Quantitative Analysis of Magnitude of Rework by Project Types and Sources of Rework

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Abstract

Rework in the construction industry can adversely affect project cost and schedule performance. Based on direct rework costs recorded on 359 construction projects, this paper presents an assessment of the magnitude of rework by various types of projects and sources of rework. The results from this paper establish that on average 4.5% and 2.5% of actual construction costs were spent on rework for owner and contractor projects, respectively. Furthermore, this paper determines that the direct rework costs differ by project types and sources of rework. Finally, it permits the development of rework reduction initiatives. By quantifying and recognizing the different magnitude of rework, the industry can be aware of the waste from rework and develop effective plans for managing rework, ultimately improving project cost performance.

Keywords : Rework, Construction Costs, Quantitative Analysis, Project Cost Performance

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1. Introduction

One of the characteristics of today's construction industry is that cost and schedule overruns can not be easily avoided due to tight schedules, multiple parties involved, and other complicated features that may negatively impact project cost and schedule performance. Under this assertion, rework in the construction industry is one of the factors increasing project cost. Research by the Construction Industry Institute (CII) (2005) revealed that rework is a significant cost making up 5% of total construction costs. Here, rework was defined as "activities that have to be done more than once or activities which remove work previously installed as part of the project." (CII 2001).

Several research efforts have attempted to define rework and to classify its causes. Unfortunately, those studies generally focused on the costs of rework and were able to provide high level summaries only, due to the small samples. Using data from 359 actual construction projects, this paper aims to reveal the magnitude of direct costs of rework by various project types and sources of rework. By measuring direct rework costs at the more detailed level, particular project types and sources of rework causing more rework costs can be identified. Furthermore, possible solutions for the costly root causes may be suggested. For meaningful comparisons, projects were categorized by industry group, project nature, project size, project location, and for contractors, distinction by work type as well. The sources of rework were classified as owner change, design error/omission, design change, vendor error/omission, vendor change, construction error/omission, construction change, transportation error, and other sources.

2. Background

2.1 Rework Definition

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Rework has various interpretations and definitions, including "quality deviations" (Burati et al. 1992), "non-conformance"(Abdul-Rahman 1995), "defects" (Josephson and Hammarlund 1999), and "quality failures" (Barber et al. 2000), in construction management literature (Love 2002). O'Conner et al. (1986) defined rework as the documented proof of inefficient and uneconomical construction of the severest nature. In addition, Love et al. (2000b) identified that rework is the unnecessary effort for redoing a process or activity that was incorrectly implemented the first time. Similarly, field rework is defined as "activities in the field that have to be done more than once or activities which remove work previously installed as part of the project." (CII 2001). Based on CII's definition, Fayek et al. (2003) proposed a definition of rework adding the constraint that rework caused by scope changes and change orders from owners should be excluded from being classified as rework.

In the sense of "conformance", there are two main definitions of rework (Love 2002; Fayek et al. 2003). The first definition is that "rework is the process to make an item conform to the original requirement by completion, or correction." (Ashford 1992). The second definition described by the Construction Industry Development Agency (CIDA) (1995) defined rework as doing something at least one extra time due to nonconformance to requirements.

While the definitions and interpretations of rework vary in terms of the wording, there is the common theme; having to redo work in the field due to non-conformance to requirements. This is the definition of rework defined for this study and especially used for collecting rework data with consistency.

2.2 Rework Cause Classification

It is essential to identify and classify the causes of rework in order to improve project performance. Due to the complicated characteristics of the construction processes many analyses have been performed on the causes and classification of rework. Using the categories of engineering rework and construction rework, O'Conner et al. (1986) argued that engineering rework is caused by owner scope and specification changes, design errors, or procurement errors. They further claimed that construction rework results from poor construction techniques or poor construction management policies. Rework can also result from "errors, omissions, failures, damage, and change orders throughout the procurement process." (Love et al. 1999b; Love and Li 2000a).

According to Davis et al. (1989), there are five origins of rework: owner, designer, vendor, transporter, and constructor and three underlying reasons: haste, fatigue, and faulty communication. Similarly, CII (1989a) and Burati et al. (1992) identified five major areas of rework: design, construction, fabrication, transportation, and operability. Each of these areas was further subdivided by type of deviation, i.e., change, error, or omission. Furthermore, Josephson et al. (2002) and Aoieong et al. (2002) generalized and classified the causes of rework into six categories: client, design, production management, material, machines, and workmanship.

The causes and classification of rework described above are slightly different in perspective from those proposed by Love et al. (1999a and 1999b) and Fayek et al. (2003). They argued rework may occur as a result of uncertainty and ineffective decision-making generated by the lack of, or unreliable, inaccurate, and conflicting information.

Based on these classifications of rework causes reviewed here, nine sources of rework were selected for this study: owner change, design error/omission, design change, vendor error/omission, vendor change, construction error/omission, construction change, transportation error, and other sources. Their definitions and some examples are included in Appendix I.

2.3 Rework Cost

The cost of rework in the construction industry has been explored by several studies. Research conducted by CII (2005) identified and quantified rework costs on nine industrial projects and concluded that rework costs an average 5% of the total construction costs. Considering that the cost of the U.S. construction industry amounted to $955 billion in 2003 (BEA 2005), almost $48 billion was wasted in that year alone. In the case of Australian construction projects, "the direct cost of rework in construction is estimated to be greater than 10% of project cost." (Josephson et al. 2002). By applying a 10% rework value to the annual turnover (A$43.5 billion) of the Australian construction industry in 1996, the cost of rework was approximately A$4.3 billion per annum. Additionally, Josephson and Hammarlund (1999) estimated that the cost of rework on residential, industrial, and commercial building projects ranges from 2% to 6%of their contract values. Similarly, Love and Li (2000a) found that the costs of rework on residential and industrial building projects are 3.15% and 2.4%of the contract values, respectively. "The non-conformance costs (excluding material wastage and head office overheads) of a highway project are estimated to be 5% of the contract value."(Abdul-Rahman 1995). This study insisted that the non-conformance costs may be significantly higher on projects where poor quality management is found. Consequently, these significant wastes of money confirm that rework costs should not be overlooked in efforts to improve project cost performance.

When compared to the previous studies providing the high level of summaries on the rework cost by a couple of project types, this paper presents greater details of rework magnitude with more breakouts of project types and sources of rework. Furthermore, relatively larger number of samples were used to draw more credible results.

3. Methodology

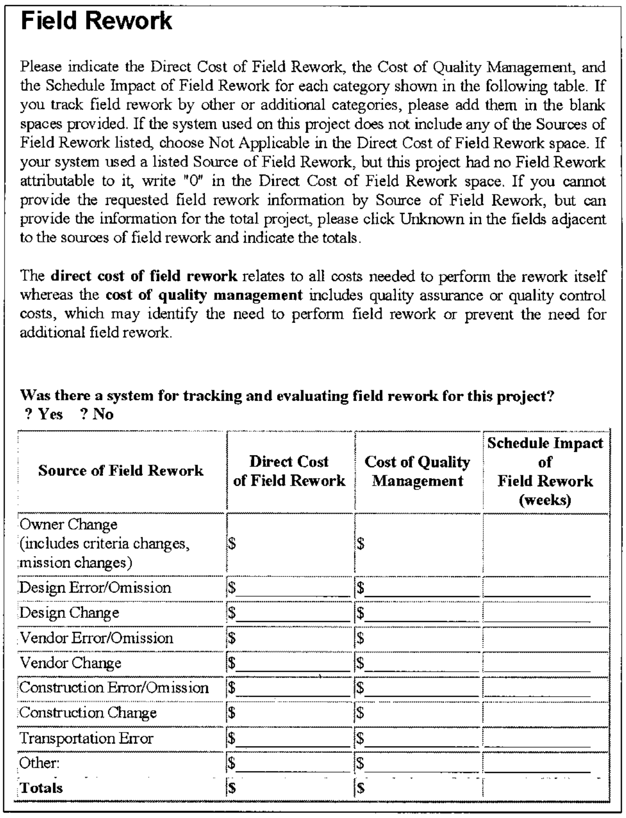
3.1 Data Collection, Preparation and Presentation

This paper used the data collected by the CII Benchmarking and Metrics (BM&M) program. At the time of this study, the CII BM&M database was composed of data from 1057 projects completed by 41 owner and 35 contractor companies. Five hundred sixty-eight projects were from owner companies and 489 projects from contractor companies. The total installed cost of all projects in the database was approximately $55 billion ($27.6 billion from the owner projects and $27.4 billion from the contractor projects).

The data from actual projects were submitted by CII member companies through CII's BM&M questionnaire. The CII BM&M program has developed different questionnaires for owners and contractors in consideration of their different perspectives and levels of involvement on projects. The questionnaire has been continuously updated through the years, from Version 1 with data from 1996, through Version 7 containing 2002/2003 data. Figure 1 shows the rework section in the questionnaire used for this study.

Although the CII BM&M database had the data from 1057 projects, the rework costs occurring on 229 projects were not recorded and these projects were excluded from this study. The remaining 828 projects had rework data including the total direct cost of rework and the cost of quality management as an indirect rework cost. Due to the lack of the indirect costs in the dataset, this paper used only total direct rework costs caused by nine sources of rework shown in Table 1. Moreover, the existence of actual construction phase costs for the 828 projects was also investigated since actual construction phase costs for each project differ and thus may affect the magnitude of rework.

Accordingly, additional 469 projects were excluded from this study. That is, either the total direct rework cost or the actual construction phase cost of 469 projects was not recorded. Based on the filtration, 359 projects were finally selected and categorized as shown in Table 1.



Field Rework

Please indicate the Direct Cost of Field Rework, the Cost of Quality Management, and the Schedule Impact of Field Rework for each category shown in the following table. If you track field rework by other or additional categories, please add them in the blank spaces provided. If the system used on this project does not include any of the Sources of Field Rework listed, choose Not Applicable in the Direct Cost of Field Rework space. If your system used a listed Source of Field Rework, but this project had no Field Rework attributable to it, write "0" in the Direct Cost of Field Rework space. If you cannot provide the requested field rework information by Source of Field Rework, but can provide the information for the total project, please click Unknown in the fields adjacent to the sources of field rework and indicate the totals.

The **direct cost of field rework** relates to all costs needed to perform the rework itself whereas the **cost of quality management** includes quality assurance or quality control costs, which may identify the need to perform field rework or prevent the need for additional field rework.

Was there a system for tracking and evaluating field rework for this project?
? Yes ? No

Source of Field Rework	Direct Cost of Field Rework	Cost of Quality Management	Schedule Impact of Field Rework (weeks)
Owner Change (includes criteria changes, mission changes)	$	$	
Design Error/Omission	$	$	
Design Change	$	$	
Vendor Error/Omission	$	$	
Vendor Change	$	$	
Construction Error/Omission	$	$	
Construction Change	$	$	
Transportation Error	$	$	
Other:	$	$	
Totals	$	$	

Figure 1. CII BM&M Questionnaire: Rework Section

Table 1. Categories Selected for Data analysis

1. Project Characteristics	
Industry Group	**Project Nature**
- Buildings	- Add-on
- Heavy Industrial	- Grass Roots
- Infrastructure	- Modernization
- Light Industrial	**Project Location**
Project Size	- Domestic
- <$15MM	- International
- $15MM ~ $50MM	**Work Type**
- $50MM ~ $100MM	- Construct Only
- >$100MM	- Design and Construct
2. Sources of Rework	
- Owner Change (OC)	- Construction Error / Omission (CE)
- Design Error / Omission (DE)	- Construction Change (CC)
- Design Change (DC)	- Transportation Error (TE)
- Vendor Error / Omission (VE)	- Other Source (OS)
- Vendor Change (VC)	

Table 2 summarizes the characteristics of these 359 projects and bold indicates the predominant group in each category. In accordance with CII policy protecting the confidentiality of companies submitting data, no statistical summaries are provided for a category containing data from less than 10 projects or less than 3 separate companies. In addition, it should be noted that there is a limitation on data availability and variety due to the data from projects performed by CII member companies only.

Table 2. Summary of Projects Used for Analysis

Project Characteristics	**Owner** (N = 181)		**Contractor** (N = 178)		**Total** (N = 359)	
Industry Group						
Buildings	32	18%	15	8%	47	13%
Heavy Industrial	**103**	**57%**	**133**	**75%**	**236**	**66%**
Infrastructure	15	8%	10	6%	25	7%
Light Industrial	31	17%	20	11%	51	14%
Project Nature						
Add-on	47	26%	59	33%	106	30%
Grass Roots	50	28%	77	**43%**	**127**	**35%**
Modernization	**84**	**46%**	42	24%	126	**35%**
Project Size						
<$15MM	**112**	**62%**	60	34%	**172**	**48%**
$15 - $50MM	49	27%	**64**	**36%**	113	32%
$50 - $100MM	12	7%	22	12%	34	9%
>$100MM	8	4%	32	18%	40	11%
Project Location						
Domestic	**152**	**84%**	**144**	**81%**	**296**	**82%**
International	29	16%	34	19%	63	18%
Work Type*						
Construct Only	NA	NA	41	23%	41	23%
Design and Construct	NA	NA	**137**	**77%**	**137**	**77%**

* = Contractor Projects Only; NA = Not Available

3.2 Average Total Direct Rework Cost

To quantify the magnitude of rework by the project types shown in Table 1, Formula 1 was developed and used for data analysis as follows:

- Formula 1 =

$$\frac{\text{Total Direct Cost of Field Rework for Projects in a Group}}{\text{Total Number of Projects in a Group}}$$

A group in Formula 1, for example, may be any one of buildings, heavy industrial, infrastructure, or light industrial for the industry group category, or add-on, grass roots, or modernization for the project nature category. The numerator is the total direct rework cost for all projects in a specific group. The denominator is the total number of projects in the group. By obtaining the values calculated by Formula 1 by groups, the magnitude of rework by each type of projects shown in Table 1 can be identified and compared.

Furthermore, the direct rework costs can be measured and compared by sources of rework, using the following formula:

- Formula 2 =

$$\frac{\text{Total Direct Cost of Field Rework for a Source in a Group}}{\text{Total Number of Projects in a Group}}$$

Each of the nine sources shown in Table 1 may be plugged into Formula 2. In both Formulas 1 and 2, the higher the value, the greater rework cost.

4. Data Analysis

The data from the 359 projects were analyzed quantifying the average total direct rework cost for the data set. The results explore the magnitude of rework as reported by owners and contractors. First, the different magnitude by project types is discussed, and then sources of rework are compared in terms of the average total direct rework cost. The findings from these analyses will provide an understanding of how much rework occurred on each type of projects and which source resulted in the greatest rework cost.

4.1 Owner Rework Magnitude by Project Types

Table 3 shows the total number of projects (N), average total direct rework cost (Mean TDRC), average actual construction phase cost (Mean ACPC), and the ratio of mean TDRC to mean ACPC as a percentage for the 181 owner projects sorted by the various project types. Bold indicates the highest mean TDRC, ACPC, and ratios of TDRC to ACPC in each category.

The mean TDRC was calculated by Formula 1 dividing the total direct rework cost by the total number of projects. Similarly, the mean ACPC was obtained from the actual construction phase cost divided by the total number of projects. The percentages of the mean TDRC to the Mean ACPC were calculated by dividing the former by the latter to check the average amount of TDRC per a unit of ACPC.

The mean TDRC and ACPC for all owner projects were $0.54 million and $11.9 million, respectively, and their ratio was 4.5%.

That is, an average of $0.54 million, which is 4.5% of the average actual construction phase cost, was spent on rework for an owner project of which the average actual construction phase cost was $11.9 million.

In the industry group category, the mean TDRC ($0.88 million) and ACPC ($14 million) for light industrial were largest. The mean TDRC for infrastructure ($0.54 million) however, should not be overlooked considering that its ACPC was $4.7 million indicating that rework on average was proportionately very high for the group (11.5%).

By project nature, the mean TDRC for add-on ($0.61 million) was largest followed by modernization ($0.52 million) and grass roots ($0.50 million). Their mean ACPC were $14.5 million, $7.3 million, and $17.3 million, respectively. The modernization slice was of interest as its mean ACPC was almost half that of add-on in spite of the almost same amount of TDRC as the add-on. This resulted that the slice has the highest percentage of TDRC to ACPC among the three groups (7.1%). Due to the characteristics of modernization projects affected by tight schedule not allowing long time of shutdown of the facilities, higher probability of rework may exist.

The results from analyses by project size are perhaps most illuminating in that a clear trend was indicated. As the mean ACPC increased, the mean TDRC increased as well. This may imply that average total direct rework costs and actual construction phase costs must be considered in tandem in order to properly understand the magnitude of rework. The ratios calculated by the mean TDRC divided by the mean ACPC of each group revealed that the proportional amount of rework is highest in the projects costing $15 million to $50 million. Due to the CII confidentiality policy as explained in Chapter 3, the result of the group greater than $100million was suppressed using the abbreviation of confidentiality, “C”.

The mean TDRC for domestic and international were nearly the same when the data were split by project location. However, the mean ACPC for domestic was higher than that of international,

Table 3. Owner Rework Magnitude by Project Types

Project Type	Owner			
	N	Mean TDRC (MM)	Mean ACPC (MM)	Mean TDRC / Mean ACPC (%)
Industry Group				
Buildings	32	0.44	9.8	4.5%
Heavy Industrial	103	0.46	13.0	3.5%
Infrastructure	15	0.54	4.7	**11.5%**
Light Industrial	31	**0.88**	**14.0**	6.3%
Project Nature				
Add-on	47	**0.61**	14.5	4.2%
Grass Roots	50	0.50	**17.3**	2.9%
Modernization	84	0.52	7.3	**7.1%**
Project Size				
<$15MM	112	0.19	3.7	5.1%
$15 - $50MM	49	0.83	15.2	**5.5%**
$50 - $100MM	12	**1.63**	**32.7**	5.0%
>$100MM	8	C	C	C
Project Location				
Domestic	152	0.53	**12.4**	4.3%
International	29	**0.54**	9.6	**5.6%**
All	181	0.54	11.9	4.5%

Table 4. Owner Rework Magnitude by Sources of Rework: Industry Group and Project Nature

Owner													
Industry Group								Project Nature					
Buildings (N = 32)		Heavy Industrial (N = 103)		Infrastructure (N = 15)		Light Industrial (N = 31)		Add-on (N = 47)		Grass Roots (N = 50)		Modernization (N = 84)	
Source	Mean TDRC (MM)	Source	Mean TDRC (MM)	Source	Mean TDRC (MM)	Source	Mean TDRC (MM)	Source	Mean TDRC (MM)	Source	Mean TDRC (MM)	Source	Mean TDRC (MM)
DE	0.157	OS	0.127	OC	0.251	DE	0.282	OS	0.171	DE	0.162	DE	0.148
OC	0.128	DE	0.119	DC	0.069	OC	0.223	DE	0.139	OC	0.128	OS	0.143
CC	0.054	OC	0.065	DE	0.066	OS	0.213	OC	0.097	CC	0.056	OC	0.125
OS	0.050	VE	0.047	OS	0.038	CE	0.063	DC	0.062	VE	0.044	VE	0.036
DC	0.041	CE	0.035	CE	0.038	VE	0.045	CE	0.054	DC	0.041	CE	0.026
VC	0.009	DC	0.034	VE	0.037	DC	0.026	VE	0.039	OS	0.036	DC	0.021
VE	0.006	CC	0.018	CC	0.033	CC	0.023	VC	0.025	CE	0.028	CC	0.012
TE	0.000	VC	0.011	VC	0.011	VC	0.006	CC	0.021	VC	0.007	VC	0.003
CE	0.000	TE	0.001	TE	0.001	TE	0.001	TE	0.000	TE	0.000	TE	0.002
Total	0.444	Total	0.458	Total	0.544	Total	0.882	Total	0.607	Total	0.501	Total	0.516

OC = Owner Change; DE = Design Error/Omission; DC = Design Change; VE = Vendor Error/Omission; VC = Vendor Change; CE = Construction Error/Omission; CC = Construction Change; TE = Transportation Error; OS = Other Source.

causing almost same ratio of the TDRC to ACPC (4.3%) as the international category (5.6%).

4.2 Owner Rework Magnitude by Sources of Rework

Owner project comparisons continue by reviewing the data sorted by rework sources. Table 4 shows the total number of projects (N), sources of rework, and average total direct rework cost for a source of rework (Mean TDRC) by industry group and project nature. The mean TDRC was calculated by Formula 2 dividing the total direct rework cost for a source in a group by the total number of projects in the group. The sum of the mean TDRC for each source within a group was equal to the mean TDRC for the group (Total). For the industry group category, DE was the most costly for buildings and light industrial projects followed by OC. Analysis by project nature reveals that the mean TDRC for DE is highest at $0.162 million and $0.148 million in grass roots and modernization projects, respectively.

In the groups categorized by project size, the mean TDRC for DE was highest in all groups except for those projects costing greater than $100 million, as shown in Table 5. Moreover, the same conclusion can be drawn for domestic and intentional projects when the data was reviewed by project location.

4.3 Contractor Rework Magnitude by Project Types

Table 6 shows the extent of rework for the 178 contractor projects by project types. The mean TDRC and ACPC for all projects were $0.82 million and $32.3 million, respectively, and their ratio was 2.5%.

Analysis by industry group revealed that the mean TDRC for light industrial ($1.17 million) was much larger than any other mean TDRC in the group. However, its mean ACPC ($22.8 million) was less than those of buildings ($35 million) and heavy industrial ($34.9 million). This indicates that contractors light industrial projects suffered from the highest proportion of rework (5.1%).

For the project nature category, the mean TDRC got larger as the mean ACPC increased. Their ratios, however, tells that the modernization projects has the largest amount of TDRC per ACPC (3.5%).

The growth of mean TDRC relative to the growth of mean ACPC was also evident in the category of project size. Although the mean TDRC for those projects costing greater than $100 million was largest at $1.86 million, it might result from their relatively large mean ACPC ($97.1 million). This was supported by the results form the ratios indicating the group has the smallest proportion of rework (3.8%).

By project location, the mean TDRC for domestic ($0.96 million) was much larger than that of international ($0.23 million), whereas the mean ACPC for international ($51.8 million) was almost twice as high as that of domestic ($27.7 million). The ratios for the groups were 3.5% and 0.4%, respectively, indicating that domestic projects tend to exhibit higher probability of rework. However, the result might be due to the lack of or limitations of rework data from much smaller samples of international projects (N = 34) than domestic projects.

In general, owners have a complete project perspective whereas contractors may have a more limited perspective for the portion that they contract. As a result, contractor projects were further classified by the work they performed, as shown in Table 6. The mean TDRC for construct only ($1.07 million) was larger than that of design and construct ($0.74 million), whereas its mean ACPC for the construct

Table 5. Owner Rework Magnitude by Sources of Rework: Project Size and Project Location

Owner											
Project Size								Project Location			
< $15MM (N= 112)		$15 - $50MM (N= 49)		$50 - $100MM (N = 12)		> $100MM (N = 8)		Domestic (N = 152)		International (N = 29)	
Source	**Mean TDRC (MM)**	**Source**	**Mean TDRC (MM)**	**Source**	**Mean TDRC (MM)**	**Source**	**Mean TDRC (MM)**	**Source**	**Mean TDRC (MM)**	**Source**	**Mean TDRC (MM)**
DE	0.056	DE	0.249	DE	0.488	OS	0.855	DE	0.151	DE	0.141
OC	0.053	OC	0.200	OC	0.378	DE	0.341	OS	0.140	OC	0.119
OS	0.030	OS	0.158	OS	0.324	DC	0.175	OC	0.118	DC	0.079
CC	0.016	CE	0.067	VE	0.140	OC	0.152	VE	0.037	CE	0.051
CE	0.012	VE	0.066	DC	0.128	CC	0.135	CE	0.030	VE	0.045
DC	0.010	DC	0.053	CC	0.091	VE	0.134	DC	0.029	VC	0.044
VE	0.009	VC	0.023	CE	0.051	CE	0.110	CC	0.025	CC	0.036
VC	0.002	CC	0.017	VC	0.022	VC	0.014	VC	0.003	OS	0.022
TE	0.001	TE	0.000	TE	0.002	TE	0.000	TE	0.000	TE	0.005
Total	0.190	Total	0.832	Total	1.626	Total	1.917	Total	0.534	Total	0.542

only ($27.1 million) was less than that of the design and construct ($33.9 million). This suggests that when design and construction are performed separately on a project, the project may suffer from a high proportion of rework (3.9%).

Table 6. Contractor Rework Magnitude by Project Types

Project Type	Contractor			
	N	Mean TDRC (MM)	Mean ACPC (MM)	Mean TDRC / Mean ACPC (%)
Industry Group				
Buildings	15	0.53	**35.0**	1.5%
Heavy Industrial	133	0.85	34.9	2.4%
Infrastructure	10	0.14	12.1	1.2%
Light Industrial	20	**1.17**	22.8	**5.1%**
Project Nature				
Add-on	59	0.61	28.3	2.2%
Grass Roots	77	**1.13**	**44.5**	2.5%
Modernization	42	0.54	15.5	**3.5%**
Project Size				
<$15MM	60	0.18	4.7	**3.8%**
$15 - $50MM	64	0.60	19.6	3.1%
$50 - $100MM	22	1.68	50.3	3.3%
>$100MM	32	**1.86**	**97.1**	1.9%
Project Location				
Domestic	144	**0.96**	27.7	**3.5%**
International	34	0.23	**51.8**	0.4%
By Work Type				
Construct Only	41	**1.07**	27.1	**3.9%**
Design and Construct	137	0.74	**33.9**	2.2%
All	178	0.82	32.3	2.5%

4.4 Contractor Rework Magnitude by Sources of Rework

Analysis by sources of rework reveals that an average $0.224 million was spent on rework caused by design error/omission (DE). Considering that the average total direct rework cost was$0.82 million for all contractor projects, 27% of the average total direct rework cost was made up of rework caused by DE.

In the industry group category (Table 7), the mean TDRC for OC and DE made up most of the mean TDRC for buildings and heavy industrial. OS and DE had two of the highest mean TDRC in infrastructure and DC had highest mean TDRC in light industrial, followed by OC.

By project nature (Table 7) and project size (Table 8), DE had the highest mean TDRC for all groups within both categories. For the project location category (Table 8), DE, OC and DC in domestic made up most of the mean TDRC for the group. In addition, DC had the highest mean TDRC in international. Similarly, in the categories of work type (Tables 8), the mean TDRC for DE was highest for both construct only, and design and construct.

5. Conclusions

This paper explored how much costs were spent on rework, based upon various types of projects and sources of rework. By analyzing the data from the 181 owner and 178 contractor projects, it was identified that an average $0.54 million was spent on rework for an owner project of which the average actual construction phase cost was $11.9 million. In the case of contractor projects, the average total direct rework cost was $0.82 million on a project of which the average construction phase cost was $32.3 million. Although owner

Table 7. Contractor Rework Magnitude by Sources of Rework: Industry Group and Project Nature

Contractor													
Industry Group								Project Nature					
Buildings (N = 15)		Heavy Industrial (N = 133)		Infrastructure (N = 10)		Light Industrial (N = 20)		Add-on (N = 59)		Grass Roots (N = 77)		Modernization (N = 42)	
Source	Mean TDRC (MM)	Source	Mean TDRC (MM)	Source	Mean TDRC (MM)	Source	Mean TDRC (MM)	Source	Mean TDRC (MM)	Source	Mean TDRC (MM)	Source	Mean TDRC (MM)
OC	0.410	DE	0.277	OS	0.056	DC	0.643	DE	0.186	DE	0.296	DE	0.145
DE	0.078	OC	0.162	DE	0.027	OC	0.238	OC	0.110	OC	0.266	OC	0.135
DC	0.022	DC	0.123	OC	0.017	OS	0.089	DC	0.092	DC	0.262	DC	0.098
VE	0.007	VE	0.122	CE	0.015	DE	0.075	CE	0.081	VE	0.148	VE	0.061
CE	0.005	CE	0.078	DC	0.013	CC	0.062	OS	0.067	CE	0.064	OS	0.055
VC	0.005	OS	0.053	VE	0.009	CE	0.028	VE	0.048	CC	0.042	CE	0.035
CC	0.001	CC	0.030	VC	0.000	VE	0.022	CC	0.024	OS	0.041	CC	0.013
TE	0.000	VC	0.006	CC	0.000	VC	0.013	VC	0.003	VC	0.011	VC	0.001
OS	0.000	TE	0.001	TE	0.000	TE	0.000	TE	0.000	TE	0.000	TE	0.001
Total	0.528	Total	0.851	Total	0.137	Total	1.170	Total	0.610	Total	1.131	Total	0.544

Table 8. Contractor Rework Magnitude by Sources of Rework: Project Size, Project Location, and Work Type

Contractor															
Project Size								Project Location				Work Type			
< $15MM (N = 60		$15 - $50MM (N = 64)		$50 - $100MM (N = 22)		> $100MM (N = 32)		Domestic (N = 144)		International (N = 34)		Construct Only (N = 41)		Design and Construct (N = 137)	
Source	Mean TDRC (MM)	Source	Mean TDRC (MM)	Source	Mean TDRC (MM)	Source	Mean TDRC (MM)	Source	Mean TDRC (MM)	Source	Mean TDRC (MM)	Source	Mean TDRC (MM)	Source	Mean TDRC (MM)
DE	0.060	DE	0.169	DE	0.355	DE	0.549	DE	0.269	DC	0.078	DE	0.280	DE	0.207
OC	0.046	OC	0.157	OC	0.352	DC	0.494	OC	0.224	OS	0.063	OC	0.254	OC	0.162
DC	0.028	DC	0.100	DC	0.266	OC	0.377	DC	0.188	DE	0.033	DC	0.235	DC	0.147
OS	0.018	VE	0.098	CE	0.229	VE	0.208	VE	0.114	CC	0.017	VE	0.136	VE	0.082
CE	0.013	CE	0.035	OS	0.194	CE	0.097	CE	0.074	CE	0.015	OS	0.104	CE	0.072
VE	0.008	OS	0.024	VE	0.154	OS	0.079	OS	0.050	VE	0.011	CE	0.030	OS	0.038
CC	0.004	CC	0.015	CC	0.108	CC	0.050	CC	0.032	OC	0.011	CC	0.026	CC	0.030
VC	0.002	VC	0.004	VC	0.019	VC	0.009	VC	0.008	VC	0.001	VC	0.008	VC	0.006
TE	0.000	TE	0.000	TE	0.002	TE	0.000	TE	0.000	TE	0.001	TE	0.001	TE	0.000
Total	0.180	Total	0.603	Total	1.677	Total	1.864	Total	0.959	Total	0.228	Total	1.074	Total	0.744

projects has the smaller average total direct rework cost, the rework cost should not be overlooked considering that its average construction phase cost was almost one third of that of contractor projects.

This means that rework on average was proportionately high for the owner group (4.5% for owners and 2.5% for contractors). The result might be caused by the larger role of owners seeing and controlling the whole project, whereas contractors only focus on the portion which they contracted. In addition, contractors do not tend to report rework due to inefficient tracking systems and the image of rework reflecting poor performance.

More specifically, rework contributed most to cost increases in add-on and international owner projects, and grass roots and domestic contractor projects. On both owner and contractor projects, light industrial projects were most susceptible and rework increased as project size increased in terms of average actual construction costs.

The results from analyses by sources of rework reveal that for owner projects, design error/omission (DE), owner change (OC), and other (OS) were most frequently ranked as three of the greatest sources by average total direct rework cost through all categories. However, the other (OS) category was a catch-all for rework sources not properly addressed by the survey. If a more comprehensive tracking system was used or more effort to track the origin and causes of rework were made, a much more accurate cost of each source could be identified. For contractor projects, owner change (OC), design change (DC), and design error/omission (DE) were most frequently ranked.

Table 9. Summary of Three Greatest Sources of Rework Ranked by Average Total Direct Rework Cost

Project Types	Owner			Contractor		
	1st	2nd	3rd	1st	2nd	3rd
Industry Group						
Buildings	DE	OC	CC	OC	DE	DC
Heavy Industrial	OS	DE	OC	DE	OC	DC
Infrastructure	OC	DC	DE	OS	DE	OC
Light Industrial	DE	OC	OS	DC	OC	OS
Project Nature						
Add-on	OS	DE	OC	DE	OC	DC
Grass Roots	DE	OC	CC	DE	OC	DC
Modernization	DE	OS	OC	DE	OC	DC
Project Size						
<$15MM	DE	OC	OS	DE	OC	DC
$15 - $50MM	DE	OC	OS	DE	OC	DC
$50 - $100MM	DE	OC	OS	OC	OC	DC
>$100MM	OS	DE	DC	DE	DC	OC
Project Location						
Domestic	DE	OS	OC	DE	OC	DC
International	DE	OC	DC	DC	OS	DE
Work Type*						
Construct Only	NA	NA	NA	DE	OC	DC
Design and Construct	NA	NA	NA	DE	OC	DC

* = contractor projects only

Particularly, design change (DC) was one of the higher ranked sources on contractor projects, whereas it caused relatively smaller direct rework cost on the owner projects. In addition, construction change (CC) was one of the higher ranked sources on owner projects, but was never indicated by contractors as the top three resources. This finding

is of interest since it shows the different perspectives in the origin of rework between owners and contractors. That is, owners tend to report rework by construction change more and contractors indicates rework by design change more. Table 9 summarizes the three greatest sources ranked by average total direct rework cost for owner and contractor projects.

Based on the findings from this study, it can be concluded that project managers responsible for those types of projects that tend to have greater rework costs should be aware of the different magnitude of rework when drafting pre-project and quality management plans. Furthermore, they should develop or implement systems for tracking and controlling owner change and design error/ omission, the sources causing more direct costs of rework on both owner and contractor projects. This may be one of the effective ways to reduce rework, depending on various types of projects and sources of rework.

6. Recommendations

It has been identified in other studies that "CII best practices have positive effects on project cost and schedule reduction." (Lee 2001). Design errors/omissions and owner changes may result from poor or ineffective project definition, pre-project planning, design, project change management, communication among owners, designers and constructors, or constructability ignored in the design process. Therefore, implementing CII best practices such as pre-project planning, project change management, design effectiveness, alignment, and constructability would be an effective method for reducing the costly root causes of rework.

Research by CII (2002) revealed that implementation of pre-project planning practice improves design base and scope before beginning detailed design, thus reducing design error/omission and design change. Furthermore, the practice enhances project team alignment and thus reduces unexpected changes.

Project change management is also useful to minimize the number of owner changes. "Project change management is the process of incorporating a balanced change culture of recognition, planning and evaluation of project changes in an organization to effectively manage project changes." (CII 2002).

"Design effectiveness is defined as an all-encompassing term to measure the results of the design effort, including input variables and design execution, against the specified expectations of the owner." (CII 2002). By improving the accuracy and usability of design documents, a common understanding among project participants can be developed and finally, design error/omission, design change, and construction error can be reduced.

"Alignment is the condition where appropriate project participants are working within acceptable tolerances to develop and meet a uniformly defined and understood set of project objectives." (CII 2002). Use of CII's alignment best practice will improve team communications which should have a positive impact on the root causes of rework.

Finally, constructability may help to enhance project quality, project team relationships, and the progress of planning, design, and construction, ultimately reducing rework by design error/omission, design change, and construction error/omission. CII (2002) defines constructability as the effective and timely integration of construction knowledge into the conceptual planning, design, construction and field operations of a project to achieve the overall project objectives in the best possible time and accuracy at the most cost-effective levels.

In closing, although this paper identified the magnitude of rework at the detailed level of project types and sources of rework, it only used data for the total direct rework cost. The analysis should be expanded to include data for total indirect rework cost, so that an integrated impact caused by total direct and indirect cost can be identified. Furthermore, studies on schedule performance affected by rework should be conducted since rework is one of the main causes of schedule overrun. A final recommendation for future study is to develop specific metrics standardizing the influence of different project size and duration on rework. By using the metrics for data analysis, the impacts of rework on project cost and schedule performance can be measured and identified more accurately.

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논문제출일: 2006.04.19
심사완료일: 2006.10.16

Appendix I. Definitions and Examples of Nine Rework Sources

Sources	Definitions & Examples
Owner Change	The changes in the project initiated by the owner, e.g., changing the scope of the project.
Design Error	The result of mistakes, errors, or omission made in the project design.
Design Omission	The result caused when a necessary item or component is omitted from the design.
Design Change	The results caused when changes are made in the project design or requirements.
Construction Error	The result of erroneous construction methods or procedures.
Construction Omission	Deviations that occur due to the omission of some construction activity or task.
Construction Change	The changes in the method of construction, such as placing concrete by pump rather than by bucket.
Vendor Error	The result of mistakes or errors made by vendors.
Vendor Omission	The result caused when a necessary item or component is omitted by the vendors.
Vendor Change	The results caused when changes are made in the vendors.
Transportation Change	Changes in the method of shipment, e.g., shipping by air to expedite delivery rather than shipping by truck.