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Unearthing the nature and interplay of quality and safety in construction projects: An empirical study

Peter E.D. Love[a], Pauline Teo[b,*], John Morrison[c]

[a] Department of Civil Engineering, Curtin University, GPO Box U1987, Perth, Western Australia 6845, Australia
[b] School of Architecture and Built Environment, Deakin University, Geelong, VIC 3220, Australia
[c] Frontline Coach Pty Ltd, 9 Ashmore Avenue, Mordialloc, Victoria 3195, Australia

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ABSTRACT

Effective implementation of quality and safety management is essential for ensuring the successful delivery of construction projects. While quality and safety possess a symbiotic relationship, there have been limited empirical lines of inquiry that have examined the nature of interaction between these constructs. With this mind, quality and safety data derived from 569 construction projects are analyzed. Quality was examined through the lens of non-conformances (NCRs), and safety under the guise of incidents. The quantity, cost and type of NCRs experienced are analyzed (n = 19,314) as well as the type and number of safety incidents (n = 20,393) that occurred. Examples of quality and safety incidents that arose in 'practice' are used to provide a contextual backdrop to the analysis that is presented. The analysis revealed that NCRs (e.g. rework, scrap, and use-as-is) were positively associated with injuries ($p < .01$). Human error is identified as the primary contributor to quality and safety issues, but the organizational and project environment within which people work provides the conditions for them to occur; people make mistakes, but there is a proclivity for organizations to enable them to materialize and result in adverse consequences occurring.

1. Introduction

A symbiotic relationship has been suggested to exist between quality and safety performance (Das et al., 2008; Pagell et al., 2014; Love et al., 2015). After all they are interdependent constructs, and depend on employees' actions and therefore cannot be considered in isolation, especially as they use similar documentation, improvement and standardization, and decision-making processes. Essentially, if an employee feels unsafe they are unlikely to ensure quality outcomes are given a priority. Love et al. (2016a) have suggested that when an *action* on a non-conforming product to ensure it conforms to specified requirements is undertaken, the potential for a safety event to occur significantly increases. Having to repeat an action is referred to as *rework*, which has been persistently identified as a chronic problem that has, and continues to plague the 'practice' of construction (e.g., Rogge et al., 2001; Robinson-Fayek et al., 2004; Palaneeswaran et al., 2008; Hwang et al., 2009; Love et al., 2016a).

If rework, and the subsequent safety incidents, which may materialize are to be mitigated, then there is a need to acknowledge its existence, measure its cost, identify its cause, predict its occurrence and learn to develop strategies to reduce and contain its adverse consequences. Despite, however, the extensive amount of research that has provided quantitative assessments of the financial impact of rework on project performance (e.g., Love and Li, 2000; Love, 2002a,b; Hwang et al., 2009; Hwang et al., 2014; Love et al., 2016a), the relationship with safety events has been generally eschewed. This issue was identified by Loushine et al. (2006) who specifically noted that there had been an absence of studies examining the impact of rework on safety performance. Explicitly, this remains the case, especially considering the dearth of empirically based research that has been undertaken.

In attempt to fill this void, research undertaken by Wanberg et al. (2013) revealed the existence of a significant association between recordable injury rates and the rate of rework and the rate of defects. A major shortcoming, however, of this research was the sample size, which was limited to 32 building construction projects. Despite this research providing an indication of the relationship between rework and incidents, the prevailing lack of empirical research may be attributable to having limited access to data due to its commercial sensitivity (Behm et al., 2007).

Building upon the work of Wanberg et al. (2013), the research presented in this paper explores the nature and relationship between quality and safety, with particular emphasis being placed on examining

* Corresponding author.
E-mail address: pauline.teo@deakin.edu.au (P. Teo).

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Table 1
Types of NCRs.

NCR Types	Projects (N)	NCR (N)	Min.	Max.	M.	Std. deviation
Frequency						
Rework	197	9098	1	1436	47	127
Scrap	87	540	1	79	6	13
Use-as-is	166	9229	1	2896	56	239
Undefined	42	448	1	114	11	23
Total	210	19,314	1	4525	92	336
Value ($)						
Rework	195	81,797,250	0.01	10,079,000	419,473	1,176,038
Scrap	85	6,740,467	0.01	1,939,610	79,300	233,262
Use-as-is	149	7,603,028	0.01	1,783,402	51,027	165,993
Undefined	20	832,946	600	296,116	41,647	71,944
Total	207	96,973,691	0.01	12,561,056	468,472	1,337,578

the association between rework and incidents. A case study is used to investigate this phenomena using secondary data provided by an Australian contractor. Quality and safety data derived from 569 construction projects undertaken from 2007 to 2015 were examined with specific reference to examples of quality and safety incidents that emerged during their construction.

The research not only provides statistical insights about the nature and relationship of quality and safety issues that arise in practice, but also provides the impetus for construction organizations to reflect and examine how rework may induce unexpected safety events to materialize. If rework can be reduced, then naturally, there will be an improvement in safety standards in projects and throughout the industry (Love et al., 2004). Due to the limited research that has been undertaken in this area (e.g., Loushine et al. 2006, Wanberg et al., 2013; Love et al., 2015; Love et al., 2016b), there is a lack of robust theoretical underpinning and as a result a case study approach is adopted to empirically explore the nature of the relationship between quality and safety in construction projects.

2. Case study

Exploratory research is undertaken to examine a problem that has not been clearly defined and/or understood and invariably relies upon secondary data (Shields and Rangarjan, 2013); in this case, the relationship between quality and safety. When the purpose of research is to gain familiarity with a phenomenon or acquire new insight in order to formulate a more precise problem or develop hypothesis, exploratory studies are a pertinent and justifiable approach to adopt (Babbie, 2007). Thus, an exploratory case study approach is used to examine the relationship between non-conformances (NCRs) and safety incidents that arose during construction for an Australian contractor with an annual turnover in excess of $1 billion per annum.

The contractor that afforded access to the data for analysis and interpretation provides engineering and contracting services to infrastructure, energy and resources, and transport sectors. Quality and safety form an integral part of the organization's mission and strategy. Testament to this dedicated focus is the number of national awards the organization has received for its safety performance and in its ability to deliver and construct facilities to the highest quality, on time and to budget.

The data made available covered the period from January 2007 until October 2015. The total number of NCRs and incidents that occurred were provided for all projects that were being undertaken and had been completed by organization during this time period. Due to the commercial sensitivity of the data provided, a detailed breakdown and examples of NCRs and incidents is unable to be provided. The incidents from the database that the researchers were provided with included a wide variety of issues such as product and system NCRs that resulted in rework, injuries, investigations, environmental incidents, unsafe acts and behaviors.

3. Empirical findings

A descriptive analysis and an examination of the relationship between NCRs and incidents is presented herein after. Noteworthy, data has been aggregated so that the details of specific projects are unable to be identified. Projects have been classified as 'Building', 'Infrastructure', and 'Rail'. Examples of 'Building' projects, include hospitals, schools, prisons, defence, and commercial assets. Civil works, such as roads, water and marine projects, were classified as 'Infrastructure'. 'Rail' refers to heavy and light rail projects. Anonymized examples of NCRs and incidents that arose during the construction of selected projects are presented so as to provide a contextual backdrop to the analysis.

3.1. Quality

Of the 569 construction projects examined 210 (37%) projects had reported that they experienced NCRs (Table 1). A total of 19,314 cases of NCRs were recorded. A total of 47% (n = 9098) were classified as rework, 48% (n = 9229) used-as-is, 3% scrap (n = 540), and 2% (n = 448) were unable to be classified. The mean number of NCRs per project was 92.

A total cost of $97 million ($96,973,691) had been incurred for all NCRs during the period sampled. This equates to $468,472 per project across all projects. The total direct cost of rework that was experienced for this period was approximately $82 million ($81,797,250) and with an average of $419,473 per project. The direct rework costs, however, ignores those of an indirect nature, which have been reported as being as high as six times the actual cost of rectification (Love, 2002b); when the direct rework cost is extrapolated to the entire 569 projects sampled a possible indirect cost of $492 million would have been incurred. The total cost of scrap was $6.8 million ($6,740,467) and a mean of $79,300 being experienced for each project. A total cost of $7.6 million ($7,603,028) was determined for used-as-is NCRs and a mean of $51,027 being experienced for each project. Undefined NCRs had a total of $832,946 and mean of $41,647.

Notably, 50% of the NCRs issued were attributed to rework, which accounted for 84% of their total cost. The remaining 16% of NCR costs were distributed as follows: 8% used-as-is, 7% scrap and 1% that were unable to be defined. An internal report published within the contractor's organization in 2010 had observed NCRs accounted for only 25% of the rework that had been reported. Moreover, only 15% of total rework costs that had been incurred was directly attributed to the contractor; the balance had been the responsibility of subcontractors and suppliers. The internal report concluded that rework had been commonly under reported and it was therefore recommended that a 'No Rework' vision be adopted throughout the organization; yet this recommendation was overlooked and rework has continued to be a

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