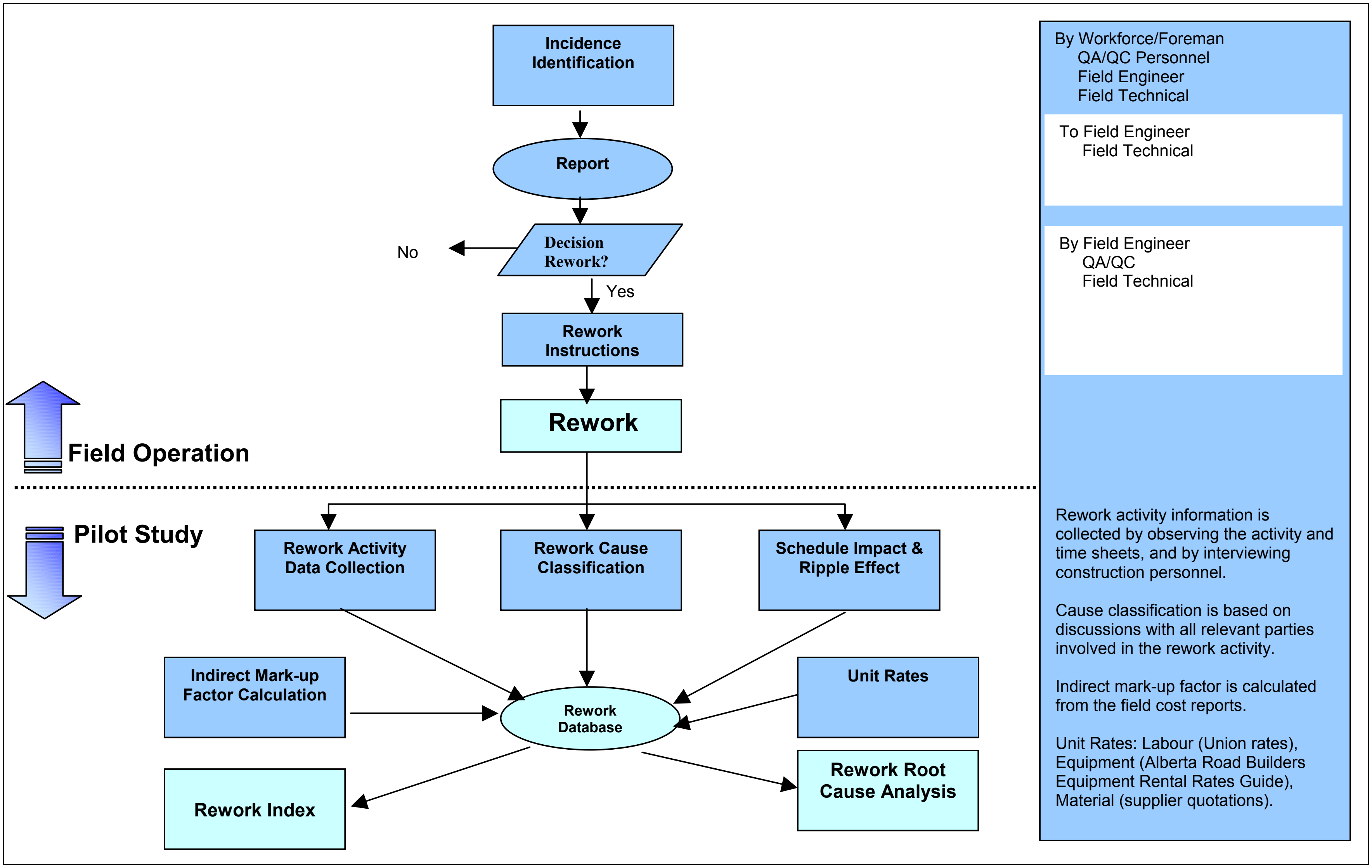

Figure 4.3 Field Rework Tracking process for Pilot Study

4.6 Field Rework Data Collection System (FRDCS)

To facilitate the proposed methodology, a Field Rework Data Collection System (FRDCS) was developed. This database was built using Microsoft ® Access 2000 with Microsoft® Visual Basic 6.0 interface. Figure 4.4 shows the main screen of the FRDCS. The FRDCS is divided into three modules: (1) data entry, (2) rate definition, and (3) data retrieval.

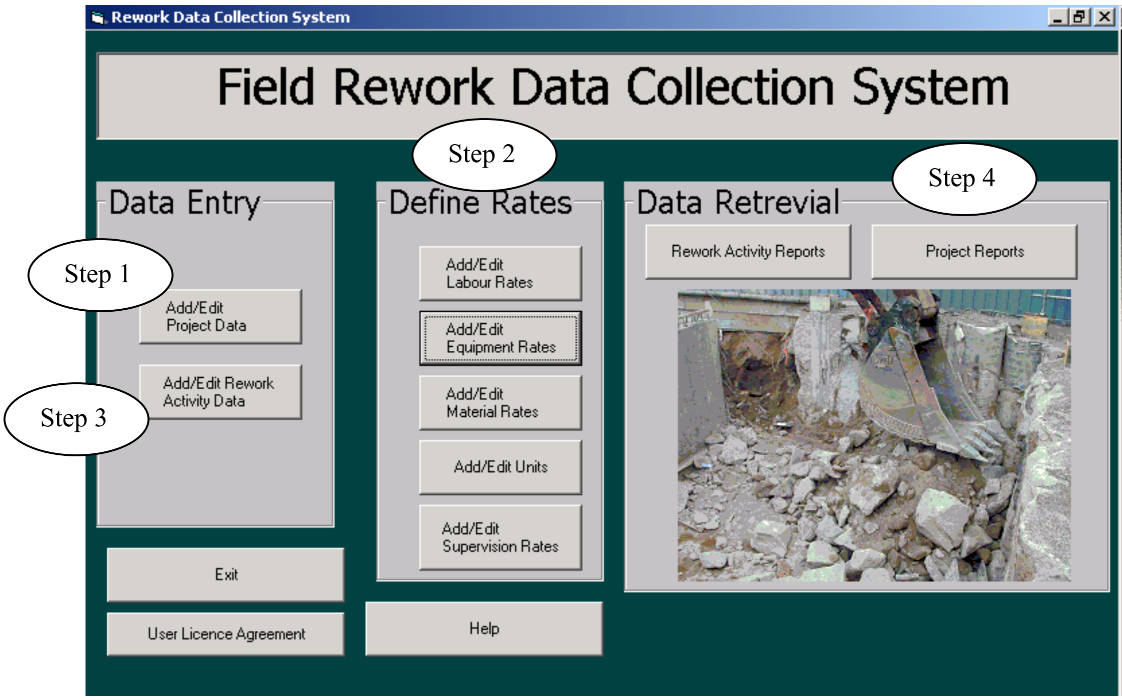

Figure 4.4. Main Screen of the Field Rework Data Collection System (FRDCS)

Firstly, the user enters project-specific data into the system such as the actual direct field costs, indirect field costs, overheads, profit fees, and total workforce hours (Step 1). This information is used to calculate the field rework index denominator. Secondly, the user defines the rates and units applicable for the particular project (Step 2). This allows the user to select the relevant rates and units from the database when the activity information is recorded.

Once the first two steps are completed, the user can start recording rework activity data (Step 3). Figure 4.5 and 4.6 show sample data sheets for a fictitious example, which the user is required to complete. Rework activity information consists of three sub-sections: (1) general activity information (Figure 4.5), (2) cost information (Figure 4.6), and (3) cause classification data (Figure 4.6). The cost information sub-section allows the user to provide labour, supervision, equipment, material, subcontract, and vendor costs associated with the rework incidence.

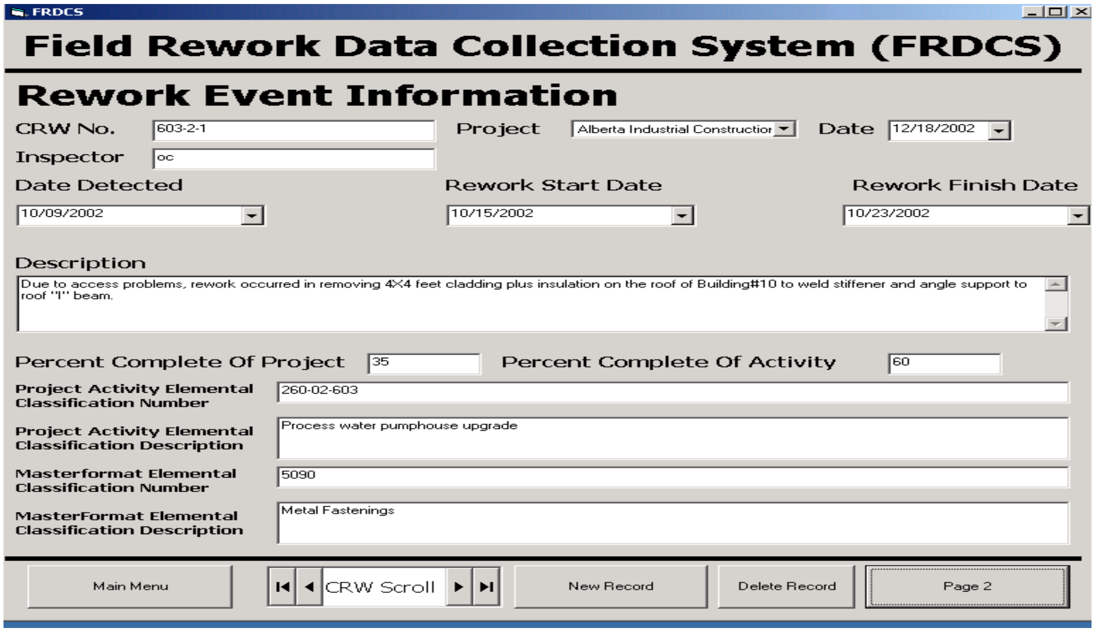

Figure 4.5 Rework Activity General Information Sheet

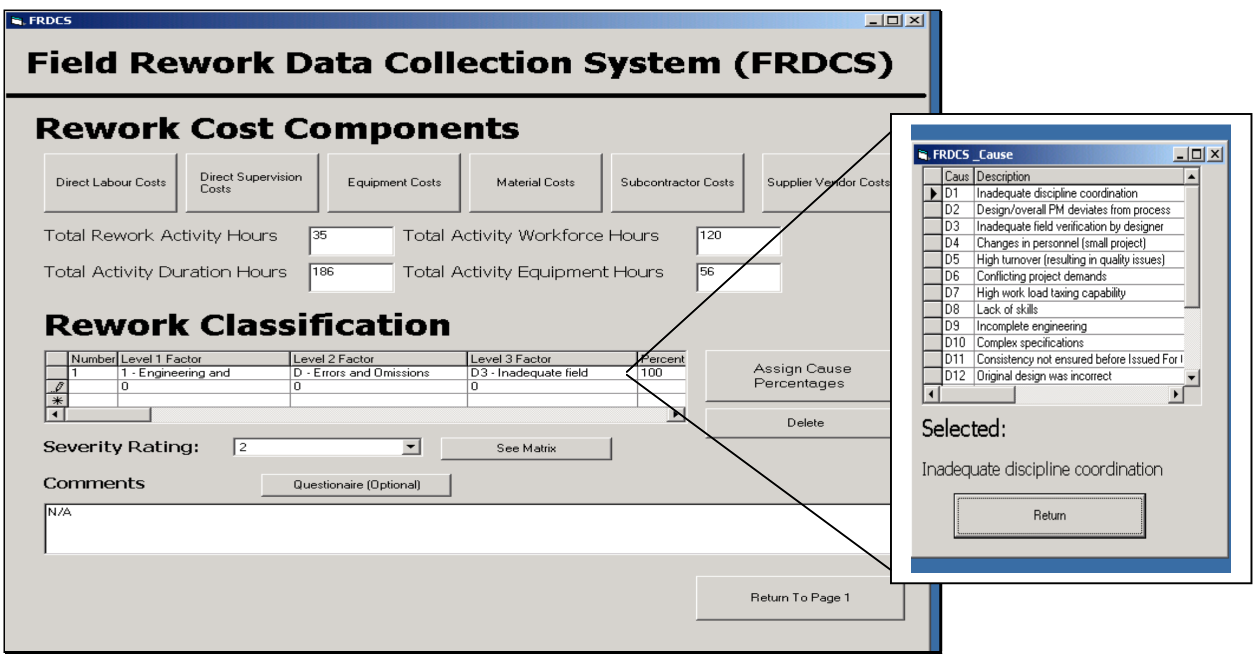

Figure 4.6 Rework Activity Cost and Cause Classification Sheet

Figure 4.7(a) highlights the direct labour cost information reported for the sample rework activity. A similar procedure is followed to provide the other cost information for supervision, equipment, material, supplier/vendor, and subcontracts. Figure 4.7(b) shows the procedure for weight assignment in the case where multiple roots causes are identified. The user is required to perform a pairwise comparison to identify the significance of the cause and its intensity. The FRDCS guides the user, step by step, in doing the pairwise comparison, as shown in the Figure 4.7(b) and automatically assigns the relative weights by performing the calculations described in Section 4.4 of this report. Alternatively, the user can subjectively assign percentages without going through the pairwise comparison.

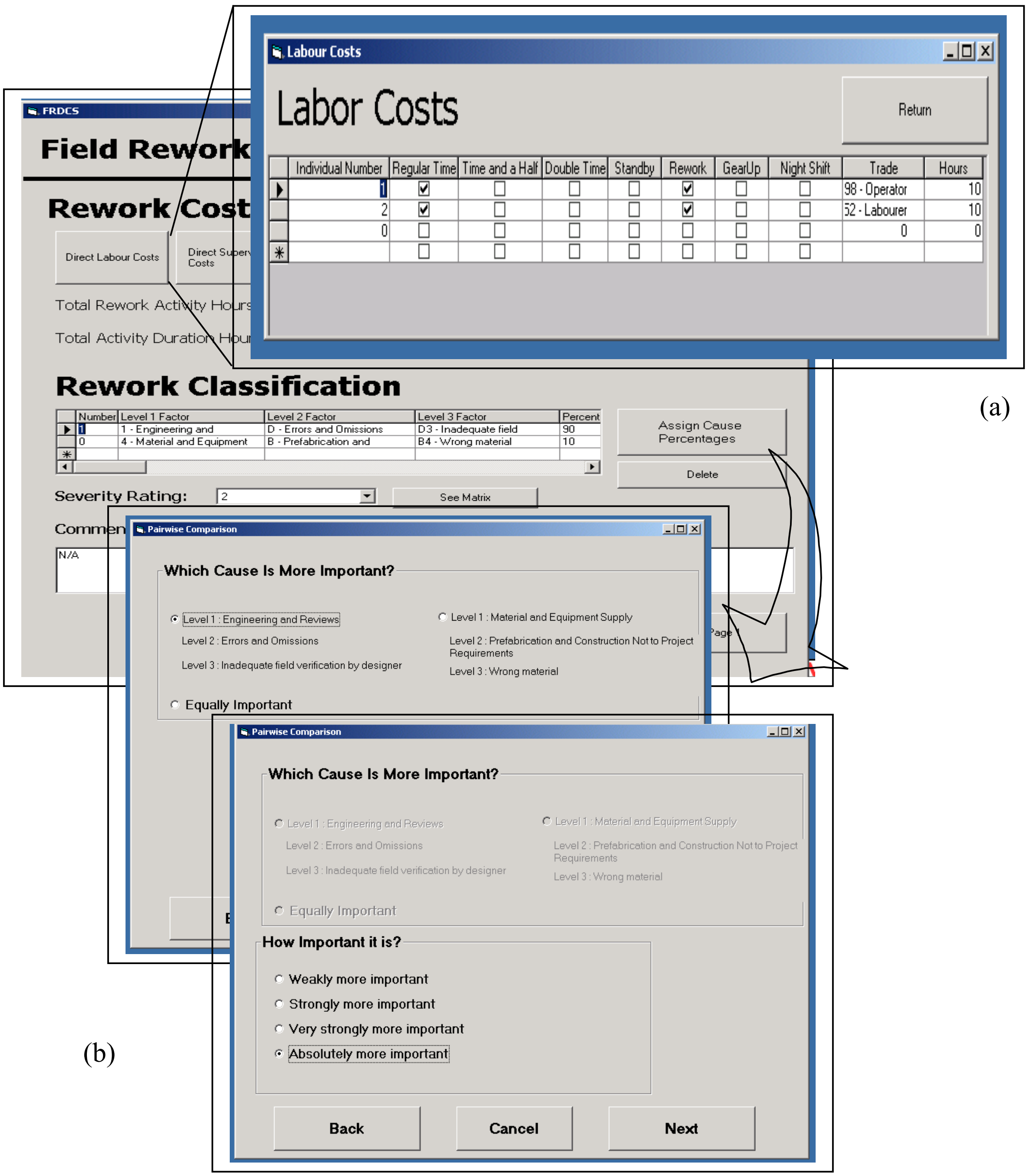

Figure 4.7(a) Direct Labour Cost Information (b) Pairwise Comparison of Multiple Root Causes

The data retrieval section of the main menu (Step 4) allows the user to generate reports of the rework activity information (Figure 4.8) and of the summary information of all rework activities, i.e. the construction field rework index (CFRI) and the field rework cause classification (Figure 4.9(a) and Figure 4.9(b)).

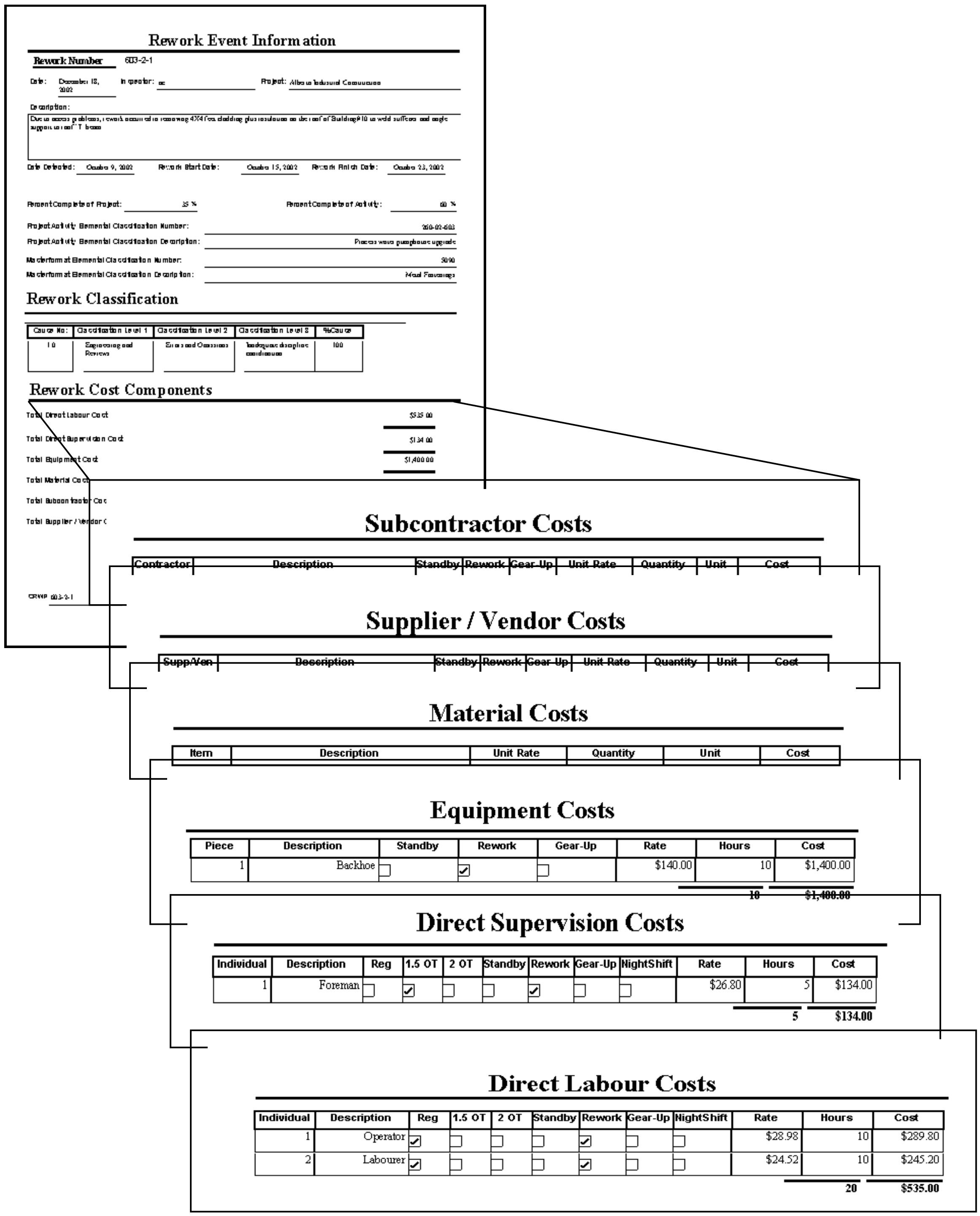

Figure 4.8 Rework Activity Reports

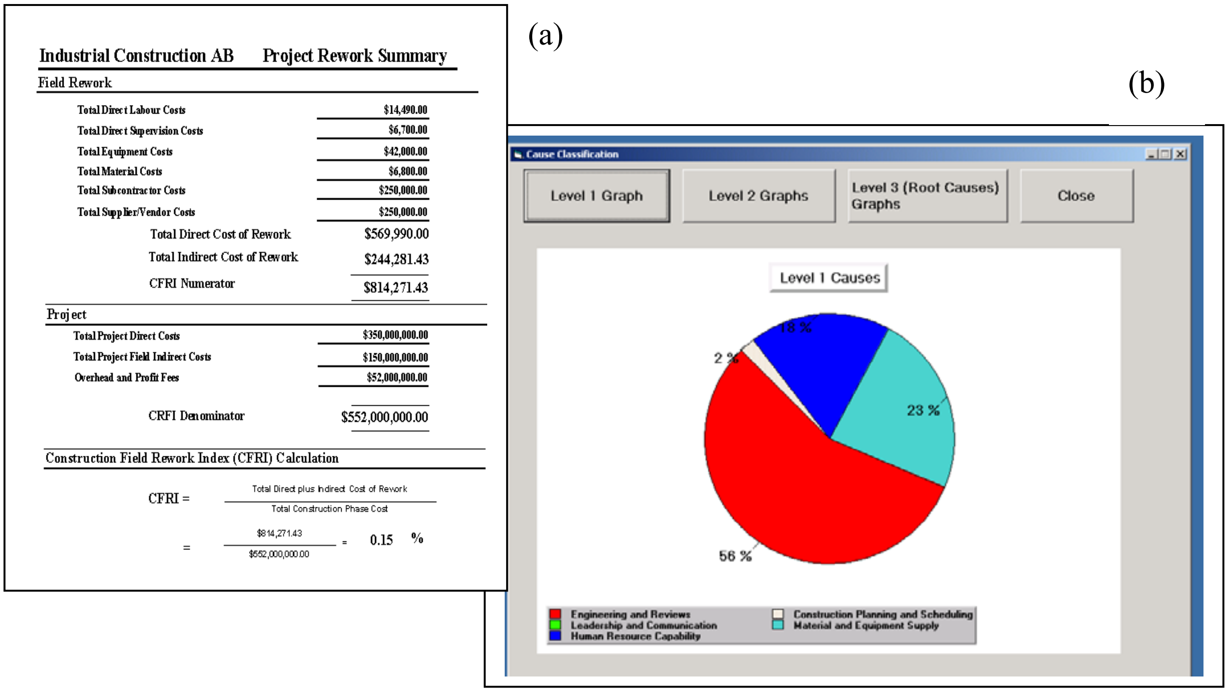

Figure 4.9 (a) Project Rework Summary Report (b) Summary Classification Chart for First Level Causes.

According to the procedure described above, the FRDCS allows an organization to keep records of the rework incidences as they occur, to construct the construction field rework index (CFRI), and to identify the root causes of field rework. Alternatively, the user can use the data collection forms given in Appendix E to manually keep these records.

5.0 CASE STUDY: SYNCRUDE AURORA 2 PROJECT

5.1 Introduction

The Aurora 2 Project, as described in Section 2, was selected as a case study for the pilot study. This project is a mining expansion venture, with the aim of processing 58 million t/a of ore to provide 38 million bbl/yr of feedstock for a related upgrader expansion project (UE-1). The project is subdivided into the following areas so as to enable its orderly execution:

- Mobile equipment
- Materials Handling (MHF)
- Extraction (Ext)
- Utilities & Off-sites (U&O)

In addition, each area is subdivided into Construction Work Packages (CWPs), each of which includes all related construction activities (civil, structural/mechanical, electrical).

The project's estimated cost is approximately $599.6 million (Canadian dollars). The Aurora 2 project is being executed by Syncrude (owner) and an alliance of major contractors, which are: AMEC (design/engineering); North American (civil works); UMA (structural/mechanical works); and Chemco (electrical works).

In addition, there are some separate major engineering, procurement, and construction (EPC) subcontracts for the supply and erection of various pieces of equipment, such as the Primary Separation Vessel (PSV), the Crusher, and the Surge Bin facility. There are also other separate contracts awarded through AMEC, as an agent for Syncrude, or through Contract Work Authorizations (CWAs) with Syncrude. These include: bussing, camps, scaffolding, cranes, and other major construction equipment.

The initial scope of the pilot study was to focus on the Water Treatment Plant (WTP - Construction Work Package #606), located in the U&O area. The reason for this was that at the starting point of the study, this package matched the original research time window and could also be observed from start to finish. Subsequently, due to a project change notice (PCN), the engineering design stage of the WTP was extended, and therefore its construction schedule was extended to April 2003. This resulted in unexpected delays of field construction activities on the WTP during most of the study period. As a result, the scope of the pilot study was expanded to include the entire Aurora 2 project scope as performed by the Alliance Contractors. Separate EPC contracts were excluded due to the unavailability of specific information (design and engineering costs, direct costs, etc.) for these contractors in the project's cost reports. Additionally, the field data collection period was extended from the original period of May 2002 to August 2002, to instead the end of December 2002, in order to enable the collection of a sufficient amount of field data for the testing of methodology and to fulfill the pilot study objectives.

5.2 Aurora 2 Construction Progress

The rework data collection started on April 29, 2002 and ended on December 19, 2002. The project's actual construction progress at the beginning of this period was 13.9%, and by the end of the study was 51%. Engineering progress was 75% complete at the end of April 2002, and 91% complete at the end of December 2002. Figure 5.1 shows the construction progress (in approximate percentages) for each discipline over the course of the study:

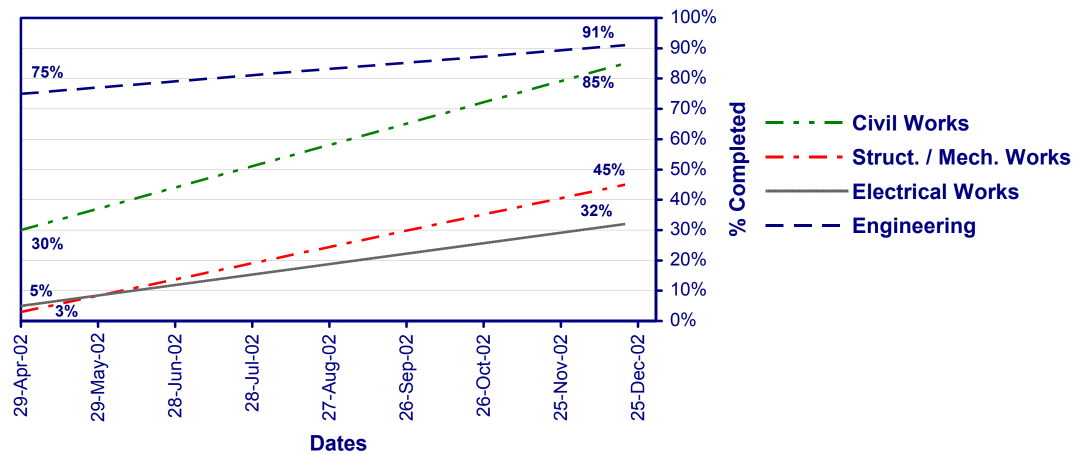

Figure 5.1. Construction Progress by Discipline over Pilot Study Period
Source: Syncrude - Aurora 2 project's weekly reports no.49 – no.68

5.3 Data Collection and Analysis

During the pilot study period, 125 field construction rework incidences (CRWs) were collected for the analysis. Each rework incidence was classified according to the COAA's fishbone diagram, and filed with additional information related to the specific rework item, such as timesheets, drawings, memos, sketches, RFI's, etc. The rework incidence was given a specific number, which contained the following information: (1) Construction Work Package (CWP) where rework occurred, (2) originator identification number, and (3) the number of rework items done by the originator in the specific CWP. For example, CRW #606-1-2 indicates that it is the second rework incidence performed by originator #1 (civil works) in the CWP #606.

As a part of the Aurora 2 Project requirement, the project control personnel maintained a rework form that was provided to all Alliance members in order to account for all rework incidences on site. (See Appendix H for Syncrude-Aurora 2 Project's sample rework form). This form was usually filed with its associated supporting documents as well (timesheets, materials & equipment quotations, engineering documents, drawings, etc.), and was later given an estimated rework cost by the project's field rework representative.

These rework items were filed in the project's construction rework log which was updated bi-weekly by the project control team. The information contained in the project's rework forms was used to support the data collected in the rework construction package (CRW) for the pilot study.

The pilot study analysis consisted of: (1) calculating a field rework index for the rework incidences collected during the study period, (2) classifying each of the 125 CRWs accordingly using the fishbone classification system provided by the COAA, and (3) evaluating different information obtained from the "Field Data Collection Form", such as:

- ***Masterformat Activity Elemental Classification***: this is used to total a figure for those key activities that contributed to rework in each discipline.

- ***Total Field Rework Workforce hours***: this is used to total a figure for the amount of hours spent on rework.

- ***Work shifts hours breakdown for field rework***: this is used to total a figure on how the rework was managed to be performed without interrupting the workflow of normal activities.

The intent of the analysis shown in the following sections is to illustrate the types of analyses that are possible using the methodology developed. Because the pilot study findings are based on a snapshot in time of the case study project, the numerical values themselves can neither be viewed as conclusive nor indicative of the final outcome of this project.

5.4 Construction Field Rework Index (CFRI)

The construction field rework index is a percentage value that determines the amount of field rework on a construction project. It is the result of Equation 4.1, as mentioned in Section 4.

Table 5.1 shows the calculated rework index for each contractor for the period studied:

Table 5.1. Aurora 2 Construction Field Rework Index (April 29th 2002 – December 19th 2002)

Ref. #	Field Construction Trade	(1) Total Rework Direct Cost	(2) Field Indirect Cost Markup factor	(3) Total Rework Cost = (1) x (2)	(4) Total Field Construction Phase Cost	(5) Rework Index = (3)/(4)
1	Civil	$179,402.84	1.72	$308,572.88	$30,484,184.10	1.01%
2	Mechanical / Structural	$219,502.76	1.72	$377,544.75	$40,011,214.70	0.94%
3	Electrical	$5,016.16	1.72	$8,627.80	$9,744,483.05	0.09%
Total:		**$403,921.76**		**$694,745.43**	**$80,239,881.85**	**0.87%**

The total rework direct cost was obtained from the Rework Data Collection forms, on which the total amount of workforce hours, equipment, materials, and subcontracts were collected from all rework incidences.

The indirect mark-up factor is the representation of the field rework impact on indirect costs. This factor is the result of dividing each contractor's direct and indirect field costs by their total direct costs during the studied period (April 29th 2002 – December 19th 2002). This information was available for every main Alliance member in the project's internal cost control system (*Convero*™ cost reports). However, for the purpose of this study, an average of the estimated figure of the mark-up factor indicated in the project's reports was used in the CFRI calculations (column 2). Column (3) of Table 5.1 shows the results of multiplying the field direct rework costs by the indirect mark-up factor, and represents the total amount of rework (direct plus indirect costs).

In general, every dollar spent on direct costs for each Alliance member costs $1.72, which includes direct and indirect costs. This value varies among Alliance members, depending on the total direct and indirect costs incurred by each during the study period. Moreover, as shown in Table 5.1, the project's field rework index for the duration of this study was 0.87%. Civil works obtained an index of 1.01%, structural/mechanical works 0.94%, and electrical works 0.09%. The main reason why electrical works has a lower CFRI is because there was relatively less construction activity related to electrical works during the study period.

For the purpose of the pilot study, neither EPC contracts nor back-chargeable costs were included in the field rework index calculations, resulting in 95 rework items studied in the CFRI calculation. The main reasons for this exclusion were: (1) there were not sufficient detailed information relative to the field rework costs performed by the subcontractors and/or EPC contractors, and (2) the lump sum amount relative to the work to be subcontracted and/or performed under EPC contracts is relatively insignificant compared to the total project construction phase cost. In addition, off-site fabrication rework costs were excluded in order to be in line with the definition of "field" rework.

Refer to Appendix D for a list of which items are included in the calculation of the cost components of the Construction Field Rework Index (CFRI).

5.5 Field Rework Classification

The classification system used in the pilot study for categorizing the causes of rework is based on the fishbone diagram developed by the COAA. Each first level cause was divided into four second level causes, and each second level cause was further divided into a number of third level root causes. The objective of this approach to rework cause classification is to identify the root causes that contribute to field rework at such a specific level that they can be remedied and prevented. A three-level classification system was found to be appropriate for this purpose. A root cause analysis of the 125 field rework incidences collected during the pilot study was performed. Appendix I contains a complete analysis of the rework causes calculations for the first, second, and third level causes. Also, Appendix J shows the field rework log, where all rework incidences were recorded with their respective causes.

Figure 5.2 shows the contribution of each first level cause to the 125 field rework incidences experienced during the pilot study. Unlike the calculation of the CFRI, the cause analysis includes all EPC contracts and back-chargeable rework incidences in order to have a larger amount of rework in the sample size.

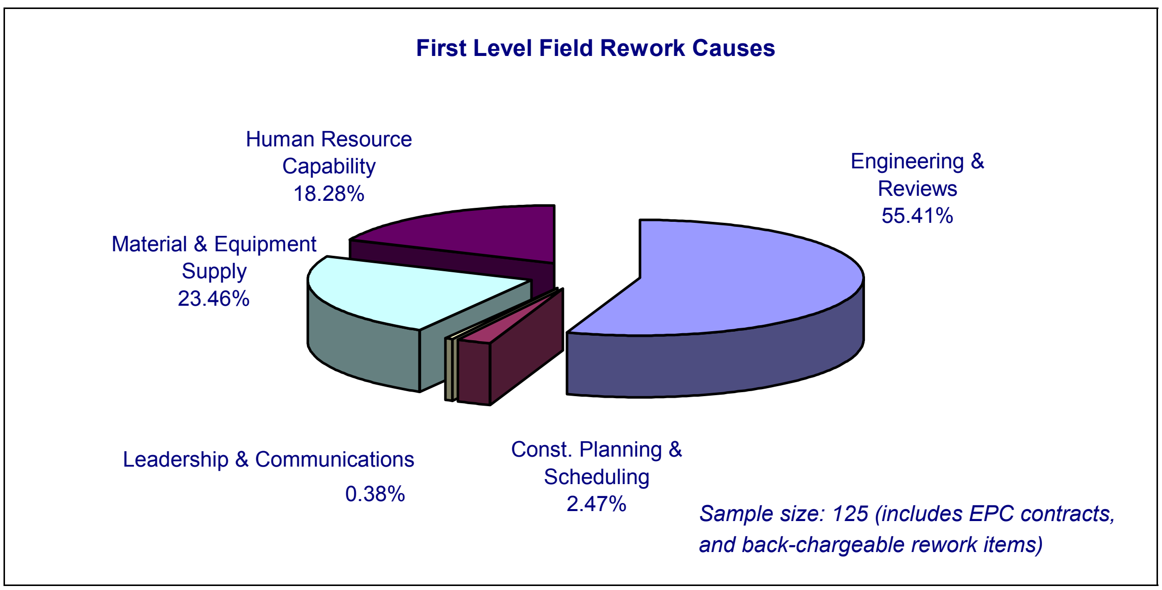

Figure 5.2. First Level Field Rework Classification Causes

"Engineering & Reviews" and "Material & Equipment Supply" were the factors that most significantly contributed to rework, with 55.41% and 23.46% respectively. "Human Resource Capability", "Construction Planning & Scheduling", and "Leadership & Communications" made relatively low contributions to rework, accounting for 18.28%, 2.47%, and 0.38% of the rework causes, respectively.

The values shown in Figure 5.2 illustrate the percent contribution of the first level causes to the overall rework amount. Three different analyses are presented to illustrate the contribution for the subsequent root causes based on:

1. Contribution to the overall rework incidences relative to the other causes based on frequency of occurrence (i.e. relative contribution).

2. Frequency of occurrence of each rework cause within its category (i.e. absolute contribution). The FRDCS's output is based on this analysis.

3. Dollar value magnitude of each rework incidence.

In Figure 5.2, the relative and absolute contributions are the same because the analysis is being made at the first level rework classification.

5.5.1 Relative Contribution Analysis

The relative contribution analysis is based on the contribution of each rework root cause to the overall rework incidences (125). In this analysis, the sum of all root causes' percentages is equal to 100%. Figures 5.3 to 5.7 show the second level causes that contributed to each first level cause. For example, in Figure 5.3, "Engineering & Reviews" contributed 55.41% to the total rework causes. Of this 55.41%, 38.48% was due to "Errors & Omissions", 10.00% was due to "Late Design Changes", and 6.93% was due to "Scope Changes". Interestingly, "Poor Document Control" did not contribute to any rework during the study period. In this way, one can see the significance of a given cause to the overall rework on the project.

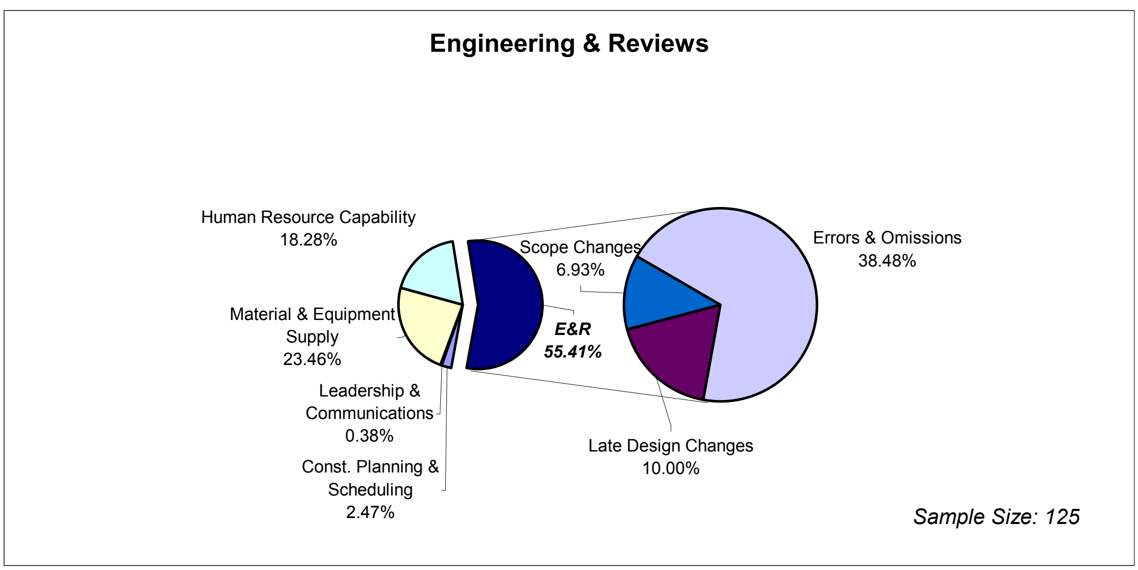

Figure 5.3. Engineering & Reviews (E&R) – Relative Contribution

In Figure 5.4, "Construction Planning & Scheduling" made a relatively small (2.47%) contribution to overall rework, with "Constructability Problems" being the largest contributor at 1.24%. "Unrealistic Schedules" and "Late Designer Input" each contributed 0.62% to overall rework.

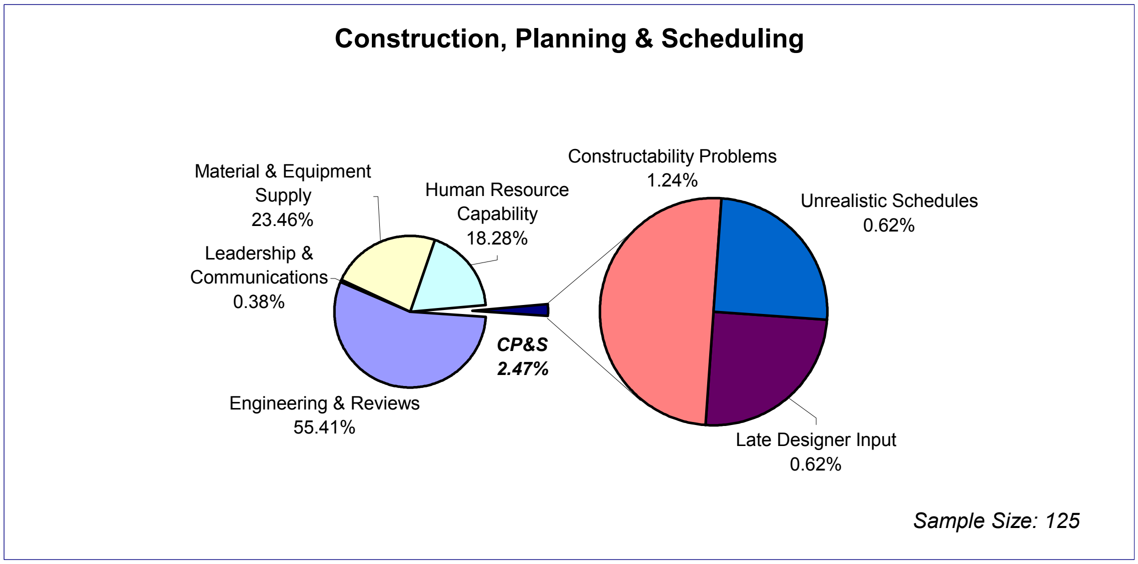

Figure 5.4. Construction Planning & Scheduling (CP&S) – Relative Contribution

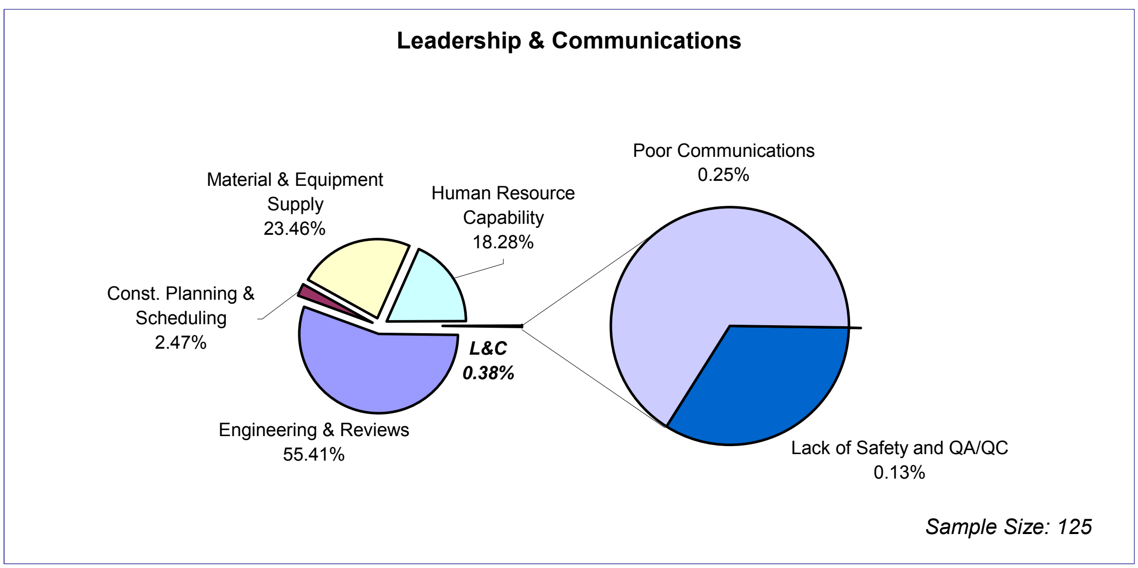

Figure 5.5. Leadership & Communications (L&C) – Relative Contribution

Referring to Figure 5.5, of the rework items caused by "Leadership & Communications", "Poor Communications" and "Lack of Safety" were found to contribute to rework by 0.25% and 0.13%, respectively. "Leadership & Communications" was found to be the cause that contributed least to field rework in this study. One main reason for this is the solid and well-structured communication procedures within the project, as a result of the contractual characteristics mentioned in Section 2.1, where all information related to the project is fully disclosed among all Alliance partners to meet common goals.

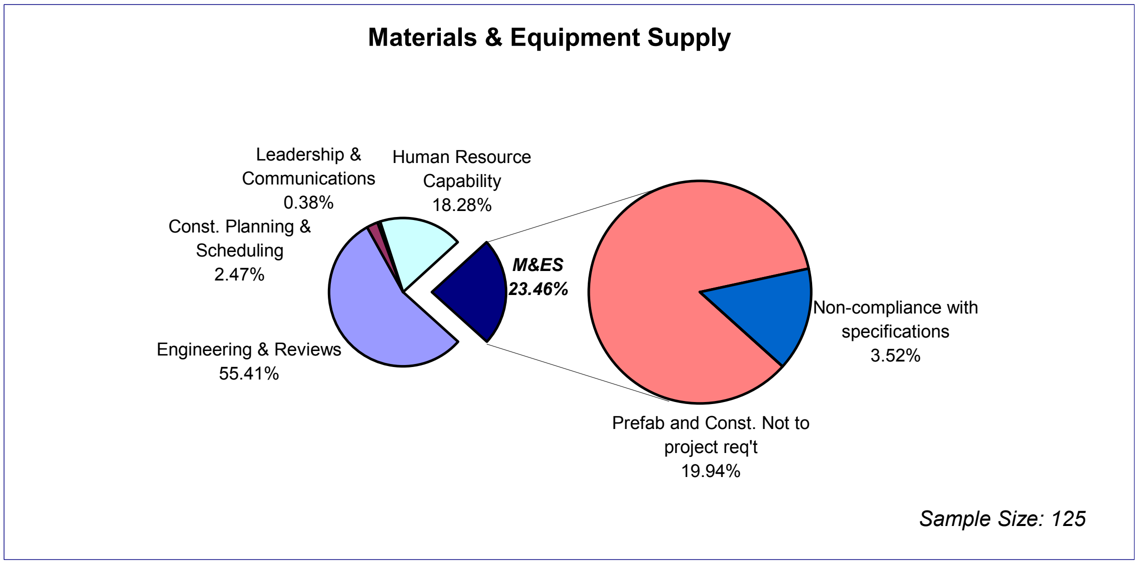

Figure 5.6. Material & Equipment Supply (M&ES) – Relative Contribution

Referring to Figure 5.6, of those subcategories within "Material & Equipment Supply", "Prefabrication and Construction Not to Project Requirements" contributed 19.94%, while "Non-compliance with Specification" contributed 3.52% to the total rework items detected on site. "Untimely Deliveries" and "Materials Not in Right Place when Needed" were not involved in any rework incidences.

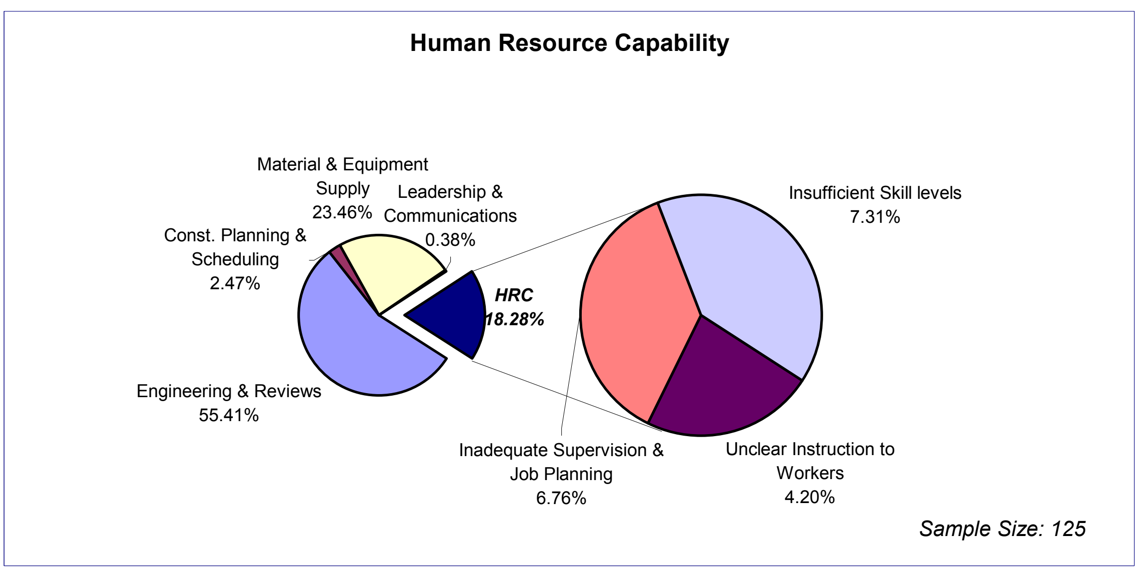

Figure 5.7. Human Resource Capability (HRC) – Relative Contribution

Referring to Figure 5.7, of those subcategories within “Human Resource Capability”, “Insufficient Skill Levels” contributed with 7.31%, “Inadequate Supervision & Job Planning” contributed 6.76%, and “Unclear Instruction to Workers” contributed 4.20% to overall rework.

A similar approach was taken to analyze the third level causes. The results are displayed in Figure 5.8 to Figure 5.20. For practical reasons, third level causes that were not involved in the rework incidences are not presented in the graphs; consequently, only causes with an assigned percentage are shown. These figures are based on the sample data obtained from the total rework incidences.

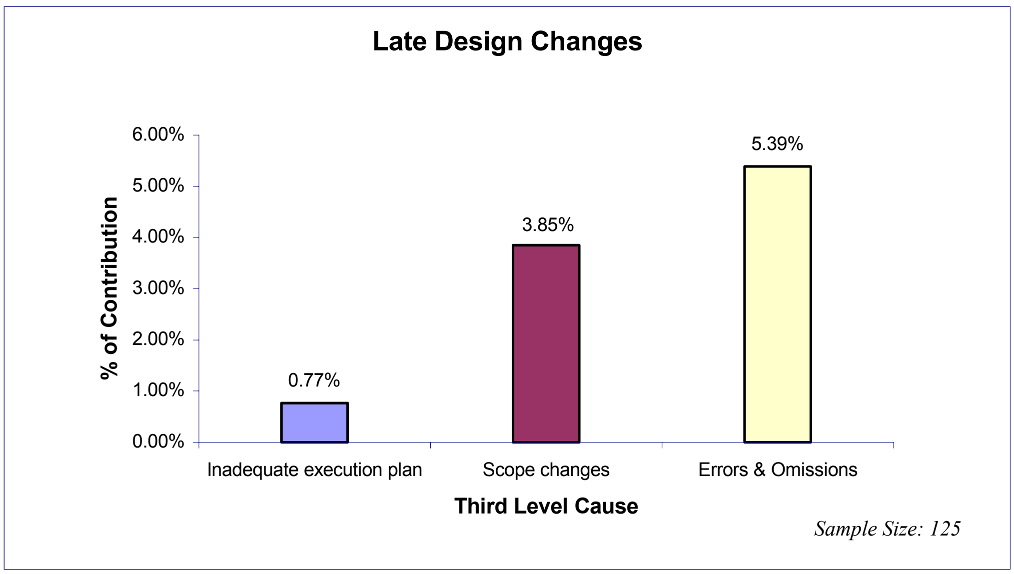

Figure 5.8. E&R – Late Design Changes

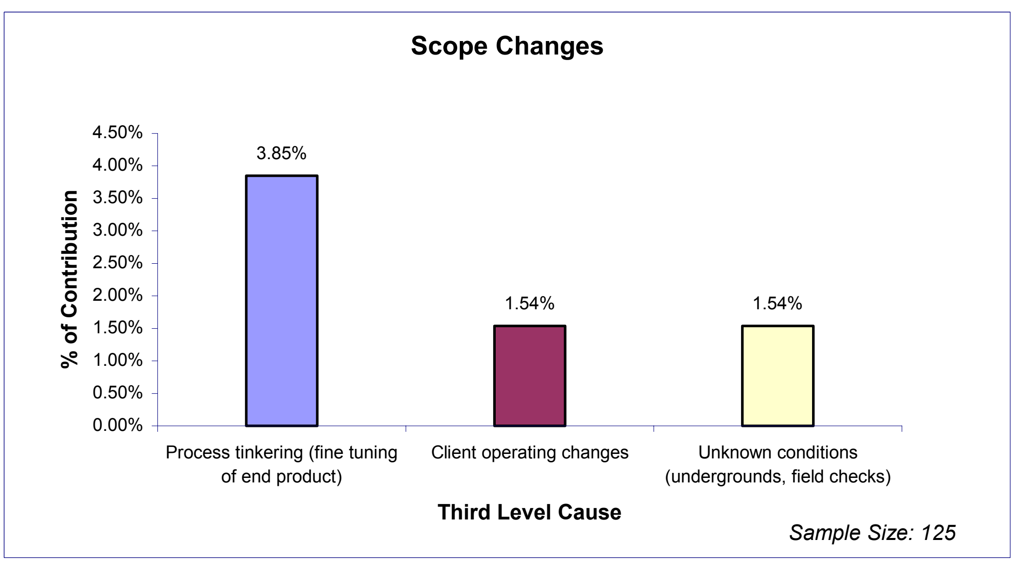

Figure 5.9. E&R – Scope Changes

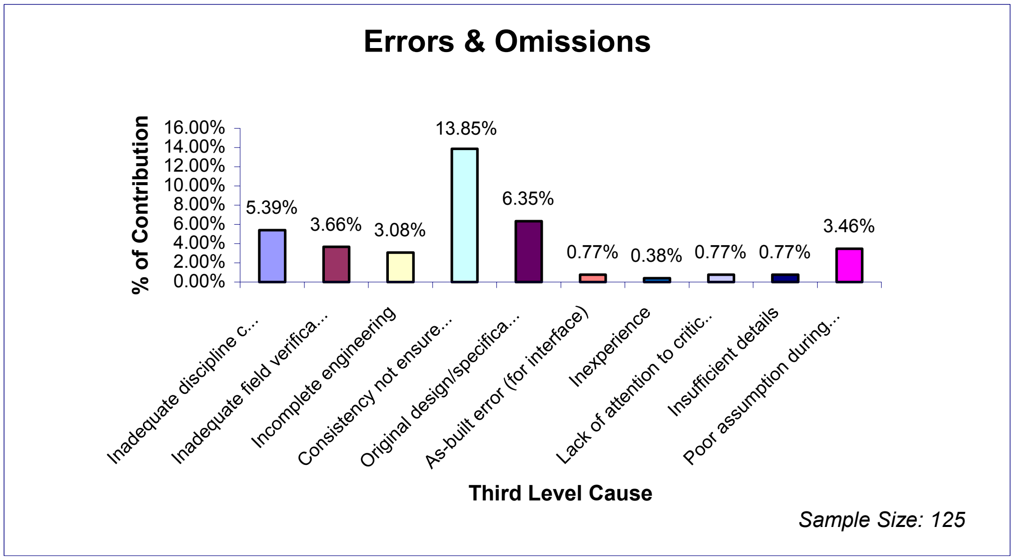

Figure 5.10. E&R – Errors & Omissions

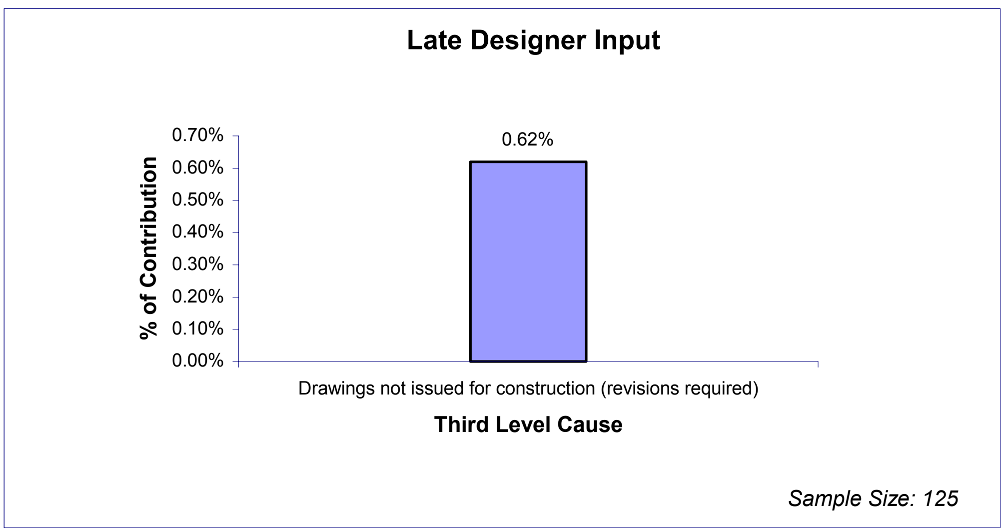

Figure 5.11. CP&S – Late Designer Input

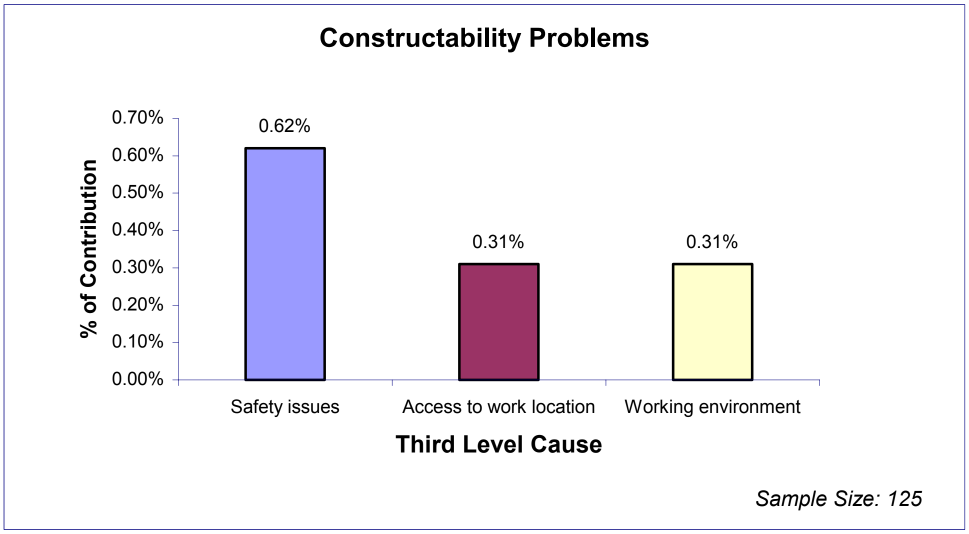

Figure 5.12. CP&S – Constructability Problems

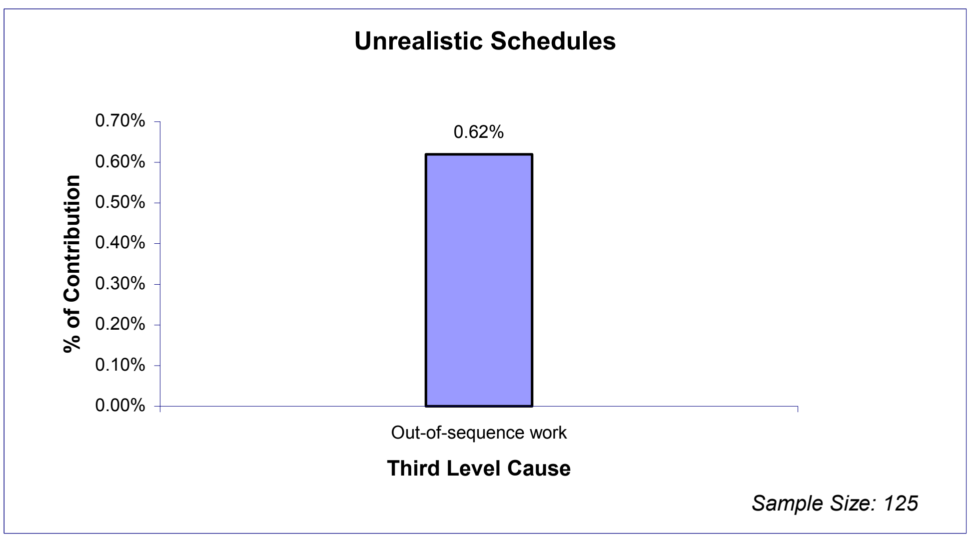

Figure 5.13. CP&S – Unrealistic Schedules

Figure 5.14. L&C – Lack of Safety and QA/QC Commitment

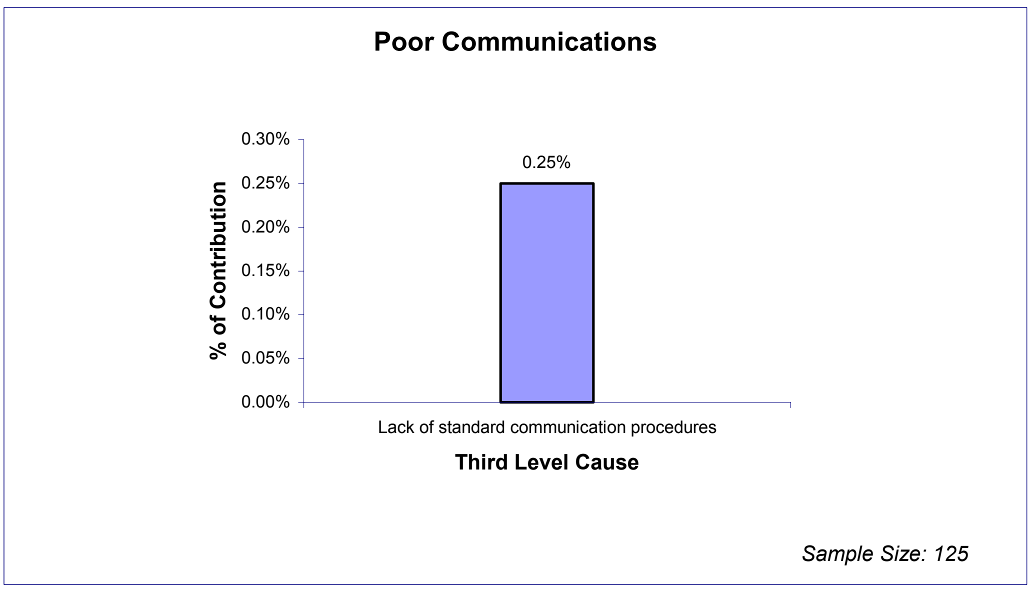

Figure 5.15. L&C – Poor Communications

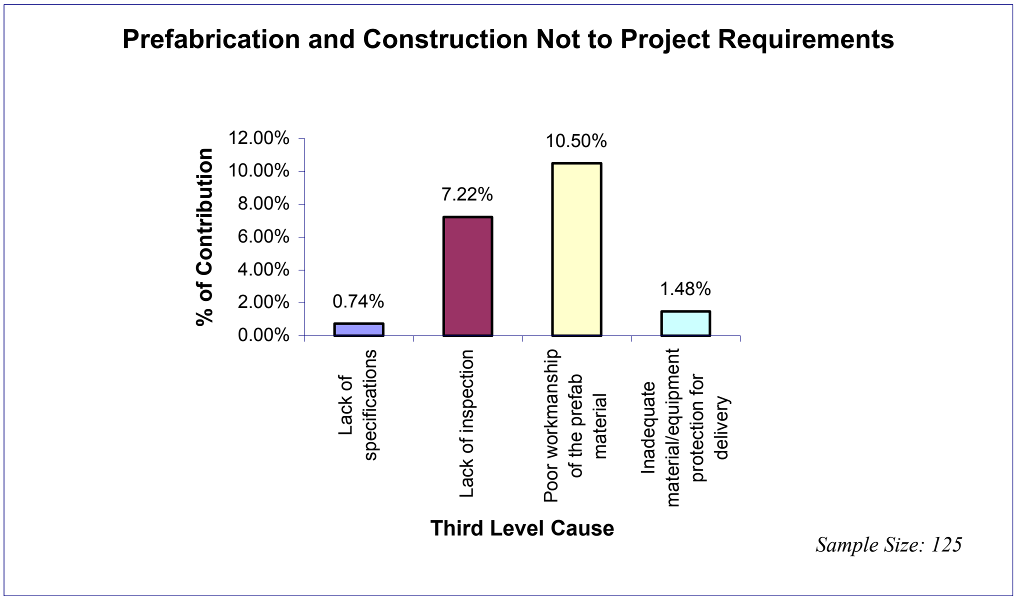

Figure 5.16. M&ES – Prefabrication and Construction Not to Project Requirements

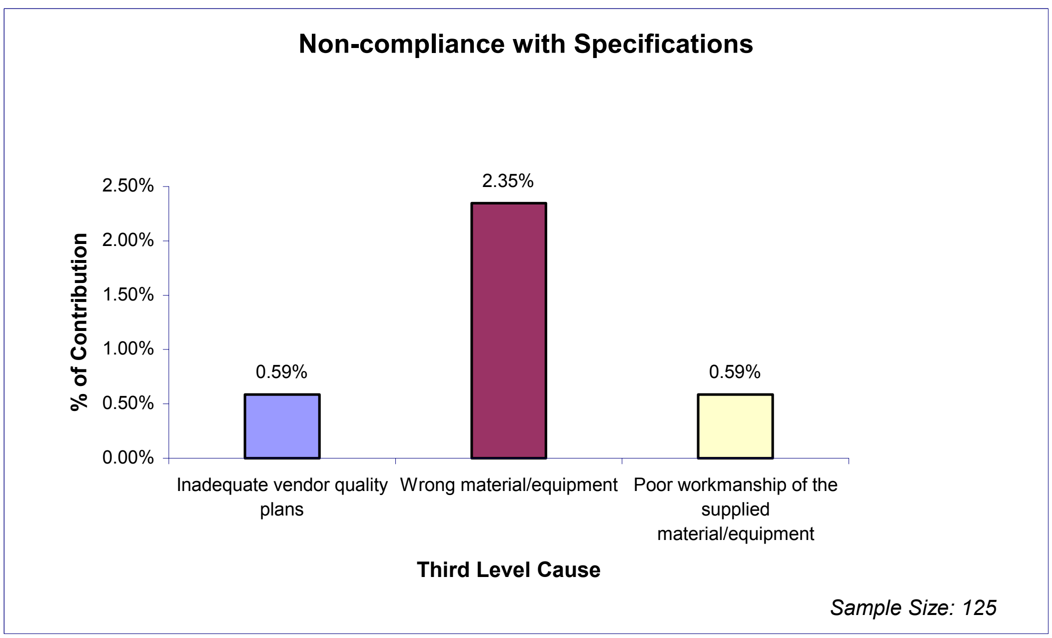

Figure 5.17. M&ES – Non-Compliance with Specifications

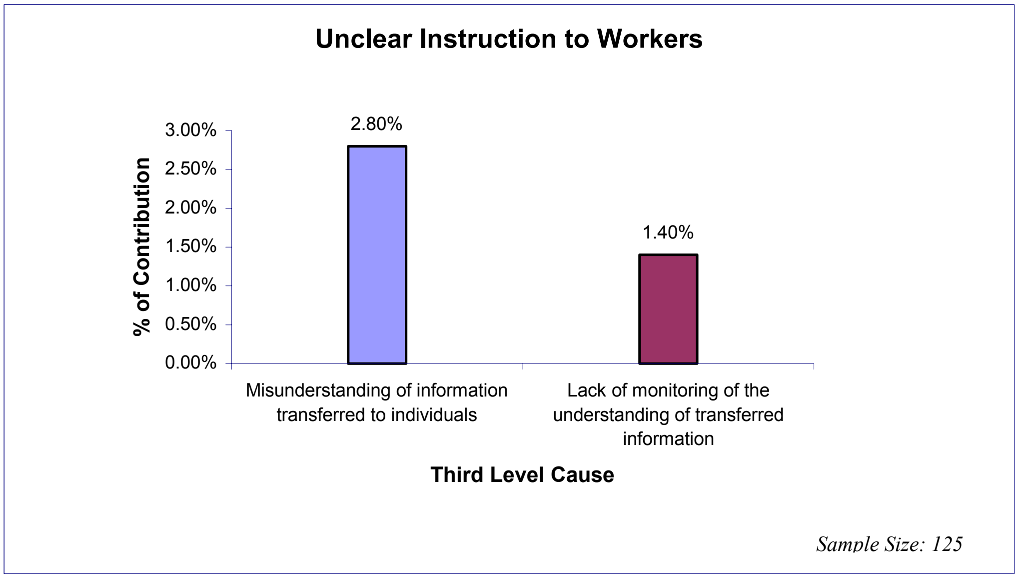

Figure 5.18. HRC – Unclear Instruction to Workers

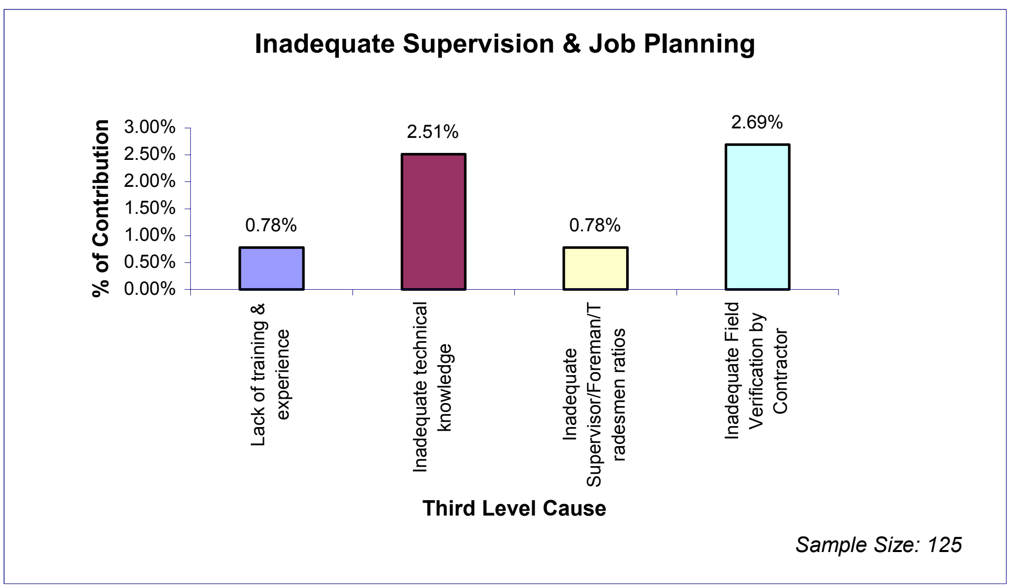

Figure 5.19. HRC – Inadequate Supervision & Job Planning

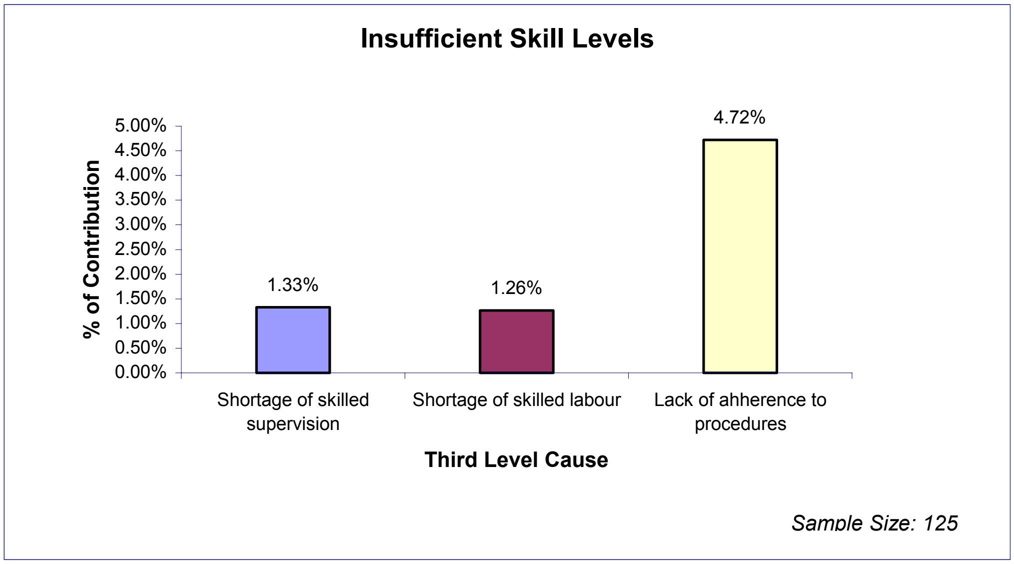

Figure 5.20. HRC – Insufficient Skill Levels

5.5.1.1 Summary

The three third level causes that most significantly contributed to rework were, in decreasing order: "Consistency Not Ensured Before Issued for Construction (IFC)", under "Errors & Omissions" in "Engineering & Reviews", with 13.85%; "Poor Workmanship of the Prefabricated Material", under "Prefabrication and Construction Not to Project Requirements" in "Material & Equipment Supply", with 10.50%; and "Lack of Inspection", under "Prefabrication and construction not to project requirements" in "Material & Equipment supply", with 7.22%. Table 5.3 lists the relative contribution (percentages) of each cause to the overall rework.

Table 5.2. Relative Contribution (%) by Cause to Overall Rework

First Level	Second Level	Third Level	Contribution to Rework (%)
Engineering & Reviews	Errors & Omissions	Consistency not ensured before Issued For Construction (IFC)	13.85%
Material & Equipment Supply	Prefab and Const. Not to project req't	Poor workmanship of the prefab material	10.50%
Material & Equipment Supply	Prefab and Const. Not to project req't	Lack of inspection	7.22%
Engineering & Reviews	Errors & Omissions	Original design/specification was incorrect	6.35%
Engineering & Reviews	Errors & Omissions	Inadequate discipline coordination	5.39%
Engineering & Reviews	Late Design Changes	Errors & Omissions	5.39%
Human Resorce Capability	Insufficient Skill levels	Lack of ahherence to procedures	4.72%
Engineering & Reviews	Scope Changes	Process tinkering (fine tuning of end product)	3.85%
Engineering & Reviews	Late Design Changes	Scope changes	3.85%
Engineering & Reviews	Errors & Omissions	Inadequate field verification by designer	3.66%
Engineering & Reviews	Errors & Omissions	Poor assumption during the design	3.46%
Engineering & Reviews	Errors & Omissions	Incomplete engineering	3.08%
Human Resorce Capability	Unclear Instructions to Workers	Misunderstanding of information transferred to individuals	2.80%
Human Resorce Capability	Inadequate Supervision & Job Plan	Inadequate Field Verification by Contractor	2.69%
Human Resorce Capability	Inadequate Supervision & Job Plan	Inadequate technical knowledge	2.51%
Material & Equipment Supply	Non-compliance with specifications	Wrong material/equipment	2.35%
Engineering & Reviews	Scope Changes	Client operating changes	1.54%
Engineering & Reviews	Scope Changes	Unknown conditions (undergrounds, field checks)	1.54%
Material & Equipment Supply	Prefab and Const. Not to project req't	Inadequate material/equipment protection for delivery	1.48%
Human Resorce Capability	Unclear Instructions to Workers	Lack of monitoring of the understanding of transferred information	1.40%
Human Resorce Capability	Insufficient Skill levels	Shortage of skilled supervision	1.33%
Human Resorce Capability	Insufficient Skill levels	Shortage of skilled labour	1.26%
Human Resorce Capability	Inadequate Supervision & Job Plan	Lack of training & experience	0.78%
Human Resorce Capability	Inadequate Supervision & Job Plan	Inadequate Supervisor/Foreman/Tradesmen ratios	0.78%
Engineering & Reviews	Errors & Omissions	As-built error (for interface)	0.77%
Engineering & Reviews	Errors & Omissions	Lack of attention to critical details	0.77%
Engineering & Reviews	Errors & Omissions	Insufficient details	0.77%
Engineering & Reviews	Late Design Changes	Inadequate execution plan	0.77%
Material & Equipment Supply	Prefab and Const. Not to project req't	Lack of specifications	0.74%
Construction Planning & Scheduling	Late Designer Input	Drawings not issued for construction (revisions required)	0.62%
Construction Planning & Scheduling	Constructability Problems	Safety issues	0.62%
Construction Planning & Scheduling	Unrealistic Schedules	Out-of-sequence work	0.62%
Material & Equipment Supply	Non-compliance with specifications	Inadequate vendor quality plans	0.59%

Cont'd

Table 5.2. Relative Contribution (%) by Cause to Overall Rework (Cont'd)

First Level	Second Level	Third Level	Contribution to Rework (%)
Material & Equipment Supply	Non-compliance with specifications	Inadequate vendor quality plans	0.59%
Material & Equipment Supply	Non-compliance with specifications	Poor workmanship of the supplied material/equipment	0.59%
Engineering & Reviews	Errors & Omissions	Inexperience	0.38%
Construction Planning & Scheduling	Constructability Problems	Access to work location	0.31%
Construction Planning & Scheduling	Constructability Problems	Working environment	0.31%
Leadership & Communications	Poor Communications	Lack of standard communication procedures	0.25%
Leadership & Communications	Lack of Safety	Misalignment of expectations between Contractor and Subcontractor	0.13%
			100.00%

5.5.2 Absolute Contribution Analysis

The absolute contribution analysis is based on the frequency of occurrence in each rework cause within its own category. Consequently, the sum of the percentages for all causes under each category equals 100%. For example in Figure 5.21, the frequency of occurrence in the first level cause, "Engineering & Reviews", is 55.41% (72 incidences). Out of these 72 rework incidences: "Errors & Omissions" contributed 69.44%; "Late Design Changes" contributed 18.06%; and "Scope Changes" contributed 12.50%. The sum of all these percentages is 100%, encompassing all the rework incidences classified under "Engineering & Reviews".

The sum of all sample sizes does not necessary equal the total amount of rework incidences studied (125). This is because one rework event may have multiple root causes. For example, if there are three rework items, and for each of them "Engineering & Reviews" and "Leadership & Communications" are root causes with specific assigned percentages, then the sample size for each cause would be three; however, the total amount of rework incidences is still three and not six.

This analysis was made for the rest of the second level causes, as shown in Figures 5.22 to 5.25.

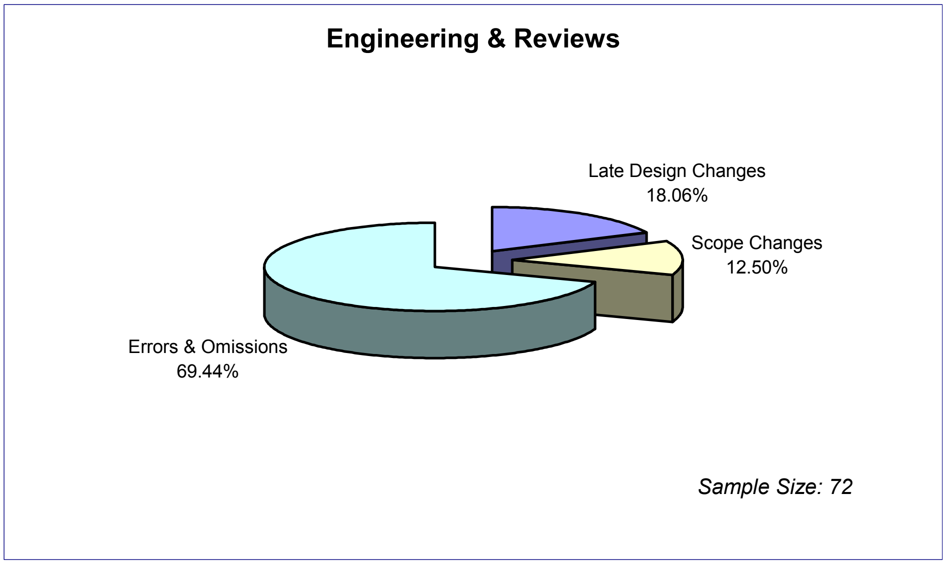

Figure 5.21. Engineering & Reviews (E&R) – Absolute Contribution

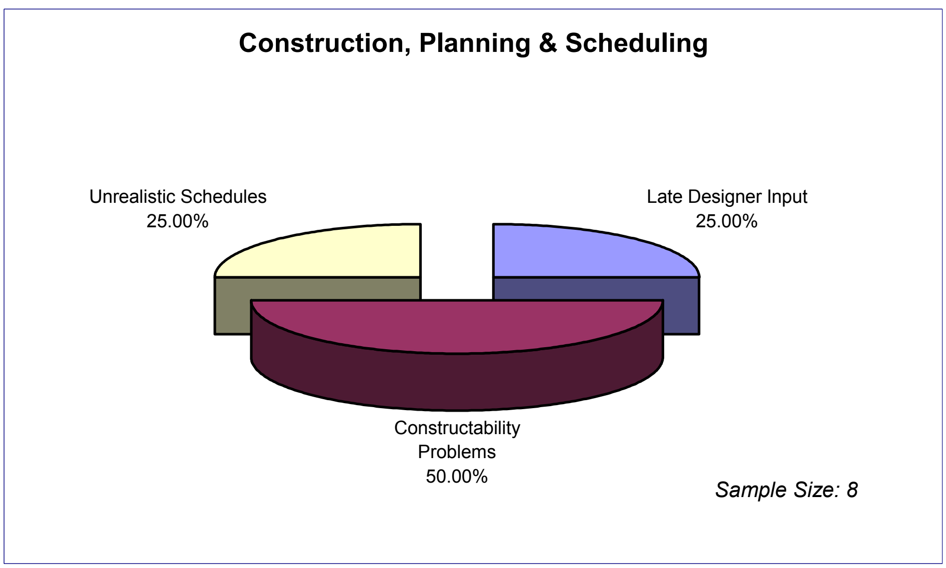

Figure 5.22. Construction Planning & Scheduling (CP&S) – Absolute Contribution

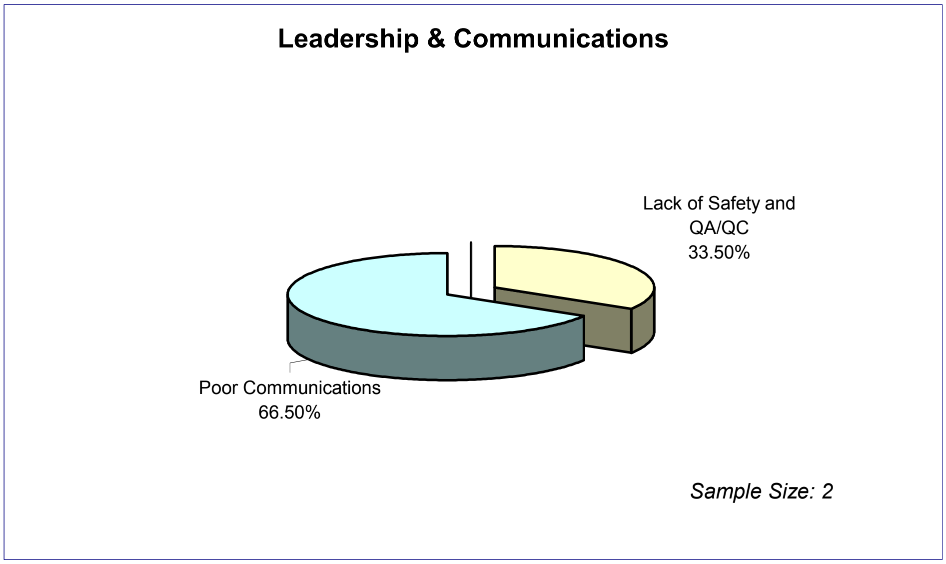

Figure 5.23. Leadership & Communications (L&C)– Absolute Contribution

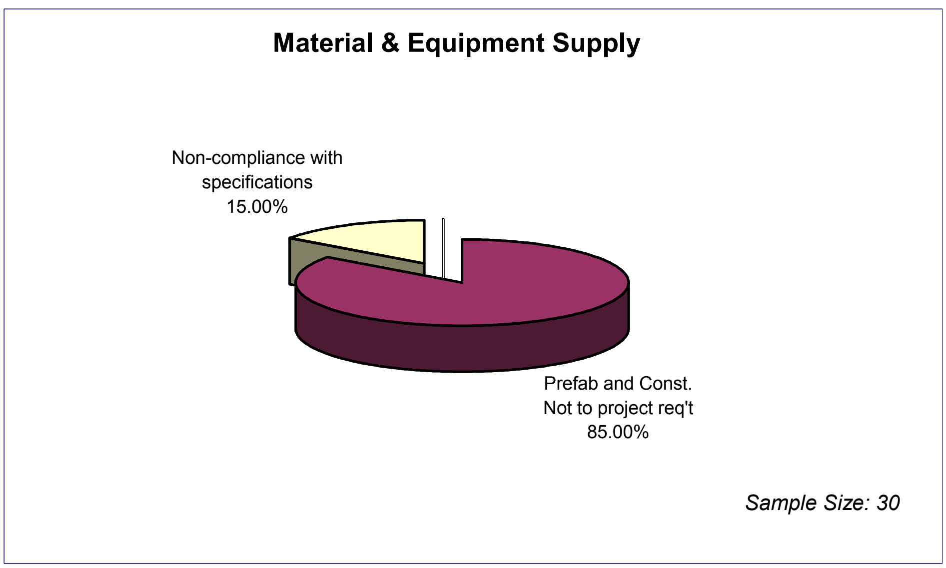

Figure 5.24. Material & Equipment Supply (M&ES) – Absolute Contribution

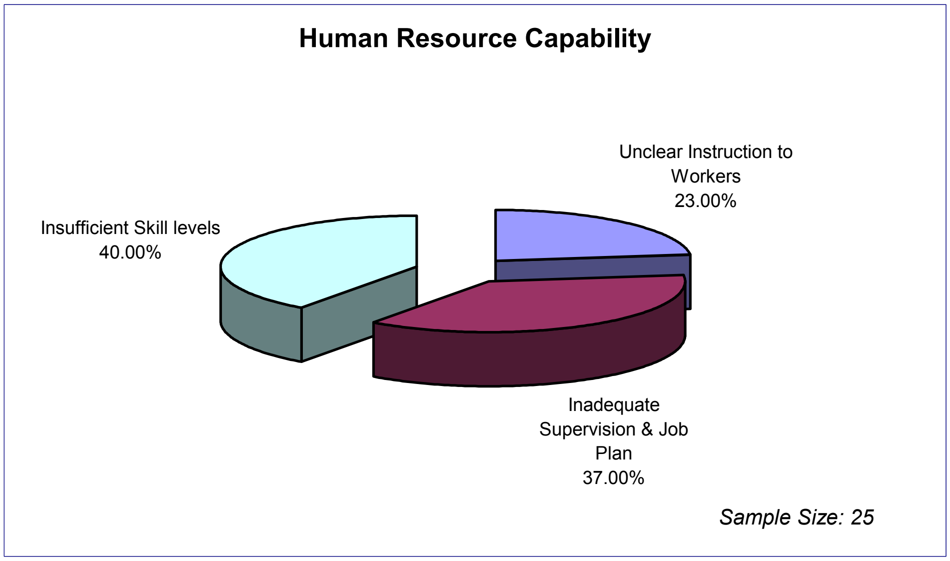

Figure 5.25. Human Resource Capability (HRC) – Absolute Contribution

Referring to Figures 5.21 to 5.25, "Errors & Omissions" was the cause that most contributed to rework in "Engineering & Reviews", with 69.44%. "Constructability Problems" contributed 50.00% to "Construction Planning & Scheduling"; "Poor Communications" contributed 66.50% to "Leadership & Communications"; "Prefabrication and Construction Not to Project Requirements" contributed 85.00% to "Material & Equipment Supply"; and "Insufficient Skill Levels" contributed 40.00% to "Human Resource Capability".

A similar approach was taken to analyze the third level causes. The results are displayed in Figures 5.26 to 5.38.

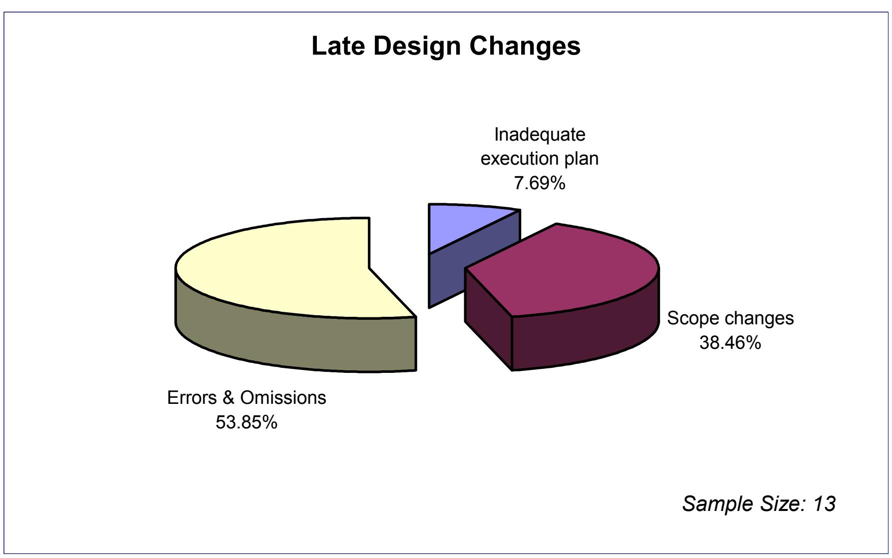

Figure 5.26. Late Design Changes – Absolute Contribution

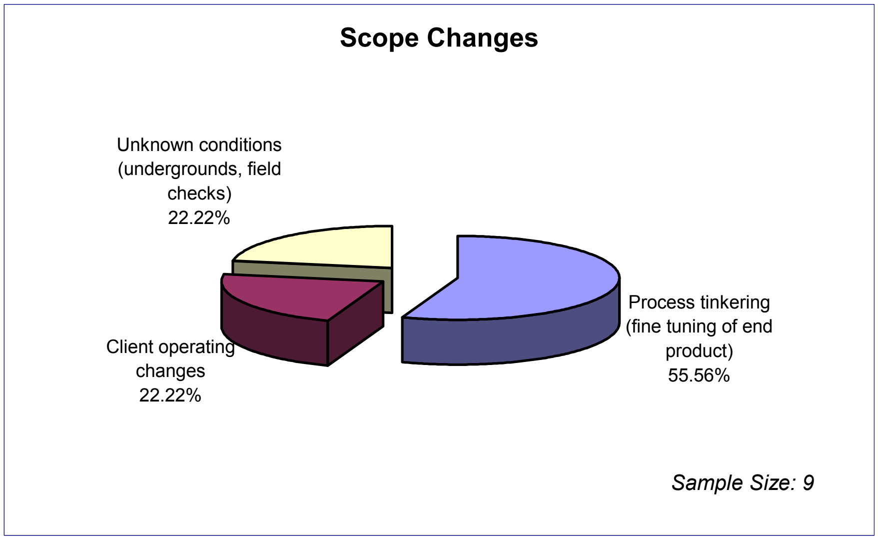

Figure 5.27. Scope Changes – Absolute Contribution

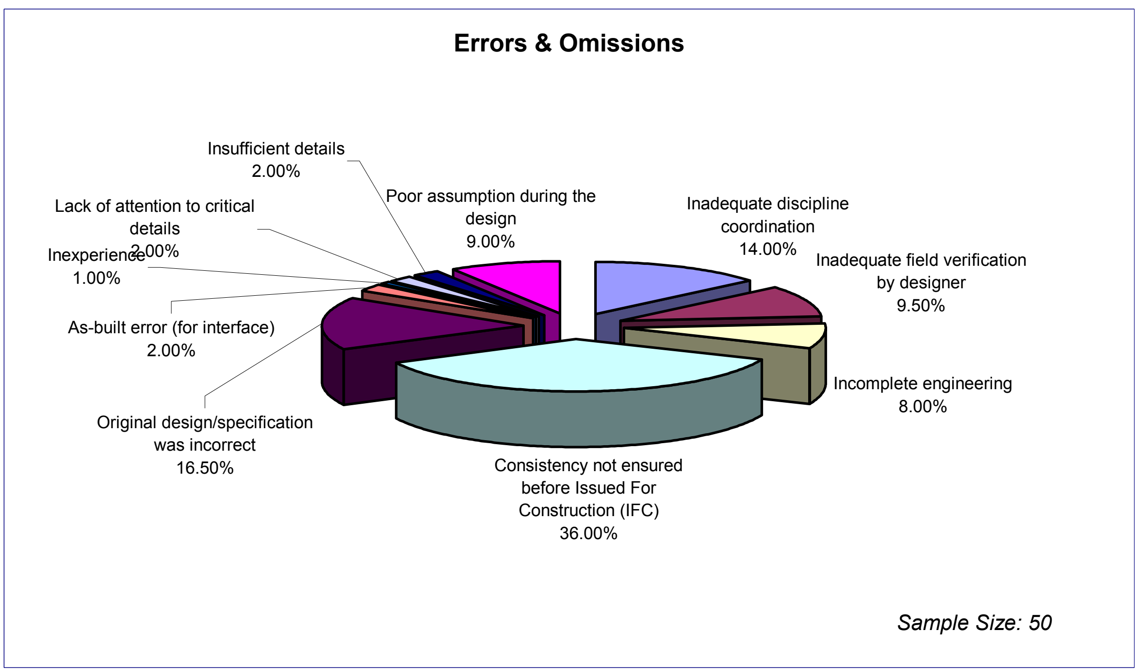

Figure 5.28. Errors & Omissions – Absolute Contribution

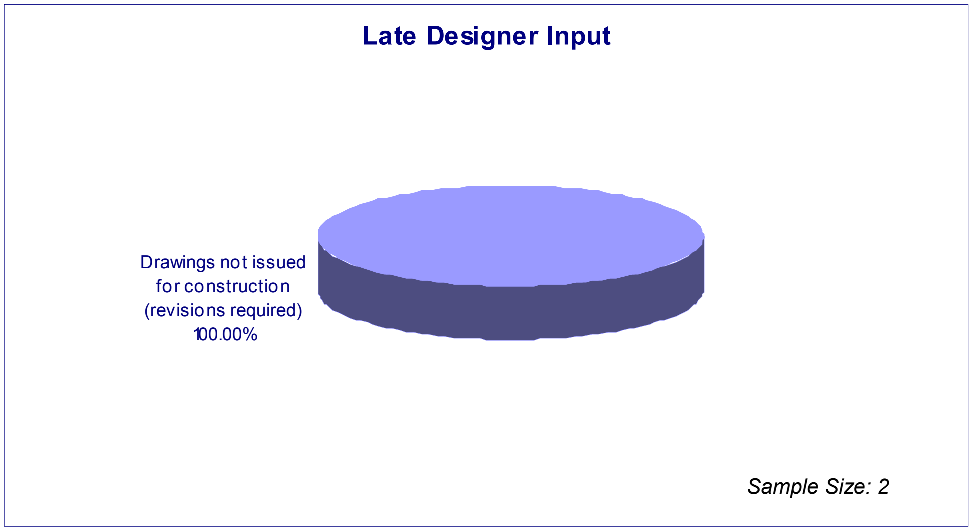

Figure 5.29. Late Designer Input – Absolute Contribution

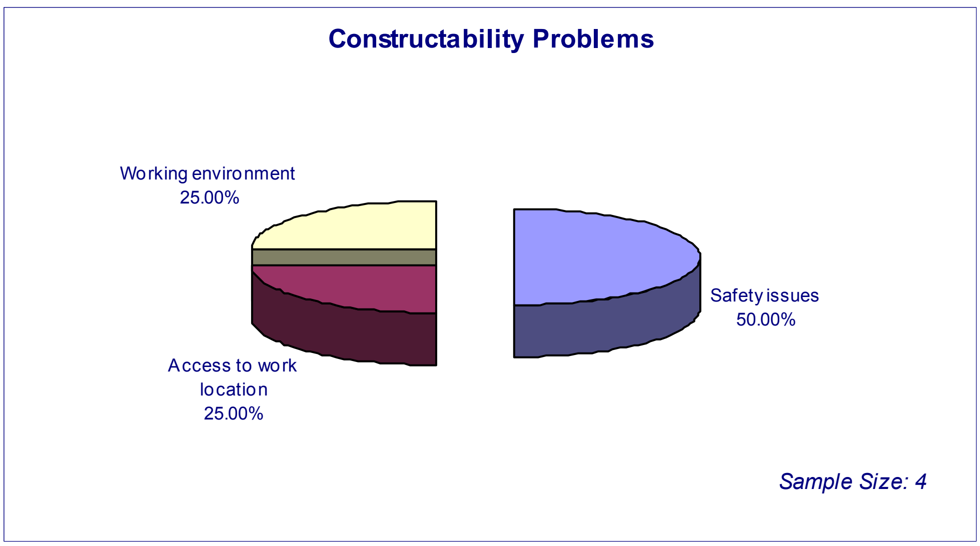

Figure 5.30. Constructability Problems – Absolute Contribution

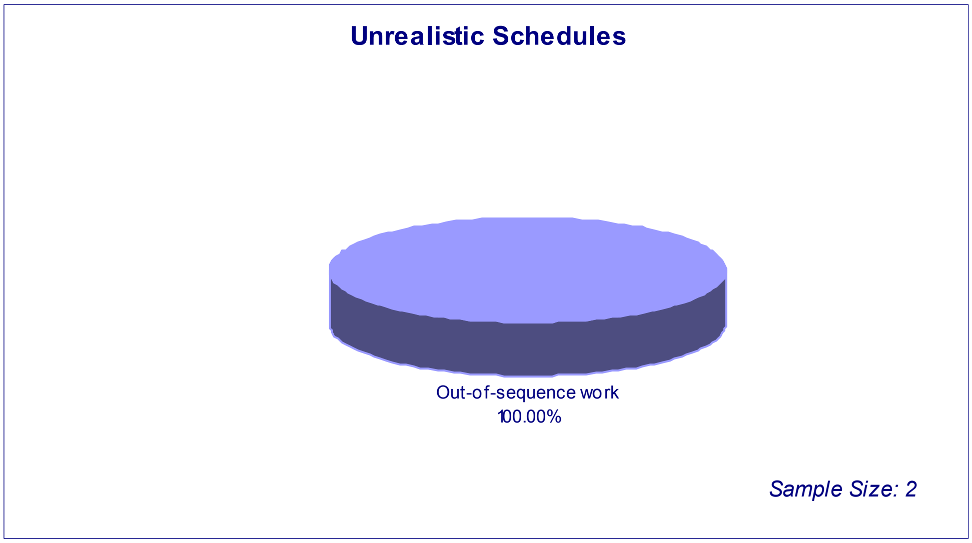

Figure 5.31. Unrealistic Schedules – Absolute Contribution

Figure 5.32. Lack of Safety and QA/QC Commitment – Absolute Contribution

Figure 5.33. Poor Communications – Absolute Contribution

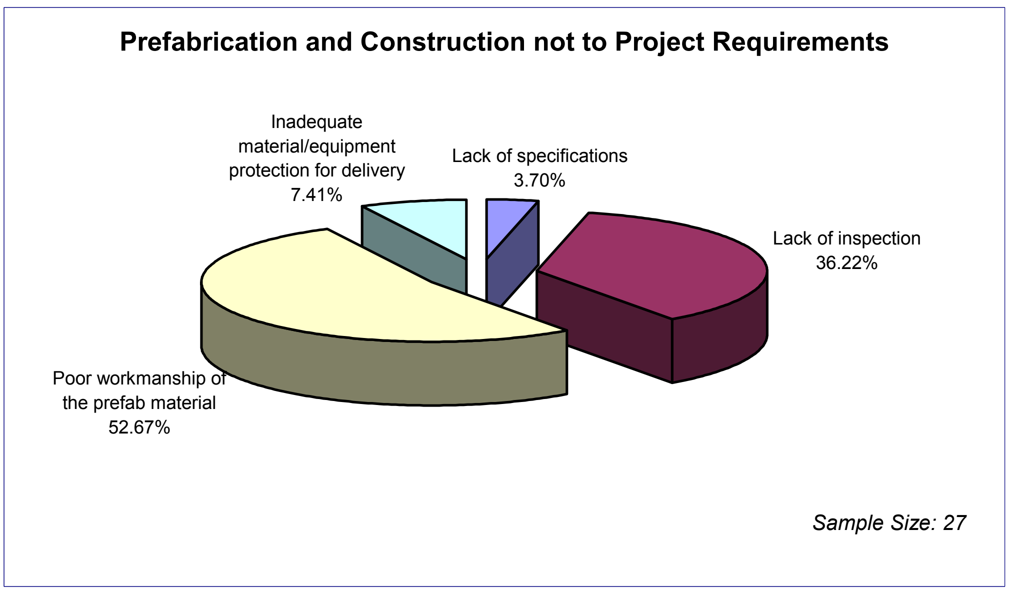

Figure 5.34. Prefabrication and Construction Not to Project Requirements – Absolute (%) Contribution

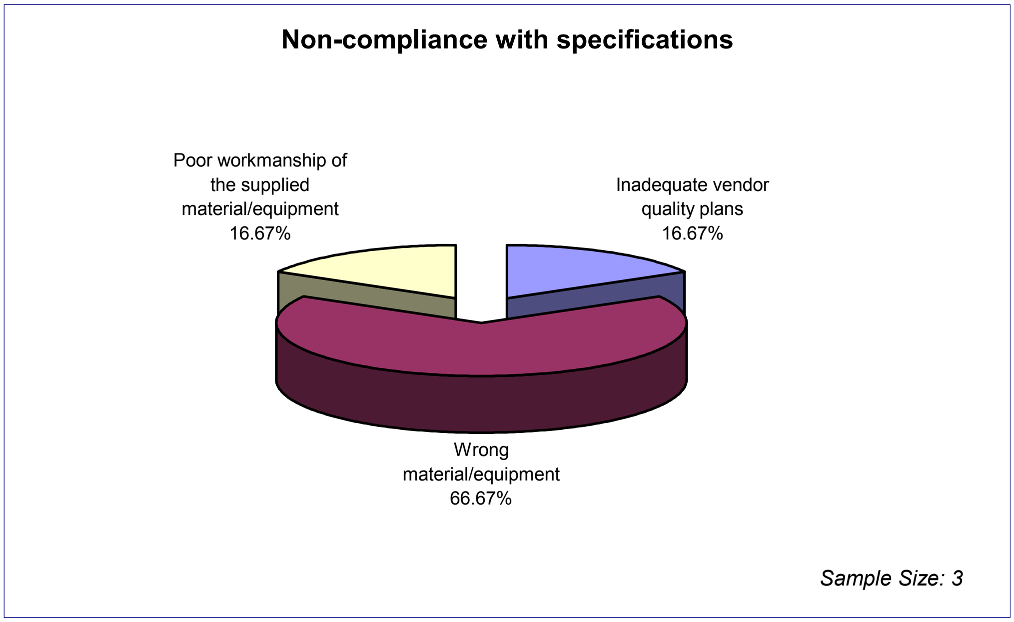

Figure 5.35. Non-compliance with Specifications – Absolute (%) Contribution

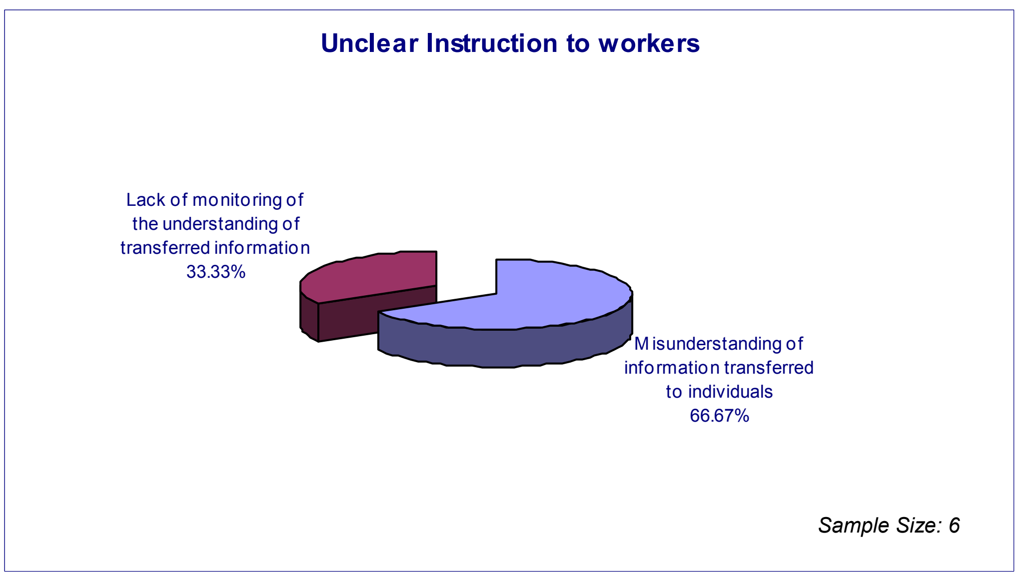

Figure 5.36. Unclear Instruction to Workers – Absolute (%) Contribution

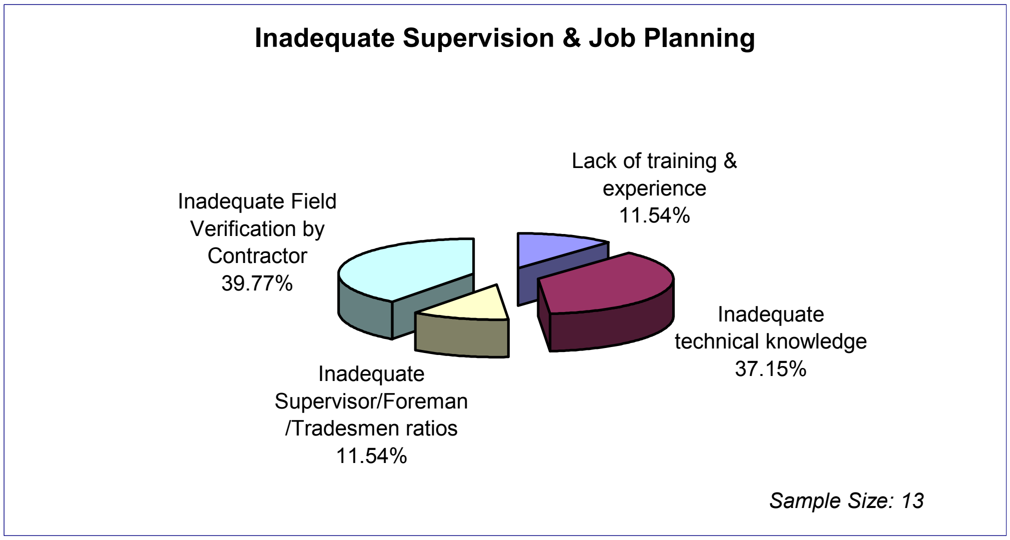

Figure 5.37. Inadequate Supervision & Job Planning – Absolute (%) Contribution

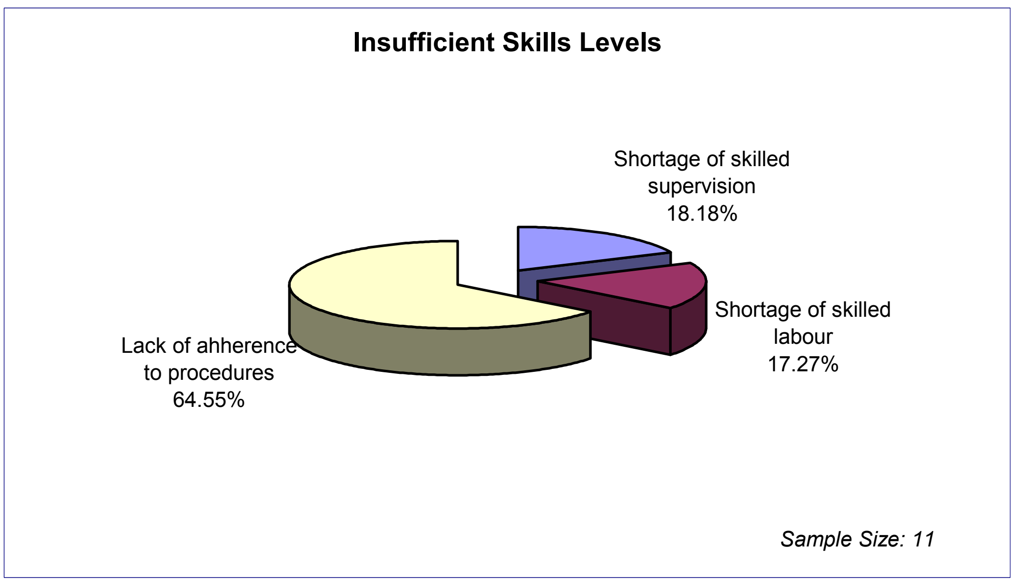

Figure 5.38. Insufficient Skills Levels – Absolute (%) Contribution

5.5.2.1 Summary

"Errors & Omissions" and "Prefabrication and Construction Not to Project Requirements" were the most frequent causes of rework, possessing 50 and 27 occurrences, respectively. Within "Errors & Omissions", "Consistency Not Ensured Before Issued for Construction (IFC)" contributed with 36.00%; and within "Prefabrication and Construction Not to Project Requirements", "Poor Workmanship of the Prefabricated Material" contributed with 52.67%. Table 5.3 summarizes the absolute contribution (%) to rework of all causes.

Table 5.3. Absolute Contribution (%) by Cause to Rework

First Level	Second Level	Third Level	Absolute Contribution to Rework (%)
Engineering & Reviews	Late Design Changes	Inadequate execution plan	53.85%
		Scope changes	38.46%
		Errors & Omissions	7.69%
			100.00%
Engineering & Reviews	Scope Changes	Process tinkering (fine tuning of end product)	55.56%
		Client operating changes	22.22%
		Unknown conditions (undergrounds, field checks)	22.22%
			100.00%
Engineering & Reviews	Errors & Omissions	Consistency not ensured before Issued For Construction (IFC)	36.00%
		Original design/specification was incorrect	16.50%
		Inadequate discipline coordination	14.00%
		Inadequate field verification by designer	9.50%
		Poor assumption during the design	9.00%
		Incomplete engineering	8.00%
		As-built error (for interface)	2.00%
		Lack of attention to critical details	2.00%
		Insufficient details	2.00%
		Inexperience	1.00%
			100.00%
Construction Planning & Scheduling	Late Designer Input	Drawings not issued for construction (revisions required)	100.00%
			100.00%
Construction Planning & Scheduling	Constructability Problems	Safety issues	50.00%
		Access to work location	25.00%
		Working environment	25.00%
			100.00%
Construction Planning & Scheduling	Unrealistic Schedules	Out-of-sequence work	100.00%
			100.00%
Leadership & Communications	Poor Communications	Lack of standard communication procedures	100.00%
			100.00%

Cont'd

Table 5.3. Absolute Contribution (%) by Cause to Rework (Cont'd)

First Level	Second Level	Third Level	Absolute Contribution to Rework (%)
Leadership & Communications	Lack of Safety and QA/QC Commitment	Misalignment of expectations between Contractor and Subcontractor	100.00%
			100.00%
Material & Equipment Supply	Prefab and Const. Not to project req't	Poor workmanship of the prefab material	52.67%
		Lack of inspection	36.22%
		Inadequate material/equipment protection for delivery	7.41%
		Lack of specifications	3.70%
			100.00%
Material & Equipment Supply	Non-compliance with specifications	Wrong material/equipment	66.67%
		Inadequate vendor quality plans	16.67%
		Poor workmanship of the supplied material/equipment	16.67%
			100.00%
Human Resource Capability	Unclear Instructions to Workers	Misunderstanding of information transferred to individuals	66.67%
		Lack of monitoring of the understanding of transferred information	33.33%
			100.00%
Human Resource Capability	Inadequate Supervision & Job Plan	Lack of training & experience	11.54%
		Inadequate technical knowledge	37.15%
		Inadequate Supervisor/Foreman/Tradesmen ratios	11.54%
		Inadequate Field Verification by Contractor	39.77%
			100.00%
Human Resource Capability	Insufficient Skill levels	Shortage of skilled supervision	18.18%
		Shortage of skilled labour	17.27%
		Lack of ahherence to procedures	64.55%
			100.00%

5.5.3 Monetary Value Analysis

In addition to the frequency with which rework causes occur, another indicator of the significance of rework causes is the dollar value of the amount of rework they result in. The total direct cost of each construction field rework item is obtained from the field rework data collection forms, on which the total amount of workforce hours, equipment hours, material quantities, and subcontract costs is recorded for each rework incidence. The monetary value analysis is based on the dollar contribution of each cause to the total direct cost of rework encountered during the study period, this includes all EPC contracts and back-chargeable rework costs. However, there were some rework incidences that were not completed by the end of the pilot study; therefore, cost information for these items was not available. In this case, these rework incidences were not considered. Consequently, total rework incidences for this analysis are reduced to 108, accounting for $582,703.13. Figure 5.39 illustrates the distribution of this total into the five major causes.

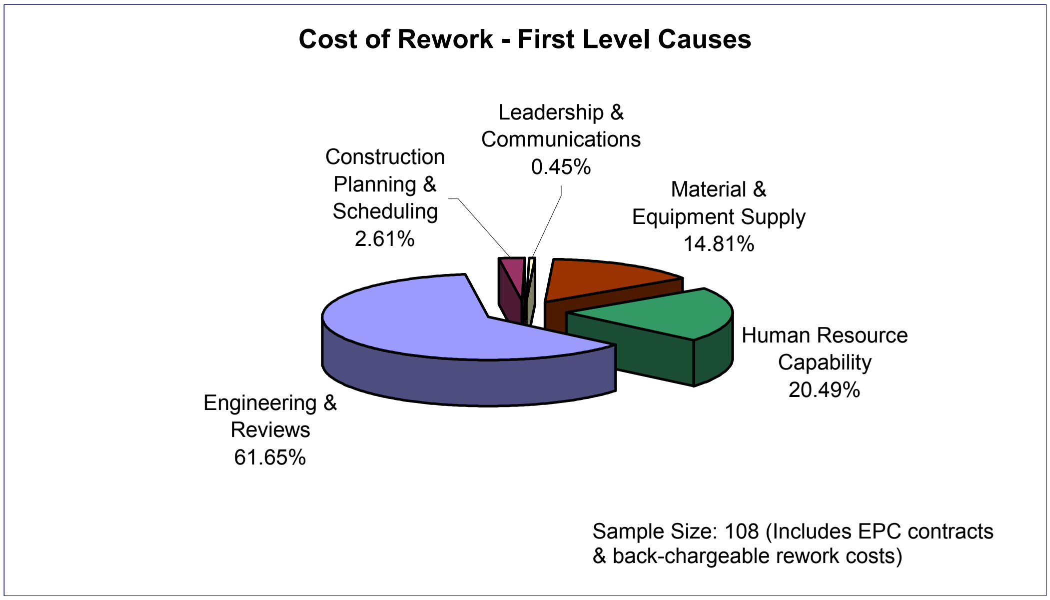

Figure 5.39(a). Rework Cost Contribution – First level causes

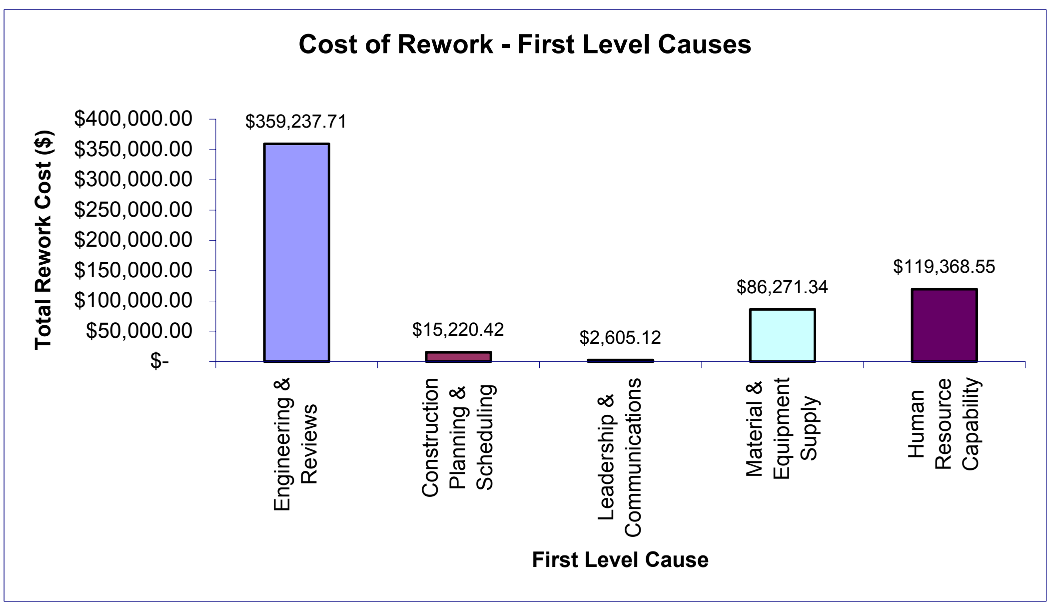

Figure 5.39(b). Total Rework Cost by Causes – First Level Cause

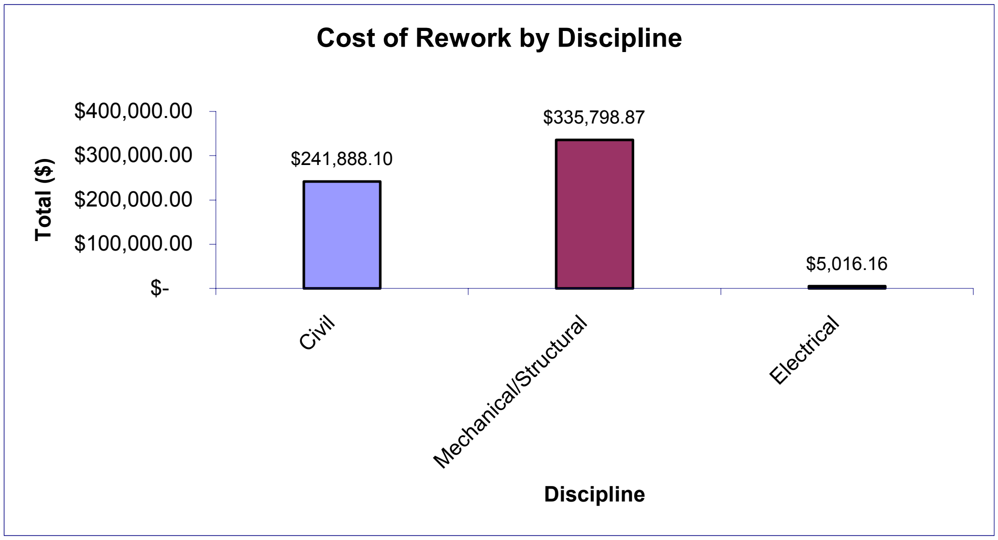

Figure 5.39(c). Total Rework Cost by Disciplines

Referring to Figure 5.39(a) and Figure 5.39(b), “Engineering & Reviews” was the most significant contribution with $359,237.71 (61.65%). “Human Resource Capability”, followed with $119,368.55 (20.49%), “Material & Equipment Supply”, with $86,271.34 (14.81%), “Construction Planning & Scheduling”, with $15,220.42 (2.61%), and “Leadership & Communications”, with $2,605.12 (0.45%).

Figure 5.39(c) displays the monetary contribution of each discipline directly performing the field rework: Civil, Mechanical/Structural, and Electrical. Civil and Mechanical/Structural works, unlike Electrical works, were the disciplines that most contributed to rework costs. Their significant level of contribution was due, in part, to the high workload they possessed during the study period, at $241,888.10 (41%) and $ 335,798.87 (58%), respectively.

Figures 5.40 to 5.60 display the results of the contributions (%) of each second and third level cause to the total cost of rework within each one’s category. For example, in Figure 5.40, “Errors & Omissions” was the cause that most contributed to the total cost of rework in “Engineering & Reviews”, with 78% ($280,205.41). In this analysis, a total of 62 rework incidences were classified under the first level category. A similar approach was made for the rest of the second level causes.

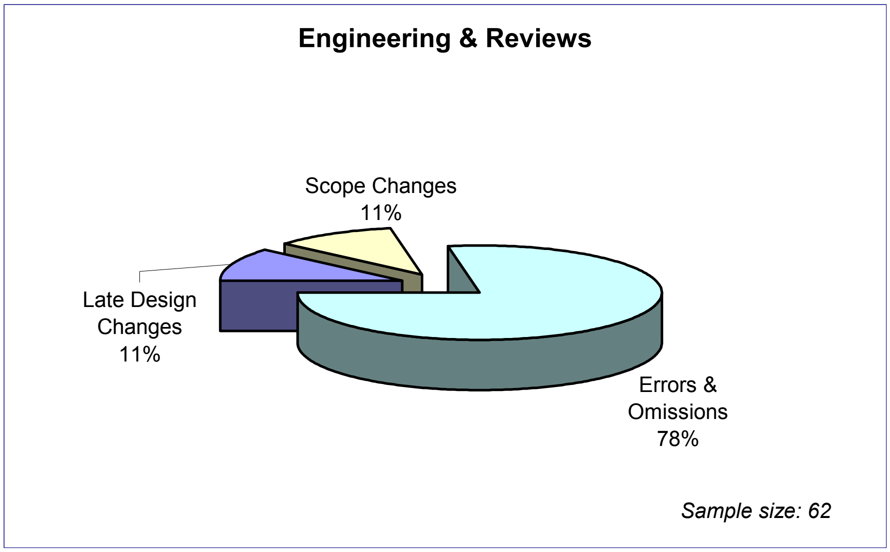

Figure 5.40. Engineering & Reviews – Rework Cost Contribution

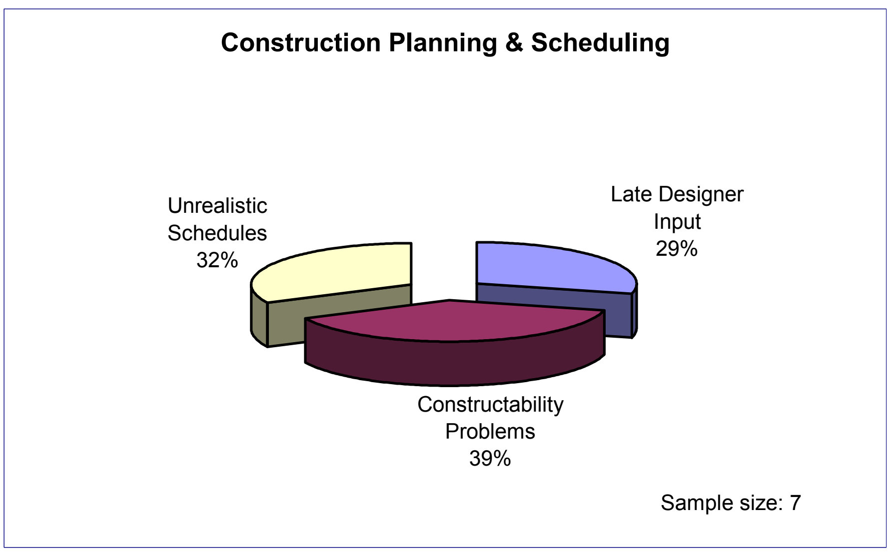

Figure 5.41. Construction Planning & Scheduling – Rework Cost Contribution

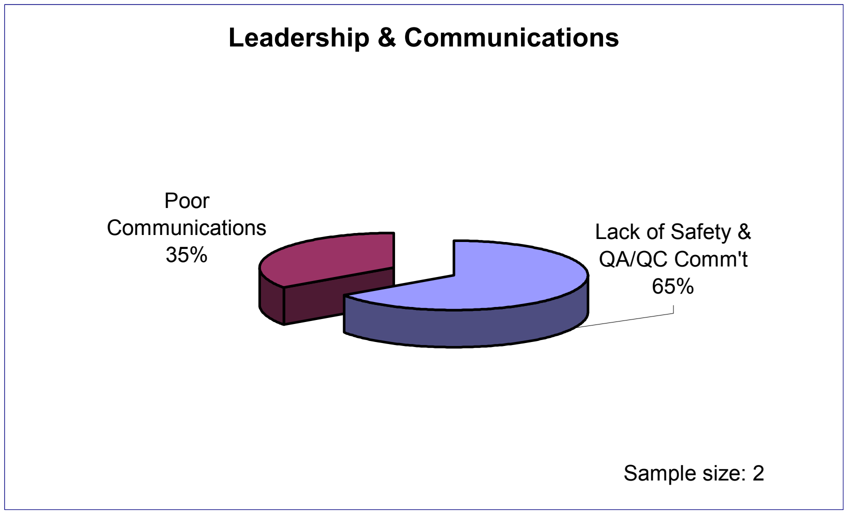

Figure 5.42. Leadership & Communications – Rework Cost Contribution

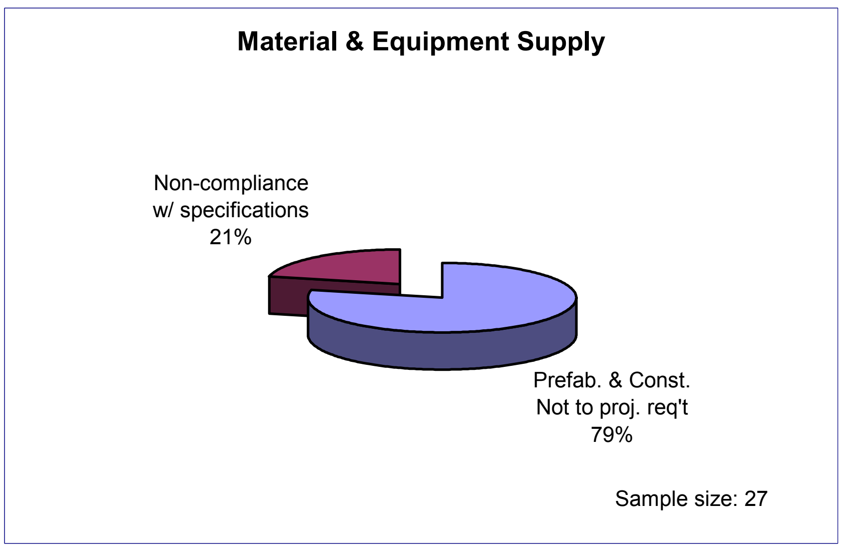

Figure 5.43. Materials & Equipment Supply – Rework Cost Contribution

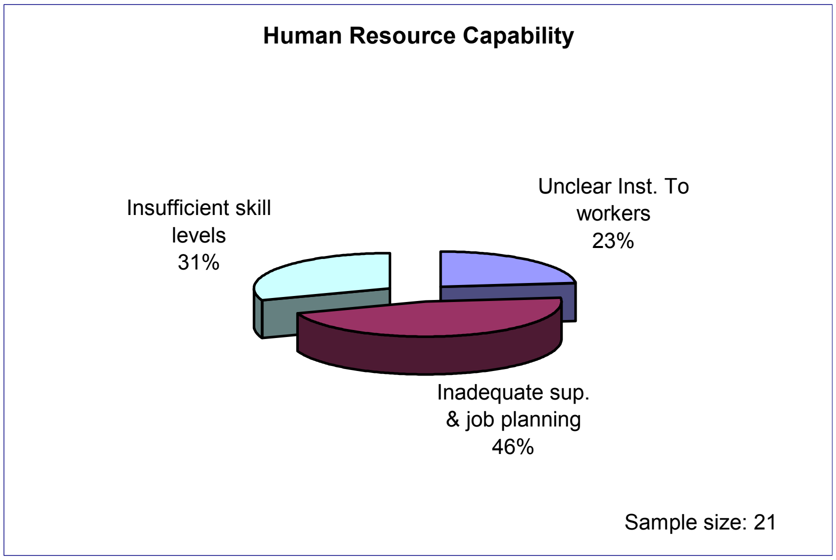

Figure 5.44. Human Resource Capability – Rework Cost Contribution

Analyzing Figures 5.40 to 5.44, "Errors & Omissions" in "Engineering & Reviews" is the second level cause that contributed most to rework costs, accounting for $280,205.41. This contribution comprises 78% of the total cost of "Engineering & Reviews". This figure is itself 48% of the total rework costs incurred during the study period ($582,703.13). Similarly, "Prefabrication and Construction Not to Project Requirements" in "Material & Equipment Supply" and "Inadequate supervision & Job Planning" in "Human Resource Capability", accounted for $68,154.35 and $54,909.53, respectively. This is 12% and 9% of the total rework costs of the study period. These three causes contributed the most significantly to rework in terms of dollar value.

Figures 5.45 to 5.57 display the distribution of those previous figures into their respective third level causes. For example, "Late Design Changes" in Figure 5.45, was involved in 12 rework incidences. Within "Late Design Changes", "Errors & Omissions" contributed 69%; "Scope Changes" contributed 19%; and "Inadequate Execution Plan" contributed 12%. The sum of all these third level causes is equal to the total cost of their respective second level causes.

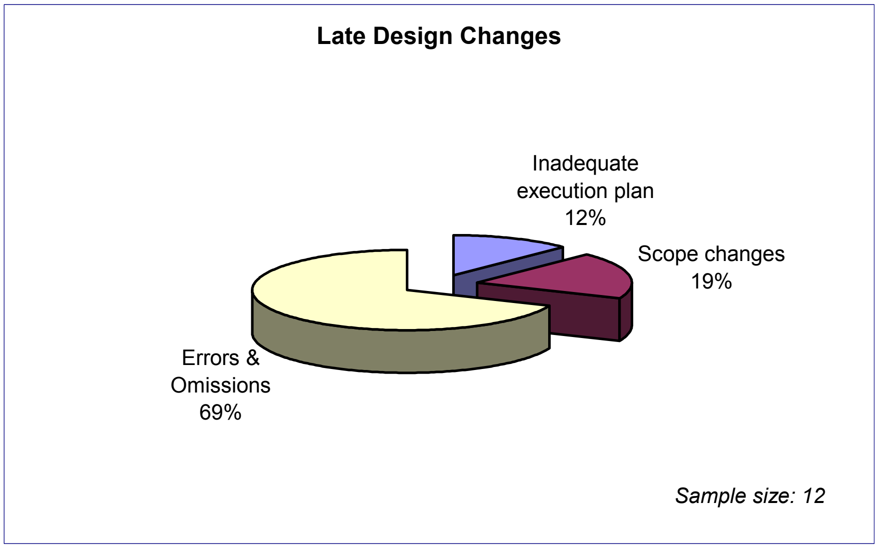

Figure 5.45. Late Design Changes – Rework Cost Contribution

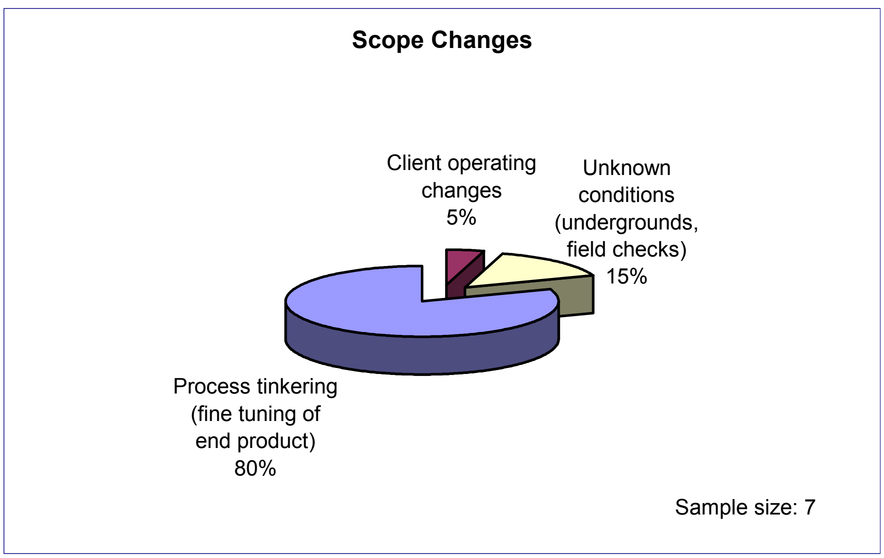

Figure 5.46. Scope Changes – Rework Cost Contribution

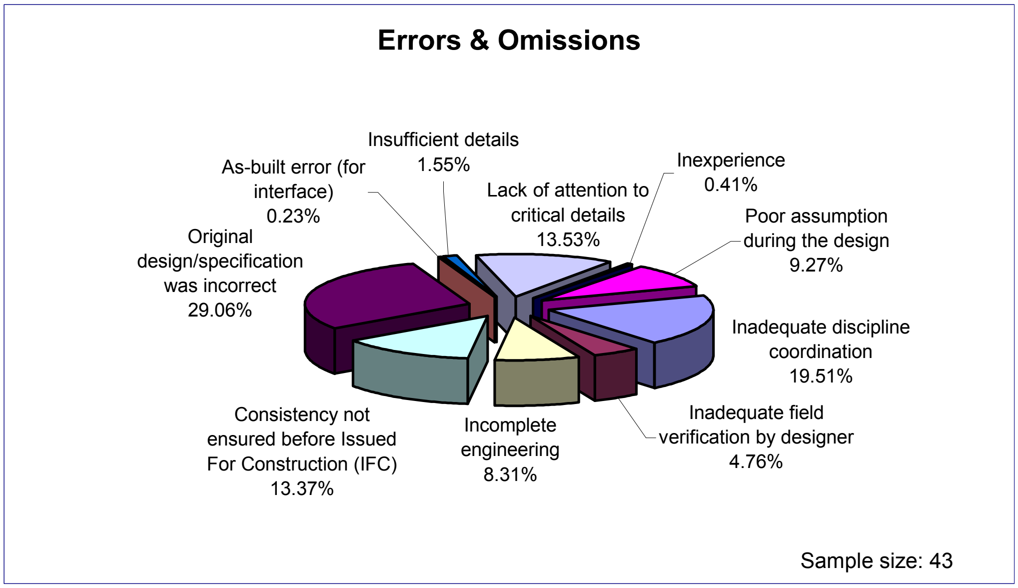

Figure 5.47. Errors & Omissions – Rework Cost Contribution

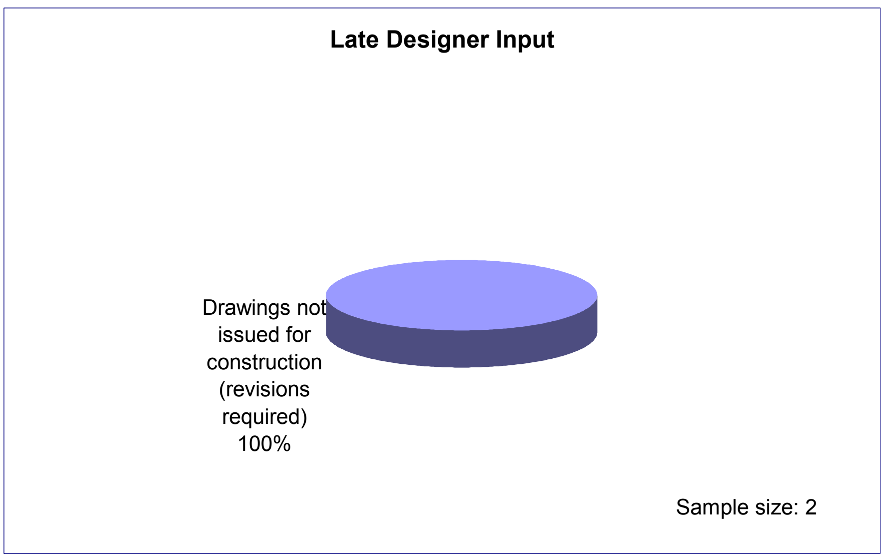

Figure 5.48. Late Designer Input - Rework Cost Contribution

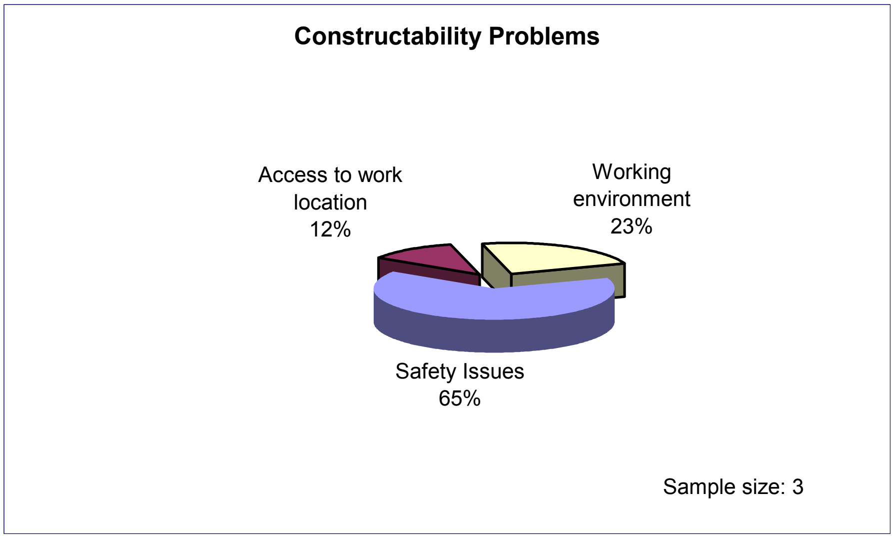

Figure 5.49. Constructability Problems – Rework Cost Contribution

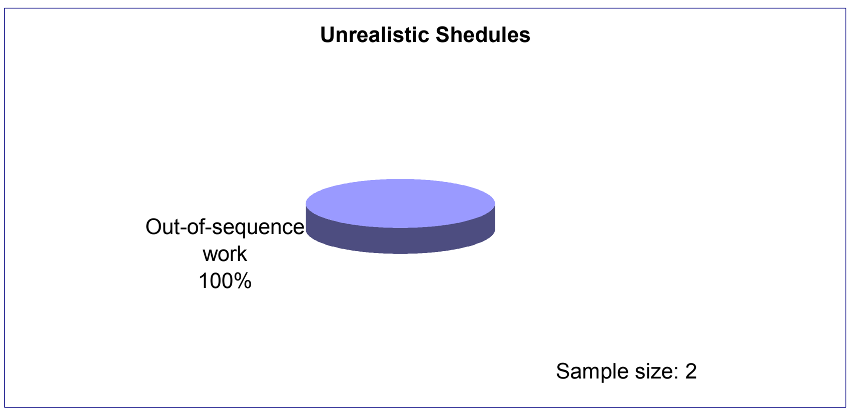

Figure 5.50. Unrealistic Schedules – Rework Cost Contribution

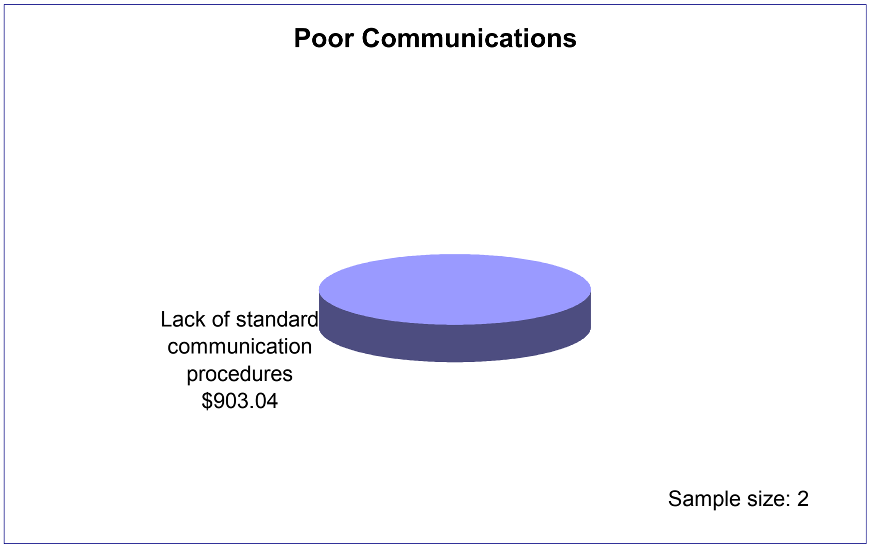

Figure 5.51. Poor Communications – Rework Cost Contribution

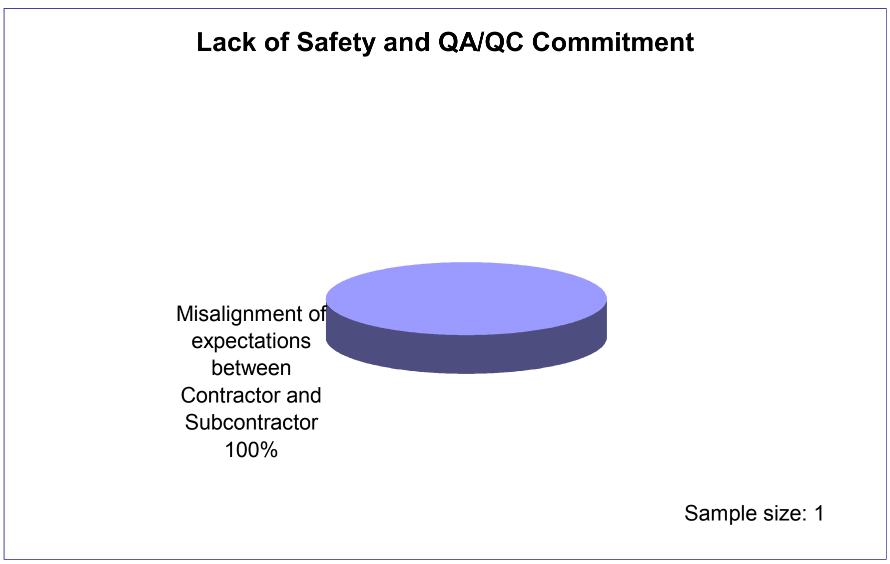

Figure 5.52. Lack of Safety and QA/QC Commitment – Rework Cost Contribution

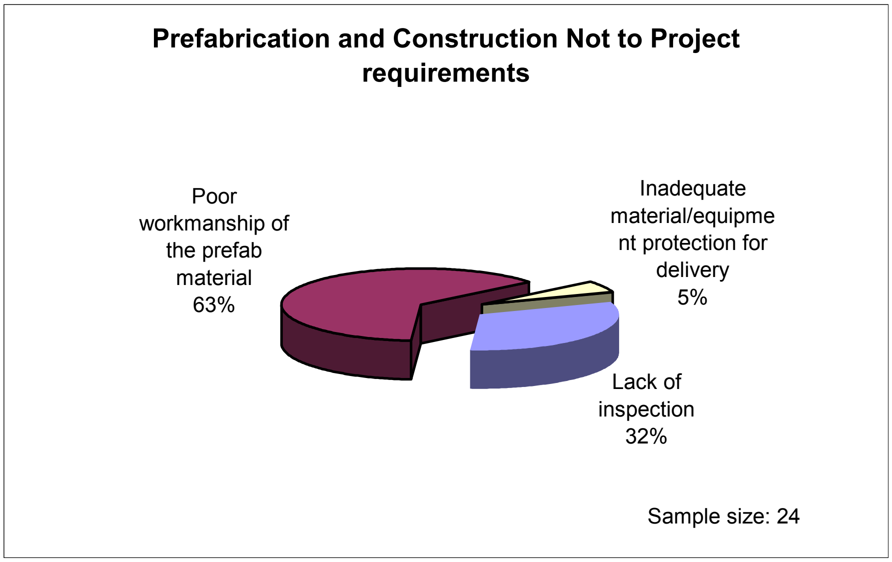

Figure 5.53. Prefabrication and Construction Not to Project Requirements – Rework Cost Contribution

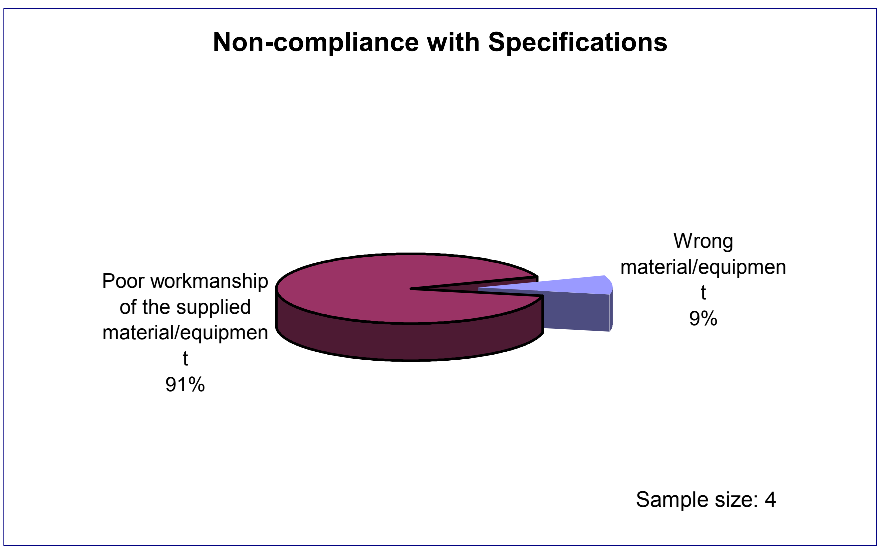

Figure 5.54. Non-compliance with Specifications – Rework Cost Contribution

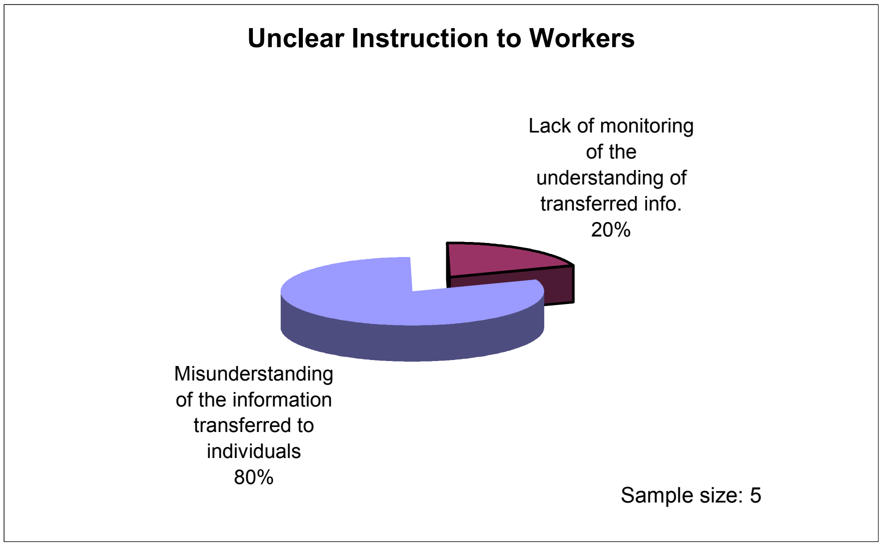

Figure 5.55. Unclear Instruction to Workers – Rework Cost Contribution

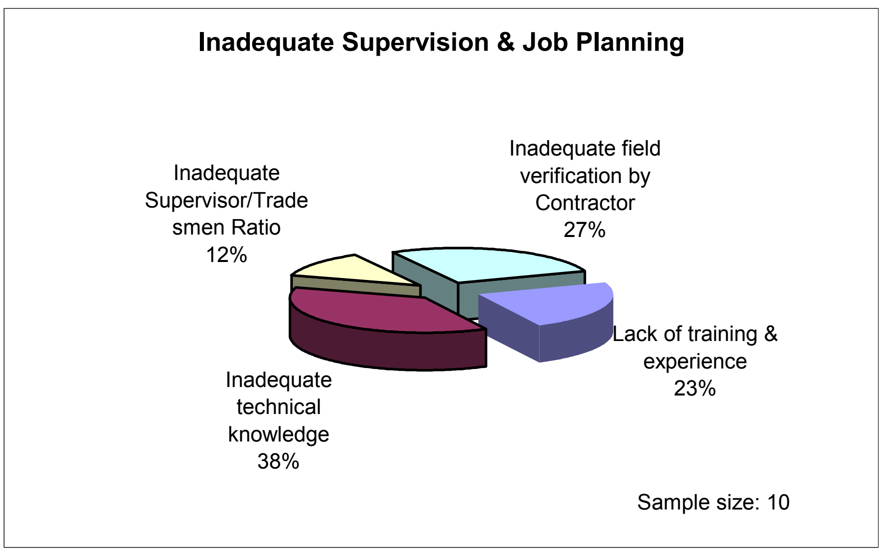

Figure 5.56. Inadequate Supervision & Job Planning – Rework Cost Contribution

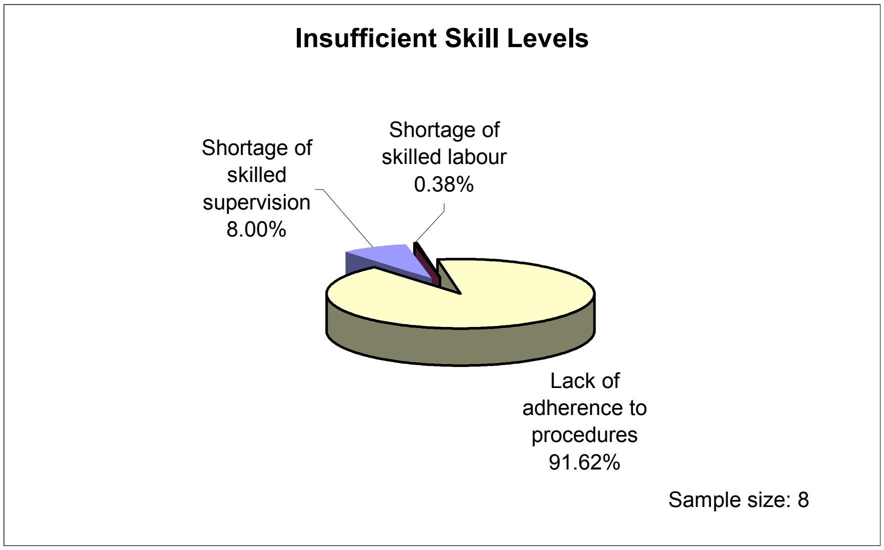

Figure 5.57. Insufficient Skill Levels – Rework Cost Contribution

5.5.3.1 Summary

"Engineering & Reviews" and "Human Resource Capability" were the first level causes that resulted in most of the overall construction rework costs, at $359,237.71 (61.65%) and $119,368.55 (20.40%), respectively. For the second level causes, "Errors & Omissions" in "Engineering & Reviews" and "Prefabrication and Construction Not to Project Requirements" in "Material and Equipment Supply", comprised $279,427.80 (48%) and $67,905.54 (12%), respectively, of the total rework. Under "Errors & Omissions", "Original Design/Specification was Incorrect" and "Inadequate Discipline Coordination" were the third level causes that most contributed to the overall rework costs, totalling $81,188.53 (14%) and $54,511.50 (9%), respectively. Table 5.4 lists all rework root causes with their relative contribution to the total rework direct costs.

Referring to Table 5.4, "Original Design/Specification was Incorrect" and "Inadequate Discipline Coordination" in "Errors & Omissions", both within the "Engineering & Reviews" classification, are the root causes that most contributed to overall direct costs of rework during the study period, at 13.93% and 9.35%, respectively. Similarly, "Poor Workmanship of the Prefabricated Material" in "Prefabrication and Construction Not to Project Requirements", under the "Materials & Equipment Supply" heading, contributed 7.37%, representing the third root cause that contributed most to the total rework costs.

Table 5.4. Total Rework Cost Contribution by Cause

First Level	Second Level	Third Level	Contribution to Rework ($)	%
Engineering & Reviews	Errors & Omissions	Original design/specification was incorrect	$81,188.53	13.93%
Engineering & Reviews	Errors & Omissions	Inadequate discipline coordination	$54,511.50	9.35%
Material & Equipment Supply	Prefab and Const. Not to project req't	Poor workmanship of the prefab material	$42,956.13	7.37%
Engineering & Reviews	Errors & Omissions	Lack of attention to critical details	$37,806.10	6.49%
Engineering & Reviews	Errors & Omissions	Consistency not ensured before Issued For Construction (IFC)	$37,356.18	6.41%
Human Resorce Capability	Insufficient Skill levels	Lack of adherence to procedures	$33,404.63	5.73%
Engineering & Reviews	Scope Changes	Process tinkering (fine tuning of end product)	$31,624.36	5.43%
Engineering & Reviews	Late Design Changes	Inadequate execution plan	$27,772.40	4.77%
Engineering & Reviews	Errors & Omissions	Poor assumption during the design	$25,900.30	4.44%
Engineering & Reviews	Errors & Omissions	Incomplete engineering	$23,232.54	3.99%
Human Resorce Capability	Unclear Instructions to Workers	Misunderstanding of information transferred to individuals	$22,301.25	3.83%
Material & Equipment Supply	Prefab and Const. Not to project req't	Lack of inspection	$21,411.31	3.67%
Human Resorce Capability	Inadequate Supervision & Job Plan	Inadequate technical knowledge	$20,630.58	3.54%
Material & Equipment Supply	Non-compliance with specifications	Poor workmanship of the supplied material/equipment	$16,717.92	2.87%
Human Resorce Capability	Inadequate Supervision & Job Plan	Inadequate field verification by Contractor	$15,105.43	2.59%
Engineering & Reviews	Errors & Omissions	Inadequate field verification by designer	$13,311.53	2.28%
Human Resorce Capability	Inadequate Supervision & Job Plan	Lack of training & experience	$12,668.31	2.17%
Engineering & Reviews	Late Design Changes	Scope changes	$7,754.30	1.33%
Human Resorce Capability	Inadequate Supervision & Job Plan	Inadequate Supervisor/Tradesmen Ratio	$6,750.00	1.16%
Engineering & Reviews	Scope Changes	Unknown conditions (undergrounds, field checks)	$5,868.10	1.01%
Human Resorce Capability	Unclear Instructions to Workers	Lack of monitoring of the understanding of transferred information	$5,451.34	0.94%
Engineering & Reviews	Late Design Changes	Errors & Omissions	$5,016.16	0.86%
Construction Planning & Scheduling	Unrealistic Schedules	Out-of-sequence work	$4,918.02	0.84%
Construction Planning & Scheduling	Late Designer Input	Drawings not issued for construction (revisions required)	$4,414.50	0.76%
Engineering & Reviews	Errors & Omissions	Insufficient details	$4,330.60	0.74%
Construction Planning & Scheduling	Constructability Problems	Safety issues	$3,810.00	0.65%
Material & Equipment Supply	Prefab and Const. Not to project req't	Inadequate material/equipment protection for delivery	$3,538.10	0.61%
Human Resorce Capability	Insufficient Skill levels	Shortage of skilled supervision	$2,917.00	0.50%
Engineering & Reviews	Scope Changes	Client operating changes	$1,774.59	0.30%
Leadership & Communications	Lack of Safety	Misalignment of expectations between Contractor and Subcontractor	$1,702.08	0.29%

Cont'd

Table 5.4. Total Rework Cost Contribution by Cause (Cont'd)

First Level	Second Level	Third Level	Contribution to Rework ($)	%
Material & Equipment Supply	Non-compliance with specifications	Wrong material/equipment	$1,647.89	0.28%
Construction Planning & Scheduling	Constructability Problems	Working environment	$1,372.99	0.24%
Engineering & Reviews	Errors & Omissions	Inexperience	$1,158.33	0.20%
Leadership & Communications	Poor Communications	Lack of standard communication procedures	$903.04	0.15%
Construction Planning & Scheduling	Constructability Problems	Access to work location	$704.91	0.12%
Engineering & Reviews	Errors & Omissions	As-built error (for interface)	$632.20	0.11%
Human Resorce Capability	Insufficient Skill levels	Shortage of skilled labour	$140.00	0.02%
			$582,703.13	**100.00%**

5.6 Total Field Rework Workforce Hours

The total amount of rework workforce hours for the period studied (April 29th – December 19th, 2002) was calculated in order to get a figure of the total direct labour accounted for rework. To obtain a more realistic number, only field rework performed directly by the Alliance partners, and with actual workforce hours, was included in this analysis. Based on these qualifications, the total rework items (125) were reduced to 81, with a total workforce hours of 4,954. The other 44 rework incidences were either performed by a third party (subcontractor), or by the EPC contractors.

This analysis classified the total field rework workforce hours by Alliance partner. In addition, each subtotal for each main contractor was subdivided into two different working shifts, day shift and night shift. Every shift was then further subdivided into straight time, overtime (x 1.5), and double-time (x 2). Figures 5.58, 5.59, and 5.60 show the field rework workforce hour breakdown for each Alliance partner.

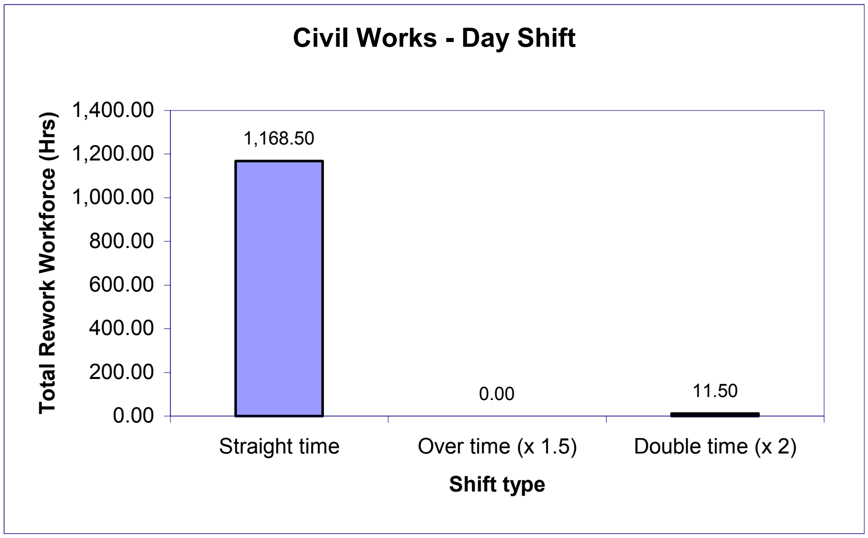

Figure 5.58. Civil Works – Total Field Rework Workforce Hours

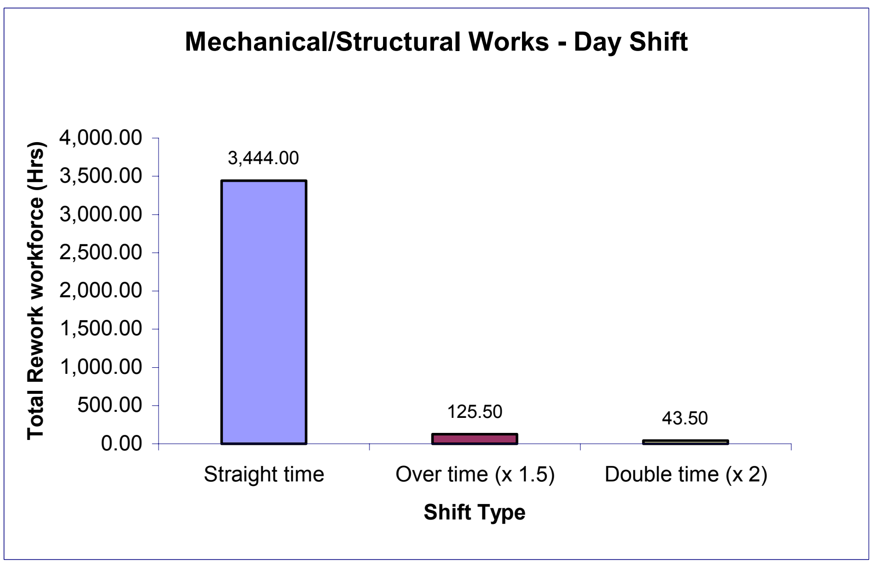

Figure 5.59. Mechanical/Structural Works - Total Field Rework Workforce Hours

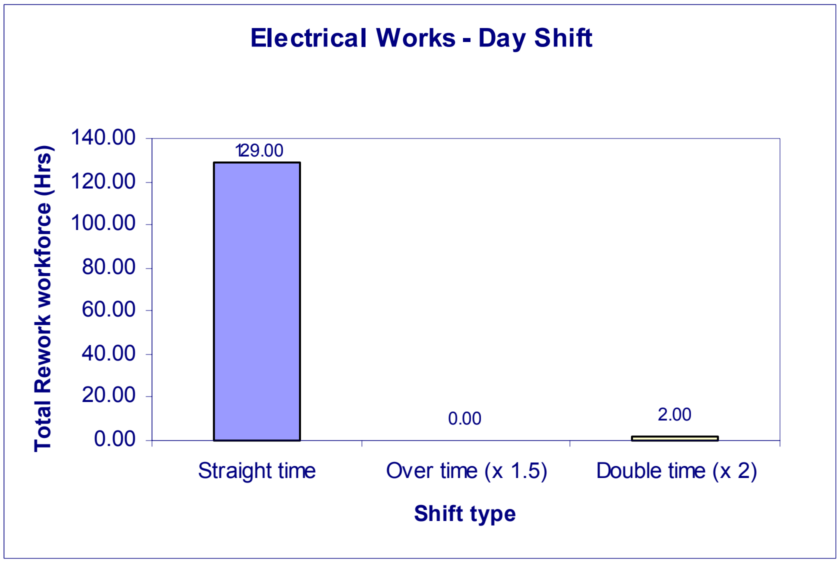

Figure 5.60. Electrical Works - Total Field Rework Workforce Hours

Generally, the majority of the field rework workforce hours (99.39% or 4,924 hours) were performed during the day shift. This figure is divided as follows: 4,741.50 hours (96.29%) during straight time; 125.50 hours (2.53%) in overtime; and 57.00 hours (1.16%) in double-time. The Civil work's Alliance partner performed only 30 hours of field rework during the night shift (not shown on the figures) in straight time. This work includes a night shift premium in addition to the day-shift straight time.

Therefore, it is reasonable to deduce that most rework was performed simultaneously with normal construction activities. One reason for this approach might be that working overtime or night shifts was considered more expensive and risky. Also, the workflow of activities was not affected to such a degree that it needed crews to be reallocated during these shifts.

5.7 Masterformat™ Activity Elemental Classification

According to the Construction Specification Institute and Construction Specifications Canada, *MasterFormat™* (1995) "is a master list of number and titles for organizing information about construction requirements, products, and activities into a standard sequence. Therefore, Masterformat facilitates standard filing and retrieval schemes throughout the construction industry". During data collection, for each rework item identified in the field, a Masterformat activity classification was made in order to later classify the rework incidences according to a construction industry standard.

The 125 rework items were classified according to Masterformat for each main discipline, as shown in Figures 5.61, 5.62, and 5.63. Only the descriptions for the activity code possessing the most rework occurrences are displayed. Appendix K contains a description for the rest of the activity codes.

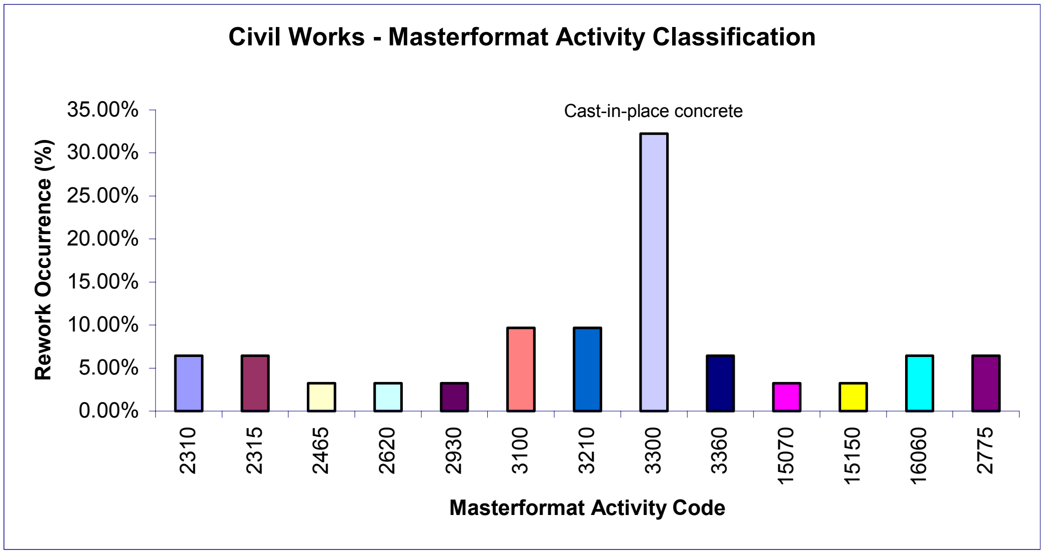

Figure 5.61. Masterformat Activity Classification – Civil Works

According to Figure 5.61, a high percentage of rework (32.26%) within the civil works occurred on the activity code #3300, which refers to "Cast-in place concrete". This is understandable since concrete work represents the majority of civil activities.

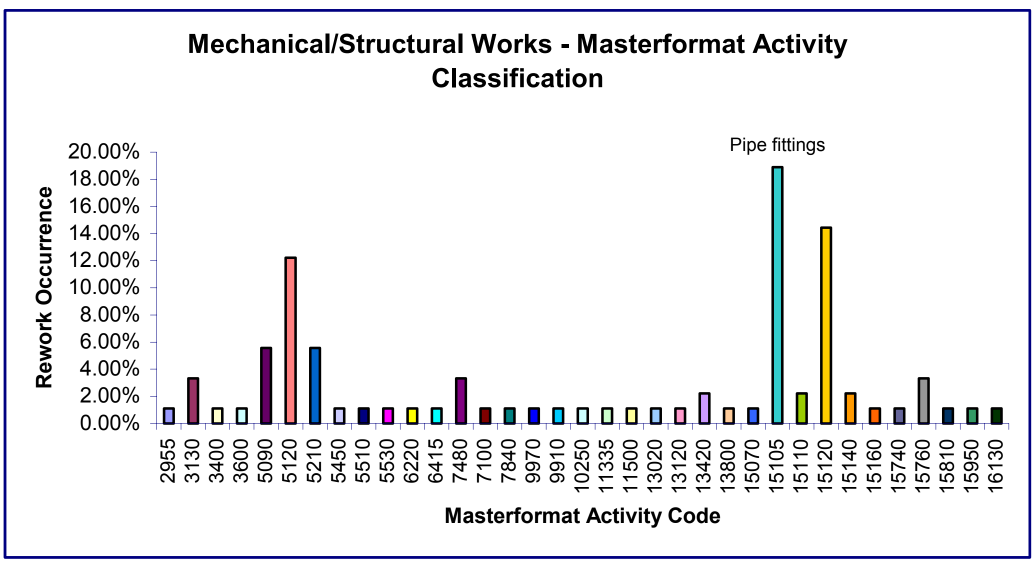

Figure 5.62. Masterformat Activity Classification – Mechanical/Structural Works

Referring to Figure 5.62, most of the rework within the mechanical/structural works occurred on activity code #15105 (Pipe fittings) with 18.89%. This activity was closely followed by activity code #15120 (Piping specialties – supports) with 14.44%. These figures represent much of the rework done on prefabricated materials that arrived to the site with defects. It is noteworthy that "Prefabrication and Construction Not to Project

Requirements" in "Material & Equipment Supply" were among the causes that most contributed to rework.

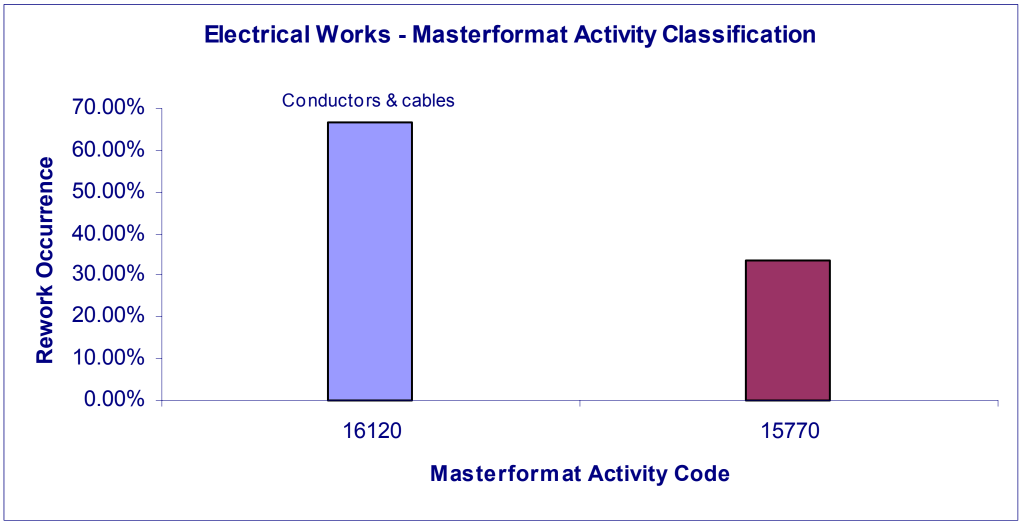

Figure 5.63. Masterformat Activity Classification – Electrical Works

Electrical works had very few field rework incidences. One major reason for this is that the electrical contractor had relatively few activities in the field during the pilot study period; consequently, few rework incidences were reported. Also, the majority of field changes experienced were promptly resolved with engineering prior to construction, thus avoiding most of the rework.

In addition to the results displayed in Figures 5.61 to 5.63, a different approach was made to analyze the monetary contribution of each Masterformat activity to the overall rework cost. For the same reasons discussed in Section 5.5.3, a total of only 108 rework items are being considered for the calculations in this analysis. Figures 5.64 to 5.66 display the results of the dollar contribution to rework of each activity code within each discipline.

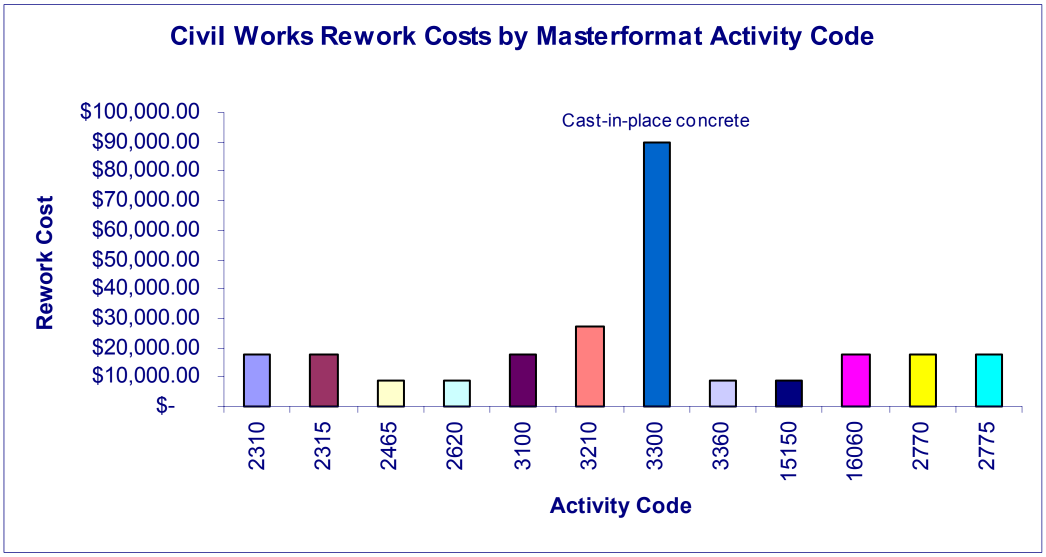

Figure 5.64. Rework Cost Contribution by Masterformat Activity Code – Civil Works

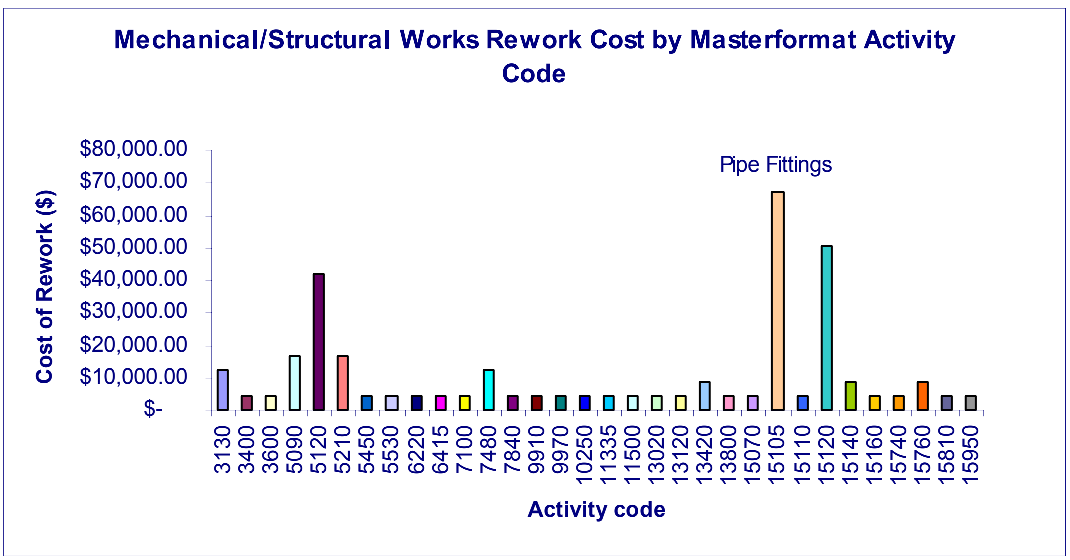

Figure 5.65. Rework Cost Contribution by Masterformat Activity Code – Mechanical/Structural Works

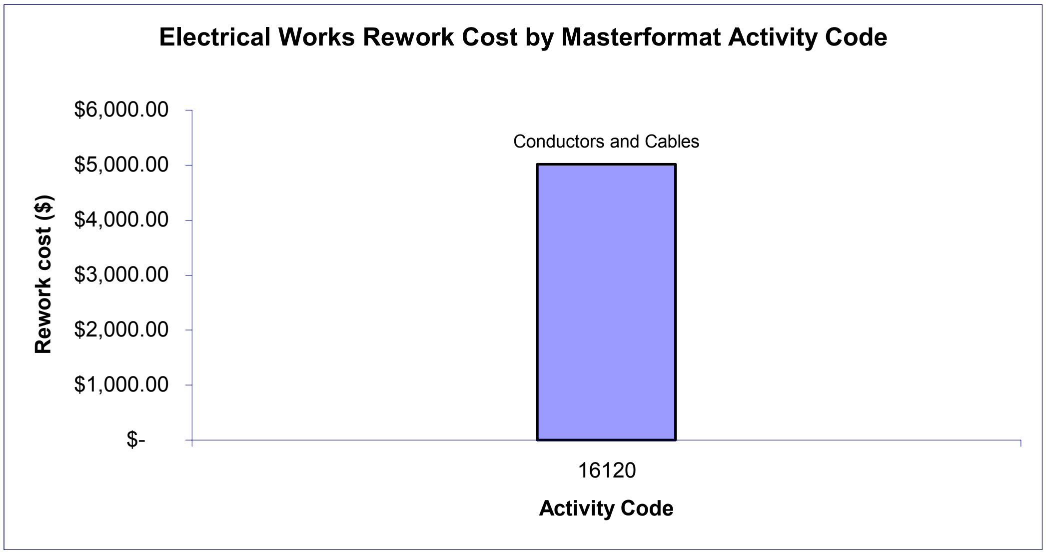

Figure 5.66. Rework Cost Contribution by Masterformat Activity Code – Electrical Works

Referring to Figures 5.64 to 5.66, "Cast-in place concrete" (#3300) totalled $89,588.19 (15%) of the overall rework direct costs of civil works. Within the mechanical/structural works, "Pipe fittings" (#15105) totalled $67,159.77 (12%), and "Piping specialties" (#15120) totalled $50,369.83 (9%) of the overall rework direct costs. Table 5.6 lists all Masterformat activity codes with their relative contribution to the total rework direct costs.

Table 5.5. Total Rework Cost Contribution by Masterformat Activity Code

Masterformat Activity Code	Description	Rework Cost Contribution ($)	% of Total Rework Cost
3300	Cast-in-place concrete	$ 89,588.19	15%
15105	Pipe fittings	$ 67,159.77	12%
15120	Piping specialties - supports	$ 50,369.83	9%
5120	Steel prefabricated elements	$ 41,974.86	7%
3210	Reinforcement steel for concrete	$ 26,876.46	5%
2310	Grading - Construction, shaping & finishing earthworks	$ 17,917.64	3%
2315	Excavation & Filling	$ 17,917.64	3%
3100	Formwork - Cast-in-place concrete	$ 17,917.64	3%
16060	Basic Electrical Materials - Grounding & Bonding	$ 17,917.64	3%
2775	Cast-in-place sidewalks	$ 17,917.64	3%
5090	Metal fastenings - Anchor bolts	$ 16,789.94	3%
5210	Steel joist members - structural steel	$ 16,789.94	3%
3130	Steel frames - permanent forms	$ 12,592.46	2%
7480	Exterior wall assemblies	$ 12,592.46	2%
2465	Drilled Caisson - Cut off elevation	$ 8,958.82	2%
2620	Pipe underdrain system	$ 8,958.82	2%
3360	Concrete Finishes	$ 8,958.82	2%
15150	Floor drains	$ 8,958.82	2%
13420	Instruments - Control valves	$ 8,394.97	1%
15140	Portable water piping	$ 8,394.97	1%
15760	Terminal heating & colling units	$ 8,394.97	1%
16120	Conductors & Cables	$ 5,016.16	1%
3400	Precast concrete structure	$ 4,197.49	1%
3600	Grouting - anchoring devices	$ 4,197.49	1%
5450	Metal supports - Electrical supports	$ 4,197.49	1%
5530	Metal fabrications - Gratings	$ 4,197.49	1%
6220	Finish carpentry (millwork) - standard pattern wood trim	$ 4,197.49	1%
6415	Countertops - installation	$ 4,197.49	1%
7100	Protective covers	$ 4,197.49	1%
7840	Firestopping - Includes material installed in cavities and around penetration	$ 4,197.49	1%
9910	Paints - Exterior & interior paintings	$ 4,197.49	1%
9970	Coatings for steel	$ 4,197.49	1%
10250	Service walls - wall assemblies and wall mounted units	$ 4,197.49	1%
11335	Sedimentation Tank Equipment	$ 4,197.49	1%
11500	Industrial and process equipment - Pumps	$ 4,197.49	1%
13020	Prefabricated building modules	$ 4,197.49	1%
13120	Prefabricated structures	$ 4,197.49	1%
13800	Door frames - installation	$ 4,197.49	1%
15070	Concrete inertia bases - for mechanical equipment	$ 4,197.49	1%
15110	Pressure regulating valves	$ 4,197.49	1%
15160	Interior rainwater drainage	$ 4,197.49	1%
15740	Water treatment equipment	$ 4,197.49	1%
15810	Ductworks - material & fabrications	$ 4,197.49	1%
15950	Equipment testing, adjusting, and balancing	$ 4,197.49	1%
	Totals:	**$ 582,703.13**	**100%**

5.8 Schedule Impact and Ripple Effect

The schedule impact for most of the rework incidences was not calculated on account of the contractors absorbing the field rework duration into other scheduled activities. All contractors have, in their field rework construction form, a schedule impact field that needs to be filled accordingly (see Appendix H). Although rework has an estimated duration for completion, this information was usually omitted due to its negligible schedule impact on the total project duration. A primary reason for this omission is that the activities were overestimated during the scheduling process, thus providing a lag time for any possible interruption. In addition, most rework items required relatively low workforce hours in order to be completed, so the contractors' had the option of relocating crews from original activities to perform the rework, and then returning them to their initial location without significantly interrupting the original activity.

5.8.1 Severity Analysis Matrix (SAM)

An alternative approach was developed to account for the impacts to the schedule based on rework on an individual activity and the cumulative effect of rework. The severity index is a simple scale of 1 to 5 that the observer uses to rank the impact severity (1 being minimal impact, and 5 being severe impact). In making this assessment, the observer would take into account the total impact of the rework on related activities, the project phase, and the amount of rework to date on the project. Appendix L shows the Severity Analysis Matrix (SAM) for rating each rework incidence based on the previous criteria.

However, the Severity Analysis Matrix was not used due to the need for clarifications to better define what constitute "few", "moderate", and "many" occurrences. Although 125 rework incidences were studied, it is unclear under which terms we could classify this figure. Also, the SAM would not have a meaningful value since the pilot study scope ended before final project completion.

5.8.2 Performance Factor (PF)

Efforts were made to obtain a performance factor value for rework activities. The intent was to get a snapshot of the Performance Factor (PF) previous to the rework event, and then a PF value of the activity after rework completion. In this way, the impact of rework on the productivity and cost of the activity could be measured.

However, the study encountered difficulties in the process of collecting data of the actual workforce hours prior to the rework event at a detailed activity level. This occurred mainly for two reasons. First, due to the contractual terms of this project and of the project control requirements, only information on main activities such as piling, structural concrete, piping, structural steel, etc. was tracked by the Alliance partners. Subcontractors directly performing the construction work kept the rest of the information at activity-specific levels. Consequently, the performance factor analysis was done based on the general activities' workforce hours and not for detailed construction tasks. This generalization became an issue for obtaining information at activity-specific levels, thus making it almost impossible to get an actual workforce hours figure prior to rework.

An example of this observation was randomly chosen for rework CRW # 705-2-12. In this rework item, the anchor bolting in one of the pile caps at the Warehouse Building was built with the wrong orientation, thus preventing it from fitting with the shelving. The resulting rework involved cutting off the anchor bolts, aligning them in the proper location, and relocating the shelving. Complications arose, however, when attempting to obtain the actual workforce hours in the field for this activity prior to the moment of rework detection (i.e. anchor bolt installation). When asking the foreman for the total actual workforce hours before the rework incidence, the response was that this data were unavailable because work was being performed on a lump-sum contract. This particular activity was the same in several other areas as well. Consequently, when focusing on this particular activity, where rework occurred, the actual hours included hours spent on the same activity in other areas. Therefore, the performance factor prior to rework occurring would not represent the actual figures for the activity in which the rework occurred. This is one of the disadvantages of using lump-sum-type contracts; most of the detailed information for particular activities is not tracked, thus making it difficult to quantify productivity at certain specific levels.

In order to properly obtain the required information to calculate the PF prior to the rework incidence, it would be necessary to keep a record of the total workforce hours for each activity and for each construction work package at every measurable level. One way to get this information would be to check the daily work sheet for each contractor. However, not only is this an extremely long and involved process, the information encountered in these sheets does not show whether the work was rework, extra work, or otherwise. Again, the resulting figure would not be accurate for the purposes of this analysis. Some of the suggestions, then, to facilitate the gathering of required information prior to rework are:

1. Instruct the foreman/supervisor to clearly check the location, workforce breakdown, and start/finish dates in the case of a rework event. This way, an accurate figure will be provided by the person directly supervising the work.

2. Contract a specific person to collect the information derived from each rework incidence detected on site. This person should have sufficient knowledge to understand the execution of construction activities and to be able to define how, when, why, and where rework occurred. This will reduce the workload of the foreman/supervisor in gathering all rework information on a large project, and will provide concise findings about rework root causes and indices.

3. Adopt a user-friendly rework reporting system to facilitate information retrieval at any moment by any person related to the project. This could also be used as a learning tool to help prevent further rework events on future projects.

5.8.3 Re-engineering Effort

Efforts were made to obtain records of the engineering time that was associated with the response given to a Request for Information (RFI). This RFI was related to rework events and/or to expended re-engineering time, itself associated with rework. The purpose of this was to obtain a perspective of the impact of field rework on engineering hours and, by extension, costs. However, this figure was difficult to obtain due to the uncertainties and lack of precision in the recording of time spent on each RFI, and also the fact that major re-engineering occurred offsite. Consequently, the reliability of the results is questionable because field engineers do not keep records of their time spent answering each RFI. In spite of this concern, informal answers were obtained by field engineers on site, and the majority agreed that between 4 and 5 RFI's were responded to daily. This figure might be used as a guideline, but it could not be considered a fact.

5.8.4 Summary

During the pilot study, efforts were made to analyze the indirect impacts of rework through the previously outlined measures (schedule impact, performance factor, re-engineering effort). However, the study discovered the difficulty in attempting to filter and to obtain certain specific information indirectly associated with a rework event. Future research, however, is recommended to clarify and acquire a standard method to assess the indirect impacts of rework, since the indirect costs associated with rework may prove to be as or more significant than the direct field costs themselves.

6.0 FINDINGS AND RECOMMENDATIONS

This study has proposed a methodology for measuring, quantifying, and classifying construction field rework, and can be adopted as an industry-wide standard for full-scale data collection and for comparison on numerous projects. A case study of an actual project was used to verify the methodology and to collect a sample data set with which to illustrate its application. This section summarizes the findings and offers some recommendations on how to improve future studies.

6.1 Rework Index

During the study period (April 29th, 2002 – December 19th, 2002), a rework index was determined based on the overall data collected and the actual figures obtained from the project's cost control system and from the field data collection. The rework index for the overall Alliance was 0.87%. Civil works' rework index was 1.01%, for structural/mechanical works the index was 0.94%, and for electrical works the index was 0.09%. The relatively low rework index for electrical works occurred as a consequence of the relatively low level of construction activity for this contractor during the study period.

These rework indices represent only a snapshot of the pilot study period. They cannot be considered a definitive number due to the fact that the pilot study ended before final project completion. Also, the associated costs of previous rework incidences acquired prior to the pilot study period were not included in the calculation.

6.2 Causes of Rework

Among the five first level rework root cause classification groups, "Engineering and Reviews" was identified as the main contributor to the overall construction field rework with 55.41% of total rework contributions. After further analysis of the second level causes for "Engineering and Reviews", "Errors and Omissions" was found to contribute 38.48%. 10.00% of the contribution was from "Late Design Changes" and 6.93% was from "Scope Changes". In the process of identifying the root causes of "Errors & Omissions" (from "Engineering & Reviews"), it was found that "Consistency Not Ensured Before Issued for Construction" (13.85%) and "Original Design/Specification Was Incorrect" (6.35%) were the major contributing causes of the rework studied during the pilot study. The second largest contributing area of rework was "Material and Equipment Supply" with 23.46%. Two key causes were identified under this broad area: (1) "Non-compliance with Specifications" at 3.52%, and (2) "Pre-fabrication and Construction Not to Project Requirements" at 19.94%. "Human Resource Capability" had an 18.28% contribution while "Construction Planning and Scheduling" and "Leadership and Communications" both made relatively low contributions to field rework, with 2.47% and 0.38%, respectively. The main root causes (third level) identified in each of these areas are, respectively: "Insufficient Skill Level", "Constructability Problems", and "Poor Communications". Syncrude's investment in the placement of a number of on-site planning personnel for each work task on each discipline, is noteworthy, as it considerably minimized the contribution of "Construction Planning and Scheduling" to field rework.

Based upon the final results of this study, it is evident that more emphasis must be placed on planning during the project's design and engineering phases in order to avoid further field rework during the construction stage. As shown in the three different types of analyses, within "Engineering & Reviews", "Errors & Omissions" was the second level cause that most contributed to field rework. Moreover, within "Errors & Omissions", "Consistency Not Ensured Before Issued for Construction", "Original Design/Specifications Was Incorrect", and "Inadequate Discipline Coordination" were the three third level causes that contributed most to field rework. One important measure, which should be taken to minimize rework, is to develop high design/engineering review standard procedures (i.e. value engineering, squad checks, etc.) and to provide more time and resources to fully review and check all engineering milestones, especially in fast-track type projects.

It is also noteworthy that within "Material & Equipment Supply", "Prefabrication and Construction Not to Project Requirements" had a high percentage of contribution to field rework. Although the prefabrication and construction of certain equipment/material can increase the project's construction progress by performing a parallel activity offsite, inconsistencies and/or omissions in the drawings can affect the prefabricated equipment/material thus needing to perform rework onsite to fix the problem. Therefore, particular attention and resources must be allocated in this field to avoid fabrication mistakes in the shop yard. This way, onsite rework on prefabricated equipment/materials can be avoided, thereby maintaining the workflow of normal construction activities.

The results presented in this study reflect the project stage and characteristics at the time when rework data was collected. The early stage of the project plus the fast tracking construction type on some components, such as the Water Treatment Plant (WTP), demonstrates "Engineering & Reviews" as the biggest cause of rework. At a later stage of the project, another field rework root cause category could potentially be the biggest contributor.

However, these findings are project-specific, and to make industry-wide conclusions, the proposed methodology must also be used on subsequent projects over varying periods of time.

6.3 Lessons Learned and Recommendation for Future Studies

The proposed methodology for measuring, quantifying, and classifying construction field rework proved to be very effective in categorizing field rework among five broad areas. These areas were further explored in order to obtain more complete results from more specific causes, within particular levels (such as the third level). The intent of this methodology is to determine which root causes contributed most to field rework and to obtain an index for field rework that can be used to quantify the magnitude of rework-associated costs on a given project. The output of the proposed methodology provides an indication of the extent and magnitude of rework on a project, and which factors most contributed to rework so that they can be remedied.

To record cost information and causes of rework, there needs to be a predefined rework tracking process in place. The purpose of this well-defined tracking system is to entirely record cost information and causes of rework as incidences of rework occur in the field. This system should be developed and maintained by an individual specifically assigned for this task (i.e. data collection, reporting, and monitoring field rework data). The cost and hours for each field rework incidence detected on site should be based on actual costs and hours counted through the rework initiator's administration system. The rework cost tracking system should also be built in such a way that enables all parties involved to take prompt actions towards managing construction rework (i.e. through preventive measures, cost forecasts, lessons learned, etc.). Also, the system should be updated regularly and distributed to the relevant parties periodically. Maximum benefits can be achieved by implementing the system at the beginning of field construction activities. By making the reporting and monitoring of rework incidences a part and partial requirement of the contractual agreement, the implementation of such a system becomes not only achievable, but also required.

Field engineering should have a designated person who reviews the newly released drawings "Issued for Construction" (IFC) in order to prevent any field inconsistency prior to construction. This person should carefully double-check all specifications and designs to verify their compatibility with actual project construction (especially when adopting the same design from a previous project). Companies should invest in acquiring such a person, who will have access to all engineering disciplines from the start to the end of the project. This person would represent the closest link between construction and engineering, and would work with the rework coordinator.

Numerous rework incidences occurred on site fixing errors originally made in the shop yard. There should be an effective and timely communication between field personnel and the shop yard to discuss any field changes that could lead to rework. For example, if a change occurs on the field, the shop yard should be immediately informed about this change, and then make the proper modifications to avoid sending the incorrect piece of material that would then need to be fixed on site (and thereby contributing to rework).

Rework cause classification should be an unbiased process. The field rework coordinator should consult all parties involved in the incidence, before classifying rework causes and apportioning percentages. The field rework coordinator should also have access to information at both field and engineering management levels.

The project's contractual agreement (Alliance concept) was the key element that contributed to the success of this pilot study. Because of the agreement, everyone was responsible for the success of the project; consequently, information and rework data were available to all Alliance partners. Sometimes, under different contractual agreements, some information is retained in order to avoid any further penalizations or loss of profits. However, with the Alliance concept, that is, the team concept, many of these issues did not exist. The effectiveness of a rework tracking process (i.e. costs, identifying causes, etc.) is greatly enhanced through the Alliance or partnership concept.

Another factor that contributed to the success of this pilot study was the pre-study preparation. This included the preparation of the preliminary field rework tracking forms after an intensive study of rework tracking processes. As the study evolved, a simpler form was developed, in addition to the more detailed forms. Based on these forms, a database was created to automate the storage and retrieval of rework data on future projects.

Finally, the involvement of the personnel on the Aurora 2 project and the involvement and feedback of the Pilot Study Steering Committee ensured that all technical matters that arose were discussed and addressed. This feedback ensured that decisions made to address ambiguities over the course of the study were in line with the COAA's vision for standardizing field rework tracking.

A number of challenges were encountered on the pilot study, as follows:

- *Schedule Extension:* The case study's project schedule was extended several times, thus affecting the data collection period. The initial scope of this pilot study was to record all information in one area from start to finish and therefore get a valid figure for the rework index. Due to schedule extensions, however, the scope of data collection was expanded to encompass all areas of the project. Since the pilot study period concluded before the entire project was complete, the values obtained for the field rework index are not meaningful unless they are re-calculated upon project completion.

- *Subjectivity of Cause Classification:* Classifying rework causes to the third level, and attributing multiple root causes to a single rework event, is a fairly subjective process. Classification decisions may vary based on an individual's own criteria and perspectives. Generally, there is a consensus as to the first level of classification, but subjectivity increases with increasing levels of detail. The proposed approach to classification of multiple root causes attempts to reduce some of this subjectivity.

7.0 CONTRIBUTIONS AND EXTENSION OF THE STUDY

One of the most significant contributions arising from this study is the thorough analysis and treatment of the field rework issue. In attempting to address this issue, the researchers faced a number of ambiguities that were subsequently resolved with industry input, thus bringing further standardization of the definition, quantification, and classification of field rework. Standardization is critical for the repeatability, predictability, and comparability of any measure, such as a field rework index and classification system.

As a result of this study, the following contributions were generated for the construction industry to use in extensions on this study:

1. A clearer definition of construction field rework.

2. A proposed index for quantifying construction field rework, as well as a clear definition of the components of this index.

3. A detailed 3-tier classification system for the causes of rework, and a systematic approach for apportioning multiple root causes.

4. A detailed approach to collecting field rework data, including a set of data collection forms.

5. A database in which to store the data collected, for the automated analysis of rework data and report generation.

While the objectives of the pilot study have been achieved, the real value of the work done is in its extension. In order for the construction industry to benefit from this research, these standards and this methodology must be used over time to populate the database with data compiled from multiple projects. In this way, meaningful field rework indices and root cause classification results will arise. With these trends, the construction industry can formulate strategies to deal with the most significant causes leading to field rework. In addition, benchmarking both within organizations and for the industry as a whole can be done to measure and ultimately reduce field rework. Finally, this methodology can be modified and extended during the engineering phase of a project, and similar studies also may be conducted for engineering rework.

The methodology developed in this study can also be used as an industry Best Practice for measuring and classifying construction field rework. The next step is to use this methodology over time and to collect sufficient data, from which the industry can develop a Best Practice for minimizing and preventing construction field rework and eventually engineering rework.

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