

Risk Distribution in the Construction Phase: Timing, Cost Impact, and Root-Cause Sources of Individual Risk Factors

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Risk management is a critical aspect of effective construction project control. In order to investigate the influence of risk management actions on project performance, this study systematically documented all risk events encountered by project teams on 68 construction projects. Whereas much risk management research in the construction industry has analyzed change orders, this study contributes an additional level of detail by studying individual risk events. This additional level of detail is important because a single change order often reflects the combined cost and schedule impacts from multiple risk events; further, many risk events occur during the construction process that do not result in change orders, yet still require substantial risk management effort to be expended by the project team. In order to investigate risk management effectiveness at this level of detail, this study catalogued 1,502 individual risk events that occurred throughout the construction phase from Notice to Proceed to final completion and project close out. For each risk event, the associated risk management actions of the project team were documented based upon the timing of risk identification actions. The corresponding cost impact of each risk was recorded along with the root-cause source that triggered each risk to occur. Results of the study indicate that unique risk sources have different characteristics related to cost impacts as well as the timing of associated risk management actions.

Key Words: Risk management, project control, cost growth, change order

Introduction

Project risk management is defined as one of the ten core knowledge areas within the Project Management Body of Knowledge (PMBOK (2008). Risks in the construction industry are defined as the threats and opportunities to the project cost and schedule (Williams 1995, Hilson 2009). As the construction industry continued to increase in complexity, projects are exposed to complex scopes and unique site conditions and therefore become more risk-intense (Bosch-Rekveldt et al. 2011, Hilson 2009). Effective risk management is therefore a critical skillset for construction project teams to possess (Perrenoud *et al.* 2015). A key aspect of risk management is the prompt, accurate, and timely communication of risk once it is encountered during the project (Batson 2009, Taroun 2014). The objective of this study was to catalogue all individual risk events that occurred on 68 public institutional sector construction projects. The cost impact, root cause source, and timing of initial identification was documented for each individual risk that was discussed during the weekly project meetings of each construction project.

Literature Review

The construction industry is subjected to a wide range of risk sources. In broad terms, industry stakeholders such as owners, contractors, design consultants, subcontractors, and suppliers may all be responsible for causing risk on a project (Sun and Meng 2009). Several studies have identified leading contractor-caused risk sources to include poor site management, improper planning inadequate experience, problems with subcontractors, and availability of resources (Chan and Kumaraswamy 1997, Hanna and Swanson 2007, Sambasivan and Soon 2006). Other studies have noted that design consultants may create risk for the construction phase by providing incomplete designs or design that include errors and omissions that must be corrected (Hanna and Gunduz 2004, Rosenfeld 2014, Taylor *et al.* 2011). Owner-caused risk items have been found to include slow decision-making, insertion of additional works (Alnuaimi *et al.* 2010, Assaf and Al-Hejji 2006, Chan and Kumaraswamy 1997). Further causes of risk in construction include unforeseen conditions (Hsieh *et al.* 2004, Sun and Meng 2009).

The timing of risk factors within the construction industry has predominantly studied in terms of the timing of change orders during the construction phase. For example, Ibbs (2005) studied 162 projects obtained from 93 contractors, and regression results concluded that change orders that occur later in the project are more adverse to labor productivity than those that occur earlier in a project. Hanna *et al.* (1999) considered the timing of change orders in their study of 61 mechanical construction projects from 26 different contractors. Their results showed that the later a change is experienced, the greater the impact to reduce productivity on site.

Numerous previous studies have analyzed the construction industry in terms of the magnitude of change orders that affect projects, yet these studies often do not quantify the impacts of individual change orders (or discrete risk factors) in relation to root-cause risk sources (Bogus et al. 2013, Cantarelli et al. 2012, Chen et al. 2016, Flyvberg et al. 2003, Hanna and Gunduz 2004, Odeck 2003). Other studies have investigated the many risk factors related to change order causes and effects, yet the methodological design of these studies has been predominantly limited to survey-based measurement of practitioner perceptions rather than empirical project data (Alnuaimi et al. 2010, Assaf and Al-Heiji 2006, Chan and Kumaraswamy 1997, Hanna et al. 2013, Hsieh et al. 2004, Rosenfeld 2014, Sambasivan and Soon 2006). Further studies have investigated the timing, occurrence, and cumulative impact of individual change orders, but do not specifically describe the discrete scope items that comprise each change order, nor do these studies account for risk events that did not result in formal project cost or schedule impacts (Ibbs 2005, Hanna and Swanson 2007, Hanna et al. 1999, Taylor et al. 2012).

Point of Departure

Although there are numerous studies related to risk management within the construction field, there is a gap in the existing body of knowledge related to the timing of *when* risks occur within a construction schedule. This study further includes the timing of when different risk sources occur. Another contribution of this study is that all risk events that occurred during the project were tracked regardless of whether they ultimately results in a change order. This meant that all risks that were actively reviewed and managed during the project were represented within the dataset. This is also a departure from previous studies that have predominantly focused on change order events.

Methodology

Data Collection and Sample

The objective of the study was to identify the frequency of occurrence, root cause source, and associated cost impact of each discrete risk events that occur throughout the construction process, and therefore require risk management action from the project team. The research data was collected from 68 completed construction projects, comprised of 53 projects located in the United States and 15 projects from Canada. The construction projects in the sample were all within the public institutional sector, including federal, state, and municipal government as well as secondary and post-secondary schools. Descriptive statistics related to project size and schedules are shown in Table 1.

Table 1

Data Sample

Overall Project Data	**Sum**	**Percentage (%)**
Number of Projects	68	-
COST		
Total Awarded Cost	$ 137,486,236.70	-
Mean Awarded Cost	$ 2,012,856.42	-
Standard Deviation of Mean Cost	$ 4,278,688.53	-
Minimum Awarded Cost	$ 103,000.00	-
Maximum Awarded Cost	$ 25,987,230.00	-
Total Project Completion Cost	$ 143,181,886.00	-
Cost Increase	$ 5,695,649.30	4.14%
Mean Cost Increase	-	7.17%

SCHEDULE		
Total Awarded Schedule (Days)	13753	-
Mean Awarded Schedule (Days)	203	-
Standard Deviation of Mean Schedule (Days)	121	-
Minimum Awarded Schedule (Days)	42	-
Maximum Awarded Schedule (Days)	519	-
Total Project Completion Schedule (Days)	16592	-
Schedule Increase (Days)	2839	20.64%
Mean Schedule Increase	-	25.56%

All individual risks that were managed by the construction teams in their weekly project meetings were documented along with their cost impact to the original project budget. The contractor's project manager and owner's lead representative also agreed upon a category for each risk item within their weekly meetings. These categories were based upon the root cause source that was most responsible for creating the individual risk, as defined in Table 2. The authors note that not all sources of risk should necessarily reflect negatively on the project's performance; for example, client scope changes may represent increased quality for the project.

Table 2

Risk Source Categories

Label	**Category for Source of Risk**	**Definition of Source**
CLSC	CLIENT: Scope Change	Change in original scope work as requested by client
CLNS	CLIENT: Non-Scope Change	Requires permission, action, or resources from the client
CLIE	CLIENT: Innovation / Efficiency	Client proposed innovative recommendations to save cost and time
CNEO	CONTRACTOR: Error / Omission / General Issues	Contractor error, means/methods, or management on project site
CNSS	CONTRACTOR: Sub / Supplier	Subcontractor performance, scheduling, and material deliveries
CNIE	CONTRACTOR: Innovation / Efficiency	Contractor proposed innovative recommendations to save cost and time
DEEO	DESIGNER: Error / Omission	Design errors or omissions within the construction documents
DEIE	DESIGNER: Innovation / Efficiency	Innovative recommendations to save cost and time from design team
UNCC	UNFORESEEN: Concealed Conditions	Existing or unknown conditions on the project site
UNUE	UNFORESEEN: Unexpected Events / Weather	Force majeure, extreme weather, market fluctuation and all other unforeseen events

Risk Identification Variable

To record the occurrence of risk as related to the project schedule, a variable known as Risk Identification was defined. The abbreviation used for this variable is "RiskID" and has percentage as the unit of measurement. The RiskID was calculated using Equation 1 below, which included the date on which risk was first formally communicated, in writing, between the contractor's project team and owner's representatives, in relation to the project start date and overall schedule duration. The RiskID denoted the time at which each individual risk item was identified and formally communicated, in writing, between the contractor and owner teams. Lower values of RiskID correspond with risks that were identified earlier in the project, whereas larger value of RiskID represented risks that were identified later in the project schedule.

Equation 1:
RiskID(%) = (Risk Identified Date – Project Start Date) / (Project Schedule Duration) x 100%

Results

Risk Identification Distribution

Figure 1 shows the combined risk identification data distributed across the original project schedule for all 68 projects included in the data sample. Although the majority of risks were identified before the originally contracted completion date (represented by 100% on the x-axis), the figure shows a non-trivial number of risks (18%) were identified after the project was originally intended to be complete. The risk identification profile shows multiple peaks during the project schedule at 20%, 60%, and 70% of the originally scheduled project completion.

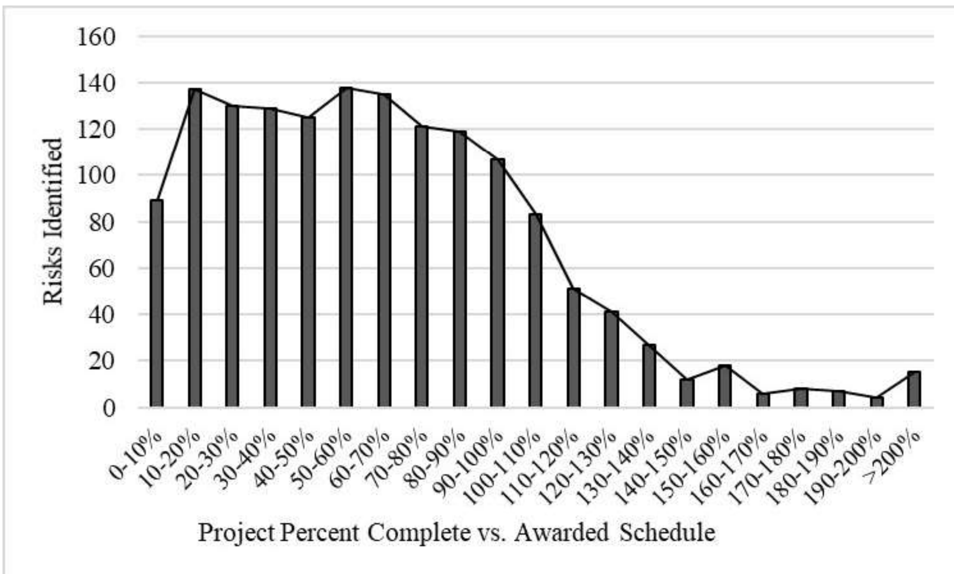

Figure 1: Risk Identification Profile

In terms of the overall frequency distribution, the risk identification profile had a positive skew, meaning that risk events are front-loaded within the construction schedule. The peak interval of risk identification was between 10 and 20% of the construction schedule, with near-peak identification of new risks continuing thereafter through much of the originally scheduled project completion date. Risk identification did not begin to decrease until 90% to 100% of the originally contracted schedule duration. An interesting finding from this study was that construction projects frequently encounter risk events even after the project's originally contracted completion date has passed. In this study, 82% of the total risks (1230 risks) were identified before the original contracted schedule of the project, whereas the remaining 18% of risks were encountered after the completion of original contracted schedule. This indicated that full, final completion of construction projects often slip beyond their contracted dates, even when substantial completion dates are maintained.

Magnitude of Cost Impacts for Individual Risks

The cost impacts associated with each risk was categorized in to ten groups by the method of sequential doubling the class intervals (Perrenoud *et. al* 2015). Table 3 shows the distribution of risks based upon sequential doubling of the cost impact magnitude (measured in terms of each risk's cost growth from the original contracted project budget). The table shows that 35% of the risks had zero cost impact, 8% of the risks resulted in cost saving on the projects, and the remaining 57% of risks were responsible for an increase in the contracted project budget. The average risk identification for each grouping are also shown in the table. Risks with higher cost impacts tend to be identified earlier in the project, on average, compared to the low dollar impact risks.

Table 3

Risks by Magnitude of Cost Impact

Grouping Based on Cost Impact Magnitude ($)	Count	Percentage (%)	Average Identification	Cumulative Cost Impact within Grouping ($)	Cumulative Percentage of all Cost Impacts (%)
<$0	119	8%	62%	-$1,164,703	-21%
$0	524	35%	54%	$0.00	0%
$1-$1,000	201	13%	77%	$111,010	2%
$1,001-$2,000	177	12%	76%	$258,561	5%
$2,001-$4,000	150	10%	75%	$437,958	8%
$4,001-$8,000	133	9%	66%	$766,903	14%
$8,001-$16,000	104	7%	71%	$1,170,384	21%
$16,001-$32,000	44	3%	63%	$954,555	17%
$32,001-$64,000	32	2%	68%	$1,478,560	26%
$64,001-$250,000	18	1%	69%	$1,649,741	29%
Total	1,502	100%	-	$5,662,967	100%

Characteristics Based Upon Risk Source

Table 4 shows the descriptive analysis of frequency, cost impact, and risk identification characteristics associated with each of the separate risk sources. Design errors and omissions were the most common source of risks (N=496, 33.02%) during the construction phase. This was closely followed by risks that occurred due to client scope changes (N=469, 31.23%). The next most common sources of risk included unforeseen concealed conditions (N=217, 14.45%), client non-scope changes (N=89, 5.93%), contractor subs or suppliers (N=66, 4.39%), contractor error or omission (N=49, 3.26%), contractor innovation or efficiency (N=48, 3.20%), and unforeseen unexpected events or weather (N=47, 3.13%).

Table 4

Distribution of Risk Frequency, Cost Impact, and Identification per Risk Source

Risk	Risks		Cost Impact		Risk Identification			
Category	Count	Percentage	Dollars	Percentage	Mean	St. Dev.	Min.	Max.
CLSC	469	31.23%	$2,640,414	42.41%	0.72	0.43	0.00	2.96
CLNS	89	5.93%	$104,298	1.68%	0.46	0.44	0.00	2.01
CLIE	8	0.53%	$(43,527)	0.70%	0.65	0.35	0.19	1.02
CNEO	49	3.26%	$86,218	1.38%	0.57	0.41	0.00	1.38
CNSS	66	4.39%	$294	0.00%	0.79	0.41	0.01	2.13
CNIE	48	3.20%	$(231,871)	3.72%	0.57	0.29	0.00	2.32
DEEO	496	33.02%	$1,919,753	30.84%	0.64	0.38	0.01	1.85
DEIE	13	0.87%	$(5,729)	0.09%	0.46	0.19	0.22	0.72
UNCC	217	14.45%	$1,057,799	16.99%	0.58	0.43	0.00	3.12
UNUE	47	3.13%	$135,319	2.17%	0.80	0.94	0.00	3.97
Total	1,502	100.00%	Abs: $6,225,222	100.00%	-	-	-	-

Based upon the magnitude of cost impact, client scope changes had by far the greatest cost implication to the projects, with a total of $2,640,414 in cost growth. This represented 42.41% of all cost growth documented in the 68 projects. The second most costly risk source was design errors and omissions, which accounted for 30.84% of all cost growth observed. Unforeseen concealed conditions also had a substantial cost impact, with a total of $1,057,799 (16.99% of all cost growth). Several risk sources also resulted in cost savings. Most notably, contractor innovations and efficiencies were by far the most likely source of cost savings on the projects.

Each of the ten risk categories were also analyzed in relation to the trends in the corresponding risk identification actions of the construction team. On average, the risks generating from to designer team (designer error/omissions, designer innovation/efficiency) were encountered earliest at 55% completion of the original contracted schedule. This was followed by risks generated by the client (client scope change, client non-scope change, client innovation/efficiency) at 61% completion of the original contracted schedule. The risks caused by the contractor (contractor error/omission, contractor sub/supplier issues, contractor innovation/efficiency) and unforeseen conditions (unforeseen concealed conditions and unforeseen events/weather) were encountered, on average, later in the project schedule at 64% and 69%, respectively.

Discussion

The majority of risks (65%) resulted in a quantifiable cost impact on the project budget, ranging from as low as a budget reduction of $223,068 to as high as a scope increase of $181,518. For risks that did have an impact to project cost, these risks were translated in to change orders that impacted the project's original contracted duration and budget. The remaining portion one-third of risks encountered by construction project teams had no cost impact on the project. The effect of these risks on the project, however, was likely not negligible. Even moderate to low level risks require particular attention by the project team to communicate, respond, and resolve the risk. These activities in turn require time, attention, and resources, which has the potential to lessen resource allocations to other areas of the project.

Of the ten categories of risk sources, client scope change, designer error/omission, and unforeseen concealed conditions were by far the most frequently encountered risk sources across the 68 projects in the study sample. The projects within this data sample followed the traditional design-bid-build project delivery approach, which means that the 100% complete construction documents were completed prior to the construction phase even beginning. Yet the most common types of risk events encountered by participating construction teams was directly linked to client scope changes, design errors and omissions, and unforeseen conditions. Taken in combination, these leading risk source categories indicate that the construction scope continually shifts during the construction phase, even within design-bid-build delivery. This finding is somewhat contrary to conventional wisdom that construction is a well-defined process, particularly in comparison to project design phases, and that the presence of complete construction documents means that the project outcomes are largely fixed, certain, or pre-determined. At times, owners act even upon this conventional wisdom by treating construction services as a commodity. The results of this study provide motivation for early contractor involvement in the design phase to perform constructability reviews and other pre-construction services, which have been shown to improve the planning and coordination between design and construction phases (Taylor 2012).

Owner-directed scope changes were among the latest-occurring risk sources (identified at 72% of the schedule, on average). Upon first glance, particularly considering the successful performance of the particular projects within the data sample, it may be expected that late-occurring Client scope changes would be a result of expenditures of unneeded project contingencies. However, as noted in the previous section, a review of the actual narrative descriptions of discrete risk events revealed that the majority of Client-direct scope changes were from late decisions and changes from the Client user groups. This result is supported by previous studies which have found that slow client decision-making often has a substantial impact on construction operations (Doloi et al. 2012, Gunduz et al. 2013, Odeh and Battaneh 2002). Furthermore, the client groups within this study were large public agencies with typically have lengthy and multi-step approval processes before scope changes can be formally integrated into the project budget.

Other late-occurring risk sources were contractor sub and supplier issues as well as unforeseen unexpected events and weather. The late timing of contractor sub and supplier risks reflects the difficulty of coordinating long lead time items as well as last-in-line sub trades, often referred to as the "parade-of-trades" (Han and Park 2011, Mitropoulos et al, 2014, Tommelein et al. 1999). The late identification of truly unforeseen and unexpected events, outside of more traditional concealed conditions, was perhaps reflective of a certain psychology wherein project teams may mutually ascribe late-occurring issues as being "unforeseen" and "unexpected" to avoid late-project "blame games" of which stakeholder was truly at fault.

Conclusion

Risk management is a critical aspect of effective construction project control. In order to investigate the influence of risk management actions on project performance, this study systematically documented all risk events (N=1502) encountered by project teams across the construction phase of 68 construction-building projects. Results indicate that unique risk sources have different characteristics related to cost and schedule impacts as well as the timing of associated risk management actions. General trends were discovered for the timeliness of the project teams' risk identification actions with the corresponding cost impact of each risk.

The study contributed to the body of knowledge by providing better understanding construction risk management at individual risk level, including visualization of risk identification distribution across the construction phase and documentation the most prevalent root-cause sources of risks within design-bid-build projects in the vertical sector (along with their cost impacts). A unique aspect of the research design was that many of the risk events within the compiled dataset did not result in a quantifiable cost impact to the project. By measuring the characteristics of all risks that occurred, and not simply restricting data collection to change orders, this study contributes a much more refined, discrete, and detailed unit of measurement within the field of construction risk management. Results from this study are useful for project management teams to understand in terms of the sheer complexity and amount of resources required to successfully manage the numerous potential risk impacts that face a construction project.

Limitations

The data sample was limited to minor construction projects (average value of $2M) within the vertical sector. Future research is recommended to include large-scale building projects and also expand into the horizontal sector. A limitation of the study was that the cost impacts that were quantified only reflect costs that directly changed the original contract values. In other words, if a risk item did not result in an approved change order, the cost impact was recorded as zero dollars. In this manner, only costs that were paid by the owner were measured. This opens the possibility that internal costs borne by the contractor (and not reimbursed by the owner) were not captured by the data collection tool.

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