

Analysis of a Construction Small- Projects Rework Reduction Program for a Capital Facility

by

Di Zhang

A thesis

presented to the University of Waterloo

in fulfillment of the

thesis requirement for the degree of

Master of Applied Science

in

Civil Engineering

Waterloo, Ontario, Canada, 2009

© Di Zhang 2009

Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Reducing field rework is widely regarded as an effective way of improving construction performance in terms of productivity, cost, schedule, quality, and safety. While existing rework reduction programs and much literature exist concerning this challenge, there is a need for further analysis and continuous improvement of rework reduction methods.

Based on such an analysis, this research develops a generalized conceptual model for a rework reduction program, which is intended to reduce rework by managing a continuous improvement loop with four functional processes: (1) rework tracking and cause classification, (2) evaluation of rework and its causes, (3) corrective action planning, and (4) integration of changes into the total management system. A case study is conducted to examine and verify the functional mechanisms and effectiveness of the generalized model, by investigating a rework reduction program implemented in practice that represents the generalized model, and by analyzing the impact trends on rework in terms of frequency, cost, and labor hours over a considerable time period. The results indicate that rework can be reduced significantly with such a program.

Acknowledgements

First, I would like to express my greatest gratitude to my research supervisor Dr. Carl T. Haas for his mentoring and encouragement during the whole process of my Master program. He gave me the opportunity to start my graduate study and research in the University of Waterloo and allowed me the freedom and opportunities to explore many interests and make this time truly enjoyable, while keeping me focused through the guidance and foresight.

I would also like to thank Ontario Power Generation for providing their database for this research. And thank Aecon, Black & Macdonald, Crosby Devar, and SNC-Lavalin for their support. In particular, I would like to thank Mr. Robin Granger, Mr. Brian Flumerfelt and Ms. Melanie Lahti of OPG for their support of investigation of OPG's rework program and database. I also extend my thanks to Mr. Paul Murray of SNC-Lavalin, Mr. Frank Kattlus of Aecon, Mr. Michael Campbell of Black & Macdonald, and Mr. Ian Morton of Crosby Devar for their support on interview and data collection.

My special thanks to Ms. Barb Trotter for her kind help of proof reading. Her valuable advices contributed greatly to this thesis.

Furthermore, I would like to acknowledge the faculty and staff of the Civil and Environmental Engineering Department at the University of Waterloo for all of their efforts to support my graduate study and research. In addition, my sincere thanks go to my fellow graduate students who work alongside and my friends.

Finally, I owe many thanks to my family: to my parents and parents in law, thank you for always being there to provide generous support; especially to my wife and daughter, you are always the cornerstone in my life.

Table of contents

Author’s Declaration	ii
Abstract	iii
Acknowledgements	iv
Table of contents	v
List of Figures	ix
List of Tables.....	x
Chapter 1 Introduction.....	1
1.1 Background and Need	1
1.2 Scope and Objectives	1
1.2.1 Scope	1
1.2.2 Objectives	2
1.3 Methodologies	3
1.4 Structure of Thesis.....	3
Chapter 2 Background and Literature Review	5
2.1 Introduction	5
2.2 Literature Review	7
2.2.1 Definition of rework.....	8
2.2.2 Impact of rework on project performance	8
2.2.3 Classification of the causes of rework.....	10
2.2.4 Rework reduction tools.....	13
2.2.4.1 The Field Rework Index (FRI).....	13
2.2.4.2 Zero field rework self-assessment opportunity checklist	14

2.2.4.3 COAA’s Project Rework Reduction Tool (PRRT)	15
2.2.5 Literature review summary.....	15
2.3 Nuclear Power Plant Maintenance and Modification.....	18
2.4 OPG’s Reporting System	19
2.4.1 Summary of OPG nuclear power generation.....	19
2.4.2 OPG’s Station Condition Record (SCR) system	21
Chapter 3 Conceptual Model for Rework Reduction Program	24
3.1 Introduction	24
3.2 Overview of Rework Reduction Program Model.....	24
3.3 Description of the Rework Reduction Program Model Process	28
3.3.1 Rework tracking and cause classification.....	28
3.3.1.1 Rework tracking and causes classification: Inputs	28
3.3.1.2 Rework tracking and cause classification: Approaches & Techniques	33
3.3.1.3 Rework tracking and causes classification: Outputs	34
3.3.2 Rework Impact evaluation and trend analysis.....	35
3.3.2.1 Rework impact evaluation and trend analysis: Inputs	36
3.3.2.2 Rework impact evaluation and trend analysis: Approaches & Techniques.....	37
3.3.2.3 Rework impact evaluation and trend analysis: Outputs	38
3.3.3 Corrective action planning	39
3.3.4 Integration with project management system.....	43
Chapter 4 Case Study and Analysis.....	44
4.1 Introduction	44
4.2 Investigation of OPG’s Rework Program.....	44
4.2.1 OPG’s SCR system and changes for supporting the rework program.....	45
4.2.2 Rework causes classification	46

4.2.3 OPG Nuclear’s rework program process	48
4.2.4 Rework program benefit	50
4.2.5 Corrective action plan program	52
4.2.6 Examples of corrective action	54
4.3 Pickering Nuclear Power Plant Maintenance and Modification.....	55
4.3.1 Project location.....	55
4.3.2 Brief of maintenance and modification program.....	56
4.3.3 Challenges of reducing rework in this type of construction.....	58
4.3.3.1 Complexity of the spatial layout and the technical specifications.....	58
4.3.3.2 Interference between new components and the existing facilities.....	60
4.3.3.3 Quality of the prefabrication.....	60
4.3.3.4 Special safety requirements of the nuclear industry	61
4.4 Data Collection and Fusion	62
4.4.1 Principles of data collection	63
4.4.1.1 Use multiple sources of data.....	63
4.4.1.2 Establish and maintain a chain of evidence.....	63
4.4.1.3 Match the rework evaluation structure	64
4.4.1.4 Collect original data from industry.....	65
4.4.2 Approaches to and content of data collection.....	65
4.4.2.1 Frequency of rework influence safety performance	66
4.4.2.2 Reduction of rework hours as a reflection of the potential for improvement in productivity	67
4.4.2.3 Cost savings as direct motivation for applying a rework reduction program	69
4.4.2.4 Classification of root causes as a guide for corrective action.....	69
4.4.3 Summary of the data collection practice	70

4.4.3.1	Timeline of data collection.....	70
4.4.3.2	Summary of the data collected	72
4.5	Rework Impact Evaluation	74
4.5.1	Overall occurrence of rework	74
4.5.2	Rework hours and cost	77
4.5.3	Rework root causes analysis.....	79
4.5.3.1	Contribution of the root causes of rework as a percentage of the overall rework amount	80
4.5.3.2	Trends in the rework occurrence for each root cause over the time	82
4.5.3.3	Magnitude of rework labor hours and dollar value by root cause	83
4.5.3.4	Percentage contribution of first level root causes to labor hours and dollar value	85
Chapter 5	Conclusions and Recommendations	87
5.1	Introduction	87
5.2	Findings and Conclusions.....	87
5.2.1	The role of the generalized rework reduction program in a management hierarchy	88
5.2.2	Learnability of the generalized rework reduction program	89
5.2.3	Comprehensive rework record	89
5.2.4	Quantitative analysis of rework.....	90
5.2.5	Effectiveness of the corrective action resulting from the rework reduction program ..	92
5.3	Recommendations for Future Studies.....	94
References	97
Appendices	102
Appendix A	Examples of SCR Reports	103
Appendix B	Examples of Rework Events.....	116

List of Figures

Figure 2-1 Generic Cause-and-Effect Rework Diagram Derived From Qualitative Data	12
Figure 2-2 COAA's Fishbone Rework Cause Classification	13
Figure 2-3 OPG Nuclear Unit Capability Factor (%)	21
Figure 3-1 Process Flow Chart of RRP	26
Figure 3-2 Rework Tracking and Cause Classification	28
Figure 3-3 Rework Tracking Process	31
Figure 3-4 Rework Impact Evaluation and Trend Analysis	36
Figure 3-5 Corrective Action Planning	42
Figure 4-1 Process Flow Chart of OPG Nuclear's Rework Program	49
Figure 4-2 Aerial Photograph of the Pickering Nuclear Power Station	56
Figure 4-3 Evidence Chain for the Rework Case Study Analysis	64
Figure 4-4 Overall Occurrence of Rework by Year	76
Figure 4-5 Overall Occurrence of Rework by Month	76
Figure 4-6 Trend in Rework Labor Hours	78
Figure 4-7 Trend in Direct Cost of the Rework	79
Figure 4-8 Percentage Contribution of Root Causes of Rework	81
Figure 4-9 Rework Occurrence by Root Causes Over the Year	83
Figure 4-10 Rework Labor Hours by Root Causes Over Time	84
Figure 4-11 Direct Cost of Rework by Root Causes Over Time	84
Figure 4-12 Rework Labor Hours by Root Cause Group Over the Time	86
Figure 4-13 Direct Cost of Rework by Root Cause Group Over the Time	86

List of Tables

Table 2-1 Deviation Categories of the Causes of Rework	10
Table 3-1 Rework Reduction Program in the Management Hierarchy	25
Table 3-2 List of Identified Root Causes of Rework.....	32
Table 3-3 Rework Evaluation Structure	39
Table 4-1 OPG's Rework Causes Category.....	47
Table 4-2 Total Number of Rework Events for Year 2006-2008.....	67
Table 4-3 Number of Rework Event Records Retrieved.....	72
Table 4-4 Number of Rework Event Records Reviewed for Investigation.....	73
Table 4-5 Numbers of Full Reports involved in Rework Impact Evaluation.....	73
Table 4-6 OPG's Nuclear Segment OM&A Expenses	75
Table 4-7 Rework Hours and Direct Cost as a Percentage of Total Work Size.....	79

Chapter 1

Introduction

1.1 Background and Need

In the construction industry, rework is widely regarded as a significant challenge that affects the productivity practice of a project. A conventional and effective approach to improving productivity rather than the implementing of expensive new technology is to integrate a rework reduction program into the construction management system.

The focus of this research is to evaluate the effectiveness of this method through a study of the rework associated with the life cycle of a program of small projects in the area of involving ongoing facility maintenance and modification. The study examines the amount by which rework can be reduced when an effective rework reduction program is implemented and determines how much time and cost savings and how much improvement in productivity and quality is possible solely through the mitigation of rework.

1.2 Scope and Objectives

1.2.1 Scope

This thesis is a study of rework control in small construction projects for a capital facility. The study focuses on analyzing the rework associated with a single construction program of many small construction projects involving ongoing facility maintenance and

modification. The research covers the activities involved in the projects over a significant period of time. A rework reduction program model is established to guide the case study of this rework reduction.

In the case study, rework is examined with respect to a specific industry: nuclear power plant maintenance and modification. The reduction of rework in this sector, while challenging, is also a worthwhile endeavor and is especially timely, given that over the next decade Ontario plans to spend \$20 billion on the construction of nuclear plants (Carr, 2006). The rework evaluation is conducted in terms of cost, labor hours, schedule, and quality & safety, which are the essential concerns of project performance.

1.2.2 Objectives

The specific objectives of this research were as follows:

1. To investigate and identify the rework problem in construction field work
2. To classify the root causes of rework in nuclear power plant maintenance and modification activities
3. To measure the rate of occurrence, the number of hours involved, and the costs of the rework for a program of small projects
4. To develop a conceptual model for a rework reduction program
5. For a rework reduction program implemented in practice, to analyze trends in the rework and its causes in order to determine how rework can be reduced by measurement combined with corrective action and to ascertain the amount of reduction that can result from such a program

1.3 Methodologies

The research was broken down into the following steps:

1. Conduct a thorough literature review.
2. Investigate Ontario Power Generation's (OPG) Station Condition Records (SCR), and study their rework measurement and corrective action programs by studying their process files, and conducting interviews with experts.
3. Collect rework data by retrieving rework and related information from the OPG SCR database.
4. Use a descriptive statistical approach to analyze the changes in the rate of rework with respect to its occurrence, the hours involved, and the cost.
5. Analyze trends in the rework rates using the moving average and smoothing techniques.

1.4 Structure of Thesis

This thesis is divided into five principal chapters. Chapter 1 outlines the need for a study of a generalized rework reduction program model and the measurement in a case study of the impact of a rework reduction program on the performance of small projects. The overall objectives, scope, and methodology of the research are also outlined in this chapter.

Chapter 2 presents a synopsis and discussion of the subject areas pertinent to this thesis. Existing information available in the literature is presented, including the definition of rework, the impact of rework on construction project performance, methods of measuring

rework, classification of the causes of rework, and tools for the reduction of rework. The literature review is followed by a summary that identifies possible further steps in this area of research, which are also the basis of this study. Fundamental information about the nuclear power industry is presented, along with background information about the company and its management program that are involved in the case study for this research.

Chapter 3 describes the new rework reduction model as a specific management program issue within the overall company management strategy. A brief discussion is included with regards to describing the operation processes, including rework tracking and classification, impact evaluation, corrective action planning and integration with the entire management system.

Chapter 4 reports a case study directed by the rework reduction model outlined in Chapter 3. OPG's Pickering Nuclear Power Plant (NPP) maintenance and modification program is the case study project. OPG's rework reduction program is first introduced, including their process, the classification of the rework causes, and their corrective action planning. Conditions specific to the case study project are also briefly discussed. The rework is measured according to the rework evaluation structure of the model, including data collection, data fusion, and calculations. The results of the evaluation are presented visually in charts and diagrams.

Chapter 5 outlines the key conclusions that can be drawn from the completed analysis and provides a list of recommendations for future work.

Chapter 2

Background and Literature Review

2.1 Introduction

As the word implies, rework means that an action must be executed more than once in order to achieve the specified objectives, which results in the unnecessary consumption of additional resources in the form of labor, materials, and facilities beyond what would have been used if the action had been performed only once. In construction activities, in addition to overruns in the schedule and cost (Hwang, Thomas, Haas, & Caldas, 2009) (Josephson, Larsson, & Li, 2002), rework has the further effect of causing potential risk with respect to quality and safety (Love P. E., 2002). Many existing studies have quantified the impact of rework on a project primarily in terms of cost and have also focused on classifying and measuring the causes of rework (Fayek, Dissanayake, & Campero, 2004).

In the construction industry, rework is widely regarded as an obvious factor that prevents improvement in productivity (McTague & Jergeas, 2002), although the hours and cost for rework represent only a small portion of the fieldwork as a whole, if fieldwork is considered to consist of the time and cost associated with direct work, support, rework, and delays (or idle time) (Assaf & Al-Hejji, 2006). However, a common belief is that a reduction in rework is a cost-effective approach to improving productivity because most rework could be mitigated by improving the management of the process and increasing

human performance, neither of which is as expensive as adopting technical innovation in order to improve productivity.

Many consider that rework can be reduced by improving a project's general construction management, and therefore, few researchers have focused on a study limited specifically to a rework reduction program (Love, Holt, Shen, Li, & Irani, 2002). However, it is possible that studying the approach, process, and program involved in rework reduction would not only go a long way towards solving the rework problem, but would also serve as a pilot study that could be extended to more of the factors that have a negative effect on productivity, such as delays. This study thus represents a road map for project management to use in their efforts to determine a plan for reducing rework, including countermeasures or interventions.

In this chapter, the literature review as the first part includes the definition of rework, the impact of rework on construction project performance, methods of measuring rework, classification of the causes of rework, and tools for the reduction of rework. The literature review is followed by a summary that identifies possible further steps in this area of research, which are also the basis of this study. In the second part, fundamental information about the nuclear power industry is presented, along with background information about the company and its management program that are involved in the case study for this research.

2.2 Literature Review

Existing studies of construction rework have been produced mainly by three institutes or researchers: the Construction Industry Institute (CII), the Construction Owners Association of Alberta (COAA), and Dr. Peter E. D. Love, a researcher from Australia.

Dr. Love focused on the project management level rather than the field construction level, and studied rework and its causes under the condition of a whole project life cycle throughout the phases of front-end planning, design, and construction including even start-up and operation. In recent decades, owners have tended to adopt a new business process model – Design-Build (DB) rather than Design-Bid-Build (DBB), because packaging design and construction into one contract significantly reduces the owner's work load of organizing and coordinating between the designer, consulting engineer and the contractor. At the same time, the DB model also gives the contractor more space to define and develop an efficient design and construction program. On the other hand, because design and construction time are compressed in the DB model, the project complexity increases due to the increased degree of overlap of activities, and the occurrence of rework increases accordingly (Love P. E., 2002). Based on this background, Love's research can be viewed as relevant to the project management level, and it explains impact and causes of rework in the project management process.

CII and COAA are research institutes founded for the benefit of the construction industry, which leads them to focus more attention on finding efficient and economical approaches for contractors' construction activities. They consider that rework directly prevents

improvements in productivity and results in further overruns with respect to the cost and schedule (Rogge, Cogliser, Alaman, & McCormack, 2001). The relevant research from these two institutes is therefore from the perspective of construction management and has investigated an effective approach to the control of field rework with respect to producing better performance in the areas of process programming, appropriate resource allocation, and human performance management.

2.2.1 Definition of rework

The construction management literature offers several interpretations of rework, which differ in terms of verbal description, scope, and measurement. Love defines rework as the unnecessary effort of redoing a process that was incorrectly implemented the first time (Love P. E., 2002). CII defines field rework as activities that have to be done more than once or activities that remove work previously installed as part of a project (Rogge, Cogliser, Alaman, & McCormack, 2001). COAA research conducted by Fayek adds a constraint with respect to field rework: rework caused by scope changes and order changes from owners is not categorized as field rework (Fayek, Dissanayake, & Campero, 2003). Because this research evaluates the impact of rework on cost, schedule, quality and construction productivity, the CII definition has been selected as appropriate for identifying rework.

2.2.2 Impact of rework on project performance

When the impact on project performance is discussed, quality, schedule, and cost are the three elements commonly used to describe it. The most direct and perspicuous metric for

displaying the impact of rework is the direct cost of the rework, which is also the most easily measured operational approach. Researchers who have studied the rework issue in construction have almost always investigated the direct cost of rework as a percentage of the actual value of the contract (Love & Sohal, 2003).

(Love & Li, 2000) conducted case studies of rework costs for a residential project and an industrial building project and found that the direct cost of rework was about 3.15 % and 2.40 % of the value of the entire contract, respectively. They also identified that the cost of rework in civil and heavy industrial engineering projects could be significantly higher, averaging up to 12.4 % of the value of the contract.

Previous CII research obtained very similar data for the cost of rework. (Smith & Haggard, 2003-1, 2005) showed that the overall range of field rework reported in surveys was from 0.5 % to 19 %, with an average rate of 3.13 %. The surveys collected significant amounts of data from 22 projects, which involved a variety of functional types of projects and included conditions associated with either greenfield projects or modification and maintenance projects. These figures categorically illustrate the fact that additional costs due to rework have a considerable adverse impact on project performance. In addition to the impact of cost on project performance, the additional time required to redo the work would also result in a time shift or delay and would probably affect the project schedule.

2.2.3 Classification of the causes of rework

Three valuable systems for classifying the causes of rework have been discussed in the literature. First, (Burati, Farrington, & Ledbetter, 1992) used deviation categories to identify the causes of rework in nine fast-tracked industrial construction projects (see Table 2-1).

Table 2-1 Deviation Categories of the Causes of Rework

Source: (Burati, Farrington, & Ledbetter, 1992)

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

Second, (Love, Mohamed, & Wyatt, 1997) established a rework classification system based on the study of two construction projects: a residential development and an industrial development. As illustrated in Figure 2-1, the causes of rework are sorted into three principle groups: people, design, and construction. A number of common causes are included in each group, which enhances a user's understanding of the system.

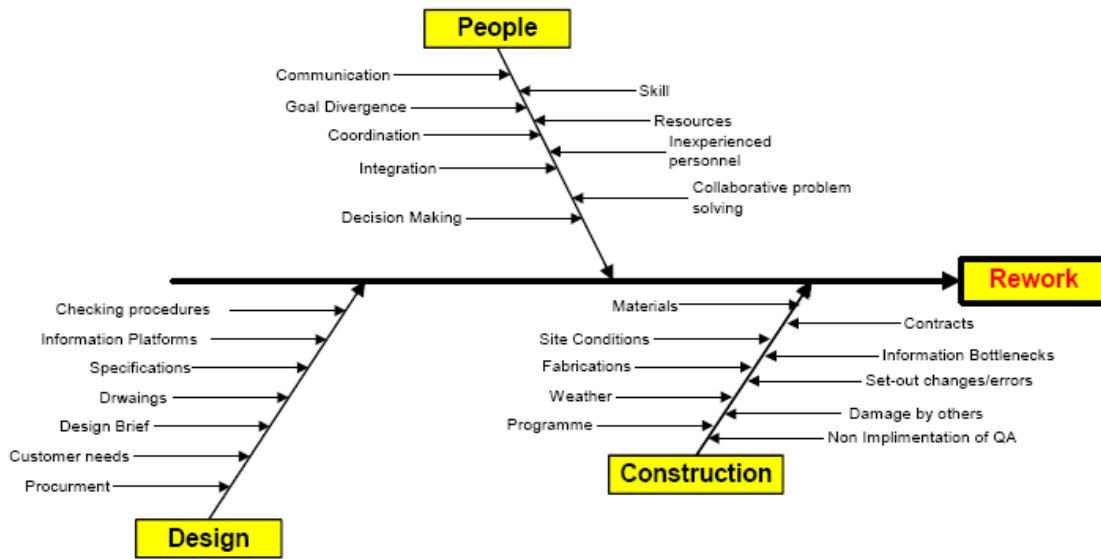


Figure 2-1 Generic Cause-and-Effect Rework Diagram Derived From Qualitative Data

Source: (Love, Mohamed, & Wyatt, 1997)

Third, Fayek determined five major causes of rework: human resources capability, leadership and communications, engineering and reviews, construction planning and scheduling, and materials and equipment supply (Fayek, Dissanayake, & Campero, 2003). Each category has four sub-causes (Figure 2-2). Their classification shows that human performance plays a significant role in the causes of rework.

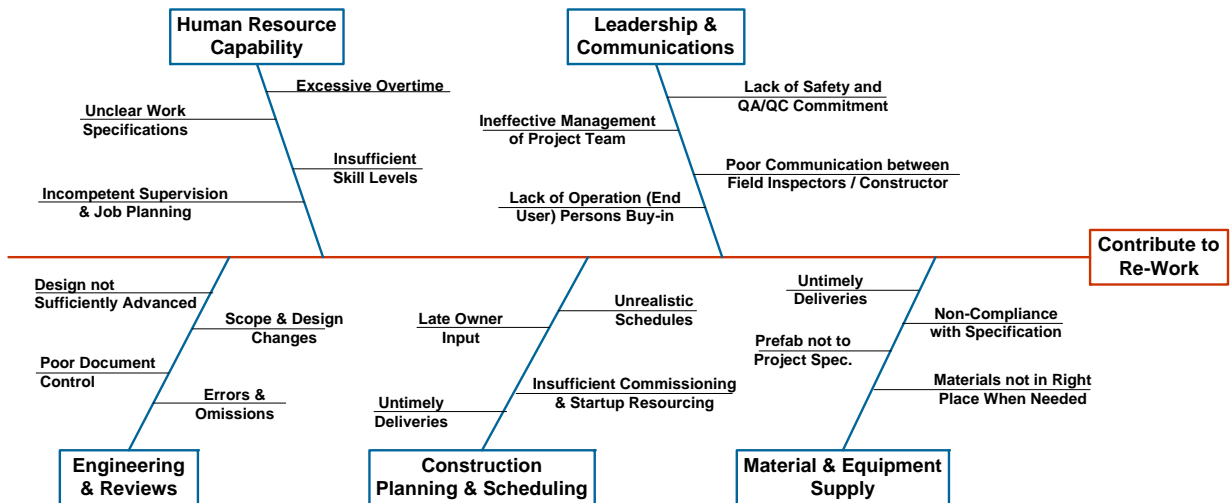


Figure 2-2 COAA's Fishbone Rework Cause Classification

Source: (Fayek, Dissanayake, & Campero, 2003)

2.2.4 Rework reduction tools

2.2.4.1 The Field Rework Index (FRI)

The Field Rework Index (FRI) is a tool developed by CII Research Team153 to provide an early warning for field rework and cost growth (Atkinson, Rogge, & Haggard, 2001). The FRI is intended for use before the start for construction. A list of 14 variables, proposed to represent the project characteristics, was developed and tested with the data taken from completed construction projects. An analysis was carried out to determine how these variables related to field rework. The FRI resulted from statistical analysis of the data collected from a number of actual projects. To apply this tool, the FRI user rates these 14 variables on a scale of 1-5, and totals the scores to get the FRI score for the

current project. By comparing the FRI score to the warning levels resulting from the analysis of the complete projects, early warning for field rework and cost growth is given.

2.2.4.2 Zero field rework self-assessment opportunity checklist

The Zero Field Rework Self-Assessment Opportunity Checklist is a tool developed by CII Research Team 203 to assist in identifying areas for improvement to further strengthen a site construction quality process on the journey to zero field rework (Coles & Haggard, 2005). The authors claim that a multitude of previous quality checklists usually focus on manuals and procedures, document and data control, and material control. Being different from previous tools, the Zero Field Rework Self-Assessment Opportunity Checklist focuses primarily on the aspect of human performance and takes a behavior-based approach to minimizing rework on a project (Smith & Haggard, 2005).

Eight elements are included in the self-assessment:

- | | |
|-------------------------------------|----------------------------|
| 1. leadership | 5. teamwork |
| 2. sufficient and capable resources | 6. documentation |
| 3. employee involvement | 7. absence of shortcuts |
| 4. communication | 8. quality/rework auditing |

After completing the assessment, the project management may determine the best way to share the results with employees in the organization in order to communicate key learning, an implementation plan, and worker involvement (Smith & Jirik, 2006).

2.2.4.3 COAA's Project Rework Reduction Tool (PRRT)

The PRRT is a commercial software developed by the COAA to facilitate project performance against known rework-causing issues. It is expected that the rework in project execution can more often be averted if there is early and honest recognition that deficiencies exist (East, 2004).

The tool is designed to take the evaluation of field rework and rate it on key field rework causing factors. The evaluation could be applied at any point in the project's timeline.

The ratings are interpreted within the 5 principal Rework Cause sections of the COAA fishbone classification of field rework cause. The overall average rating may be used for trending and benchmarking against similar projects, while the suggestion for practical solutions is given to improve future works (COAA, 2006).

2.2.5 Literature review summary

Most studies have conducted an appropriate evaluation of the impact of rework on project performance. Their achievements can be summarized as follows:

1. Most of the research uses the direct cost as the essential factor for evaluating the impact of rework. According to the result, the cost consumed through rework is quite significant and cannot be neglected. It is widely considered that the overrun cost of rework can be mitigated or even eliminated by improving management and adopting specific measures.

2. Through the application of statistical analysis to data from different types of construction projects, both in Australia and in North America, the research by (Love P. E., 2002) and by (Hwang, Thomas, Haas, & Caldas, 2009) proves the following two hypotheses:

- The impact of rework on construction cost performance is significantly different for different project groups.
- The rank orders of the sources of rework are statistically significantly different.

For this research, the general rework reduction model was therefore designed as an open system with considerable flexibility for various construction groups.

3. The above research classified the root causes of rework and also conducted quantitative analysis of the causes, in order to determine the most direct and effective approach to mitigating the occurrence of rework. Since the studies approach the control of rework from different perspectives, different breakdown structures were used to sort the categories of the root causes of rework. However, several common aspects were also addressed:

- Human performance is imperfect.
- Instructions are sometimes inappropriate or incorrect.
- Supplies are sometimes not accurate or prompt.
- The schedule is sometimes not rational.

Summarizing the causes of rework that are listed in the literature was helpful for classifying the causes of rework for this study. This information was required for

the design of the model because an important principle is that the planning of corrective action is based on the classification of the causes.

4. One point common to previous studies should be noted: The tracking and measurement of the impact of rework on a construction project is conducted in a static state, which means that the measurement reveals the severity of the rework up to one point in time or within a specific duration. However, further questions required answers in order to facilitate improvements in a general rework reduction program model:

- How much of the rework and its cost could be reduced through the application of a specific rework reduction program in construction management?
- How significantly do some causes, or related corrective actions, affect the reduction in rework?
- Can rework or additional costs be reduced?

To answer these questions, this research conducted a case study in a current facility maintenance and modification construction project over a considerable period of time. Variations in the influence of rework over the whole project timeline were observed with the goal of revealing whether the new rework program applied to construction management could have a significant positive effect on the reduction of the rework and its impact on project performance.

For the purposes of this study, the case chosen needed to have the following features:

- The project has a timeline that is long enough to provide sufficient data to enable an effective comparison and trend analysis of the rework.
- The adverse impact of rework on project performance is significant enough to have merited the attention of the project management group.
- An adequate amount of data can be accumulated over a long enough period to permit meaningful quantitative analysis.

OPG's Pickering Nuclear Power Station maintenance and modification construction project fit these requirements. This facility was already using a rework program, which was implemented for a period of a few years, and data were collected during that time. The background related to this project is summarized in the following section.

2.3 Nuclear Power Plant Maintenance and Modification

The characteristics of construction with respect to nuclear power plant maintenance and modification differ from those in other sectors of the construction industry. A nuclear power plant project has a long life cycle, and reliability of equipment is thus important for both economic and safety reasons. An owner therefore invests a large amount of capital in maintenance and modification.

The construction aspect of maintenance and modification entails many challenges, such as connections between old and new facilities, the compatibility of old and new specifications, conflict between maintaining an existing structure and making modifications, and the spatial limitations of conducting construction operations in the

existing structure. Under these kinds of conditions, reducing rework also involves additional challenges (Pyy, 2001).

Quality and safety are paramount in a nuclear power plant, so a rework reduction program could be valuable for other reasons in addition to improving productivity and saving money (CNSC, 2008). A reduction in the rework associated with the maintenance and modification of a nuclear power plant is therefore both challenging and worthwhile.

2.4 OPG's Reporting System

2.4.1 Summary of OPG nuclear power generation

Ontario Power Generation (OPG) is an Ontario-based electricity generation company whose principal business is the generation and sale of electricity in Ontario. Their focus is on the efficient production of electricity from their generation assets, while operating in a safe, open and environmentally responsible manner (OPG, 2005).

As one of the largest producers of electricity in North America, Ontario Power Generation operates 65 hydroelectric, 5 fossil and 3 nuclear stations producing more than 21,000 megawatts of electricity. OPG makes an effort to operate the most diversified, low-cost and low-emission electricity production facilities, and to continually improve the efficiency of their generating stations in order to meet the power needs in Ontario for the future (OPG, 2005).

OPG owns and operates the Pickering and Darlington Nuclear Power Stations: two of their three nuclear generation assets. The two stations have a combined generating capacity of about 6,600 megawatts, which meets more than 50% of Ontario's electricity needs. Nuclear power has two major benefits: low operating costs and virtually none of the emissions that lead to smog, acid rain, and global warming. These benefits make nuclear a very attractive option for meeting the province's electricity needs well into the future (OPG, 2005).

OPG's performance report of mid-year 2009 (OPG, 2009) documented the recent condition of the nuclear unit capability as present in Figure 2-3. The report explained the reasons of the changes of the capability factor: "The decrease in Darlington's capability factor was the result of a Vacuum Building Outage (VBO), required every 12 years, which involved the shutdown of the station's four reactors for approximately six weeks. Prior to the start of the VBO, Darlington's unit capability in Q1 2009 was 99.9%. The decline in Pickering A's unit capability reflects higher planned outage days during the first quarter of 2009. Pickering B's reliability improved relative to its Q1-Q2 2008 unit capability, which reflected the shutdown of a unit to replace a calandria tube and an extension to a planned outage." This information reflects two considerations: (1) improving the efficiency of maintenance and modification activities could shorten the outage of units, thus improving production capability; (2) an adequate maintenance and modification program would ensure that production capability would be retained.

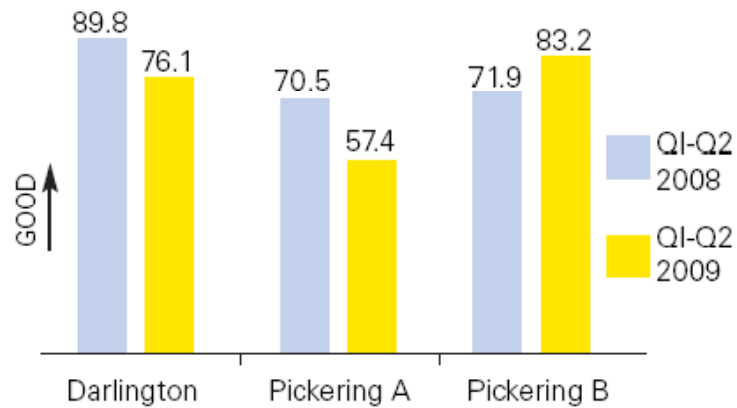


Figure 2-3 OPG Nuclear Unit Capability Factor (%)

Source: (OPG, 2009)

2.4.2 OPG’s Station Condition Record (SCR) system

Tracking and analyzing trends in the events that occur in a nuclear power plant is just one means that OPG uses to identify trends that require corrective or preventative action. OPG Nuclear invests significant time and resources in the tracking and trending program to ensure that all observations by the staff are captured, investigated, tracked, and documented for remediation if needed. The Station Condition Record (SCR) system is designed for this purpose.

The SCR system is composed of a database, forms, reports, and a viewer. The main components of the SCR system are designed to be accessed by initiators, managers, management review meetings, viewers, and reporters. The first component of the SCR

system is the user interface for the SCR computer-supported database that allows users to create, edit, and view SCRs (OPG, 2007).

The SCR database documents complete and systematic records for all adverse conditions and events that have occurred in the nuclear stations for all stages of project and work groups, including construction, operation, maintenance, and modification. Information stored in the SCR database is intended solely for the corrective action program. Usually, an SCR cannot be marked complete until the work required in order to correct the adverse condition has been completed or cancelled, and the condition is considered resolved. Thus the solution to the problem is also documented in the same record, which is convenient for experience exchanging and knowledge management.

In addition, the SCR system operates based on a well established procedure, which provides a consistent process for reporting and evaluating adverse conditions identified at OPG nuclear facilities so that the following procedures are ensured:

- The adverse condition is adequately documented.
- When possible, the cause of the adverse condition is determined.
- The appropriate corrective action is implemented in order to correct the adverse condition as required and, when possible, to prevent the recurrence or reduce the risk of recurrence of a similar adverse condition.
- The lessons learned are communicated to other facilities.

The SCR produces written reports that document the events or conditions and the circumstances related to the events or conditions as well as the initial actions taken or

planned. The SCR thus provides management with a factual summary of an event or condition, including initial actions and observations.

Chapter 3

Conceptual Model for Rework Reduction Program

3.1 Introduction

The purpose of this chapter is to develop and to present a general model for a Rework Reduction Program (RRP). The overall structure of the RRP model including purpose, components, functions, and features is introduced in the first section. The next section provides detail for the procedures, techniques and tools of each process of the RRP model.

3.2 Overview of Rework Reduction Program Model

The Rework Reduction Program model is designed as a secondary supportive management program to be used at the level below the total quality management (Powell, 1995) program in a company's management strategies (See Table 3-1). The program implements the specific remediation task to reduce rework in construction performance. It is a long term program taking into account and intended to impact all ongoing projects of the company.

The purpose of the rework reduction model is to track construction rework, to decrease the occurrence of rework and its adverse impact on project performance, and to improve productivity. The model specifies the following functions:

- Identify the construction field rework
- Determine and classify the rework root causes

- Document the rework events and deliver the rework lessons to the relevant group
- Quantify the impact of the rework on project performance
- Develop a correction action plan to eliminate the cause
- Plan an updated improvement scenario for changes to the project management system.
- Implement the corrective action plan
- Verify the effectiveness with respect to eliminating the causes

Table 3-1 Rework Reduction Program in the Management Hierarchy

	Management Level	Content
I	Enterprise strategies	Performance Management, Total Quality Management, Supply Chain Management, Human Resource Development strategy, Financing strategy, ...
II	Specific management program	Rework Reduction Program , Corrective Action Plan, Zero Defect Performance, ...
III	Project execution	Quality Control, Schedule Control, Cost Control, Risk Control, Scope Management, Procurement management, ...
IV	Techniques	Cause and Effect Analysis, Impact Matrix, Human Performance Techniques (HPT), WBS, Earned Value Management (EVM), Computer Aided Tools, ...

The Rework Reduction Program model includes the following processes:

1. Rework tracking and cause classification: detecting and identifying the rework that occurs in the defined work scope and identifying the causes of the rework

2. Impact evaluation and trend analysis: conducting data fusion and quantifying the impact of the rework on project performance in terms of cost, schedule, and quality, and identifying trends in the impact over time as well as the causes
3. Corrective action planning: developing options and actions that will bring about changes in the project management system with the goal of reducing construction rework
4. Intervention and integration with the project management system: integrating the input, output, and functions of the rework reduction model into the project monitoring and control process, using the information system as the platform for the integration.

Figure 3-1 provides a flow chart of these processes.

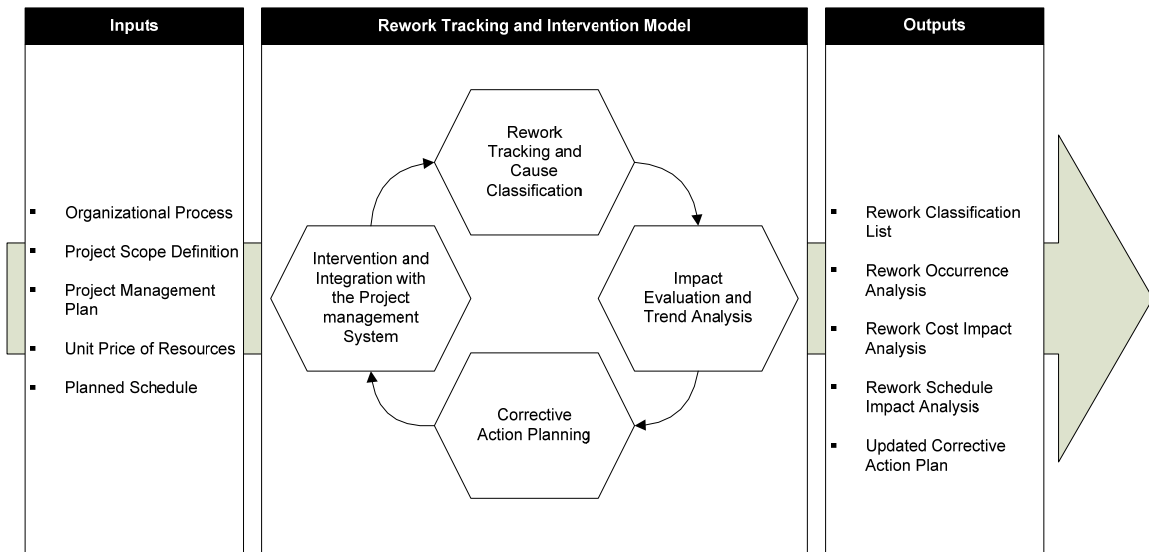


Figure 3-1 Process Flow Chart of RRP

The rework reduction program model has the following features:

1. Open circulation system: The rework tracking and intervention process model includes four processes which are illustrated in a cycle in Figure 3-1. Output from the upper process is the prerequisite for the next process, but the procedures are not simply repeated. The model tracks and analyzes the updated condition of the rework and identifies the updated corrective action plan that will produce changes and improvement to the management system for each iteration of this constantly repeated cycle.
2. Results-oriented system: The rework reduction model is a results-oriented system. The result is the demonstration of the impact of the rework on project performance according to the classification of the causes, a quantitative analysis, and a monetary evaluation, all of which indicate how and how much the rework wastes time and money. The demonstration could indicate efficient action that could be taken to control the rework from warning the management staff to the need for remedying the rework. The analysis and demonstration of the impact of the rework can efficiently guide corrective action planning.
3. Self-teaching system: The process in this system is repetitive over the duration of individual project performance timelines, as well as a program of small projects. This facilitates the ability of the management system to learn to recognize and control rework.

3.3 Description of the Rework Reduction Program Model Process

3.3.1 Rework tracking and cause classification

Rework tracking and cause classification determines which activities are rework and which types of conditions have resulted in the rework. The events should be documented and should especially include the time, duration, participants, labor hours, schedule shift, materials, equipment, and characteristics of the cause. The process is initiated by the workforce supervisor, and the participants can include the site manager, the site management team, the project manager, and consultant engineer. All project personnel should be encouraged to record rework events.

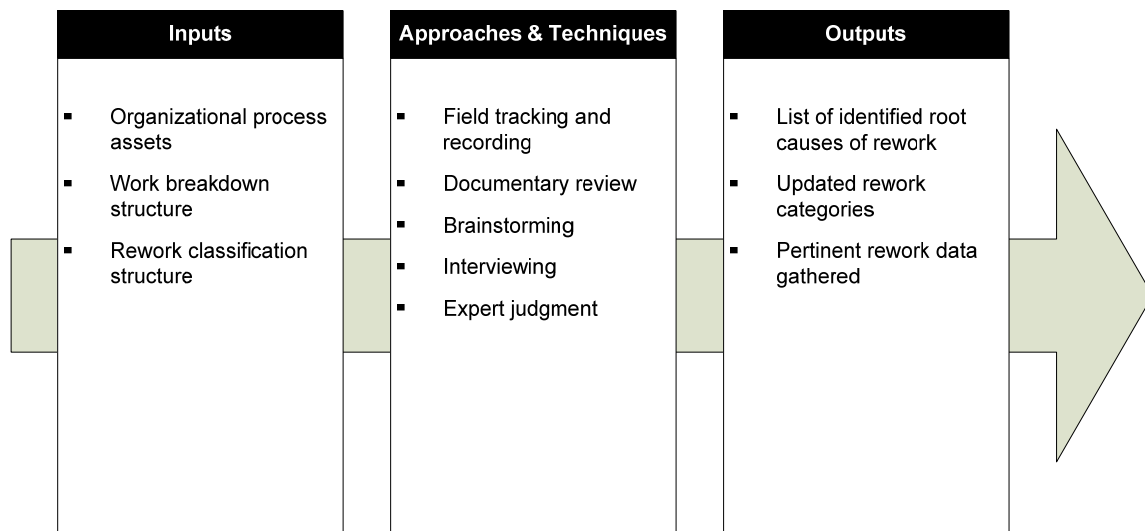


Figure 3-2 Rework Tracking and Cause Classification

3.3.1.1 Rework tracking and causes classification: Inputs

The following components are included in the inputs:

1. Organizational Process Assets:

Information from previous projects about rework tracking and classification, including actual data and lessons learned, may be available for the present project.

The experience derived from previous projects could enhance the ability to recognize and analyze the causes of the rework for both experienced and inexperienced personnel.

2. Work Breakdown Structure (WBS):

The WBS is a deliverable-oriented hierarchical decomposition of the work to be executed by the project team, to accomplish the project objectives and create the required deliverables. The WBS organizes and defines the total scope of the project (Heldman, 2007). The planned work contained within the lowest-level WBS components, which are called work packages, can be scheduled, cost estimated, monitored, and controlled. This information for work packages is the essential background information for identifying rework and its causes.

3. Rework Classification Structure:

The rework classification structure provides a guideline and structure for tracking and classifying the rework, which should be proposed according to the condition of a physical project that has a particular organization and specific contractual conditions and construction characteristics. There are two experiential models for rework tracking and classification process, and cause classification structure, which synthesized the experience and knowledge from relevant literature and rework practice in actual projects.

- Rework tracking and classification process model: The functional process flow chart (Figure 3-3) shows the operation of the rework tracking process, which also assigns appropriate functional groups to execute the each process.
- Rework root cause classification structure model: As the foregoing statement, the rework reduction program is a results-oriented system, which means that the correction is based on the classification and measurement of the rework. Therefore, the ultimate purpose of the rework classification and measurement is to provide a direction for remedial action for the rework problem. The rework root cause classification structure is the essential part for producing this measurement. The design of the classification of the causes is based on two considerations: one is the requirements of the management level, and the others is need for the designed categories to be related to the executive group, technology, and schedule required for the implementation of the corrective action.

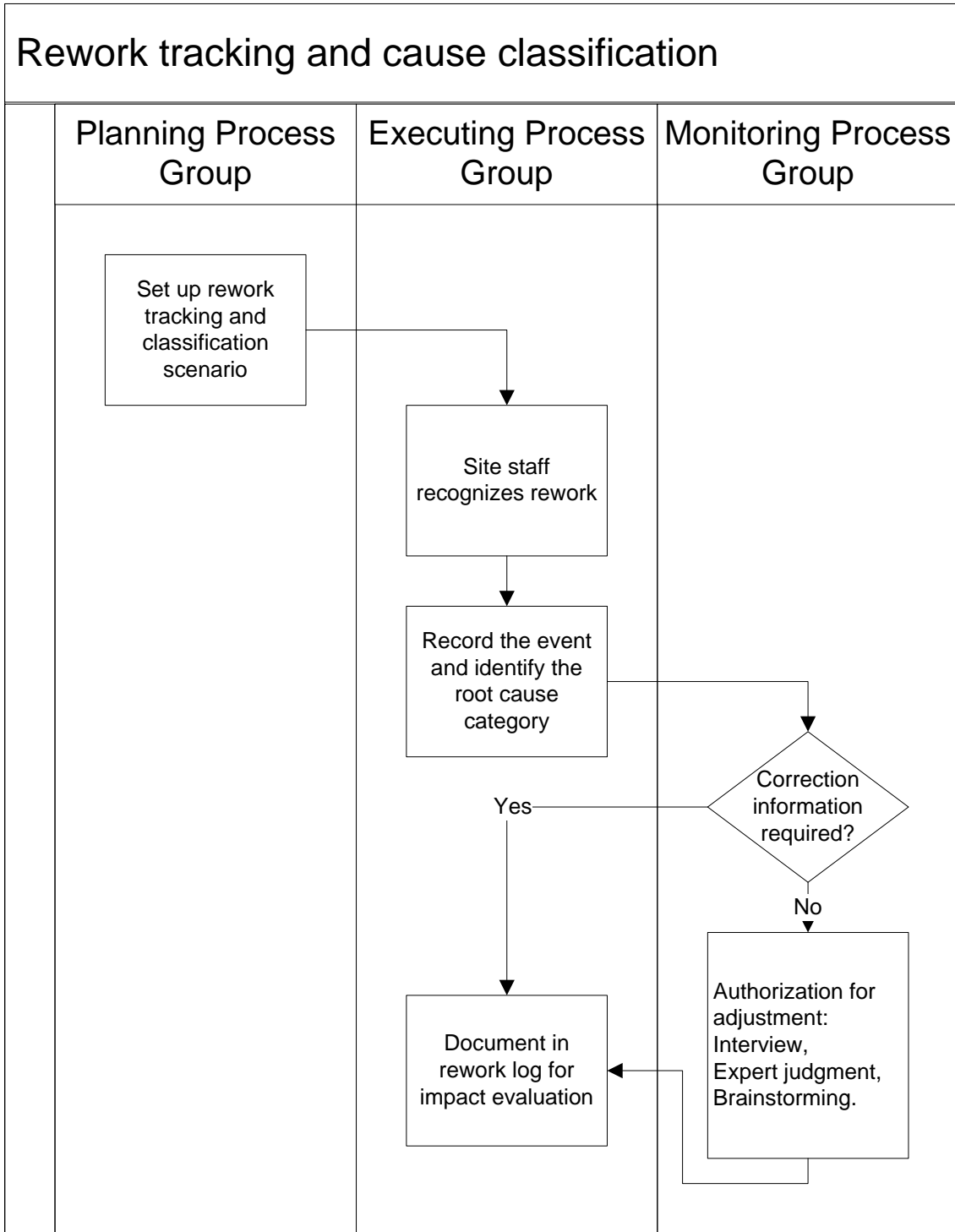


Figure 3-3 Rework Tracking Process

Table 3-2 List of Identified Root Causes of Rework

Rework Root Causes		Description (or sub-causes)
Process Group		
1	Design & Engineering	<ul style="list-style-type: none"> ▪ Drawings and specification errors or omissions ▪ Deficiencies in documentation control ▪ Scopes and design changes ▪ Lack attention to detail
2	Instruction & Inspection	<ul style="list-style-type: none"> ▪ Ineffective communication ▪ Poor decision making process ▪ Poor monitoring and control
3	Schedule	<ul style="list-style-type: none"> ▪ Deficiencies in forecasting field conditions ▪ Poor scheduling of construction resources ▪ Poor development and application of realistic work procedures
4	Material & Equipment Supply	<ul style="list-style-type: none"> ▪ Untimely deliveries or misplacement ▪ Defect of prefabrication ▪ Equipment and tools not sufficiently advanced
Human Performance Group		
5	Knowledge	<ul style="list-style-type: none"> ▪ Inadequate knowledge of action required to complete task successfully
6	Skill	<ul style="list-style-type: none"> ▪ Lack of domain-specific skill ▪ Deficiencies in personnel training
7	Self-discipline	<ul style="list-style-type: none"> ▪ Violation of rules or policy, or failure to adhere to work instructions or procedure ▪ Lack of motivation

From a performance management perspective, the factors that influence performance are normally categorized according to three management levels: organizational, process, and job/performer. The organizational level encompasses many variable factors, including non-productivity factors, which are not within the scope of this research. It is assumed that the organizational structure and groups are built appropriately for project performance. The factors in this level were therefore not considered in the classification of the causes of rework used in this model, as shown in Table 3-2. The sub-causes are related to the consideration of the deficiencies of performance to be related to the executive group, circumstance of construction, technology, and schedule that could cause rework activities.

3.3.1.2 Rework tracking and cause classification: Approaches & Techniques

The following components are included in the approaches and techniques section:

1. Field tracking and recording:

Site staff, including foremen, site engineers, and the site supervisor, recognize the rework based on their experience and the lessons they have learned. They are encouraged to provide an initial identification of the root causes of the rework and to note all pertinent information.

2. Documentary review:

Documentary review facilitates the learning of lessons from the rework events that occur in the current project or that have occurred in a previous project, which

enhances the recognition of rework and its causes on the part of personnel and also serves as a warning so that staff can avoid similar rework.

3. Brainstorming:

The goal of brainstorming is to obtain a comprehensive list of possible root causes of the rework. The project team usually performs brainstorming often in order to correct information from the site with respect to the initial identification of the classification of the rework cause, which overcomes a biased judgment from a specific individual. Categories of rework causes, such as the ones included in the designed cause classification structures mentioned previously, can be used as a framework for brainstorming.

4. Interviewing:

Interviewing experienced project participants and experts in specific areas can help identify rework and its causes. Interviews are one of the main sources of information for gathering pertinent rework data.

5. Experts' judgment:

Expert judgment is an approach for soliciting informed opinions from individuals with particular expertise. This approach is used to obtain a rapid assessment of a particular aspect of nonconformance and is integral to most other decision making tools to identify the root cause.

3.3.1.3 Rework tracking and causes classification: Outputs

The following components are included in the output:

1. List of identified root causes of rework:

The rework events identified, including their root causes and uncertain project assumptions, are described. Rework events could have a single or multiple root causes.

2. Updated rework categories:

The process of tracking rework can lead to the addition of a new category of rework causes.

3. Pertinent rework data gathered:

Pertinent data includes the frequency of the occurrence of rework events; direct labor hours; direct costs; and schedule delays caused by the rework.

3.3.2 Rework Impact evaluation and trend analysis

An impact evaluation of rework illustrates its potential and substantial adverse impact on project performance. The evaluation also demonstrates the effect of corrective action with respect to improving rework management.

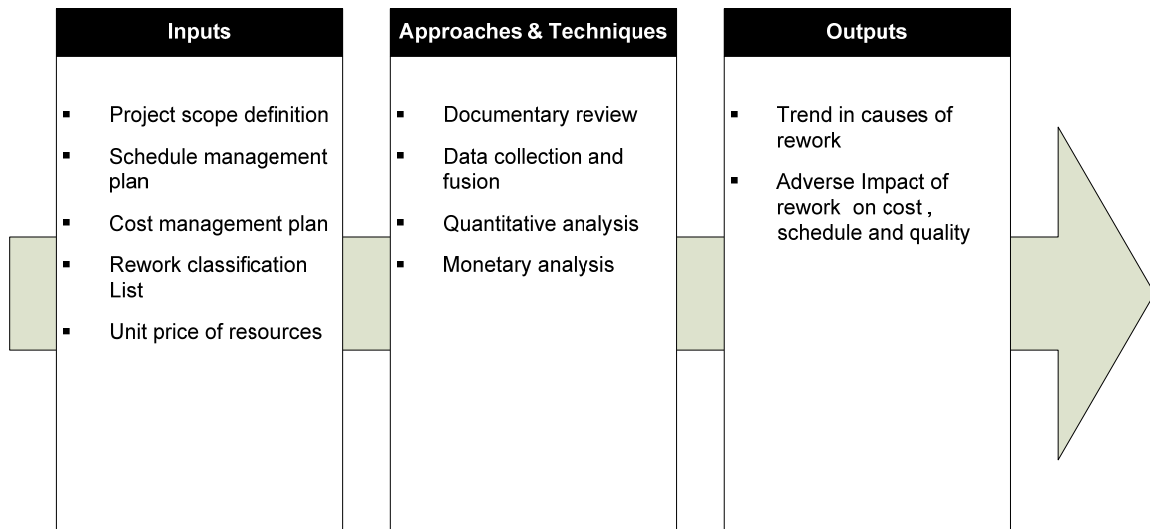


Figure 3-4 Rework Impact Evaluation and Trend Analysis

3.3.2.1 Rework impact evaluation and trend analysis: Inputs

The following components are included in the input:

1. Project scope definition:

Highly complex projects tend to have a better understood rework potential, which can be evaluated through an examination of the project scope statement.

2. Schedule management plan and cost management plan:

The project schedule plan and cost management plan set the format and establish the criteria for developing and controlling the project. Their primary content is the breakdown of the schedule and cost, which constitutes the reference metric according to which rework can be measured.

3. Rework classification list:

The rework classification list is created and updated by the previous process: rework tracking and classifying. The list sorts the rework events into categories and counts them as a series of units of time duration.

4. Unit price of resources:

This component is the base information used for conducting the monetary analysis.

3.3.2.2 Rework impact evaluation and trend analysis: Approaches & Techniques

The following components are included in the approaches and techniques section:

1. Data collection and fusion:

Data for rework studies may come from six sources: documents, archival records, interviews, direct observation, participant observation, and physical artifacts. Each source calls for different methodological procedures; however, there are also overriding principles that are important to any data collection effort, including the use of (1) multiple sources of evidence (evidence from two or more sources, but converging on the same set of facts or findings); (2) a case study database (a formal assembly of evidence distinct from the final case study report); and (3) a chain of evidence (explicit links between the questions asked, the data collected, and the conclusions drawn) (Yin, 2003).

2. Quantitative analysis:

The rework quantitative analysis process analyzes the effect of the rework events and assigns a numerical rating to each one. The frequency of rework events and the

number of labor hours required for the rework can be quantified to show the effect of the rework on the overall project. The quantitative analysis can be conducted in greater depth by examining the effects of the root causes, in order to reveal an appropriate weight for each cause.

3. Monetary analysis:

The purpose of the monetary analysis component is to analyze the direct cost of the rework, based on the deeper analysis of its cause, including the cost of labor, materials, equipment, and related resources. The additional impact of a relative direct cost, for example, any penalty or production loss due to the delay caused by the rework, could also be considered.

3.3.2.3 Rework impact evaluation and trend analysis: Outputs

The following components are included in the output:

1. Trends in causes of rework:

As the analysis is repeated, trends may become apparent and may lead to conclusions that affect the rework and the corrective actions. The results of the analysis may include a trend in the frequency of the rework over time, in changes in an individual root cause over time as a result of applying a specific corrective action, and in the weighting of the root causes in the rework as a whole.

2. Adverse impact of rework on cost, schedule, and quality:

This component represents the quantified effect of the rework on project performance, which is expressed in terms of cost, schedule, productivity, and

quality & safety. This mechanism complies with the rework evaluation structure
(See Table 3-3):

Table 3-3 Rework Evaluation Structure

Performance	Criterion	Measurement
Quality and Safety	Frequency of rework events	<ul style="list-style-type: none"> ▪ Occurrences of rework in units of time duration ▪ Rework events that result in human health hazard or equipment failure.
Productivity	Labor hours over unit production	<ul style="list-style-type: none"> ▪ Total work value for a specific duration ▪ Total labor hours in the specific duration ▪ Total labor hours for rework in the specific duration
Cost	Direct cost & relative direct cost	<ul style="list-style-type: none"> ▪ Expenses of labor, material, equipment and related resources directly consumed in rework ▪ Monetary loss due to the delay of work
Schedule	Time shift for schedule	<ul style="list-style-type: none"> ▪ Time shift of the subsequent job ▪ The impact of time shift on critical path of the project

3.3.3 Corrective action planning

Corrective Action Planning (CAP) is a process with a pattern of activities which traces the symptoms of rework to its causes, produces solutions for preventing the recurrence of

the rework, implements changes and monitors the effectiveness of the changes (See Figure 3-5).

The CAP process requires that the corrective action taken to eliminate the cause of a rework is appropriate to the magnitude of the rework and commensurate with the causes encountered. This means that corrective action may not be required for every rework event, but should only be taken on vital rework causes. Therefore, the effective collection and analysis of data will be able to determine those vital rework causes needing corrective action and the scope of the action required. The data collection and analysis are based on a systematic investigation of rework events which has been well done in last two processes – classification of causes of rework and evaluation of impact of rework. The inputs for the process of corrective action planning are therefore comprised mainly of the measurements of the rework, including the classification of the causes, the trends in the number of occurrences, the labor hours, and the cost, and the information of when, where and under what conditions rework occurred.

The corrective action planning process should be required by the total quality management system for implementing corrective and preventive actions. It may be associated to many possible procedures including: investigation procedure, schedule review procedure, material supply review procedure, site crew complaints review, quality system document change procedure, specification change procedure, etc. Also, a corrective action procedure may involve many departments, areas and processes. Therefore, it may be practical to apply corrective action provisions in procedures rather than a single corrective action procedure from simple intradepartmental analysis with

solutions that affect only one area, process or group of staff. As such, the corrective action planning process can accommodate various construction groups.

The CAP process also has an important function of determining or designing the corrective action needed to eliminate the cause of rework. Anyone can propose corrective action but the responsibility for taking action rests with those responsible for the management. So the first view of the categorization of corrective actions consists as being part of the process level or human performance level. Viewed as an enterprise management plan, the corrective action could be categorized as immediate action such as warning notices and alerts; longer term action such as a regular scenario of training and a schedule for upgrading techniques; and record both the cause and proposed solutions for the requirement of total quality management. Some corrective actions may be multidimensional in that they may require changes to training, changes to procedures, changes to specifications, changes in the organization, adopting advanced equipment and changes to processes. Due to so many changes, the corrective action planning process becomes more like an improvement project. When corrective actions require interdepartmental action, it may be necessary to set up a corrective action team to implement the changes with project management.

The main requirement of implementing corrective action in this RRP model is to implement and record changes to documented procedures resulting from corrective action. This process includes tracking the implementation of corrective actions, linking a procedural change within the total management system to the corrective action procedure, and preventing recurrence of rework causes.

The RRP requires that controls should be applied to ensure that corrective actions are taken and that they are effective. A report of rework should define the corrective action to be taken and when the action has been completed so that it can be verified. The effectiveness of some actions can be verified at the same time, but quite often the effectiveness can only be checked after a considerable lapse of time. The same analysis it took to detect and evaluate rework needs to be run repeatedly to see if the causes of rework have been eliminated or reduced. Thus, the RRP makes up a control loop which fixes the processes by eliminating the root causes of rework so that construction field rework will be reduced.

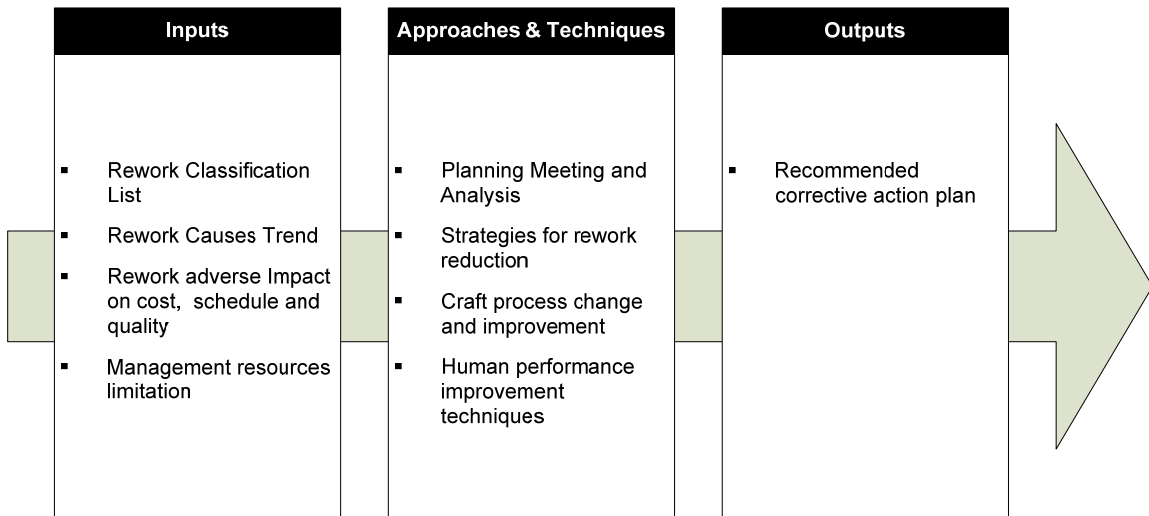


Figure 3-5 Corrective Action Planning

3.3.4 Integration with project management system

As a secondary supportive tool, the rework reduction program can not by itself perform the task of controlling rework. Only if the program is integrated into the project management system so that it can make changes to that system can the system be improved and the rework be reduced. The result of an improvement, which can be called the feedback, is collected and analyzed by the rework reduction program in order to facilitate the adjustment of the next iteration of the improvement plan.

The rework program is typically integrated into the project management system, especially into the first line management system for a particular project. When the corrective action is integrated into the global management system, three factors should be considered: execution groups, procedures, and techniques. A perfect integration process could result in the effective implementation of the corrective action, but increased resources may not be required from the execution groups, and changes will be applied to the existing procedures only when necessary.

Chapter 4

Case Study and Analysis

4.1 Introduction

Based on the rework reduction program model developed as outlined in chapter 3, the intent of this chapter is to present and discuss a real rework reduction program case study for a program of small construction projects. This chapter includes a discussion of this case and an analysis of the rework involved in order to demonstrate the impact of rework on such a series of small projects. The demonstrated improvement in the amount of rework that resulted from the application of the rework reduction program is also presented. The chapter therefore includes an introduction to Ontario Power Generation's (OPG) rework program, which is an enterprise-level specific management program; a description of the real project – the Pickering Nuclear Power Station maintenance and modification project; an investigation of the quantification of the rework and related data collection; and the data and graphs that demonstrate the effectiveness of the rework reduction program for improving productivity, quality, and safety and for reducing production costs.

4.2 Investigation of OPG's Rework Program

OPG's rework reduction program is a long-term special program, which is part of their enterprise production management strategies and is mandated for all the nuclear power

generation under OPG. The objective of this program is to improve productivity and to implement better quality and safety standards.

The OPG rework program is a formal process that ensures that rework events are documented, classified, and evaluated in a consistent manner so that the factors that caused them can be determined. An understanding of the problems that cause rework can then provide the basis for guidelines and directions for adjusting and improving pertinent management practices and even the overall organization. This process is an essential part of a learning-based culture.

4.2.1 OPG's SCR system and changes for supporting the rework program

A Station Condition Record (SCR) consists of a system and database that provides a consistent reporting and evaluation process for detecting adverse conditions at OPG nuclear power segment. Plenty of information about adverse conditions is documented in the SCR reports, including time of event occurs, time of report, correlative persons in each management level, location of event, description of condition, how the adverse condition is discovered, apparent cause of condition, immediate action taken, and recommended resolution. Examples of SCR reports are presented in Appendix A.

Because rework events constitute a kind of adverse condition, they have been reported consistently from the introduction of SCRs. On October 17, 2005, SCRs were changed in order to provide better identification of rework:

- Mandatory reports were added to the SCRs for addressing rework and its causes.

- Correction action plans were adequately documented in order to enhance learning and increase the effectiveness of improvements in related management.

However, because rework was viewed as a common adverse condition related to project performance, the impact of which was not significant from overall management's perspective, OPG's SCR only recorded the rework events for trending purposes, including the information of its occurrence time, location, work scope, nonconformance and its causes, labor hours, materials, and schedule shifts. No additional consistent and regular analyses or studies on rework program were conducted to verify the impact of rework and the effectiveness of rework reduction program. This case study fills in these gaps.

4.2.2 Rework causes classification

The causes of rework are indicated in the SCR program by rework causal codes, which represent categories called design, parts, maintenance, operation, instruction, skill, knowledge, rule, delays, and to be decided (See Table 4-1)

These cause categories can be sorted in the three groups shown in Table 4-1 as Process, Human Performance (HP), and Equipment reliability. The skill, knowledge, and rules categories are included in the human performance group. Maintenance and operation are mainly associated with equipment reliability, and all other categories are sorted as part of the process group.

Table 4-1 OPG's Rework Causes Category

SCR Causal Category	Group	Description
Design	Process	Equipment failure rate is higher than expected due to existing design problem or inappropriate application of a component in the system
Parts	Process	Inadequate quality or grade of parts/ equipment received from the manufacturer
Maintenance	Equipment reliability	Inadequate or inappropriate preventative maintenance measures, which result in higher than expected failure rate of equipment
Operation	Equipment reliability	Improper operation or start-up of equipment or system
Instruction	Process	Inaccurate or incomplete procedure or work instruction to perform work
Skill	HP	Intended action is not carried out successfully
Knowledge	HP	Inadequate knowledge of action required to complete task successfully
Rule	HP	Violation of rules or policy, or failure to adhere to work instructions or procedure
Delays	Process	Inaccurate or improperly performed prerequisites that impact schedule or a maintenance related issue that extends work window by 10% or one shift.

Considering the uniqueness of the nuclear power industry, the causes sorted in the groups of Process and HP are considered directly associated with construction field rework. But the maintenance and operation categories are related only to the reliability of operation of

equipment rather than to problems in field construction, so in this research, they are not involved in the analysis.

4.2.3 OPG Nuclear's rework program process

OPG Nuclear's rework program is generally executed by four functional groups (See Figure 4-1). The Site Group (SG) is assigned to identify the rework events and initially classify the root causes for the rework. Meanwhile, all the pertinent information is filed by this group in SCRs, including description of events, correlative persons, labor hours and dollar value, immediate action taken, etc.

The purpose of the Management Review Meeting (MRM) is to review the rework event report, verify the rework root causes classification, determine the need for corrective action, and review the corrective action plan. The MRM is the pivot of information fusion and delivery, and plays the important role of making decision.

The Evaluation Organization (EO) is assigned to evaluate the impact of rework on the project performance by terms of cost, schedule, productivity, and quality. By reviewing the evaluation of rework for every considerable lapse of time, the effectiveness of the corrective action can be verified.

The Corrective Action Control Group (CACG) takes the tasks of developing the corrective action plan and monitoring the implementation. To do this, the CACG has to investigate the existing management system to determine which procedures or tools can be of help for corrective action, and then integrate the corrective action plan with the project management system.

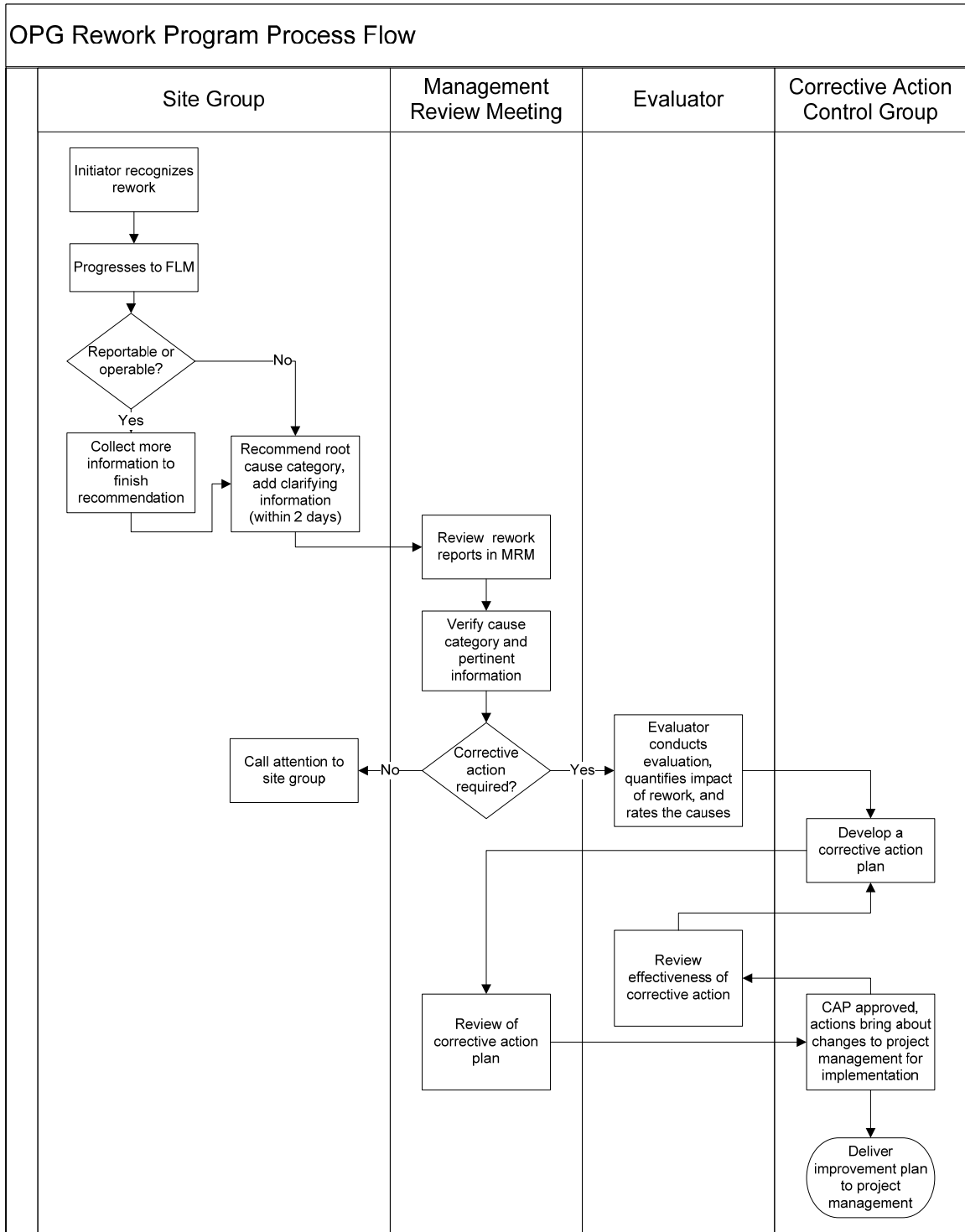


Figure 4-1 Process Flow Chart of OPG Nuclear’s Rework Program

Four functional groups have execution procedures individually for their general function other than rework control. The rework program process flow chart shown in Figure 4-1 is made up by picking and combining the processes associated with rework control from them. This process flow chart verifies the philosophy of the design of RRP model.

4.2.4 Rework program benefit

The OPG's rework program is a formal process that ensures that rework events are documented, categorized, and evaluated in a consistent manner in order to determine the causal factors. Understanding the problems that cause rework provides numerous benefits for the maintenance and modification department and for the entire organization and. The specific benefits this program has provided since its implementation as stated by OPG staff include the following:

1. The occurrence of rework has decreased due to the implementation of the corrective actions that resulted from the investigation of rework and the lessons learned.
2. The quality of work has improved because of the increased awareness of the issues that cause rework and because of the implementation of the resultant corrective actions.
3. The opportunity to share the lessons learned about rework with others through communications, monthly reports, quarterly reports, maintenance tailboards, plasma screens, and shared experience with other sites.

4. Formal analysis has identified trends in the causes of rework and has indicated which areas should be the focus of subsequent improvements.
5. Rework has been recorded at the individual crew level. Rework occurrence records has been used as metrics to evaluate the performance of the site manager, which has provided an opportunity to compare the performance of all the site managers.
6. Rework event review meetings have provided an opportunity for the site manager and related department managers to participate in face-to-face discussions about the lessons learned from the investigation of the rework and to implement immediate coaching or reinforcement where required.
7. Rework analysis has been a factor in stabilizing the work schedule. Work performed correctly the first time permits more accurate scheduling and maximizes the availability of resources.
8. Reducing rework has saved money because rework is expensive.
9. Reducing rework has improved unit rates of production because work is performed in as timely a manner as possible without the need for repeating work prior to closing the work order.
10. In a nuclear power plant, reducing rework has resulted in lower exposure to radiation.
11. Reducing rework has decreased the production pressure caused when critical path work must be repeated.

12. Rework analysis has provided an opportunity for the company to compare performance in some areas against industry standards.

4.2.5 Corrective action plan program

OPG's Corrective Action Plan (CAP) program establishes the processes to ensure that deficiencies, nonconformance, weaknesses with a process, document, or service, or conditions that adversely impact, or may adversely impact plant operations, personnel, nuclear safety, the environment or equipment and component reliability, are promptly identified and corrected (Goodman & Charlebois, 2006). Remedying the rework causes is one of the principal tasks of the CAP.

For those deficiencies considered significant, or repetitive in nature, these processes ensure that appropriate levels of management are notified, causes identified, and actions taken to preclude recurrence. They also ensure that the actions taken to address the identified issues are verified to be complete and effective.

This program is applicable to all personnel performing activities at OPG's nuclear facilities or on nuclear property. This includes on-site and off-site OPG's nuclear organizations, non-Nuclear organizations performing work on nuclear property, and contractor organizations performing activities for the nuclear power plant. The maintenance and modification program and the involved contractors are all related to this correction program.

From the aspect of the mechanism of corrective action response to cause classification, if the analysis reveals that the causes of the rework have occurred at the process group (design, parts, instruction, and delays), the system indicates appropriate corrective actions by adjusting and improving the related technical processes, the schedule, the engineering solution, or communication in order to reduce the probability of rework. On the other hand, the nuclear power industry considers that human performance is a critical factor in the occurrence of rework, which directly influences quality and safety. Therefore, three causes of rework that are related to human performance are included in the analysis of the trends in causes in order to develop directions for improvement. The corrective action plan provides information about the trends in causes and scenarios for improvement. When the trends are related to human performance, input is provided to the training curriculum review meetings and subsequently feeds the continuing training program. With respect to techniques, OPG uses the appropriate Event Free Tools to suggest adjustments that will correct rework caused by human performance:

- 3-way communication
- Attention to detail
- Conservative decision making
- Pre/post job briefing
- Procedure use/adherence
- Questioning attitude
- Self-check

4.2.6 Examples of corrective action

Two rework event reports are presented here as examples to illustrate the associated corrective action. The short reports below of the rework events are taken from the SCRs are presented in Appendix B.

1. A rework example with the root cause in the Process group

This is a rework event (SCR No. P-2008-06595) occurred in scaffolding work. Some rework had to be done to an existing scaffold built by another work group to allow access to the base of the boilers to allow water lancing to begin. The cause of this condition was determined to be that the improper prerequisite needs were performed for the water lancing, which is classified in Process group with the code, “Delays”.

The SCR report also documented the corrective action in the items of “Immediate Action Taken” and “Recommended Resolution”, and the adverse condition was recorded for trending purposes; it was emphasized that the procedure is that the task outlines should state what is prerequisites to be done and that the work group building scaffolds should check with the end user if what was built suits their needs. (See Appendix B-1)

2. A rework example with the root cause in the Human Performance group

The rework event report (SCR No.P-2008-02807) record a rework event during the installation of the new Liquid Zone Control pipe. The contractor chose to bend the existing conduit bracket upward by hammering the threaded rod supporting the ductwork, rather than by temporarily supporting the load of the ductwork, resulting in damaging the

support and stripping paint from a structural beam. The contractor was required to repair the support and beam. The root causes were addressed as a lack of attention to detail and poor work practices, which are classified in the Human Performance group with codes of “Skill” and “Knowledge”.

Corrective actions were also taken promptly and filed for trending purposes: firstly, first-line management was notified and contractor’s supervision was questioned concerning their attention; secondly, the contractor was to be coached to avoid similar incidents in the future. (See Appendix B-2)

4.3 Pickering Nuclear Power Plant Maintenance and Modification

4.3.1 Project location

The Pickering Nuclear Power Station is one of the largest nuclear facilities in the world and is comprised of 8 CANDU nuclear reactors. Divided between Pickering A and Pickering B Nuclear Generating Stations (PNGS A, PNGS B), the plant is located in Pickering, on the shore of Lake Ontario, just east of Toronto (OPG, 2000) (Figure 4-2). A separate management group is assigned to implement the maintenance and modification program, and professional contractors are engaged to undertake specific jobs.



Figure 4-2 Aerial Photograph of the Pickering Nuclear Power Station

Source: (OPG, 2006)

4.3.2 Brief of maintenance and modification program

In Pickering Nuclear Power Station including two generation stations, PNGS A currently has two operating reactors. Initially, four reactors were in continuous service from 1971 until 1997, when they were placed in voluntary lay-up as part of Ontario Hydro's nuclear improvement program. Two of the reactors were returned to commercial operation, and the other two units remain in a safe shutdown state. PNGS B has four operating reactors that have been in continuous operation since 1983. Together, PNGS A and B produce a

total output of 3,100 MW; approximately 2,100 MW are produced from PNGS B. The station will reach the end of its original design life in the next 10 years. To make up the additional demand for electricity due to economic growth, nuclear power must continue to supply a substantial portion of the base-load electricity. In addition to developing a new greenfield nuclear power station, maintaining and refurbishing the existing units is an effective and economical approach to maintaining OPG's ability to generate the required electricity. Maintenance and modifications are therefore essential strategies for extending the lifespan of the Pickering station, and OPG is proposing to refurbish the units at PNGS B so that it can be operated until 2050-2060.

Refurbishing a nuclear power station generally consists of the following elements:

1. Refurbishing the reactor components
2. Replacing the generating units and related systems
3. Refurbishing the supporting structures and feeder pipes
4. Upgrading the control system
5. Protecting human health and the environment, an especially serious component for nuclear power plants

For the purposes of this research, only rework related to the supporting structures and piping work was considered, which is representative both of the common characteristics of civil construction and also of the benefits of applying rework reduction in the nuclear industry. According to OPG's maintenance and refurbishment program, supporting structures and feeder pipes will be reformed, removed, and replaced as necessary. The techniques involved in this type of construction at this stage are not especially difficult,

but the complexity of their spatial position and the redundancy in the technical specifications add considerable challenges to construction activities such as in craft process programming and materials supply.

4.3.3 Challenges of reducing rework in this type of construction

As discussed in Chapter 3, the evaluation of the impact of rework on a project by the new rework model should include consideration of the effect of unproductive rework activities on nonconformance with requirements and the related risk to quality. In light of the characteristics of this research case project, it is worth addressing the particular conditions relevant to specific challenges involved in construction in a nuclear power plant: the complexity of the spatial layout and the technical specifications of the components, interference between new components and the existing facilities, the quality of the prefabrication, and the special safety requirements of the nuclear industry.

4.3.3.1 Complexity of the spatial layout and the technical specifications

Many kinds of pipes are used in power plant buildings: fuel, gas, cooling water, air, steam, and other special types. The combined configuration of the pipe systems can be very complicated (Hsu & Mohan, 1991). The pipes vary in diameter from .1 inch to hundreds of inches, and so that they are suitable for a variety of fluids, they are manufactured from many different materials, such as steel, copper, aluminum, plastic, and fiberglass. Many types of connections are used for different materials and pressures, such as flanges, welding, and plugs and sockets. The in-line components, known as fittings, valves, and other devices, typically sense and control the pressure, flow rate, and

temperature of the transmitted fluid. A vast number of technical specifications are required so that these complex components are configured correctly, which creates difficulties and challenges with respect to supply management and assembly during construction.

Pipes of all sizes and types intersect in a limited space in the power plant building, each following a separate route. To avoid interference in the space where they must be manipulated, the numerous components must be installed in the proper order. Spatial interference includes obstruction on the pipe's stretching route, the constraints of lateral or vertical clearance between pipes, and the limited space available for accessing and working on a specific workface. Any of these types of interference may result in rework, such as a redesigned installation order, adjustment to the approach access, and even the need to disassemble components that have already been installed in order to provide additional space.

Meeting these challenges can require changes to the corrective action plan. For example, CII RT-252 research identified 3D scanning as a very effective technology for solving problems associated with spatial complexity. Analyzing the as-built model created by 3D scanning along with the as-designed CAD model and pipe work plans can reveal potential clashes between components. If an automated clash detection program is run for the new design, each engineering discipline can determine whether demolition work will overcome an interference problem or whether they need to modify the design or construction plans.

4.3.3.2 Interference between new components and the existing facilities

A nuclear power plant normally has a lifecycle of more than 30 years, which can be further extended by refurbishment. During this considerable length of time, engineering materials, technology, and crafting techniques are being continually upgraded and updated, which produces significant changes in construction behavior. For example, with respect to materials, new types of polyethylene (PE) pipe are gradually replacing some metal pipes, because the new PE pipe is qualified in terms of pressure, temperature, chemical environment, etc., to be used in some facilities and is more economical than metal pipe. Another example is the weld-less connection (such as grooved systems, press-to-connect systems, and push-to-connect systems) that is taking the place of welded or flange connections. Although a weld-less connection has a higher connection material cost, it is typically offset by the tremendous savings in labor, resulting in substantial improvement in productivity and lower total installed costs. The development of new materials and equipment is accompanied by changes in technical specifications, which adds to the challenges of reducing rework. Specific training as an essential corrective action is required, so that staff can acquire advanced skills and new knowledge to deal with this challenge.

4.3.3.3 Quality of the prefabrication

As is well known, compared with stick construction, off-site prefabrication can provide significant benefits because it requires less time and reliance on on-site labor, site inspection is easier, and quality control is improved. Prefabrication is increasingly being applied in the general construction industry, and the prefabricated modules are becoming

larger and more complex as well. Especially for structure and piping work, prefabrication has already become an irreplaceable process that is leading to significant improvements in productivity.

A subject of primary concern with respect to prefabrication is whether the prefabricated components can be installed precisely and smoothly. The quality of prefabrication of interest in this discussion is exactly how precisely the prefabricated module can be fitted to the site. Any misalignment or misplacement of the components in the prefabricated module and any over-tolerance deformation in either the existing facility or the prefabricated module lead to rework, including disassembly, relifting, adjustments, and refabrication.

Some technologies have been identified as a means of improving the quality of pipe module prefabrication, which should be considered as part of the corrective action plan. For example, CII RT-252 research discussed an innovative method for eliminating cut lengths for prefabricated pipe installation, which increases the quality of prefabrication and reduces the amount of work on-site as much as possible.

4.3.3.4 Special safety requirements of the nuclear industry

Safety requirements for construction include making adequate provision for the protection of the environment and of human health and safety. The nuclear industry requires a higher level of environmental protection beyond these requirements and must also maintain national security and meet international obligations (CNSC, 2008). Events that can potentially compromise the safety of a nuclear power plant (NPP) are the subject

of the safety analysis and assessment. The scope of events includes component and system failures or malfunctions, operational errors, and common-cause initiated events (CNSC, 2008). Rework in NPP maintenance and modification is one type of common-cause initiated event that occurs quite frequently on the site. Reassembling pipe components an additional time may increase the risk for the environment and human safety. Furthermore, before any nonconformance is repaired through rework, the facility is in an off-normal condition because of an existing nonconformance with the designed requirement, which also increases the potential risk to safety. Therefore, due to the special safety requirements of the nuclear industry, the rework reduction program adds value by improving quality and safety in addition to the benefits with respect to cost and schedule.

4.4 Data Collection and Fusion

Data collection and fusion is not only an essential component of this case study but also an important process in the rework reduction model. In OPG's management system, the SCR is a competent data carrier that records and synthesizes information about all the adverse events that occur during the operation of the station, including rework events, and is the primary source of rework data. As discussed, in the rework reduction model, the rework program is typically implemented by being integrated into the general production management system. To conduct the case study for this rework research, it was necessary to filter the rework events from the SCRs and refine the pertinent information for implementing the rework evaluation. The following subsection explains the principles and the content and approaches with respect to data collection and fusion.

4.4.1 Principles of data collection

Maximizing the benefits of using multiple sources of data requires the appropriate use of the principles of good data collection in order to establish the validity and reliability of the case study evidence (Gerring, 2007).

4.4.1.1 Use multiple sources of data

OPG's SCR events records are existing data collected for general management purposes, which represent complete documentation containing all adverse events from the implementation of the SCR to the present. The obvious advantage of collecting data from the SCR is to gain broad coverage and exact and unobtrusive information (Yin, 2003).

For the rework case study, "broad coverage" means that the SCR contains records that cover a long time span and contain multiple pieces of information about the event.

"Exact" means that the SCR contains detailed stable and physical data from the industry.

"Unobtrusive" means that the data is not obtained as a result of an experiment. However, documentation data has the weakness of biased selectivity, which means that the collection is incomplete for research purposes. Therefore, data sources such as interviews with experts and archival records are useful supplements.

4.4.1.2 Establish and maintain a chain of evidence

A chain of evidence is maintained in order to increase the reliability of the information through the implementation of a traceable system. The chain of evidence for this rework case study is summarized as shown in Figure 4-3.

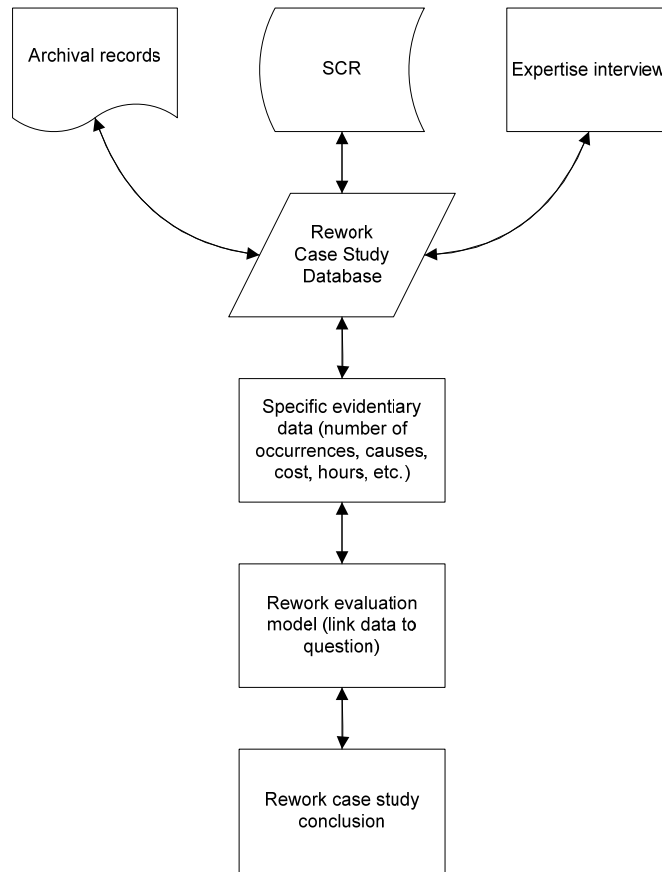


Figure 4-3 Evidence Chain for the Rework Case Study Analysis

When the reader has read the conclusion in the case study research report and wants to know more about the basis for the conclusion, the above scenario will enable the evidentiary process to be traced backward.

4.4.1.3 Match the rework evaluation structure

Navigation for the selection of data operates according to the model established for the rework evaluation structure. Section 3.2.2 in Chapter 3 discusses the data used in the evaluation structure model, including the type, quantity, formulas, and data conversion process. Collecting data for a specific purpose could save man-hours and related

resources with respect to field investigations, especially for implementing a rework reduction program in physical construction rather than for the case study research. In section 4.4.2, approaches to the collection of data and the content are discussed in detail.

4.4.1.4 Collect original data from industry

The intent of conducting this case study was to accurately and clearly illustrate the impact of rework on project performance in a maintenance and modification program for an NPP and to introduce guidelines and empirical examples for practical applications of the rework reduction model in order to achieve improved productivity, cost, quality, and safety. Therefore, all data were actual data collected from industry rather than experimental data.

4.4.2 Approaches to and content of data collection

The specific rework data for the case study generally consist of four parts crossmatched with one another: (1) the number of occurrences of rework, (2) the classification of the root causes of rework, (3) the number of labor hours and time shifts required because of the rework, and (4) the direct cost of the rework. All the data were obtained from three sources in the OPG's Pickering NPP maintenance and modification program: the SCR, archival records, and interviews with experts. Of these sources, the SCR provided the majority of the detailed information about the rework events; the archival records were used to obtain records of specific contractual claims between contractors and OPG, which contain supplemental information about rework hours and cost. Data fusion took place within the rework evaluation structure model, which produces effective data organization

from the raw data. Organizing the data in an orderly manner according to purpose and with a reliable method of tracing the sources maintains the evidential chain for the data collected and provides the basis for a persuasive logical framework for the results and conclusions. The details of this process are discussed in the following sections.

4.4.2.1 Frequency of rework influence safety performance

As discussed in section 4.3.3, with respect to the special safety requirements of an NPP, a high frequency of rework events could potentially have a serious effect on the safety or control functions of a nuclear power plant (CNSC, 2008). The frequency of rework events can thus be used as an index for measuring the impact of rework on the performance of an NPP with respect to safety. If the number of rework events during a specified period decreases over time, and the potential safety hazard is reduced accordingly, the performance of the NPP with respect to safety can be considered improved.

Rework events occur randomly over time, which means that rework events are not uniformly distributed over a timeline. The number of occurrences in a continuous unit time must therefore be shown as an uncertain oscillation. To determine the trend in the occurrence of rework as well as the degree to which the rework reduction program affects project performance, it is necessary to mitigate the effect of the uncertain oscillation on trending and to enhance the accuracy and reliability of the result. Two steps can be taken in order to achieve this goal: one is expanding the sample space of rework events; another is taking samples over a larger, more adequate time span.

In this case study, all of the rework events that occurred in the Pickering NPP maintenance and modification program from 2006 to 2008 and that are recorded in the SCR were used as measurements. The total number of rework events identified for each year is presented in Table 4-2.

Table 4-2 Total Number of Rework Events for Year 2006-2008

Year	2006	2007	2008
Total number of rework events	1590	1284	926

The average number of rework events that occurred during one month is approximately 105. The number of occurrences varied from 40 to 180. The total number of rework events in each month was also counted for analysis. The total number of adverse events and the total amount of the Operation, Maintenance and Administration (OM&A) expenses for OPG's nuclear segment were also collected as a reference, in order to reflect the level of the production value for each period. It was assumed that all this occurred in an established stable production system on an annual basis. This assumption was verified by OPG staff.

4.4.2.2 Reduction of rework hours as a reflection of the potential for improvement in productivity

Rework hours have two levels of impact on productivity:

1. Direct rework labor hours: hours per person × number of people who spend time directly redoing the task that was in nonconformance with requirements

2. Hours the schedule is shifted due to the rework: the duration from the initial “standby” caused by the rework until the original activity is resumed

In this case study, the performance of three major contractors engaged in structure and piping work formed the basis of the measurements:

1. Aecon, who were working on the piping and supporting structures
2. Black & Macdonald, who were replacing the condenser tubes and related components
3. Crosby Dewar, who were responsible for the insulation and related temporary support

The SCR and related archival records contain relatively complete data for the hours and costs related to these three major contractors, and these data are also representative of the rework situation for the entire maintenance and modification program.

The number of direct rework labor hours for each rework event is typically presented as a text description in the Description of Condition section in the SCR event report (e.g. Appendix A). The description notes the number of people and the number of hours for each person that has been spent on the rework. If any time delay occurs beyond the duration of the direct rework, it is noted separately. The combination of the extra time delay and the duration of the direct rework constitute the time shift that could have an impact on the construction schedule.

The total work hours for these three contractors were obtained from the contractual claim records that are archived in OPG’s project office. The claim records reflect the actual

labor hours spent by the contractors during the construction whether the payment for each claim has been finally approved or not.

4.4.2.3 Cost savings as direct motivation for applying a rework reduction program

OPG's rework program mainly uses direct expenses to measure the rework impact. In the "Description of Condition" section of the SCR events report, the direct cost of rework is formally noted for documentation. It is noted as a lump sum for each event but not detailed in the labor cost, material cost and related miscellaneous expenses (see an example of events report in Appendix A). However, this information is enough to illustrate the potential cost effective of rework reduction.

4.4.2.4 Classification of root causes as a guide for corrective action

As discussed in Chapter 3, the principle behind classifying the root causes of rework is that the classifications are to be important guidelines for planning corrective action. The classification of rework records in the SCR embodies this principle and is discussed in detail in section 4.2.2.

In the SCR, seven root causes, designated DESIGN, PARTS, INSTRUCTION, DELAYS, SKILL, KNOWLEDGE, and RULE are sorted into two categories (process and human performance), and are used to classify the rework events. Each rework event has at least one root cause and can have multiple causes. Every occurrence of each root cause is counted as one point, whether the event has a single or multiple causes. The classification data collected for this case study includes the number of rework events for

each root cause for each year and each month as well as the hours and cost of the rework events for each root cause.

For a significant proportion of rework events, the cause is not indicated in the SCR.

These events are marked with codes such as “To Be Decided”, and they had to be classified by the author before they could be counted as part of the trend analysis. The description of the code for each rework causal factor in Table 4-1 is the set of principles and guidelines used for effective classification practices by the author. The existing classification of rework events can be used as a valuable reference for adhering to appropriate classification practices. Interviews with experts were also helpful for difficult or unclear cases.

4.4.3 Summary of the data collection practice

In this section, the author summarizes the timeline of data collection and the data collected.

4.4.3.1 Timeline of data collection

June 2008	▪ Learned about OPG’s SCR system and the plethora of information of the adverse condition reports in the SCR database from a representative of OPG in a CII research conference, and it was proposed to use their data to study some factors affecting construction productivity such as rework and delay.
-----------	--

September 2008	▪ OPG agreed to permit use of their SCR database to conduct a rework study.
----------------	---

January 2009

- After reaching an agreement about the confidentiality of OPG's data and the related copyright issues, a series of internal procedures were processed to get the authorization and technical support to access the SCR database. The authorization and the required technology to access the database were acquired in January 2009.

April 2009

- Completed the retrieval of rework events from the SCR database, and obtained the complete data of rework events had been reported from 1998 to 2008. Among this data, it was determined that the reports in 2006, 2007 and 2008 were adequate for the case study.
- Therefore, the reports related to rework from 2006 to 2008 were reviewed; and the rework root causes for each event are verified.
- Delivered the result of the preliminary investigation to OPG for verification.

June 2009

- Completed the detailed review of rework event reports and collected the data of labor hours and dollar value consumed in rework for all three contractors.
- Obtained the overall work hours and dollar value for all three contractors.
- Completed some interviews about the data verification.

4.4.3.2 Summary of the data collected

1. Data retrieval in the SCR database

The numbers of rework event reports retrieved for each year are shown in Table 4-3.

Table 4-3 Number of Rework Event Records Retrieved

Year	Number of Rework Reports	Year	Number of Rework Records
1998	28	2004	944
1999	68	2005	1000
2000	61	2006	1590
2001	114	2007	1284
2002	750	2008	926
2003	1000		

Two reasons drove to choose taking only the rework events occurred in year 2006, 2007 and 2008 into the rework evaluation: (1) the record about rework is not sufficient and complete from 1998 to 2005; (2) there is no specific rework program before October of 2005. Therefore, the rework event records in SCR for year 2006, 2007 and 2008 were retrieved and reviewed; and the root causes of each rework events were verified. Total number of adverse condition records and rework event records involved in the investigation are shown in Table 4-4.

Table 4-4 Number of Rework Event Records Reviewed for Investigation

Year	Total Number of Adverse Condition Records in SCR	Number of Rework Event Records
2006	25,256	1,590
2007	28,739	1,284
2008	30,270	926

2. Data collected for rework impact evaluation

The data for rework impact evaluation including labor hours and dollar value was collected from the full event reports. The events occurred to three contractors were drawn into evaluation. Total numbers of the full event reports for these three contractors in each year is shown in Table 4-5.

Table 4-5 Numbers of Full Reports involved in Rework Impact Evaluation

Year	Total Number of Full Reports of Rework Events for three contractors
2006	41
2007	44
2008	45

The data of total work hours and dollar values of all three contractors were obtained from the contractual claim records that are archived in OPG's project office.

3. Other files reviewed for understanding OPG Nuclear's rework program

- SCR database help file
- OPG Nuclear Procedure file – Processing Station Condition Records
- OPG Nuclear Procedure file – Maintenance Rework
- OPG Nuclear List file – Trend Codes Applied to Station Condition Records
- OPG Nuclear Program file – Corrective action
- OPG annual reports 2006, 2007 and 2008, especially focusing on nuclear segment

4.5 Rework Impact Evaluation

In this section, the evaluation result of the rework impact for the project performance will be present in three parts: (1) the overall rework occurrences trend, (2) total rework hours and direct cost for the specified three contractors, (3) contribution analysis of rework root causes.

4.5.1 Overall occurrence of rework

The overall frequency of the occurrence of rework events determines the probability of rework events occurring within a specific unit period. From the measurements of the occurrence of rework events in a series of unit periods (years and months), management will discover whether the rework reduction program is effective and will be able to determine by how much the number of rework events have been reduced in general. The reduction of in the occurrence of rework events also determines to what extent the potential adverse impact on the quality of the project performance has been mitigated.

The Operation, Maintenance and Administration (OM&A) expenses for OPG’s nuclear sector for 2006, 2007, and 2008 taken from OPG’s annual reports are listed in Table 4-6. Little change is evident in the OM&A expenses over these three years. The annual reports explain that the increase in OM&A expenses was due primarily to higher outage expenditures, higher costs related to the increase in nuclear technical services provided to external parties, and higher pension costs. On the other hand, interviews with the management of the maintenance and modification program at the Pickering station revealed that their overall contract amount was relatively stable for those years. Information from two sources confirmed that the total amount of maintenance and modification work was almost identical for all three years, which led to the use of the number of rework events in each year as a means of comparing the severity of the rework for those years.

Table 4-6 OPG's Nuclear Segment OM&A Expenses

Source: OPG's Annual Report

Year	2006	2007	2008
OM&A expenses (million \$)	1,967	2,061	2,098

Figure 4-4 shows that the overall number of occurrences of rework events for 2008 was 926, which is 28% lower than the 1284 reported during 2007. The decrease from 2006 to 2007 was 19 % (from 1590 to 1284). These results clearly demonstrate that the rework reduction program has been effective in mitigating the occurrence of rework events in the case study project.

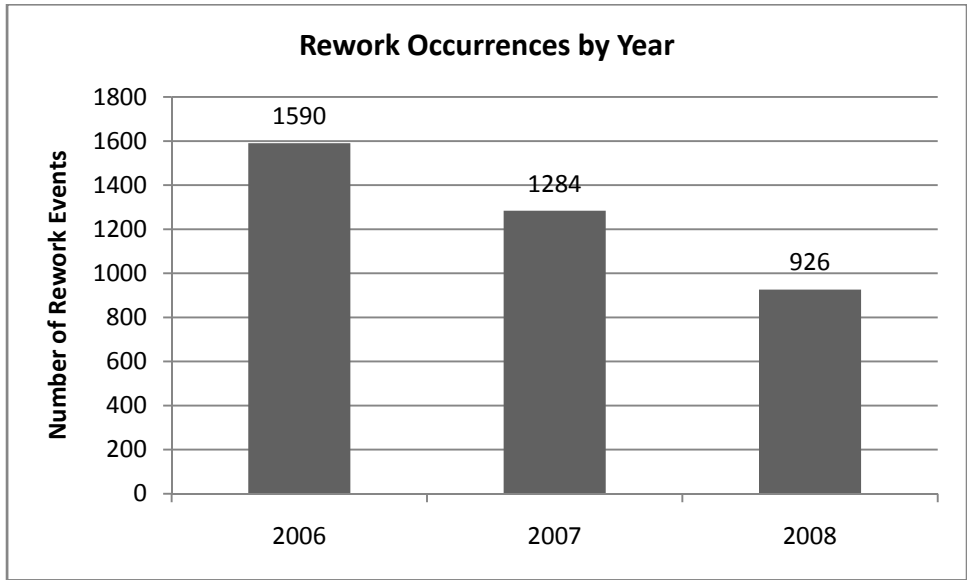


Figure 4-4 Overall Occurrence of Rework by Year

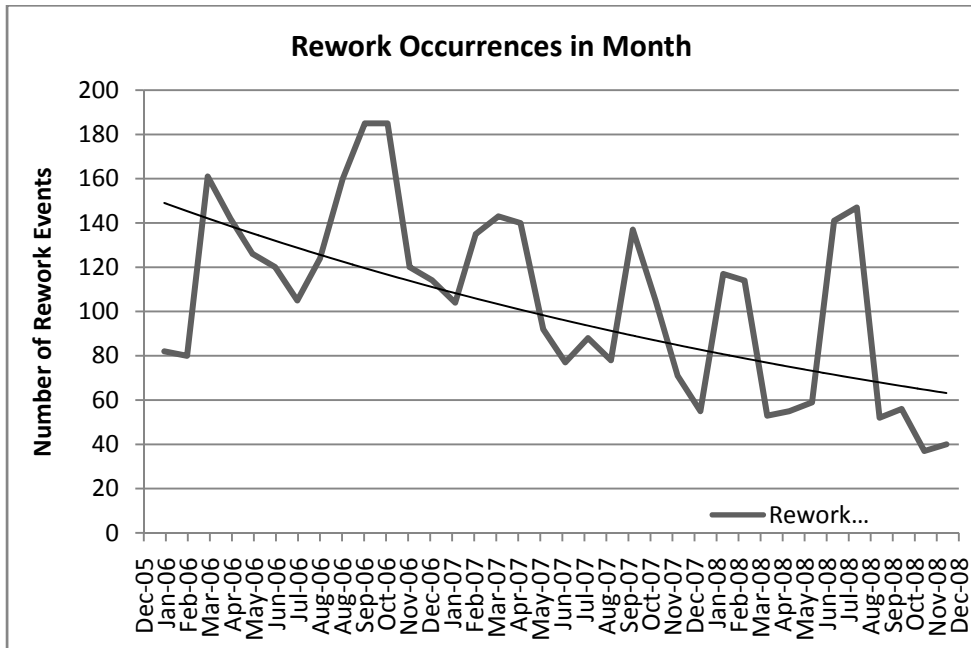


Figure 4-5 Overall Occurrence of Rework by Month

As shown in Figure 4-5, if the occurrence of rework events is plotted as a shorter time interval (monthly), it can be observed that the occurrence of rework events also has a general downward trend from 2006 to 2008. The exponential trend line in Figure 4-5 clearly illustrates this. However, the monthly changes oscillate around the trend line rather than decline monotonically. Several factors could produce this phenomenon:

- The amount of overall work fluctuates monthly.
- The corrective action designed to prevent the rework is not guaranteed to be exact and effective enough for every remediation due to limitations with respect to estimation, judgment, experience, knowledge, and individual human performance.
- Work is not scheduled early over the course of any year.

4.5.2 Rework hours and cost

Rework is a major element in unproductive activities that have a negative effect on productivity. Reducing rework labor hours translates into an improvement in labor productivity, which leads to lower costs for labor for the project.

For the case study, the rework labor hours for three contractors were measured. As discussed with respect to the occurrence of rework in section 4.5.1, a basic fact is that the overall contract amount and labor hours for the three contractors were generally equal during the three years of the study. The total cost of the work was about \$22.34 million, and the total labor hours were 292,929.

As shown in Figure 4-6, the rework labor hours declined respectively by 6.9 % from 2006 to 2007 and 19.6 % from 2007 to 2008. As can be seen in Figure 4-7, the direct cost of rework declined respectively by 31.2 % from 2006 to 2007, and by 23.1 % from 2007 to 2008. These data prove the clear effectiveness of the rework reduction program in improving productivity and cost control performance.

Table 4-7 presents the proportion of the total work hours and cost represented by rework labor hours and direct cost. Rework consumed about 1 % of the total labor hours and cost for the project, which also indicates the potential saving that can be expected from the application of a specific rework reduction program.

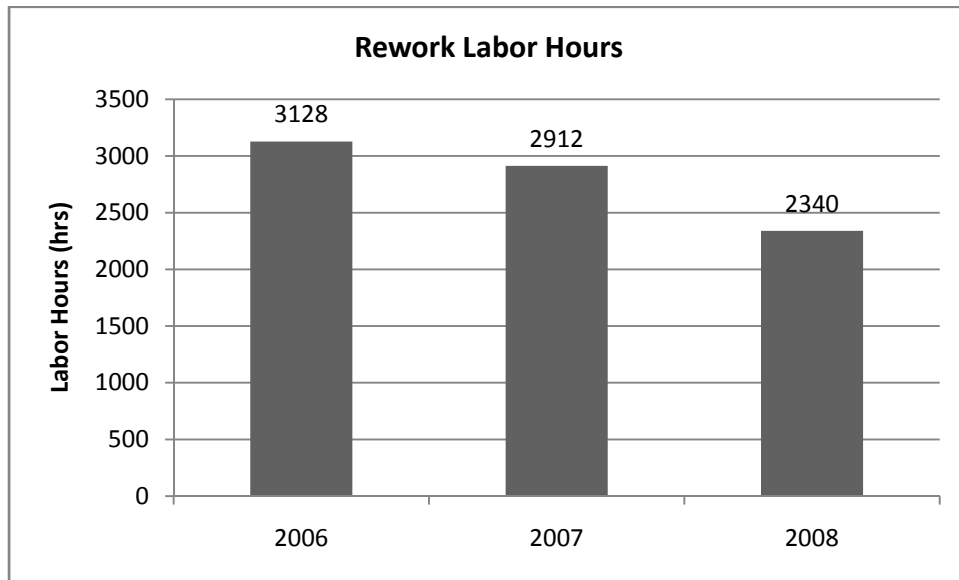


Figure 4-6 Trend in Rework Labor Hours

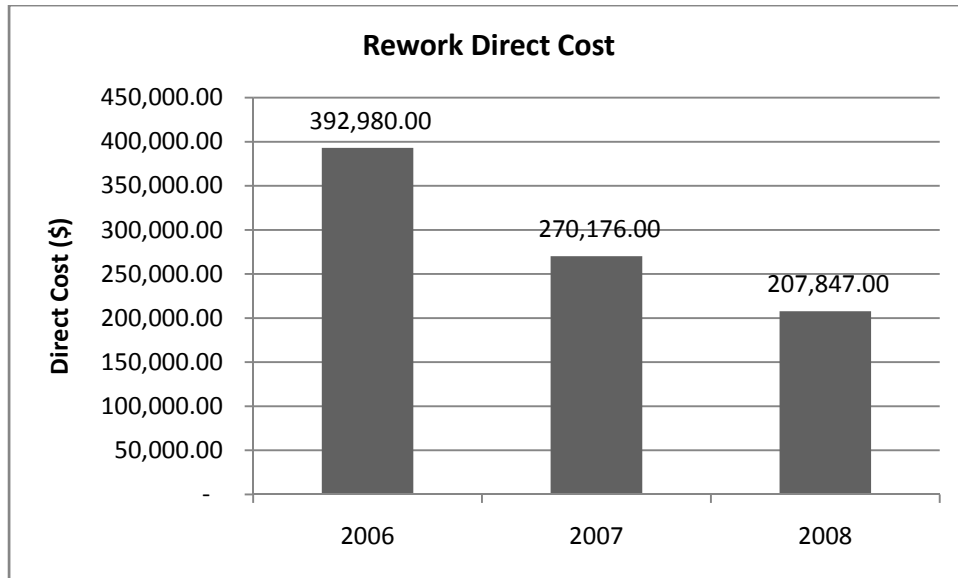


Figure 4-7 Trend in Direct Cost of the Rework

Table 4-7 Rework Hours and Direct Cost as a Percentage of Total Work Size

	Labor Hours		Cost	
	hrs	%	\$ CAD	%
Total Work Size	292,929		22,346,242.00	
Rework	hrs	%	\$ CAD	%
2006	3,107	1.06%	302,010.00	1.35%
2007	2,912	0.99%	270,176.00	1.21%
2008	2,340	0.80%	207,847.00	0.93%

4.5.3 Rework root causes analysis

The system used in the case study for classifying the root causes of rework is based on the categories of rework developed by the OPG SCR system. The first level of causes

contains two groups: Process and Human Performance. These groups then include second-level root causes: Design, Parts, Instruction, and Delays in the Process group, and Skill, Knowledge, and Rules in the Human Performance group. The objective of this approach to the classification of the causes of rework is to identify the root causes that contribute to field rework at such a specific level that they can be remedied and prevented.

Four different analyses are presented in order to illustrate the contribution of the root causes and the changes that occurred as a result of the implementation of the rework reduction program:

- The contribution of the first level and second level root causes as percentages of the overall rework occurrence amount
- The trend in the frequency of occurrence of rework caused by each second-level root cause from 2006 to 2008
- The magnitude of the labor hours and the dollar value of the rework events by each root cause along with the trends in these values from 2006 to 2008
- The contribution of the first-level root causes as a percentage of the total number of labor hours and the total dollar value along with the trends in these values from 2006 to 2008

4.5.3.1 Contribution of the root causes of rework as a percentage of the overall rework amount

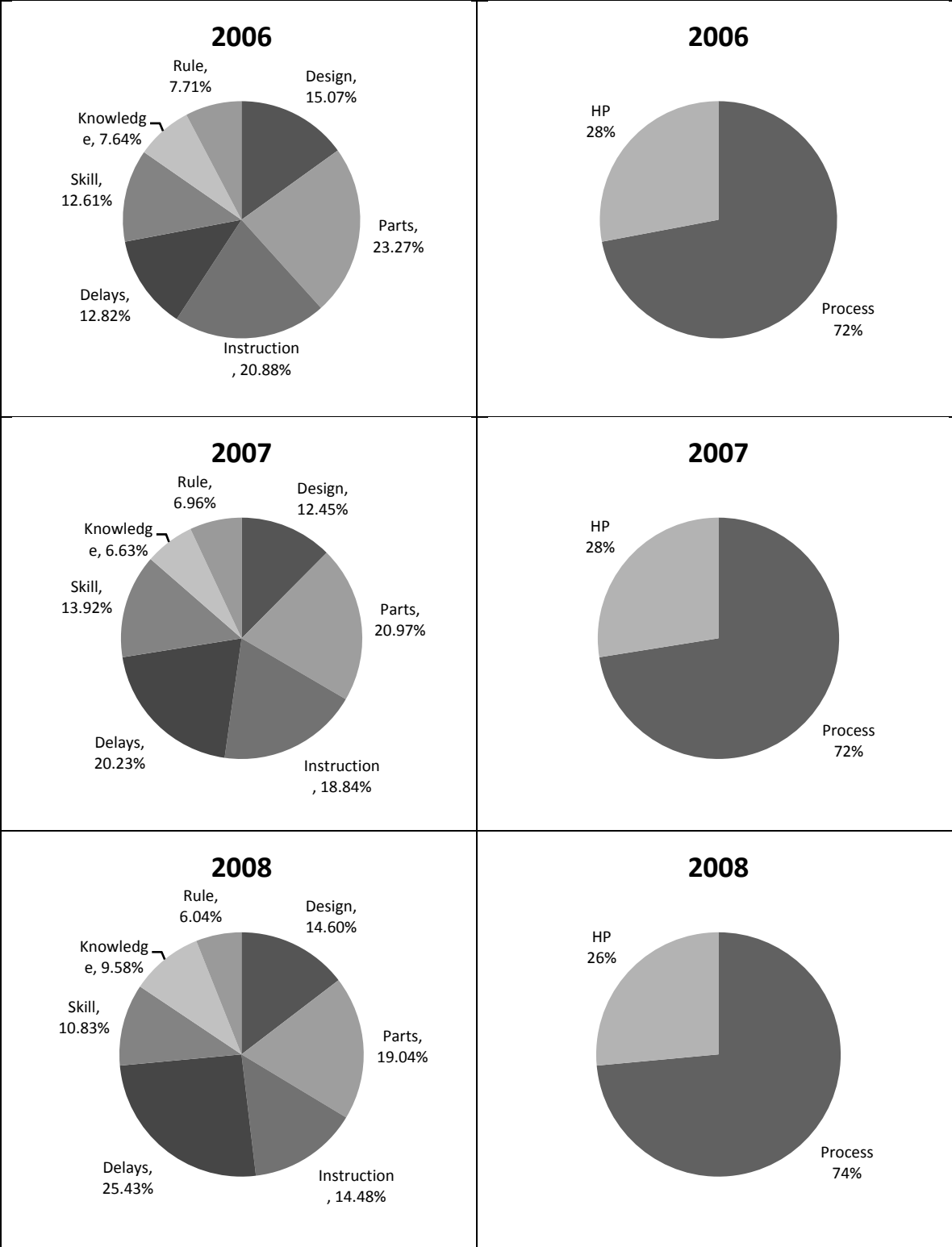


Figure 4-8 Percentage Contribution of Root Causes of Rework

As shown in Figure 4-8, Parts, Instruction, and Delays are the factors that contribute most significantly to rework, with averages of 21 %, 19 %, and 18 %, respectively. Knowledge and Rule contribute relatively little to the total amount of rework, accounting for averages of 8 % and 7 % of the causes of rework, respectively. In the Human Performance group, Skill represents the most significant contribution at 13 %.

With respect to the first-level categories, the causes of rework related to the Process group contribute most to the total occurrence of rework events, at 72 %. Rework due to Human Performance declined by 2 % in 2008, more importantly taken with the decrease in the overall occurrence of rework, it can be concluded that a series of measures for improving human performance implemented by OPG Nuclear was clearly effective in reducing rework.

4.5.3.2 Trends in the rework occurrence for each root cause over the time

As shown in Figure 4-9, except for Delays, the number of rework events by each root cause clearly declines from 2006 to 2008. These results demonstrate that specific corrective actions are effective in remedying most causes of rework. Of these causes, the number of rework events caused by Parts shows a considerable decline. Prefabricated components are used extensively in power plant piping work, and OPG's Corrective Action Plan placed a great deal of emphasis on attention to the prefabrication details. The quality of component prefabrication has therefore improved considerably so that on-site rework has been mitigated. The final results shown in Figure 4-9 also illustrate a substantial improvement in the Human Performance category.

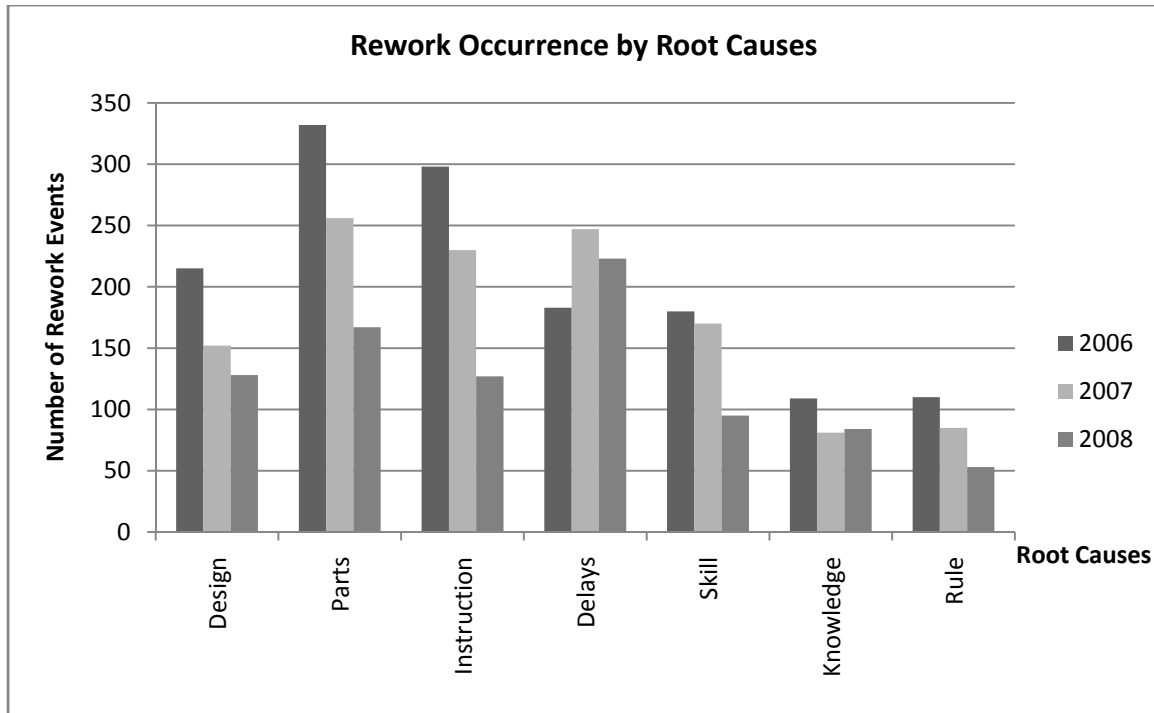


Figure 4-9 Rework Occurrence by Root Causes Over the Year

4.5.3.3 Magnitude of rework labor hours and dollar value by root cause

The frequency of rework is the first perspective for measuring the severity of rework, which, in a nuclear power plant, is generally relevant to safety. The number of rework labor hours and the dollar value provide management and staff with a direct picture of the impact of rework on project performance. As the illustrations in Figure 4-10 and Figure 4-11 show, the skill of the crew is the largest factor affecting the number of rework labor hours and the dollar value. However, changes in the magnitude of the hours and dollars by each root cause over time did not occur uniformly, because the magnitude of the hours and dollar value for an individual event vary randomly from case to case.

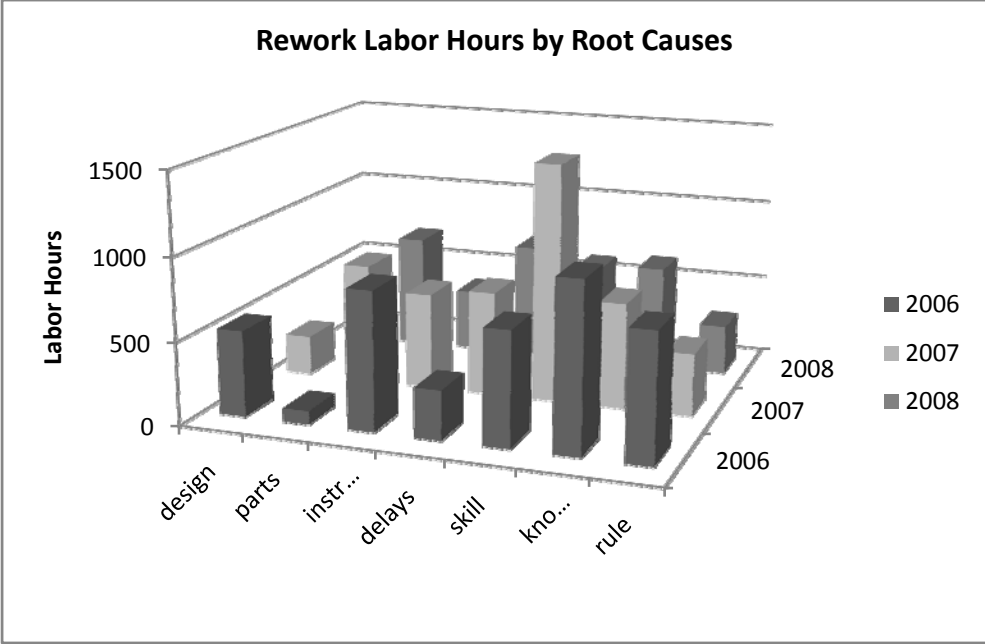


Figure 4-10 Rework Labor Hours by Root Causes Over Time

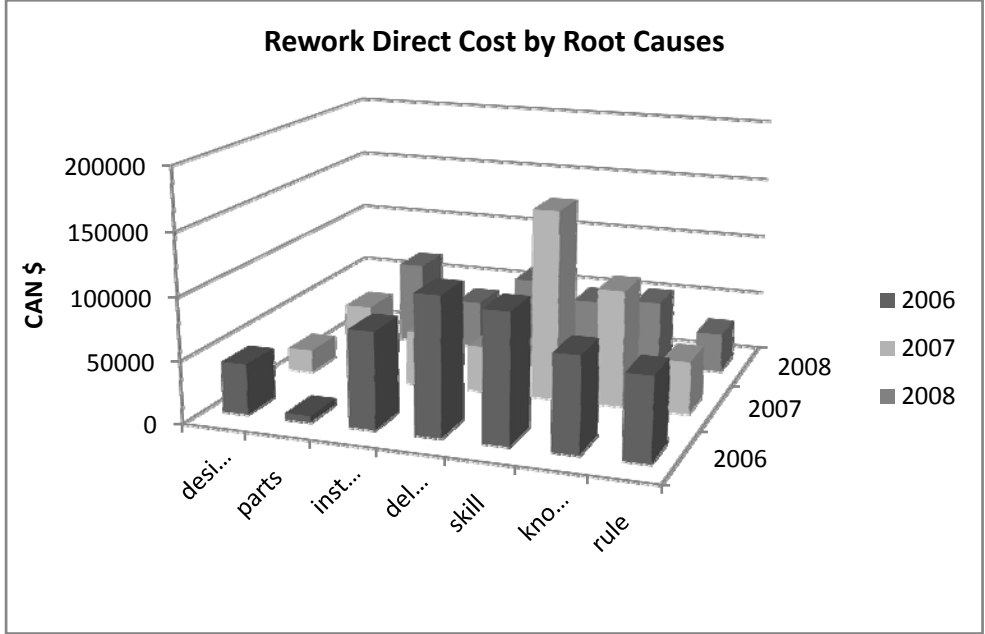


Figure 4-11 Direct Cost of Rework by Root Causes Over Time

4.5.3.4 Percentage contribution of first level root causes to labor hours and dollar value

In Figures 4-12 and 4-13, the term “Combined” indicates the portion of rework hours or dollars caused by both Human Performance factors and Process factors. As the data in Figures 4-12 and 4-13 show, the contribution of Human Performance factors declined from 43 % in 2006 to 36 % in 2008, which reflects and demonstrates the effectiveness of the attention OPG Nuclear gives to the improvement of Human Performance, and success of their series of applicable Event Free Tools for improving human performance.

The contribution of the combined causes also declined from 26 % in 2006 to 16 % in 2008, which reflects the fact that the evaluation provided by the RRP can address the root causes of rework accurately and without ambiguity. Because the dollar value of the rework is random and related to individual events, the trends in the direct cost of rework by root cause group over time are not pronounced.

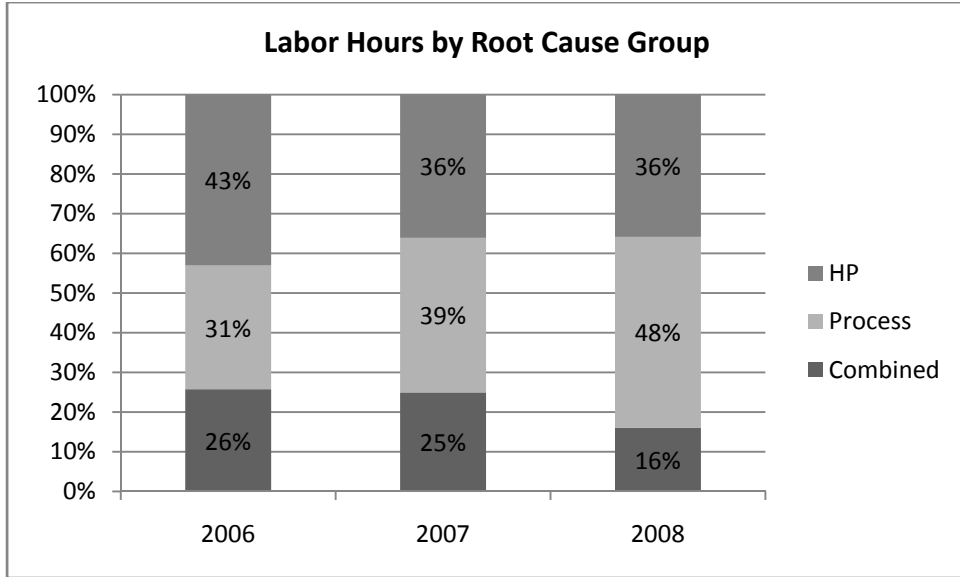


Figure 4-12 Rework Labor Hours by Root Cause Group Over the Time

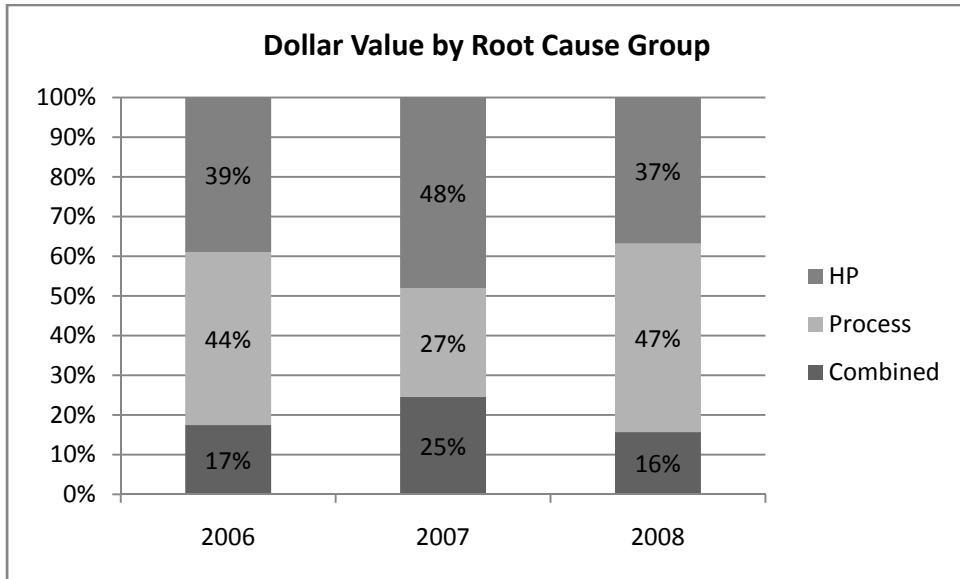


Figure 4-13 Direct Cost of Rework by Root Cause Group Over the Time

Chapter 5

Conclusions and Recommendations

5.1 Introduction

This study has presented a conceptual model for rework reduction with the goal of measuring, quantifying, and classifying construction rework; designing a corrective action plan for remedying the rework; and integrating the rework reduction program into the global management system of the company. A case study of an actual rework reduction program implemented on a program of small projects over a course of several years was used in order to verify the pertinent methodologies and the results produced by the conceptual model. This chapter summarizes the findings and conclusions and offers recommendations for future studies.

5.2 Findings and Conclusions

The findings and conclusions are drawn from the completed investigation of the results produced by the conceptual model for a rework reduction program (RRP) as applied to OPG Nuclear's actual rework program. The investigation covered the implementation process of the rework reduction program, the classification of the causes of the rework, the corrective actions currently in practice, and a quantitative analysis of the impact of the rework on the project as a whole. The quantitative analysis was based on the measurement of the frequency of rework events, the number of labor hours, and the dollar value. The reduction in rework over the course of the year was also quantified using the

same metric in order to reflect the effect of the individual root causes of the rework as well as the effectiveness of the corrective action. In these ways the benefits and effectiveness of the rework reduction program have been demonstrated.

Because the quantitative analysis was based on data and information collected from a nuclear power plant maintenance and modification project, the construction scope and technical characteristics determined the overall circumstances related to rework for this specific construction group, and the results of the evaluation reflect the characteristics of the rework for this specific construction group. However, the functions of the RRP related to project performance, the structure for evaluating the rework, and the means of measuring the effectiveness of the RRP are generally suitable for use in common construction “maintenance” programs as well.

5.2.1 The role of the generalized rework reduction program in a management hierarchy

The generalized rework reduction program developed in this thesis is intended to play a role at the secondary management level as a special tool that is part of the performance management strategy. In this respect the RRP is designed for remedying rework encountered in general constructions work and is not limited to a specific type of work in one particular industry segment. The new mechanism not only provides a significant benefit for the project or program of small projects evaluated by the RRP but also acts as a vehicle for the addition of further valuable practices that can enhance productivity and reduce waste in the construction process as a whole.

5.2.2 Learnability of the generalized rework reduction program

The conceptual model for the generalized RRP described in Chapter 3 has the important feature of learnability, which is also an aspect of two other features of the RRP model that are discussed in section 3.2: the open loop system and the results-oriented system, which determine changes to the management system based on the lessons learned from each update to the rework evaluation and to the corrective actions. From a practical perspective, the learnability of the RRP model appears in three levels:

- Perceptual learning based on shared experience
- Quantitative learning based on the classification and quantification of the rework
- Responsive learning based on the corrective action planning

The following sections summarize the findings and conclusions drawn from the case study, with respect to each of these types of learning. The investigation and quantitative analysis of the case study demonstrate that the RRP implemented in the case study achieved the goals established for its development.

5.2.3 Comprehensive rework record

Setting up a comprehensive rework record is the primary function of the RRP. The rework record itself provides the following benefits with respect to reducing rework, which is shown by the rework events recorded in OPG's SCRs.

1. The rework record is an opportunity to share with others the lessons learned and experience acquired from the rework. The approaches include recording specific

- conversations, regular meeting communications, routine reports, and site notices and sharing them with staff working on future jobs and at other sites. The investigation conducted for the case study proved that the sharing experience is effective for in improving the quality of work by increasing awareness of rework.
2. A rework record that indicates a high frequency of rework events acts as a reminder and warning to the site crew and management.
 3. The rework record also acts as a metric for comparing levels of site management performance, which has the effect of promoting competition among the crews, thereby increasing productivity.

5.2.4 Quantitative analysis of rework

The quantitative analysis of rework and its causes in terms of the occurrence of rework, the number of labor hours, and the dollar value should be learned in order to motivate and drive the remediation process, which is an important process, like an engine in the RRP management loop. First, the severity of the rework needs to be addressed, and then the contribution of each root cause of the rework must be measured.

The overall number of labor hours and dollar value were based on the data collected from three main contractors in the Pickering Nuclear maintenance and modification program. The fact that these three contractors have undertaken similar work at Pickering Nuclear for years minimized the variation in the quality of the rework data collected from them.

The overall rework labor hours were 1.06 % of the total work hours, and the overall rework dollar value was 1.35 % of the total work cost for the year 2006. When these

percentages are compared with those of the construction industry as whole, the severity of rework in the case study project is revealed as lower than the average rate of 3.13 % reported in CII Research Report 203-1, and it declined further during 2007 and 2008. However, even applying a rate of 1.35% to the entire Operation, Maintenance, and Administration (OM&A) expenses in OPG's nuclear segment yields significant potential savings if the RRP is implemented.

Quantifying the contribution of the root causes of the rework with respect to the occurrence of rework events, the number of labor hours, and the dollar value can assist with the choice of the most effective remediation plan. The causes that represent the largest contribution to the cost of the rework could also be selected as having the highest priority for remediation.

Of the seven root causes of rework, Parts, Instruction, and Delays, with averages of 21 %, 19 %, and 18%, respectively, are the factors that most significantly contribute to the occurrence of rework. Based on this result, it is evident that more emphasis should be placed on improving the quality or grade of parts or equipment received from the fabrication workshop, on delivering accurate and complete instructions, and on developing a more reliable and practicable construction schedule. For example, prefabricated components are a large part of the parts supply, which significantly increases construction productivity compared with on-site stick-built construction, and also speeds up the construction progress because parallel activities are performed offsite. Inconsistencies, misalignment, and misplacement of the elements in a prefabricated component can result in rework that must be performed onsite to fix the problem.

Therefore, more attention must be paid to detail, and/or more advanced technology must be developed with respect to prefabrication so that mistakes in the fabrication workshop can be avoided.

With respect to the number of labor hours and the dollar value expended on rework, skill is the most significant factor that affects expenses and labor hours related to rework. The first level in the classification of the root causes is Process and Human Performance: the contribution of human performance factors represents 43 % of the rework labor hours, which is much higher than the contribution of process factors, at 31 % in 2006. These figures reflect the fact that productivity is most affected by the average skill level of the crews. More emphasis should be placed on providing training in advanced skills, on enhancing pertinent knowledge required for completing a task, and on strengthening discipline. As the materials, construction technologies, and the technical specifications are upgraded, the capability of human performance to deal with these changes is always the greatest challenge for improving productivity.

5.2.5 Effectiveness of the corrective action resulting from the rework reduction program

The RRP model creates a consistent evaluation system and a regular monitoring system for rework control. Analyzing the rework using a consistent metric over time permits the tracking of the following trends:

- Changes in the overall magnitude of the rework over time in terms of number of occurrences, number of labor hours, and dollar value.

- Changes in the number of rework labor hours and the dollar value associated with each individual root cause over time.
- The appearance of new factors that cause rework.

Tracking changes in the magnitude of the rework and its associated causes over time can provide feedback about the effectiveness of the RRP and related corrective action, which has been demonstrated through the case study.

According to the results of the evaluation of the rework in the Pickering Nuclear maintenance and modification project, the number of rework events declined from 1590 in 2006 to 926 in 2008, the percentage of rework labor hours declined from 1.06 % in 2006 to 0.80 % in 2008, and the percentage of the dollar value of the rework declined from 1.35 % in 2006 to 0.93 % in 2008. These data provide clear proof of the effectiveness of the RRP.

For changes in the contribution of the individual root causes of the rework, the contribution of human performance factors declined from 43 % in 2006 to 36 % in 2008, which reflects and demonstrates the effectiveness of that fact that OPG Nuclear places a great deal of emphasis on improving human performance. The tactic of human performance improvement is primarily used for improving safety performance, while this benefit also applies to the control of field rework in OPG Nuclear.

5.3 Recommendations for Future Studies

With its particular focus on the field of nuclear power plant maintenance and modification, the case study used in this research is not perfectly representative of the overall construction industry. Several areas of research therefore remain to be examined:

- An appropriate classification of the causes of the rework is an essential link in the RRP: awareness of rework increases if the categories of causes are defined according to an intelligent structure with a guidable first-level leading group and practicable root causes and sub-causes. Seven root causes sorted into two groups are defined in the developed generalized RRP model, which may not be suitable for all kinds of construction groups. A more extensive investigation of the causes of rework and a deeper analysis of sub-causes would expand and facilitate the identification of root causes.
- The rework evaluation in the case study has the limitation of focusing on a nuclear power plant maintenance and modification construction group. This type of construction group does not experience the severe magnitude of rework encountered by general construction groups. More pilot studies involving a variety of construction groups will increase awareness of the impact of rework.
- The impact of rework on a construction schedule has not been fully investigated in this case study, although it has been incorporated into the design of the RRP model. To analyze this effect, the delay time due to the rework should first be measured and the effect of the delay time on the critical path of construction schedule then determined. Maintenance and modification work is a serial routine job that entails a

critical path not for the entire progress but only for specific controlling time points for individual jobs. Analysis of the impact of rework on the construction schedule for other general construction groups would prove worthwhile.

- The additional cost of remedying the causes of rework has not been included in the analyses in this study. Because the cost of remediation is mingled with a number of cost groups, calculating it separately is difficult, especially since a corrective action plan is usually integrated into the total management system. However, when advanced technologies such as 3D scanning are implemented in order to mitigate rework, it is necessary to measure the cost of the remediation so that the economic feasibility can be evaluated. Therefore, from a research standpoint, such an evaluation of corrective action represents an area that requires further examination.

Much of the research to date has focused on quantifying and classifying the causes of construction rework. Therefore, the corrective actions can be planned appropriately. In actual practice in the case study, routine countermeasures are the most often used remediation tactic, which can lead to high remediation costs. On the other hand, when the problem is viewed from the perspective of prevention, if an area that has a high possibility of rework can be detected, and appropriate preventive action can be taken, the costs will be significantly reduced. To implement such a process, one approach recommended for the further studies is to quantify and classify the characteristics of the job during which the rework occurs according to the terms of the detailed scope of the work, the technology applied, the skills required on the part of the crew, the materials and

equipment, and the specific circumstances. Recognizing similar job characteristics can enable the detection of areas that have a strong possibility of rework.

References

- Alwi, S., Hampson, K., & Mohamed, S. (1999). Investigation into the Relationship Between Rework and Site Supervision. *Proceedings The 2nd International Conference on Construction Process Re-engineering* (pp. 189-195). Sydney: QUT ePrints.
- Assaf, S. A., & Al-Hejji, S. (2006). Causes of Delay in Large Construction Projects. *International Journal of Project Management* , 349–357.
- Atkinson, J., Rogge, D. F., & Haggard, R. (2001). *RS 153-1 The Field Rework Index: Early Warning for Field Rework and Cost Growth*. Construction Industry Institute. Austin: CII.
- Burati, J. L., Farrington, J. J., & Ledbetter, W. B. (1992). Causes of quality deviations in design and construction. *Journal of Construction Engineering and Management* , Vol. 118 (No. 1), 34-49.
- Carr, J. (2006, February 23). Nuclear Power in Ontario -- Future Conditional. *Canadian Nuclear Association Annual Seminar 2006* . Ottawa, Ontario, Canada.
- CNSC. (2008). *RD-310 Safety Analysis For Nuclear Power Plants*. Ottawa: Canadian Nuclear Safety Commission.
- COAA. (2006, July 1). *Project Rework Reduction Tool -- Construction Owners Association of Alberta*. Retrieved October 26, 2009, from Construction Owners Association of Alberta:
<http://www.coaa.ab.ca/BESTPRACTICES/Rework/ProjectReworkReductionTool/tabid/92/Default.aspx>
- Coles, L., & Haggard, R. (2005). *IR 203-2 Zero Field Rework Self-Sessment Opportunity Checklist*. Construction Industry Institute. Austin: CII.

- East, K. (2004). *Project Rework Reduction Tool - PRRT*. Retrieved from Construction Innovation Forum: http://www.cif.org/noms/2004/08_-_Project_Rework_Reduction_Tool.pdf
- Fayek, A. R., Dissanayake, M., & Campero, O. (2004, December 21). Developing a Standard Methodology for Measuring and Classifying Construction Field Rework. *Canadian Journal of Civil Engineering* , 1077–1089.
- Fayek, A. R., Dissanayake, M., & Campero, O. (2003, May). *Measuring and Classifying Construction Field Rework: A Pilot Study*. Retrieved from The Hole School of Construction Engineering: <http://www.construction.ualberta.ca/rework/>
- Gerring, J. (2007). *Case Study Research Principles and Practices*. New York: Cambridge University Press.
- Goodman, R. M., & Charlebois, P. (2006). *OPG Nuclear Program Corrective Action*. Toronto: Internal Use Only.
- Heldman, K. (2007). *PMP Project Management Professional Exam Study Guide* (Fourth ed.). Indianapolis, Indiana: Wiley Publishing, Inc.
- Hsu, L., & Mohan, S. (1991). Computer Aided Configuration of Pipe Systems in Buildings. *Microcomputers in Civil Engineering* , 15-26.
- Hwang, B.-G., Thomas, S. R., Haas, C. T., & Caldas, C. H. (2009, March). Measuring the Impact of Rework on Construction Cost Performance. *Journal of Construction Engineering and Management* , 187.
- Josephson, P.-E., Larsson, B., & Li, H. (2002). Illustrative Benchmarking Rework and Rework Costs in Swedish Construction Industry. *Journal of Management in Engineering* , VOL. 18 (No. 2), 76-83.

- Lau, A. W., & Tang, S. (2009). A survey on the advancement of QA (quality assurance) to TQM (total quality management) for construction contractors in Hong Kong. *International Journal of Quality & Reliability Management* , 410-425.
- Love, P. E. (2002). Auditing the Indirect Consequences of Rework in Construction: A Case Based Approach. *Managerial Auditing Journal* , VOL. 17 (No. 3), 138-146.
- Love, P. E. (2002, February). Influence of Project Type and Procurement Method on Rework Costs in Building Construction Projects. *Journal of Construction Engineering and Management* , 18-29.
- Love, P. E., & Li, H. (2000). Quantifying the Causes and Costs of Rework in Construction. *Construction Management and Economics* , 479-490.
- Love, P. E., & Sohal, A. S. (2003). Capturing Rework Costs in Projects. *Managerial Auditing Journal* , VOL. 18 (No. 4), 329-339.
- Love, P. E., Irani, Z., & Edwards, D. J. (2004). A Rework Reduction Model for Construction Projects. *IEEE Transactions on Engineering Management* , VOL.51 (No. 4), 426-439.
- Love, P. E., Mohamed, S., & Wyatt, A. (1997). Understanding rework in construction. *Construction Process Re-Engineering* (pp. 269-278). Gold Coast, Australia: Griffith University.
- Love, P., Holt, G., Shen, L., Li, H., & Irani, Z. (2002). Using Systems Dynamics to Better Understand Change and Rework in Construction Project Management Systems. *International Journal of Project Management* , 425–436.
- Love, P., Mandal, P., Smith, J., & Georgiou, J. (2000). A Design and Construction Rework Minimisation Model. *Proceedings of the International Conference on Systems Thinking in Management* (pp. 377-382). Geelong, Victoria: Deakin University.

- McTague, B., & Jergeas, G. (2002). *Productivity Improvements on Alberta Major Construction Projects*. Calgary: Alberta Economic Development.
- OPG. (2005, January 1). *Ontario Power Generation: Power Generation: Nuclear Power*. Retrieved October 12, 2009, from Ontario Power Generation:
<http://www.opg.com/power/nuclear/>
- OPG. (2000). *Ontario Power Generation: Power Generation: Nuclear Power: Pickering*. Retrieved September 29, 2009, from Ontario Power Generation:
<http://www.opg.com/power/nuclear/pickering/>
- OPG. (2007). *OPG Nuclear SCR Help File*. Toronto: Internal use.
- OPG. (2009). *Performance Report Mid-year 2009*. Toronto: Ontario Power Generation.
- OPG. (2006). *Project Description for the Pickering Refurbishment for Continued Operation Environmental Assessment*. Toronto: Ontario Power Generation.
- Powell, T. C. (1995). Total Quality Management as Competitive Advantage: A Review and Empirical Study. *Strategic Management Journal* , VOL. 16 (No. 1), 15-37.
- Pyy, P. (2001). An Analysis of Maintenance Failures in a Nuclear Power Plant. *Reliability Engineering and System Safety* , 293-302.
- Rogge, D. F., Coglisier, C., Alaman, H., & McCormack, S. (2001). *RR 153-11 An Investigation of Field Rework in Industrial Construction*. Construction Industry Institute. Austin: CII.
- Smith, G. R., & Haggard, R. (2005). *RS 203-1 Making Zero Rework A Reality*. Construction Industry Institute. Austin: CII.
- Smith, G. R., & Haggard, R. (2005). *RS 203-1 Making Zero Rework A Reality*. Construction Industry Institute. Austin: CII.

Smith, G. R., & Jirik, T. (2006). *RR 203-11 Making Zero Rework A Reality: A Comparison of Zero Accident Methodology to Zero Rework and Quality Management*. Construction Industry Institute. Austin: CII.

Smith, G. R., & Jirik, T. (2006). *RR 203-11 Making Zero Rework A Reality: A Comparison of Zero Accident Methodology to Zero Rework and Quality Management*. Construction Industry Institute. Austin: CII.

Yin, R. K. (2003). *Case Study Research Design and Methods (Third Edition)*. London: Sage Publications Inc.

Appendices

Appendix A – Examples of SCR Reports

Appendix B – Examples of Rework Events

Appendix B-1 – An Example of Rework Events with the Root Causes in Process
Group

Appendix B-2 – An Example of Rework Events with the Root Causes in Human
Performance Group

Appendix A Examples of SCR Reports

SCR No	SCR Status	SCR Date/Time	Date Occurred	Discovery Date
P-2008-09615	COMPLETE	2008/04/15 07:47 AM	2008/04/07 12:00 PM	2008/04/07

Initiator	Phone Ext	First Line Manager	Phone Ext	Initiating Department Manager
*** *****	*****	J PUOPOLO		ROB GRANGER

	Significance Level	Resolution Category	Unit	Power
Recommended:	4	D	8	NA
Final:	4	D		

Equipment Failure? : **Critical Codes** :

Equipment Tags :

Device

OPEX Flag : N

OPEX Category :

Event Title

PO164822 P881 Outage - Extra Costs (Maronite Panel Rework)

Description of Condition

During P881 Outage quality issues arose related to fabrication of maronite panels by contractor staff. Rework was documented in SCR's P-2008-09044, 09143, 09349, 09351, 09352. At the time of the reworks the root cause and cost impact of the reworks was not fully understood.

Discovered While Performing

Review of P881 Scope

Immediate Action Taken

Contractor along with CMO initiated an investigation to determine cause and cost of rework. Results of investigation noted below indicate that there is shared responsibility between Contractor and OPG for the rework issues and the cost should be shared equally between the two parties. Contractor shall not charge OPG for 77 hrs of time spent on rework which relates to a cost of approx \$7,400.00

Apparent Cause of Condition

Two main issues arose from discussions between contractor and CMO.

- 1: work practices of field crew - field crews were relying on sketches and measurements taken of maronite panels from other units taken during previous outages. No one was taking measurements of current locations to ensure accurate fit.
- 2: OPG supplied hardware - during previous outages OPG was supplying contractor with latches that had slotted screw holes. Slotted latches would allow adjustments to be made to ensure 75% engagement of latches. Standard latches as supplied from warehouse do not have slotted holes. Standard latches are machined by Mech Maintenance to provide slotted holes. This practice has been used in other units and approved by ENG. Current CMO staff was unaware of this practice as a solution to ill-fitting latches

Recommended Resolution(s)

1: Staff involved in fabrication of maronite panels are to measure exact locations of each panel to ensure accurate dimensions. Contractor will ensure this happens on all subsequent outages.
2: Prior to outage, required latches will be machined to provide slotted screw holes thus allowing adjustment to ensure proper latch engagement.
These two practices will be incorporated into "P881 Lessons Learned"

Reportable? Reportable To

N

Applicable S99 Section(s)

Notification Criteria

Affects Operability?	TOE Required?	TOE Status
N	N	

Attachments :

SCR No	SCR Status	SCR Date/Time	Date Occurred	Discovery Date
P-2008-18807	COMPLETE	2008/08/06 09:05 AM	2008/07/23 04:00 PM	2008/07/23

Initiator	Phone Ext	First Line Manager	Phone Ext	Initiating Department Manager
*** *****	*****	PAT MCANULTY		ROB GRANGER

	Significance Level	Resolution Category	Unit	Power
Recommended:	4	D	014	NA
Final:	4	D		

Equipment Failure? : **Critical Codes** :

Equipment Tags :

Device

OPEX Flag : N

OPEX Category :

Event Title

Financial Performance - cost overrun Project # 10-25911- Cost Issue

Description of Condition

Project # 10-25911 has suffered a cost overrun due to delays to 4 men for 3.5 days at a cost of approx. \$ 10,400. Delays resulted from material supply issues and rework.

Discovered While Performing

Normal duties

Immediate Action Taken

Informed C/A filed SCR.

Apparent Cause of Condition

MCANULTP 2008/08/11 Material not available when required resulting in delays.

Recommended Resolution(s)

MCANULTP 2008/08/11 SCR to document delay.

Reportable? Reportable To

N

Applicable S99 Section(s)

Notification Criteria

Affects Operability?	TOE Required?	TOE Status
N	N	

Attachments :

SCR No	SCR Status	SCR Date/Time	Date Occurred	Discovery Date
P-2007-26416	COMPLETE	2007/11/27 12:21 PM	2007/11/27 02:00 PM	2007/11/27

Initiator	Phone Ext	First Line Manager	Phone Ext	Initiating Department Manager
*** *****	*****	DOU AUSTON		ROB GRANGER

	Significance Level	Resolution Category	Unit	Power
Recommended:	4	D	2	NA
Final:	4	D		

Equipment Failure? : Critical Codes :

Equipment Tags :

Device

OPEX Flag :

OPEX Category :

Event Title

Re-work - Switchyard Project # 13-49466

Description of Condition

PA Cable had to be reworked as original cable route was revised; Delay to Project 4 men X 8 hours= \$2400.00 AUSTOND 2007/11/28
 Contractor had partially installed PA cable as instructed by Project (at risk) while awaiting final routing of cable. Final routing of PA cable was changed from 225 elv to a route on 254 elv. This change created rework for the contractor as cable had been placed in pans and fastened in place with cable ties and pan covers installed . Pan covers had to be removed so cable ties could be cut and cable was pulled back to 254 elv. Contractor has indicated that estimate for rework shown above is inaccurate. Time spent on rework was 12 hrs for 4 men. Approx cost of rework \$3,500.00

Discovered While Performing

when new routing was issued

Immediate Action Taken

Informed CA of rework issue's

Apparent Cause of Condition

AUSTOND 2007/11/28 Change in routing for PA cable

Recommended Resolution(s)

AUSTOND 2007/11/28 SCR intended to document a rework and for trending purposes

Reportable? Reportable To

N

Applicable S99 Section(s)

Notification Criteria

Affects Operability?

N

TOE Required?

N

TOE Status

Attachments :

SCR No	SCR Status	SCR Date/Time	Date Occurred	Discovery Date
P-2007-15263	COMPLETE	2007/07/09 03:53 PM	2007/07/09 10:00 AM	2007/07/09

Initiator	Phone Ext	First Line Manager	Phone Ext	Initiating Department Manager
*** *****	*****	JAM BRINE		ROB GRANGER

	Significance Level	Resolution Category	Unit	Power
Recommended:	4	D	2	NA
Final:	4	D		

Equipment Failure? : **Critical Codes** :

Equipment Tags :

Device

OPEX Flag :

OPEX Category :

Event Title

Rework on Floor EP for Switchyard Project # 13-49266

Description of Condition

Rework required for Floor EP as obstruction could not be removed. Cost to project 2.5 men X 8 hours on overtime = \$2,500.00

Discovered While Performing

Trying to install floor EP, Change recieved from Field Eng.

Immediate Action Taken

Informed Contract Administrator & Contract monitor for tracking

Apparent Cause of Condition

BRINEJ 2007/07/11 Floor EP was built as per drawing . Could not install EP as per design because of interference below 254' elevation.

Recommended Resolution(s)

BRINEJ 2007/07/11 FIC was issued to rework EP. SCR filed to document cost of rework.

Reportable? Reportable To

N

Applicable S99 Section(s)

Notification Criteria

Affects Operability?	TOE Required?	TOE Status
N	N	

Attachments :

SCR No	SCR Status	SCR Date/Time	Date Occurred	Discovery Date
P-2006-05262	COMPLETE	2006/03/29 11:36 AM	2006/03/23 01:30 PM	2006/03/23

Initiator	Phone Ext	First Line Manager	Phone Ext	Initiating Department Manager
*** *****	*****	J PUOPOLO		HOMAN

	Significance Level	Resolution Category	Unit	Power
Recommended:	4	D	058	NA
Final:	4	D		

Equipment Failure? : **Critical Codes** :

Equipment Tags :

Device

OPEX Flag :

OPEX Category :

Event Title

Human Performance Issue - Lack of attention to detail EPG Rv replacement project (cost of rework.\$2000)

Description of Condition

While teamster was unloading material from a flatbed truck the forklift forks came into contact with other material on truck causing damage to 6" pre-fabricated pipe. As a result of the damage more material and some rework is required (1 length of 6" Stainless Steel Sch 10 pipe and approximately 16 hours of rework)

Discovered While Performing

Material handling.

Immediate Action Taken

Notified Contract monitor, contract administrator, line management.

Apparent Cause of Condition

Workers in the ground crew were staging materials previously unloaded. Operator was attempting to offload 2 spool pieces. He determined that it wasnt safe to unload more than one section at a time. Operator then lowered his forks and backed out, when the forks came into contact with another spool piece on the truck. PUOPOLOJ 2006/03/29 The cost to the project for this rework is approx. \$2000. New pipe has been ordered and damaged section will be cut out and replaced.

Recommended Resolution(s)

Operator should be taking directions from ground crew and signal man.

Reportable? Reportable To

N

Applicable S99 Section(s)

Notification Criteria

Affects Operability?

N

TOE Required?

N

TOE Status

Attachments :

SCR No	SCR Status	SCR Date/Time	Date Occurred	Discovery Date
P-2006-08825	COMPLETE	2006/05/26 11:16 AM	2006/05/25 08:00 AM	2006/05/25

Initiator	Phone Ext	First Line Manager	Phone Ext	Initiating Department Manager
*** *****	*****	LAUGHLIN	4486	HOMAN

	Significance Level	Resolution Category	Unit	Power
Recommended:	3	D	058	NA
Final:	3	D		

Equipment Failure? : **Critical Codes** :

Equipment Tags :

Device

OPEX Flag :

OPEX Category :

Event Title

Contract Issue-Worker Safety Mods rework

Description of Condition

During the execution of the Worker Safety Mods Project commissioning has been delayed due to many issues. The bulk of the work was completed approx 1 year ago. As the work has progressed it has been discovered that rework will need to be completed. Due to the nature of the modification it was difficult to determine if the assembled piping would fit in the field to meet tie-ins. There was no fixed points in the field to be able to accurately verify that the fabricated piping would mate with the piping in the field as well with the new pumps to be installed. All work has passed weld examinations and pressure tests. New assembled piping does not fit due to poor workmanship (pipe not square, level, plum, correct dimensions etc.) LAUGHLIS 2006/06/01 est. cost of rework \$50,000.

Discovered While Performing

Continuation of the Worker Safety Mods Project.

Immediate Action Taken

Met with Project, Contractor, FE and CMO to determine extent of rework and a plan to carry on.

Apparent Cause of Condition

Lack of supervisory oversight during the fabrication and partial installation prior to pie-ins. The obstruction of the existing equipment made it very difficult to assess the fit up to the related equipment. Poor workmanship

Recommended Resolution(s)

LAUGHLIS 2006/05/31 The parties involved have agreed to a path forward which involves approx. 2 weeks of rework. The intent is to complete the project prior to the promised date of July 06 LAUGHLIS 2006/06/01 . Project to look into a cost recovery plan.

Reportable? Reportable To

N

Applicable S99 Section(s)

Notification Criteria

Affects Operability?

N

TOE Required?

N

TOE Status

Attachments :

Appendix B Examples of Rework Events

*Appendix B-1 An Example of Rework Events with the Root Causes in Process
Group*

SCR No	SCR Status	SCR Date/Time	Date Occurred	Discovery Date
P-2008-06595	COMPLETE	2008/03/11 12:46 PM	2008/03/11 08:00 AM	2008/03/11

Initiator	Phone Ext	First Line Manager	Phone Ext	Initiating Department Manager
*** *****	*****	W POWER	7857	ROB GRANGER

	Significance Level	Resolution Category	Unit	Power
Recommended:	4	D	8	GSS
Final:	4	D		

Equipment Failure? : **Critical Codes** :

Equipment Tags :

Device

OPEX Flag : N

OPEX Category :

Event Title

P881 Waterlancing Delay - Delay due to scaffolding rework

Description of Condition

Delay to build of scaffold at East Bank boilers 1, 2, & 3. Contractors asked to address tripping hazard due to sample line on access platform between BO3 & 7. The height of the debris netting along handrail was not sufficient. The netting is to be installed up to the top of the handrails. POWERW 2008/03/15 Total delay was 20 hours x \$70.00 per hour for a cost of \$1400.00.

Discovered While Performing

P881 Waterlancing Pre-Reqs for East Bank

Immediate Action Taken

SCR was initiated to document adverse condition.

Apparent Cause of Condition

POWERW 2008/03/15 Some rework had to be done to an existing scaffold built by another work group to allow access to the base of the boilers to allow waterlancing to begin. The debris netting on the handrail which is there to keep debris from falling onto the blowout panel also needed some rework.

Recommended Resolution(s)

POWERW 2008/03/15 Task outlines should state what is require to be done and the work group building scaffolds should check with the end user if what was built suits their needs.

Reportable? Reportable To

N

Applicable S99 Section(s)

Notification Criteria

Affects Operability?

N

TOE Required?

N

TOE Status

Attachments :

*Appendix B-2 An Example of Rework Events with the Root Causes in Human
Performance Group*

SCR No	SCR Status	SCR Date/Time	Date Occurred	Discovery Date
P-2008-02807	COMPLETE	2008/02/04 11:29 AM	2008/01/29 01:00 PM	2008/01/30

Initiator	Phone Ext	First Line Manager	Phone Ext	Initiating Department Manager
*** *****	*****	JUA GARCIA		AGOSTA

	Significance Level	Resolution Category	Unit	Power
Recommended:	3	C	8	100
Final:	3	C		

Equipment Failure? : **Critical Codes** :

Equipment Tags :

Device

OPEX Flag : N

OPEX Category :

Event Title

REWORK P881: Human Performance Issues: Poor Work Practices (Liquid Zone Control)

Description of Condition

During installation of new Liquid Zone Control pipe support HG2005/2006 an existing I-beam J-bracket supporting welded HVAC ductwork encroached on a gusset plate (part of new support) by approximately 1/8". Field Engineering approved the loosening and sliding of J-bracket by about 3/4" of an inch to avoid interference. Contractor chose to bend existing conduit bracket upward and hammer threaded rod supporting ductwork rather than temporarily supporting the load of ductwork and sliding J-bracket, resulting in damaging the HVAC support and stripping paint from structural I-beam. Field Engineering has before and after photos of event. Field Engineering is requesting the contractor repair the HVAC support.

Discovered While Performing

Routine Field Engineering inspections.

Immediate Action Taken

Notified line management, questioned contractor's supervision.

Apparent Cause of Condition

GARCIAJU 2008/02/07 Lack of attention to detail and poor work practices

Recommended Resolution(s)

GARCIAJU 2008/02/07 Contractor to be coached to avoid incidents like this in the future. Also rework is required by the contractor to repair the damaged HVAC support. Recommend C3 NFE.

Reportable? Reportable To

N

Applicable S99 Section(s)

Notification Criteria

Affects Operability?

N

TOE Required?

N

TOE Status

Attachments :