Measuring the Impact of Rework on Construction Cost Performance

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Abstract: Rework continues to affect both cost and schedule performance throughout the construction industry. The direct costs alone often tally to 5% of the total construction costs. Using the data obtained from 359 construction projects in the Construction Industry Institute database, this paper assesses the impacts of rework on construction cost performance for projects in various categories. In addition, it identifies the sources of this rework, permitting further analyses and the development of rework reduction initiatives. The results of this study establish that the impacts of rework differ according to project characteristics and that the sources of rework having the greatest impact are not significantly different among project categories. By recognizing the impacts of rework and its sources, the construction industry can reduce rework and ultimately improve project cost performance.

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Introduction

Construction projects often experience cost and schedule overruns and rework is a significant factor that directly contributes to these overruns. Research by the Construction Industry Institute (CII) reveals that direct costs caused by rework average 5% of total construction costs (CII 2005). Considering that the U.S. construction industry expended $1,502 billion in 2004 for total installed costs (Bureau of Economic Analysis 2006), almost $75 billion was wasted on direct costs caused by rework in that year alone. Therefore, rework must be considered a significant factor affecting cost performance in the construction industry.

Several research efforts (O'Conner and Tucker 1986; CII 1989; Davis et al. 1989; Burati et al. 1992; Love et al. 1999a, b; Love 2002b; Fayek et al. 2003; Love and Edwards 2004) have attempted to identify and classify the root causes of rework, and to quantify its overall extent. Employing the metric, total field rework factor, and the classification of rework sources developed by CII, this paper assesses the direct impacts of rework on construction cost performance using data from 359 actual projects. More specifically, the objectives of the research described in this paper were: (1) to identify the impacts of rework on construction cost performance for various characteristics of projects; (2) to determine the impacts of different sources of rework on construction cost performance; and (3) to isolate the root causes of rework and recommend possible solutions for those causes.

By comparing the impacts of rework according to project characteristics and by measuring sources of rework, those projects most affected by rework are identified. Additionally, those sources of rework having the biggest impact on construction cost performance are discussed. After the analysis of the cost impact of rework is summarized, the root causes of rework will be assessed and possible solutions can be suggested.

The recognition of the various impacts of rework is important for project managers. For those projects on which cost tends to be more affected by rework, project managers should focus on minimizing rework by developing systems for addressing the sources of rework. Preproject and quality management plans should be drafted with an understanding of the causes of rework in order to minimize its impact. This paper provides an understanding of the impact of rework on construction cost performance, thus helping to reduce rework and improve project cost performance.

Background

According to Love (2002b) rework has various definitions and interpretations within the construction management literature: terms for it include "quality deviations" (Burati et al. 1992), "nonconformance" (Abdul-Rahman 1995), "defects" (Josephson and Hammarlund 1999), and "quality failures" (Barber et al. 2000). Love et al. (2000) characterize rework as the unnecessary effort of redoing a process or activity that was incorrectly implemented the first time. Similarly, field rework is defined as activities that have to be done more than once or activities that remove work previously installed as part of a project (CII 2001). Based upon CII's definition, Fayek et al. (2003) proposed a definition of rework that adds the constraint that rework caused by scope changes and change orders from owners should not be classified

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as rework. In the sense of conformance, there are two main definitions of rework (Love 2002b; Fayek et al. 2003). The first definition is that rework is the process by which an item is made to conform to the original requirements by completion or correction (Ashford 1992). The second definition given by the Construction Industry Development Agency (1995) holds that rework involves doing something at least one extra time due to nonconformance to requirements. Although the wording of the definitions and interpretations of rework vary, there is a common theme—rework means having to redo work due to nonconformance with requirements.

Several studies have explored the cost of rework in the construction industry. Research conducted by CII reports that direct costs caused by rework average 5% of total construction costs (CII 2005). Josephson and Hammarlund (1999) estimated that the cost of rework on residential, industrial, and commercial building projects ranges from 2 to 6% of contract values. Similarly, Love and Li (2000) found that the costs of rework for residential and industrial building projects are on average 3.15 and 2.4% of the contract values, respectively. The nonconformance costs (excluding material wastage and head office overhead) of a highway project are estimated to be 5% of the contract value (Abdul-Rahman 1995). These authors suggest that nonconformance costs may be significantly higher on projects where poor quality management is found. The potential for such significant losses make it critical that rework costs should not be overlooked in efforts to improve project cost performance.

To manage rework, it is first necessary to identify and classify its causes. Many analysts have suggested that rework is often due to the complicated characteristics of the construction processes. By distinguishing between engineering rework and construction rework, O'Conner and Tucker (1986) have argued that engineering rework is caused by owner scope and specification changes, design errors, or procurement errors and that construction rework is a result of poor construction techniques or poor construction management policies. Focusing on the origins of rework, Davis et al. (1989) reported that there are five origins of rework: owner, designer, vendor, transporter, and constructor. Similarly, CII (1989) 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. These classifications differ in perspective from those proposed by Love et al. (1999a, b) and Fayek et al. (2003). These authors argue that rework occurs as a result of uncertainty, poor leadership and communications, and ineffective decision-making.

CII's Benchmarking and Metrics Committee has built on these previous studies to define a set of metrics appropriate for the industry sector that CII serves and also to examine how construction cost performance is affected by rework. The following two hypotheses were established in this study.

1. There are statistically significant differences in the impacts of rework on construction cost performance for the various project groups.
2. There are statistically significant differences in the rank orders of rework sources.

The research methodology, including the statistical methods used to test these hypotheses, is described in the next section.

Table 1. 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[a]	Construct only	NA	NA	41	23%	41	23%
	Design and construct	NA	NA	**137**	**77%**	**137**	**77%**

Note: Bold indicates the predominant group in each category. NA=not available; MM=million

[a]Contractor reported projects only.

Methodology

Data Collection and Presentation

The CII Benchmarking and Metrics (BM&M) program collects capital project data by means of an online questionnaire. At the time of this study, the CII BM&M database was composed of data from 1,057 projects completed by 41 owner and 35 contractor companies. Although the database contained 1,057 projects, rework costs were not reported for 229 of these projects and of the remaining 828 projects, 469 projects did not report either direct rework costs or construction phase costs. As it is desirable to measure direct rework costs as a portion of actual construction costs, the projects not reporting these costs were excluded from this study. Three hundred fifty-nine projects were finally selected and depending on project characteristics, the data were categorized by industry group, nature, size, location, and work type (contractor projects only) as shown in Table 1. Detailed types of projects included in the industry group category are provided in the Appendix.

Total Field Rework Factor

CII developed a metric for quantifying the impact of rework on construction cost performance. The metric is defined as the total field rework factor (TFRF) and its formula is as follows:

$$\text{TFRF} = \frac{\text{Total direct cost of field rework}}{\text{Total construction phase cost}}$$

In the formula, the TFRF is expressed as a ratio of the total direct cost of rework to the total construction phase cost. The construction phase cost includes all costs associated with the construction phase. Fig. 1 provides an example interpretation of the TFRF. The costs used for the example are not derived from real data, but are for illustrative purposes only. The total construction phase costs in the first and second example projects are $10 million each, with the total direct rework costs of $1 million and $0.1 million, respectively. The TFRF are thus 0.1 for Project 1 and 0.01 for Project 2. If rework had not occurred on either project, the construction phase costs of the projects would have been $9 million and $9.9 million, respectively. In other words, due to rework, the cost of Project 1 grew by $1 million and that of Project 2 increased by $0.1 million. Therefore, it can be concluded that the rework that occurred on Project 1 contributed more to the increase of the actual construction phase cost and thus had a relatively greater impact on construction cost performance. The higher the value, the greater impact on actual construction phase cost.

To quantify the impacts of rework by various project characteristics, statistics for each group shown in Table 2 (1. Project Characteristics) is calculated using the aforementioned TFRF formula. A group, for example, may be any one of buildings, heavy industrial, infrastructure, or light industrial for industry group, or add-on, grass roots, or modernization for project nature. By averaging and comparing the values calculated by the formula by group, mean TFRFs for each group can be obtained and those types of projects most affected by rework can be identified.

As shown in Table 2 (2. Sources of Rework), sources of rework were classified as owner change (OC), design error/omission (DE), design change (DC), vendor error/omission (VE), vendor change (VC), constructor error/omission (CE), constructor change (CC), transportation error (TE), and other (OS), and their definitions are provided in the Appendix. The sources of rework having the most impact on cost performance can be also identified using the same formula. One difference in the numerator is that the total direct rework cost for a single source of rework is used. Each of the nine sources of rework may be plugged into the formula.

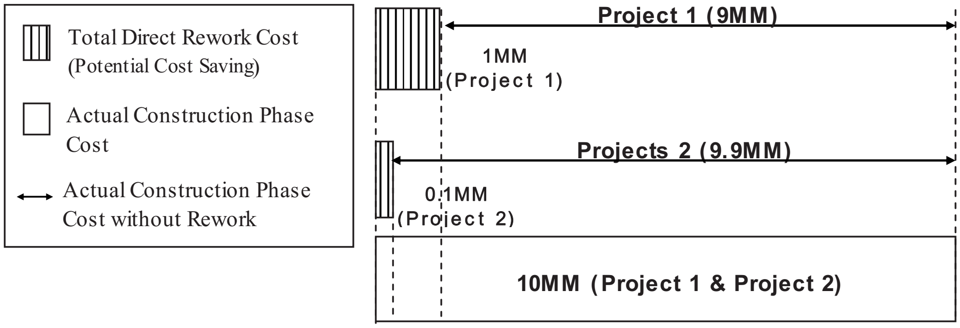
Statistical Analysis Methods

The one-way analysis of variance (ANOVA) or t-test was applied to test for Hypothesis 1, which was introduced earlier in the section entitled "Background." The ANOVA and t-test are the commonly used methods to evaluate the differences in means between two groups and more than two groups, respectively. The levels of significance for the ANOVA and t-test were 0.05. For significant differences, a post hoc test was performed as the second stage of the ANOVA procedure to determine specific groups that were different. This later test identified statistically different means by checking the 95% confidence intervals which is equivalent to a level of significance of 0.05. For Hypothesis 2, also presented in the previously, the Spearman rank-order correlation was calculated and statistically tested. The Spearman rank-order correlation is a method of computing a correlation between the ranks of scores on two variables. The correlation is calculated on the ranks of scores, not the scores themselves. As a result, without the consideration of normality or equal variance of data, this statistical method can be used focusing on difference in rank orders of data rather than difference in means. The coefficient equals 1 for a perfect positive correlation and −1 for a perfect negative correlation. When the correlation is not perfect, the coefficient lies between −1 and 1. A level of significance of 0.05 was also applied for this analysis.

Table 2. Categories Used for Data Analysis

1. Project characteristics					2. Sources of rework	
Industry group	Project nature	Project size	Project locations	Work type (contractor projects only)		
• Buildings	• Add-on	• <$15MM	• Domestic	• Construct only	• Owner change (OC)	• Constructor error/omission (CE)
• Heavy industrial	• Grass roots	• $15MM–$50MM	• International	• Design and construct	• Design error/omission (DE)	• Constructor change (CC)
• Infrastructure	• Modernization	• $50MM–$100MM			• Design change (DC)	• Transportation error (TE)
• Light industrial		• >$100MM			• Vendor error/omission (VE)	• Other (OS)
					• Vendor change (VC)	

Note: MM=million.



Project	Actual Construction Phase Cost (MM)	Total Direct Rework Cost (Potential Cost Saving) (MM)	Total Field Rework Factor	Rework Impact
1	10	1	**0.1**	**High**
2	10	0.1	0.01	Low

Fig. 1. Examples for total field rework factor

Data Analysis

The rework data from the 359 projects were analyzed separately for owners and contractors. The impacts of rework by project characteristics are first discussed, and then sources of rework are compared.

Owner Reported Projects: Rework Impact by Project Characteristics

Table 3 shows the results for the owner reported projects by project characteristic. Table 3 is composed of two parts: one part describes results from the ANOVA or t-test and provides the total

Table 3. Rework Impact for Owner Reported Projects by Project Characteristics

		Owner					
		ANOVA or t-test ($p<0.05$)				Post hoc (CI=95%)	
Project characteristics		N	Mean TFRF	SD	P-value	High	Low
Industry group[a]	Buildings	32	0.046	0.055	**0.0021**	Light industrial	Buildings
	Heavy industrial	102	**0.044**[b]	0.043		Light industrial	Heavy industrial
	Infrastructure	14	0.057	0.046			
	Light industrial	31	**0.093**[c]	0.110			
	All	179	0.054	0.062			
Project nature[a]	Add-on	47	**0.038**[b]	0.032	**0.0130**	Modernization	Add-on
	Grass roots	48	0.041	0.043			
	Modernization	82	**0.062**[a]	0.063			
	All	177	0.050	0.051			
Project size[a]	<$15MM	107	0.049	0.053	0.0893	No significant differences	
	$15–$50MM	49	0.059	0.051			
	$50–$100MM	12	**0.073**[c]	0.102			
	>$100MM	7	**0.010**[b]	0.007			
	All	175	0.052	0.056			
Project location[d]	Domestic	150	**0.051**[c]	0.054	0.5787	No significant differences	
	International	27	**0.045**[b]	0.045			
	All	177	0.050	0.052			

Note: CI=confidence interval and bold indicates statistically significant results at the 0.05 level. MM=million.
[a]ANOVA and post hoc test.
[b]Lowest mean TFRF.
[c]Highest mean TFRF.
[d]t-test.

Table 4. Rework Impact for Owner Reported Projects by Sources of Rework (Industry Group and Project Nature)

Industry group										Project nature							
Buildings ($N=32$)		Heavy industrial ($N=102$)		Infrastructure ($N=14$)		Light industrial ($N=31$)		All ($N=179$)		Add-on ($N=47$)		Grass roots ($N=48$)		Modernization ($N=82$)		All ($N=177$)	
Source	Mean TFRF	Source	Mean TFRF	Source	Mean TFRF	Source	Mean TFRF	Source	Mean TFRF	Source	Mean TFRF	Source	Mean TFRF	Source	Mean TFRF	Source	Mean TFRF
DE	0.015	DE	0.016	OC	0.020	DE	0.032	DE	0.018	DE	0.013	DE	0.013	OC	0.018	DE	0.015
OS	0.014	OS	0.008	CE	0.010	OC	0.028	OC	0.013	OC	0.008	OC	0.009	DE	0.018	OC	0.013
OS	0.006	OC	0.007	DE	0.009	OS	0.012	OS	0.008	OS	0.004	CC	0.004	OS	0.014	OS	0.009
CC	0.006	VE	0.005	OS	0.008	CE	0.008	CE	0.004	DC	0.003	OS	0.004	VE	0.004	CE	0.003
DC	0.003	CE	0.004	DC	0.007	CC	0.007	VE	0.003	CE	0.003	VE	0.004	CE	0.004	VE	0.003
VC	0.001	DC	0.002	VE	0.002	VE	0.003	CC	0.003	VE	0.002	CE	0.003	CC	0.003	CC	0.003
VE	0.001	CC	0.002	CC	0.001	VC	0.002	DC	0.002	VC	0.002	DC	0.003	DC	0.002	DC	0.002
TE	0.000	VC	0.001	VC	0.000	DC	0.001	VC	0.001	CC	0.001	VC	0.000	VC	0.001	VC	0.001
CE	0.000	TE	0.000	TE	0.000	TE	0.000	TE	0.000	TE	0.000	TE	0.000	TE	0.001	TE	0.000
Total	0.046	Total	0.044	Total	0.057	Total	0.093	Total	0.054	Total	0.038	Total	0.041	Total	0.062	Total	0.050

Note: OC=owner change; DE=design error/omission; DC=design change; VE=vendor error/omission; VC=vendor change; CE=constructor error/omission; CC=constructor change; TE=transportation error; and OS=other.

number of projects (N), average total field rework factor (mean TFRF), standard deviation (SD), and p-value (p). The other part of Table 3 summarizes the post hoc test indicating the group for which the mean TFRF was significantly different from those other groups within each category. The mean TFRF for each group was calculated by Formula 1 by dividing the sum of the TFRF of each project in a group by the total number of projects within the group. The mean TFRF of the "All" category was the sum of the TFRF of all projects divided by the total number of all projects.

In the industry group category, the mean TFRF for light industrial (0.093) was highest and that of heavy industrial (0.044) was lowest, indicating that for this sample, the cost impact of rework in light industrial projects is significantly greater than that of buildings or heavy industrial projects ($p=0.0021$). According to project nature, rework in modernization projects contributed to the increase of the actual construction phase cost almost twice as much as it did in add-on projects and this finding is also significant ($p=0.0130$). Although modernization projects reported on average approximately 50% more rework than grass roots projects, this finding lacks statistical significance. Based on project size, the mean TFRF for projects between \$50 million and \$100 million was calculated as being the highest at 0.073, however, this is based on a small sample of 12. The lowest mean TFRF (0.049) was recorded for projects costing less than \$15 million, but again, these findings lack significance. Finally, results by project location reveal that the mean TFRF for domestic (0.051) projects was higher than for international ones (0.045), but as indicated by the p-value, the results are not significant. It was quite possible that the statistically insignificant differences might be due to randomness in the data.

Owner Projects: Rework Impact by Sources of Rework

Further owner reported project comparisons were made with analysis of data sorted by source of rework. Tables 4 and 5 show the average TFRF for the sources of rework by industry group,

Table 5. Rework Impact for Owner Reported Projects by Sources of Rework (Project Size and Project Location)

Project size										Project location					
<\$15MM ($N=107$)		\$15–\$50MM ($N=49$)		\$50–\$100MM ($N=12$)		>\$100MM ($N=7$)		All ($N=175$)		Domestic ($N=150$)		International ($N=27$)		All ($N=177$)	
Source	Mean TFRF	Source	Mean TFRF	Source	Mean TFRF	Source	Mean TFRF	Source	Mean TFRF	Source	Mean TFRF	Source	Mean TFRF	Source	Mean TFRF
OC	0.014	DE	0.019	OC	0.022	DE	0.004	DE	0.015	DE	0.015	DE	0.017	DE	0.015
DE	0.014	OC	0.015	DE	0.020	CE	0.001	OC	0.014	OC	0.014	OC	0.009	OC	0.013
OS	0.008	OS	0.010	OS	0.009	VE	0.001	OS	0.008	OS	0.010	CE	0.004	OS	0.009
CE	0.004	VE	0.006	DC	0.006	OC	0.001	VE	0.004	VE	0.004	DC	0.004	CE	0.003
CC	0.003	CE	0.004	CC	0.006	DC	0.001	CE	0.004	CE	0.003	CC	0.004	VE	0.003
VE	0.003	DC	0.003	VE	0.006	CC	0.001	DC	0.003	CC	0.003	VC	0.002	CC	0.003
DC	0.002	CC	0.001	CE	0.002	VC	0.000	CC	0.003	DC	0.002	VE	0.002	DC	0.002
VC	0.001	VC	0.001	VC	0.002	OS	0.000	VC	0.001	VC	0.001	TE	0.002	VC	0.001
TE	0.000	TE	0.000	TE	0.000	TE	0.000	TE	0.000	TE	0.000	OS	0.001	TE	0.000
Total	0.049	Total	0.059	Total	0.073	Total	0.010	Total	0.052	Total	0.051	Total	0.045	Total	0.050

Note: OC=owner change; DE=design error/omission; DC=design change; VE=vendor error/omission; VC=vendor change; CE=constructor error/omission; CC=constructor change; TE=transportation error; OS=other; and MM=million.

project nature, project size, and project location. The table includes the total number of projects (N), the sources of rework, and the average TFRF (Mean TFRF). The mean TFRF for a single source was calculated by dividing the sum of the TFRF for the source within a group by the total number of projects in the group. The sum of the mean TFRF for each source within a group was equal to the mean TFRF for the group (Total). The mean TFRF for each source in the All category was the sum of the TFRF of a single source in all projects divided by the total number of all projects.

Analysis by industry group (Table 4) reveals that the mean TFRF for DE (0.015) and OC (0.014) in buildings were higher than those of other sources in the group. This indicates that DE and OC contributed much more to the increase in the actual construction phase cost than other sources for buildings. In the case of heavy industrial, the mean TFRF for DE (0.016) was highest and twice as high as that of OS (0.008), the next highest source. In infrastructure, OC had the highest mean TFRF (0.020), followed by CE (0.010). For light industrial, DE (0.032) and OC (0.028) were ranked, respectively, as the first and second most common sources of rework by cost impact. The mean TFRF for DE was highest at 0.018 in the All category. That is, for an owner reported project, an average $0.018 million per $1 million actual construction phase cost was spent on rework caused by DE.

Table 6 shows the Spearman rank-order correlations of the nine sources of rework between each group within industry group, project nature, project size, or project location categories. The bolded entries represent the correlations that are statistically significant at the 0.05 level. In the industry group category, the rank orders of rework sources in heavy industrial, infrastructure, and light industrial categories were significantly correlated with each other. This suggests that the greatest sources ranked by cost impact were significantly similar between the groups. Therefore, as shown in Table 4, DE, OC, or OS had greater cost impacts than DC, VC, or TE on heavy industrial, infrastructure, and light industrial projects. The same conclusion can not be drawn for buildings however, as its rank order was significantly correlated only with that of light industrial.

In all groups categorized by project nature (Table 4), the mean TFRF for DE and OC were higher than those for other sources. In addition, all rank-order correlations in this category (Table 6) were statistically significant, indicating that rework caused by DE or OC contributed more to cost increase than DC, VC, or TE. For project size category (Table 5), the source contributing the most to rework is OC for projects costing less than $15 million and projects between $50 million and $100 million. In the cases of those projects between $15 million and $50 million, and greater than $100 million, DE contributes the most to rework. Further, except for projects costing greater than $100 million, the rank orders in each group were significantly correlated with one another, as shown in Table 6. In the case of projects costing greater than $100 million, the rank order was unique, showing that DE, CE, or VE contributed more to rework than VC, OS, or TE, however, these rankings are not significant. Table 5 also shows the cost impact of the sources of rework by project location. Although DE contributed the most to rework for both domestic and international projects, the finding is not statistically significant as shown in Table 6.

Contractor Reported Projects: Rework Impact by Project Characteristics

Table 7 shows the analysis results for the contractor reported projects by project characteristic. When the data from contractor

Table 6. Spearman Rank–Order Correlations of Sources of Rework for Owner Reported Projects

Variable		Industry group: Buildings	Heavy industrial	Infrastructure	Light industrial	Project nature: Add-on	Grass roots	Modernization	Project size: < $15 MM	$15–$50MM	$50–$100MM	> $100 MM	Project location: Domestic	International
Industry group	Buildings	1.000	—	—	—									
	Heavy industrial	0.650	1.000	—	—									
	Infrastructure	0.417	**0.783**	1.000	—									
	Light industrial	**0.683**	**0.867**	**0.800**	1.000									
Project nature	Add-on					1.000	—	—						
	Grass roots					**0.683**	1.000	—						
	Modernization					**0.833**	**0.883**	1.000						
Project size	< $15MM								1.000	—	—	—		
	$15–$50MM								**0.900**	1.000	—	—		
	$50–$100MM								**0.850**	**0.850**	1.000	—		
	> $100MM								0.550	0.650	0.400	1.000		
Project location	Domestic												1.000	—
	International												0.467	1.000

Note: Bold indicates statistically significant correlations at 0.05 level. MM=million.

Table 7. Rework Impact for Contractor Reported Projects by Project Characteristics

		Conctractor					
		ANOVA or t-test ($p<0.05$)				Post hoc (CI=95%)	
Project characteristics		N	Mean TFRF	SD	P-value	High	Low
Industry group[a]	Buildings	12	**0.000**[b]	0.001	**0.0417**	Heavy industrial	Buildings
	Heavy industrial	127	**0.024**[c]	0.029			
	Infrastructure	10	0.016	0.022			
	Light industrial	18	0.021	0.032			
	All	167	0.022	0.028			
Project nature[a]	Add on	57	0.023	0.027	0.8814		
	Grass roots	72	**0.021**[b]	0.031		No significant differences	
	Modernization	40	**0.024**[c]	0.033			
	All	169	0.022	0.030			
Project size[a]	<$15MM	56	0.019	0.034	**0.0293**	$50–$100MM	>$100MM
	$15–$50MM	60	0.020	0.024			
	$50–$100MM	21	**0.037**[c]	0.030			
	>$100MM	30	**0.015**[b]	0.014			
	All	167	0.021	0.027			
Project location[d]	Domestic	138	**0.027**[c]	0.031	**0.0000**	Domestic	International
	International	31	**0.002**[b]	0.006			
	All	169	0.022	0.028			
Work type[d]	Construct only	39	**0.030**[c]	0.044	0.1414	No significant differences	
	Design and construct	132	**0.022**[b]	0.027			
	All	171	0.024	0.032			

Note: CI=confidence interval and bold indicates statistically significant results at the 0.05 level. MM=million.
[a]ANOVA and post hot test.
[b]Lowest mean TFRF.
[c]Highest mean TFRF.
[d]t-test.

reported projects were sorted by industry group, heavy industrial had the highest TFRF at 0.024 and the lowest mean TFRF (0.000) was recorded for building projects. This difference is statistically significant ($p=0.0417$), meaning that rework in heavy industrial projects contributed much more to the increase in the total construction cost than that of building projects. A mean TFRF of zero indicates that the total direct rework cost divided by the actual construction cost was zero, or so small that it was near to zero. That is, although rework occurred and a total direct rework cost was recorded, the actual impact on the construction phase cost was small. Based on project nature, the mean TFRF for add-on, grass roots, and modernization were 0.023, 0.021, and 0.024, respectively, indicating that the cost impact of rework was almost equal without statistically significant differences. Projects costing between $50 million and $100 million generated a mean TFRF (0.037) more than twice as high as projects costing greater than $100 million (0.015) and this finding is significant ($p=0.0293$). Domestic projects were found to be significantly affected by rework almost 14 times as much as international projects ($p=0.0000$). When the category of work type was considered, the mean TFRF for construct only (0.030) was higher than that of design and construct (0.022), but this result is not significant as indicated by the p-value in Table 7.

Contractor Reported Projects: Rework Impact by Sources of Rework

Tables 8 and 9 detail the average total field rework factor found for the recorded sources of rework. Further, the rank-order correlations of the sources of rework between the groups are shown in Table 10.

Table 8 shows that DE (0.009) had the greatest cost impact on heavy industrial projects, followed by OC (0.005). Unexpectedly for infrastructure projects, OS had the greatest cost impact, meaning that the true causes were not clearly identified. This result also affected the rank-order analysis for infrastructure, causing the rank order of the group to be not significantly correlated with that of any other group, as shown in Table 10. This is because OS was the first rework source ranked for infrastructure, whereas it ranked relatively lower in other groups. In addition, the rank order for light industrial was negatively correlated with that of buildings. This negative correlation means that the sources having the greatest impact on light industrial could be those having the least impact on the buildings or vice versa. However, the correlation was very weak and not statistically significant.

In the project nature category, DE and OC were ranked as the first and second sources by cost impact (Table 8) and the rank order correlations of all groups within the category were statistically significant (Table 10). This result indicates that the cost

Table 8. Rework Impact for Contractor Reported Projects by Sources of Rework (Industry Group and Project Nature)

Industry group										Project nature							
Buildings ($N=12$)		Heavy Industrial ($N=127$)		Infrastructure ($N=10$)		Light industrial ($N=18$)		All ($N=167$)		Add-on ($N=57$)		Grass roots ($N=72$)		Modernization ($N=40$)		All ($N=169$)	
Source	Mean TFRF	Source	Mean TFRF	Source	Mean TFRF	Source	Mean TFRF	Source	Mean TFRF	Source	Mean TFRF	Source	Mean TFRF	Source	Mean TFRF	Source	Mean TFRF
CE	0.000	DE	0.009	OS	0.006	DC	0.007	DE	0.007	DE	0.007	DE	0.006	DE	0.007	DE	0.007
DE	0.000	OC	0.005	DC	0.003	OC	0.007	OC	0.005	OC	0.006	OC	0.004	OC	0.006	OC	0.005
VE	0.000	VE	0.003	DE	0.003	DE	0.003	DC	0.003	DC	0.003	DC	0.004	DC	0.004	DC	0.003
OC	0.000	DC	0.003	CE	0.002	CC	0.002	VE	0.003	OS	0.002	VE	0.003	VE	0.003	VE	0.003
DC	0.000	CE	0.002	OC	0.001	OS	0.001	CE	0.002	CE	0.002	CC	0.002	CE	0.002	CE	0.002
VC	0.000	CC	0.001	VE	0.001	VE	0.001	OS	0.001	VE	0.002	CE	0.001	OS	0.001	OS	0.001
CC	0.000	OS	0.001	VC	0.000	VC	0.000	CC	0.001	CC	0.001	OS	0.000	CC	0.000	CC	0.001
TE	0.000	VC	0.000	CC	0.000	CE	0.000	VC	0.000	VC	0.000	VC	0.000	VC	0.000	VC	0.000
OS	0.000	TE	0.000	TE	0.000	TE	0.000	TE	0.000	TE	0.000	TE	0.000	TE	0.000	TE	0.000
Total	0.000	Total	0.024	Total	0.016	Total	0.021	Total	0.022	Total	0.023	Total	0.021	Total	0.024	Total	0.022

Note: OC=owner change; DE=design error/omission; DC=design change; VE=vendor error/omission; VC=vendor change; CE=constructor error/omission; CC=constructor change; TE=transportation error; and OS=other.

impacts of DE, OC, or DC on add-on, grass root, and modernization projects were greater than those of CC, VC, or TE.

Table 9 shows the cost impact of the sources of rework by project size. Except for the projects costing between \$50 million and \$100 million, DE has the highest mean TFRF and all rank-order correlations were statistically significant (Table 10). Thus, DE, OC, or VE contributed more to cost increase than CC, VC, or TE in this category. For domestic and international projects, the analysis result indicates that DE, OC, or DC has a greater impact than CC, VC, or TE with the significant rank correlation between the two groups. Last, work type comparisons reveals that rework by the DE, OC, or DC contributed more to cost increase than CC, VC, or TE.

Discussion

In the case of owner reported projects, the cost impact of rework was least in heavy industrial. Conversely, heavy industrial projects for contractors were most affected by rework. This may imply that contractors on heavy industrial projects should make more effort to prevent and track rework to reduce the cost impact of rework and ultimately improve cost performance. It was also revealed that on both owner and contractor reported projects, rework contributed most to cost increases of modernization and domestic projects, and those projects with a cost range between \$50 million to \$100 million. Unexpectedly, the result showed that rework rarely influenced the cost increase of those projects costing greater than \$100 million. This might result from the relatively larger construction costs of these projects that make them relatively less sensitive to the direct rework costs. Another possible reason is that the projects were performed with better implementation of best practices that might positively affect reduction of rework.

When the cost impacts of rework were compared between owners and contractors, the cost for owners was over twice as high as for contractors. Although it was clear that the difference in the impacts is significant at the 0.05 level of significance, the result might be caused by the larger role of owners on projects. Owners see and control the whole project, whereas contractors only focus on the portion for which they are contracted.

For owner reported projects, OC, DE, and OS were most frequently ranked the three greatest sources by cost impact through all categories. However, the OS category is a catch-all for rework sources not properly addressed by the survey. If a more comprehensive tracking system is used or more effort to track the origin and causes of rework is made, a much more accurate impact of each source can be identified. CE was also found as a major source of rework on infrastructure, international projects, and on those projects costing greater than \$100 million.

For contractor reported projects, OC, DE, DC, and VE were most frequently ranked as the greatest sources of rework by cost impact. Particularly, DC was one of the higher cost impact sources on contractor reported projects, whereas it had relatively lesser cost impact on owner reported projects. In addition, CE is one of the more highly ranked sources on owner reported projects, but is less indicated by contractors. This finding is of interest as it shows the different perspectives on the origin of rework held by owners and contractors. That is, owners tend to report rework by constructor error/omission more and contractors more often attribute the need for rework to design error/omission. Table 11 summarizes the three most highly ranked sources by cost impact for owner and contractor reported projects.

The ANOVA, post hoc, and Spearman rank-order correlation tests were performed to see if the analysis results support the research hypotheses discussed before. The summary of the test results is presented in Table 12. For owner reported projects, the cost impacts of rework between the light industrial and buildings, light industrial and heavy industrial, and modernization and add-on were significantly different at the 0.05 level of significance. In addition, the rank orders of the greatest cost impact sources between the groups were significantly correlated at the same level of significance. In the case of contractor reported projects, the cost impact of rework in heavy industrial was significantly different from those of buildings. In addition, the differences between those projects with a cost range of \$50 million and \$100 million and those projects costing greater than \$100 million were also statistically significant. Similar to the rank-order correlation test results for owner reported projects, the rank orders between the groups for the contractor reported projects

Table 9. Rework Impact for Contractor Reported Projects by Sources of Rework (Project Size, Project Location, and Work Type)

Project size										Project location						Work type					
<$15MM (N=56)		$15–$50MM (N=60)		$50–$100MM (N=21)		>$100MM (N=30)		All (N=167)		Domestic (N=138)		International (N=31)		All (N=169)		Construct only (N=39)		Design and construct (N=132)		All (N=171)	
Source	Mean TFRF	Source	Mean TFRF	Source	Mean TFRF	Source	Mean TFRF	Source	Mean TFRF	Source	Mean TFRF	Source	Mean TFRF	Source	Mean TFRF	Source	Mean TFRF	Source	Mean TFRF	Source	Mean TFRF
DE	0.008	DE	0.007	OC	0.009	DE	0.005	DE	0.007	DE	0.008	DC	0.001	DE	0.007	DE	0.011	DE	0.006	DE	0.007
OC	0.006	VE	0.004	DE	0.009	VE	0.003	OC	0.005	OC	0.007	DE	0.000	OC	0.006	DC	0.007	OC	0.006	OC	0.006
DC	0.002	OC	0.003	CE	0.006	OC	0.002	VE	0.003	DC	0.004	OS	0.000	DC	0.003	OC	0.006	VE	0.003	DC	0.003
VE	0.001	DC	0.003	DC	0.004	DC	0.002	DC	0.003	VE	0.003	CE	0.000	VE	0.003	VE	0.002	DC	0.002	VE	0.003
CE	0.001	CE	0.002	VE	0.003	CE	0.001	CE	0.002	CE	0.002	OC	0.000	CE	0.002	OS	0.002	CE	0.002	CE	0.002
CC	0.001	OS	0.001	OS	0.003	OS	0.001	OS	0.001	OS	0.001	VE	0.000	OS	0.001	CE	0.001	CC	0.001	OS	0.001
VC	0.000	CC	0.001	CC	0.003	CC	0.000	CC	0.001	CC	0.001	VC	0.000	CC	0.001	CC	0.001	OS	0.001	CC	0.001
OS	0.000	VC	0.000	VC	0.001	VC	0.000	VC	0.000	VC	0.000	CC	0.000	VC	0.000	VC	0.000	VC	0.000	VC	0.000
TE	0.000	TE	0.000	TE	0.000	TE	0.000	TE	0.000	TE	0.000	TE	0.000	TE	0.000	TE	0.000	TE	0.000	TE	0.000
Total	0.019	Total	0.020	Total	0.037	Total	0.015	Total	0.021	Total	0.027	Total	0.002	Total	0.022	Total	0.030	Total	0.022	Total	0.024

Note: OC=owner change; DE=design error/omission; DC=design change; VE=vendor error/omission; VC=vendor change; CE=constructor error/omission; CC=constructor change; TE=transportation error; OS=other; and MM=million.

Table 10. Spearman Rank Order Correlations of Sources of Rework for Contractor Reported Projects

		Industry group				Project nature			Project size				Project location		Work type	
Variable		Buildings	Heavy industrial	Infrastructure	Light industrial	Add-on	Grass roots	Modernization	<$15 MM	$15–$50MM	$50–$100MM	>$100 MM	Domestic	International	Construct	Design and construct
Industry group	Buildings	1.000	—	—	—											
	Heavy industrial	**0.676**	1.000	—	—											
	Infrastructure	0.223	0.424	1.000	—											
	Light industrial	−0.055	**0.667**	0.492	1.000											
Project nature	Add-on					1.000	—	—								
	Grass roots					**0.850**	1.000	—								
	Modernization					**0.933**	**0.950**	1.000								
Project size	<$15MM								1.000	—	—	—				
	$15–$50MM								**0.900**	1.000	—	—				
	$50–$100MM								**0.883**	**0.850**	1.000	—				
	>$100MM								**0.900**	**1.000**	**0.850**	1.000				
Project location	Domestic												1.000	—		
	International												**0.750**	1.000		
Work type	Construct														1.000	—
	Design and construct														**0.900**	1.000

Note: Bold indicates statistically significant correlations at the 0.05 level. MM=million.

Table 11. Summary of Three Greatest Sources of Rework Ranked by Cost Impact

Project characteristics		Owner			Contractor		
		First	Second	Third	First	Second	Third
Industry group	Buildings	DE	OC	OS	CE	DE	VE
	Heavy industrial	DE	OS	OC	DE	OC	VE
	Infrastructure	OC	CE	DE	OS	DC	DE
	Light industrial	DE	OC	OS	DC	OC	DE
Project nature	Add-on	DE	OC	OS	DE	OC	DC
	Grass roots	DE	OC	CC	DE	OC	DC
	Modernization	OC	DE	OS	DE	OC	DC
Project size	<$15MM	OC	DE	OS	DE	OC	DC
	$15–$50MM	DE	OC	OS	DE	VE	OC
	$50–$100MM	OC	DE	OS	OC	DE	CE
	>$100MM	DE	CE	VE	DE	VE	OC
Project location	Domestic	DE	OC	OS	DE	OC	DC
	International	DE	OC	CE	DC	DE	OS
Work type[a]	Construct only	NA	NA	NA	DE	DC	OC
	Design and construct	NA	NA	NA	DE	OC	VE

Note: OC=owner change; DE=design error/omission; DC=design change; VE=vendor error/omission; VC=vendor change; CE=constructor error/omission; CC=constructor change; TE=transportation error; OS=other; and MM=million.

[a]Contractor reported projects only.

were significantly correlated as shown in Table 12.

In summary, the statistical analyses revealed that although the cost impacts of rework were different between groups, the rank orders of the greatest cost impact sources in the groups were highly correlated. This means that the sources having a relatively greater impact than other sources in a group may not be significantly different from those of other groups. Therefore, DE and OC, most frequently ranked as two of the greatest sources by cost impact, can be considered to be the most important root causes of rework for both owner and contractor reported projects. Further, CE for owner reported projects and DC for contractor reported project can also be a major source of rework.

Conclusions and Recommendations

By measuring and comparing various project characteristics and sources of rework, this study explored how construction cost per-

Table 12. Summary of Statistical Test Results

Project characteristics		Owner			Contractor		
		ANOVA or t-test	Post hoc	Rank-order correlation	ANOVA or t-test	Post hoc	Rank-order correlation
Industry group	Buildings versus heavy industrial	•			•	•	•
	Buildings versus infrastructure						
	Buildings versus light industrial		•	•			
	Heavy industrial versus infrastructure			•			
	Heavy industrial versus light		•	•			•
	Infrastructure versus light industrial			•			
Project nature	Add-on versus grass roots	•		•			•
	Add-on versus modernization		•	•			•
	Grass roots versus modernization			•			•
Project size	<$15MM versus $15–$50MM			•	•		•
	<$15MM versus $50–$100MM			•			•
	<$15MM versus >$100MM						•
	$15–$50MM versus $50–$100MM			•			•
	$15–$50MM versus >$100MM						•
	$50–$100MM versus >$100MM					•	•
Project location	Domestic versus international				•		•
Work type[a]	Construct only versus design and construct	NA	NA	NA			•

Note: A bullet (•) indicates statistically significant results at the 0.05 level. MM=million.

[a]Contractor reported projects only.

formance is affected by rework and concluded that rework contributed most to cost increases in light industrial owner reported projects and heavy industrial contractor reported projects. Moreover, modernization and domestic projects, and those projects with a cost range between $50 million to $100 million for both owners and contractors were also among the most susceptible. On both owner and contractor reported projects, owner change and design error/omission appeared to be the root causes of rework having a relatively greater cost impact than other sources. Constructor error/omission was indicated more as one of the greatest cost impact source on owner reported projects, whereas design change was reported more on the contractor reported projects.

Based on these conclusions, it is recommended that project managers responsible for the most affected types of project should be aware of the different cost impacts of rework when drafting preproject and quality management plans. Further, they should develop or implement systems for tracking and controlling constructor error/omission for owners, design change for contractors, and owner change and design error/omission for both owners and contractors in order to reduce rework by these sources. In particular, it has been identified in other studies that adopting CII best practices has a positive effect on project cost and schedule reduction (CII 2003). According to CII (2002) it is known that design errors/omissions and owner changes may result from poor project definition, inadequate preproject planning, ineffective design, inadequate project change management, poor communication among owners, designers and constructors, or constructibility ignored in the design process. Therefore, implementing CII best practices, such as preproject planning, project change management, design effectiveness, alignment, and constructibility, would be an effective approach to reducing the root causes of rework.

In closing, further studies on the cost impact of rework are recommended as the CII benchmarking and metrics database expands and accumulates additional project data. Although this study provided a comprehensive investigation of the relationship between rework and cost performance, it only used data for total direct rework costs. Based upon the previous study on the indirect consequences of rework in construction performed by Love (2002a), the analysis should be expanded to include data for total indirect rework costs, so that an integrated impact caused by total direct and indirect costs can be identified. Further, studies on the impacts of rework on schedule performance should be conducted because rework is one of the main causes of schedule overrun. A final recommendation for future study is that the influences of an organization's management practices and project management strategies on reducing rework cost should be quantified as Love et al. (2003) suggested as well, and the most effective practices for each root cause should be identified.

Appendix

Definitions of Sources of Rework

Sources	Definitions and examples
Owner change	Result caused by the owner changing the project definition, scope or requirements.
Design error/omission	Result caused when necessary items or components in the project design are erroneous or omitted.
Design change	Result caused when changes are made in the project design or requirements.
Constructor error/omission	Result caused by contractors' errors or omissions in construction methods, procedures, activities or tasks.
Constructor change	Result caused by changing constructors, construction methods or procedures.
Vendor error/omission	Result caused when necessary items or components are erroneous or omitted by vendors.
Vendor change	Result caused when vendors are changed.
Transportation error	Result caused by mistakes, accidents, or errors in transportation.
Other	Result caused by all other sources

Types of Projects by Industry Group

Industry group	Project type
Buildings	Communication center, courthouse, dormitory/hotel/housing/residential, embassy, hospital, laboratory, office, theatre, prison, school, warehouse, or other buildings
Heavy industrial	Chemical manufacturing, gas distribution, gas exploration/extraction/distribution, metals refining/processing, mining, natural gas processing, oil exploration/production, oil refining, pulp and paper, power, or other heavy industrial
Infrastructure	Airport, electrical distribution, flood control, highway, navigation, rail, tunneling, water/wastewater, telecom/wide area network, or other infrastructure
Light industrial	Automotive manufacturing, consumer products manufacturing, foods, microelectronics, manufacturing, office products manufacturing, pharmaceutical manufacturing, pharmaceutical labs, clean room (hi-tech), or other light industrial

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