Unearthing the Nature and Interplay of Quality and Safety in Construction Projects: An Empirical Study

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Peter E.D Love
Curtin University

Pauline Teo
Deakin University

John Morrison
Frontline Coach Pty Ltd

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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

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* 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

Table 2
Groupings of NCRs.

NCR group	Projects (N)	NCR (N)	Mean	Std. deviation
Frequency				
Group 1 (> $100 K)	43	127	3	3
Group 2 ($20–$100 K)	84	589	7	141
Group 3 (< $20 K)	209	18,598	89	327
	Total	**19,314**		
Value ($)				
Group 1 (> $100 K)	42	40,726,161	969,671	1,718,441
Group 2 ($20–$100 K)	83	21,736,663	261,888	528,569
Group 3 (< $20 K)	206	34,510,867	167,528	453,472
	Total	**96,973,691**		

problematic issue, as evident from the results presented.

The descriptive statistics for the different groups of NCRs identified are presented in Table 2. Here NCRs are classified according to their level of cost: (1) 'Group 1' > $100 K; (2) 'Group 2' between $20 to $100 K; and (3) 'Group 3' < $20 K.

It can be seen in Table 2 that 'Group 3' NCRs were the most prevalent type that were experienced in the projects sampled (96%). However, the 'Group 3' NCRs only accounted for 36% ($34,510,867) of the total costs that were incurred. While the frequency of 'Group 1' and 'Group 2' NCRs were low, they accounted for 42% ($40,726,161) and 22% ($21,736,663) of total cost incurred, respectively.

The types of 'Group 1' NCRs varied significantly between projects, but commonalities were identified such as incorrect installation, not adhering to the required specification/Australian Standards, and incorrect detailing in the documentation. For example, in the case of a "Water Infrastructure Alliance Project' the non-return valves for the pipework to each Surge Tank were installed in reverse to their intended flow. In the case of a "Buildings and Utilities Project", underground fire cables from the laundries to the Medical Assessment Unit's (MAU) rooms were installed without the protection barriers as outlined in the specification. Similarly in a "Marine Structure Project" several size bolts on lighting brackets and cables trays were installed as Grade 304 when they should have been Grade 316, as specified in the technical specification. In a 'Tail End Extension', a flat return idler that had been built up with packers had been used in place of a 'vee return idler' in order to avert a clash with a beam.

3.2. Analysis of different groups of NCRs between project types

The descriptive statistics for the groups of NCRs that occurred for different project types are presented in Table 3. It can be seen that 'Infrastructure' had the highest mean number (M = 129) of NCRs per project followed by 'Building' (M = 41), and 'Rail' (M = 28). This is also the case for rework, scrap, use-as-is and undefined incidents.

The costs of NCRs occurring for each of the project types are presented in Table 4. It can be seen that 'Infrastructure' had the highest mean cost (M = $593,767) of NCRs followed by 'Building' (M = $441,327), and 'Rail' (M = $78,191). This pattern is again, observed for rework, scrap, use-as-is and undefined.

Table 5 provides the average cost of each NCR for each project type. Interestingly, 'Building' has the highest mean cost per NCR at $10,689 followed by 'Infrastructure' $4605, and 'Rail' $2751. A similar pattern is again observed for rework and use-as-is, though in the case of scrap 'Infrastructure' experienced higher costs than 'Building'.

3.3. Safety

Of the 569 construction projects that were examined, 461 were found to have reported safety incidents (Table 6). A total of 20,393 incidents were found to have occurred; 87% (n = 17,783) were attributable to injuries, 2% (n = 497) near misses, 8% (n = 1678) as rail safety, and 1% (n = 229) were unsafe act, and 1% (n = 206) unsafe conditions.

The descriptive statistics for the different categories of safety incidents are presented in Table 7. The levels of actual and potential severity were rated by the worker in each incident report at the time of occurrence. Here incidents are classified according to the following levels of severity: (1) Category 1A/P is the most severe and includes injuries that permanently alters the individual and can result in a disability or even lead to death; (2) Category 2A/P is medium severity where an individual is temporarily disabled or time lost; and (3) Category 3A/P, which is regarded as low severity includes minor cuts and sprains. As can be seen from Table 7, Category 1A comprised of only 0.2% (n = 42) and Category 2A 14% (n = 2855) incidents. The majority of incidents 86% (n = 17,496) were attributable to Category 3A. A similar pattern was found to occur for potential safety categories for the 33,227 incidents that were identified: (1) Category 1P 2.2% (n = 719 incidents); (2) Category 2P 18.4% (n = 6115 incidents); and (3) Category 3P at 79.4% (n = 26,393 incidents).

The Category 1A incidents occurred over 28 projects and varied in nature. For example, one worker inadvertently received a fatal shock *via* electrical induction on a 'Transmission Line Project'. On a 'Highway Project' a worker attempted to crimp/bend a 20 mm PVC tendon pipe, which dislodged at the base of a concrete segment, causing pressurized grout to discharge and strike the worker's face. On doing so, the grout

Table 3
Groups of NCRs by project type.

NCR types	Project types	Projects (N)	Min.	Max.	NCR (N)	M.	Std. deviation
Frequency							
Rework	Building	43	1	235	1335	31	50
	Infrastructure	123	1	1436	7045	57	153
	Rail	31	1	363	718	23	66
Scrap	Building	16	1	21	77	5	5
	Infrastructure	61	1	79	443	7	14
	Rail	10	1	5	20	2	1
Use-as-is	Building	32	1	84	413	13	22
	Infrastructure	110	1	2896	8481	77	291
	Rail	24	1	125	335	14	27
Undefined	Building	7	2	16	33	5	5
	Infrastructure	33	1	114	407	12	26
	Rail	2	1	7	8	4	4
Total	Building	45	1	319	1858	41	68
	Infrastructure	127	1	4525	16,376	129	424
	Rail	38	1	406	1080	28	71

Table 4
Costs for groups of NCR by project type.

NCR group	Project types	Projects (N)	Min ($)	Max ($)	NCR ($)	M ($)	Std. deviation
Costs							
Rework	Building	43	3000	10,079,000	18,283,991	425,209	154,304
	Infrastructure	123	100	8,541,928	61,259,215	498,042	1,156,837
	Rail	29	0.01	950,015	2,254,044	77,726	178,985
Scrap	Building	16	1	215,533	823,628	51,477	71,184
	Infrastructure	60	200	1,939,610	5,789,466	96,491	273,756
	Rail	9	182	72,965	127,373	14,153	24,080
Use-as-is	Building	31	1	226,075	612,522	19,759	45,098
	Infrastructure	96	0.01	1,783,402	6,478,848	67,488	202,726
	Rail	22	1	179,102	511,658	23,257	43,298
Undefined	Building	5	1500	70,174	139,576	27,915	27,420
	Infrastructure	15	600	296,116	693,370	46,225	81,975
	Rail	–	–	–	–	–	–
Total	Building	45	600	10,088,450	19,859,717	441,327	1,520,872
	Infrastructure	125	100	12,561,057	74,220,900	593,767	1,442,419
	Rail	37	0.01	1,056,030	2,893,074	78,191	179,615

Table 5
Mean cost of NCRs for project types.

Project type	Mean cost of an NCR ($)	Mean cost of an NCR ($)			
		Rework	Scrap	Use-as-is	Un-defined
Building	10,689	13,696	10,696	1531	5921
Infrastructure	4605	8695	13,287	875	3748
Rail	2751	3356	7076	1666	0.00
Total	5021	8992	12,482	824	1859

Table 6
Statistics for different categories of incidents.

Incident categories	Number of projects (N)	Incidents (N)	Mean (M)	Std. deviation
Injury	456	17,783	39	122
Near misses	176	497	3	3
Rail safety	92	1678	18	101
Unsafe act	56	229	4	12
Unsafe condition	88	206	2	2

Table 7
Statistics for different categories of incidents.

Category	Projects (N)	Incidents (N)	M.	Std. deviation
Actual				
1A	28	42	2	1
2A	320	2855	9	24
3A	444	17,496	39	122
	Total	**20,393**		
Potential				
1P	208	719	3	5
2P	408	6115	15	39
3P	476	26,393	55	195
	Total	**33,227**		

dislodged the worker's safety glasses and entered their left eye. In a 'Hospital Project' a connection between a polyethylene pipe and flexible hose connection behind a temporary water bubbler failed, which caused extensive water damage/flooding. There were no injuries recorded nor were people at risk, but this was classified as a Category 1A due to the replacement costs that were incurred.

A similar situation occurred on a 'Highway Project', when during the excavation process it was identified by a superintendent that an excavator operator and spotter had incorrectly excavated the top of a batter and fell short of the correct location by approximately 1.2–1.5 m. Poor ground conditions, however, restricted haulage truck access, so it was decided to continue to excavate in the opposite direction and rectify the batters when the haulage route could be improved. A procedure had been put in place to enable the team to excavate within the 3 m exclusion zone of a Uecomm (i.e. a SingTel Optus Group company) cable, which ran through the excavation area (east-west) and was completed without incident. However, when the rectification works for the batter commenced the excavator struck and damaged the Uecomm cable. Uecomm knew immediately of the damage through their monitoring systems. In this case a Category 1A was raised due to the damage cost, but notably this event occurred while rework was being undertaken.

While a significant number of incidents were categorized as Category 3A they had the potential to be life threatening and as a result were also identified as being a Category 1P when rework was required. For example, in a 'Prison Project' two of the contractor's employees were installing a lockable control cabinet that housed an operable door control box and isolator. The box had been incorrectly installed and needed to be rotated 180 degrees. While one of the employees was holding the control box, the other was aligning dyna-bolts that needed to be installed; they both encountered a minor electric shock. It was later identified that one of the dyna-bolts had been charged with electricity from a cable that was in a concrete masonry.

3.4. Analysis of different categories of incidents between project types

The categories of incidents occurring within different project types were examined and are presented in Table 8. It can be seen that 'Infrastructure' had the highest mean number (M = 47) of incidents, followed by 'Building' (M = 43), and finally 'Rail' (M = 38). Noteworthy, the mean number of people injured was the greatest within the 'Infrastructure' projects (M = 44, SD = 149). A specific 'Highway Project' significantly contributed to the increased mean number of people that had been injured (n = 2138). This particular project had experienced more than five times greater injuries than the worst performing building project, which was a 'Hospital Project'.

The 'Highway Project' mentioned above had the greatest incidence of rework (n = 1436) and NCRs (n = 4525); the costs of the NCRs that were incurred was $12,561,056. When the injury statistics for the 'Highway Project' were removed from the analysis, the standard deviation for the 'Infrastructure' projects significantly decreased (M = 38, SD = 78). Consequently, 'Building' possessed the highest mean injury per project (M = 43).

In Table 9 the mean number of safety incidents per million hours

Table 8
Statistics for different categories of incidents by project type.

Incident category	Project type	Projects (N)	Incidents (N)	M.	Std. deviation
Injury	Building	76	2955	42	62
	Infrastructure	343	12,006	44	149
	Rail	137	2250	22	55
	Unknown	5	194	65	68
Near misses	Building	76	57	2	1
	Infrastructure	343	314	3	4
	Rail	137	113	3	4
	Unknown	5	5	3	1
Rail safety	Building	76	1	1	
	Infrastructure	343	80	4	4
	Rail	137	1597	23	117
	Unknown	5			
Unsafe Act	Building	76	25	2	1
	Infrastructure	343	183	6	16
	Rail	137	10	1	1
	Unknown	5	9	9	
Unsafe Condition	Building	76	22	1	1
	Infrastructure	343	119	2	2
	Rail	137	53	3	3
	Unknown	5	11	11	
Total	Building	76	3060	43	63
	Infrastructure	343	12,702	47	156
	Rail	137	4023	38	127
	Unknown	5	219	73	80

Table 10
Safety injury frequency rates.

Injury frequency rates	N	Min	Max	Mean	Std. deviation
TRIFR	389	0.7	1295	50	113
LTIFR	185	0.3	809	17	66
AWIFR	260	0.3	1295	26	90
MTIFR	322	0.3	580	30	60
FAIFR	400	1.4	1078	75	109
LTI Mean Days Lost Rate	143	0.3	186	16	24
LTI Severity Rate	156	0.0	1538	123	255

Table 11
Mean injury frequency rates for each project type.

Injury frequency rates	Building	Infrastructure	Rail
TRIFR	88	77	50
LTIFR	5	11	43
AWIFR	12	24	54
MTIFR	15	26	102
FAIFR	79	67	11
LTI Mean Days Lost Rate	15	17	179
LTI Severity Rate	47	121	115

(pmh) for each of the project types is presented. 'Rail' had the highest occurrences at 129 pmh, followed by 'Infrastructure' at 74, and 'Building' at 65. In terms of the mean injury, the highest is 'Rail' at 72 pmh, followed by 'Infrastructure' at 70, and 'Building' at 63. 'Infrastructure' projects were therefore expected to have higher number of safety incidents (including injury), but a lower incidents/injury rate pmh when compared to 'Building'.

Table 10 provides the statistics for the Total Recordable Injury Frequency Rate (TRIFR), Lost-Time Injury Frequency Rates (LTIFR), Alternate Work Injury Frequency Rate (AWIFR), Medical Treatment Injury Frequency Rate (MTIFR), First Aid Injury Frequency Rate (FAIFR), and Loss Time Injury (LTI) mean days lost rate and LTI severity rates at the project level. Table 11 provides a breakdown of the mean value of the injury frequency rates per project type.

The mean LTIFR per project for the period of the study was 5 for building, 11 for infrastructure and 43 for rail. Worksafe from the Government of Western Australia, for example, have made available the industry standard for LTIFR from 2009 to 2012 to be: 6.6 for building construction, and 25.62 for heavy and civil engineering construction. The LTIFR for building and infrastructure in this study were close to the WA average LTIFR, but is twice as high for rail projects. SafeWork Australia, for example, has also published national standards for frequency rates for serious claims, which involves all injuries and diseases experienced resulting in a person being off work for longer than a week. The industry standard in Australia for serious claims from 2009 to 2014 ranges from 4.5 to 6.5 for building construction, and 11.4–14.4 for heavy and civil engineering construction.

3.5. Association between quality and safety performance

Rework generally arises as people make errors, which can take an array of guises. Thus, predicting the likely occurrence of rework and safety is an impossible task, as its causal nature often involves a collection of interdependent events. It was observed from the dataset that several safety incidents had occurred while workers were carrying out repair work or attending to rework, such as fixing a dam wall, and jack hammering concrete pile caps. A rope technician, for example, performed painting repairs to the underside of a marine berth. The belaying positioning rope attached to the harness became detached, which resulted in the worker swinging uncontrollably in a pendulum motion. The worker used their foot to stop themselves from colliding with a pile and sustained injury to their foot. A support technician retrieved the worker and sought medical attention. It was later confirmed that the belaying positioning rope had been mistakenly attached to the gear loop of the harness instead of its approved side attachment point.

In the case of the enlargement of a 'Reservoir Project', for example, a Category 1P safety incident arose due to incorrect work during the formation and installation of a placement toe wall, which was being constructed using the Roller Compacted Concrete (RCC) process. The system of work for the formation and installation of the placement toe wall involved the fitting of a pre-fabricated reinforcement cage on a concrete edge (toe), which would then have been formed with shutters. The reinforcement cage had been designed to be 'tied' to the existing concrete surface using 20 mm dowel (reinforcement bars) into the face of the existing RCC. It had been agreed during the installation process that handrails at the front edge would be removed to allow ease of

Table 9
Mean number of safety incidents per million person-hours (phr) based on project types.

Project type	N	Total person-hours	Mean hours per project	Injury		Near misses		Rai safety		Unsafe Act		Unsafe condition		Total	
				Total	M (phr)	Total	M (phr)	Total	M (phr)	Total	M (phr)	Total	M (phr)	N	M (phr)
Building	76	47,131,488	620,151	2955	63	57	1	1	0	25	1	22	0	**3060**	**65**
Infrastructure	343	172,041,318	501,578	12,006	70	314	2	80	0	183	1	119	1	**12,702**	**74**
Rail	137	31,140,685	227,304	2250	72	113	4	1597	51	10	0	53	2	**4023**	**129**
Unknown	5	4,676,747	935,349	194	41	5	1		–	9	2	11	2	**219**	**47**
Total	**561**	**254,990,238**	**454,528**	**17,405**	**68**	**489**	**2**	**1678**	**7**	**227**	**1**	**205**	**1**	**20,004**	**78**

placement of the cage. When the handrails were to be removed safety harnesses needed to be worn by workers, as they would be working at a height. When the reinforcement cage was positioned, it was agreed the handrails would be re-installed. Then, the worker would be required to climb on to the reinforcement cage, reach inside and install the dowels.

The first reinforcement cage was installed, but a delay of thirty minutes had been experienced, which hindered the installation of the next one. The normal system of re-establishing the handrails was interrupted, and while a worker was waiting they commenced installing the dowels to the reinforcement cage that had been installed. The worker realized that three pre-drilled holes were in the wrong position and the dowel bars were unable to be installed. A decision was made not to alter the configuration of the reinforcement cage as it had been pre-certified prior to being put into position, and would need to be re-certified. The worker was instructed to drill another layer of three holes. The worker climbed on to the reinforcement cage without the additional elevated handrails being installed and without a safety line and harness; the worker was simply not aware that they were working near an unprotected edge. The worker could have potentially fallen and been seriously injured or even killed.

To establish a statistical link between quality and safety, Spearman correlation coefficients were computed using data from the sample of 569 projects (Table 12). Due to the sensitivity of Pearson correlation to the presence of outliers and requirements of bivariate normality (Kowalski, 1972), Spearman correlation is used to examine monotonic trends (Hauke and Kossowski, 2011), which does not require the assumptions of normality for the dataset. In this case, Spearman's correlation provides a more robust test to determine the association between variables.

Safety indicators comprised of number of injuries, near misses and other safety incidents, which included unsafe acts, unsafe conditions and rail safety. Quality indicators consisted of number of NCRs, which were rework, use-as-is and scrap. The Spearman's rho were computed and the results presented in Table 12. The results show that the association between injuries and NCRs are strong and significantly correlated at the 0.01 level.

The *p*-values of Spearman's rho correlation demonstrate that there is a statistically significant correlation between injuries and NCRs at the 0.01 level. The Spearman's rho ρ values (between 0.612 and 0.563) and demonstrate a very strong correlation. For near misses and NCRs, the Spearman's rho ρ values (between 0.204 and 0.075) are lower, though significant at 0.05 level. The results indicate that injuries and other incidents are highly correlated with NCR frequencies, as compared to near misses. Though, it should be pointed out that there is a proclivity for people not to report 'near misses'. The association between injuries and rework is significantly strong ($\rho = 0.631$ or 63%); this indicates that 63% of the variance in injuries can be attributable to changes due to rework.

Table 12
Association between quality and safety indicators.

Safety	Quality	Spearman's rho, ρ	p-value
Injuries	NCR (N = 199)	0.612**	.000
	Rework (N = 189)	0.631**	.000
	Scrap (N = 84)	0.444**	.000
	Use-as-is (N = 160)	0.563**	.000
Other Safety Incidents	NCR (N = 201)	0.596**	.000
	Rework (N = 190)	0.618**	.000
	Scrap (N = 85)	0.440**	.000
	Use-as-is (N = 161)	0.560**	.000
Near Misses	NCR (N = 98)	0.204*	.043
	Rework (N = 95)	0.276**	.007
	Scrap (N = 44)	0.183	.235
	Use-as-is (N = 79)	0.075	.510

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Table 13
Association between injury and quality indicators by project type.

Project type	Safety indicator	Quality indicator	Spearman's rho, ρ	p-value
Building	Injury	NCR	0.430**	.004
Infrastructure	Injury	NCR	0.689**	.000
Rail	Injury	NCR	0.647**	.000
Building	Injury	Rework	0.463**	.002
Infrastructure	Injury	Rework	0.679**	.000
Rail	Injury	Rework	0.672**	.000

** Correlation is significant at the 0.01 level (2-tailed).

The associations between injuries and NCRs are examined by 'Project Type' and presented in Table 13. The association between injuries and NCRs are significant, $p < .05$ based on both tests across 'Project Type'. Based on Spearman's ρ-values, 'Infrastructure' projects revealed the strongest association between injuries and NCRs, followed by 'Rail' and 'Building' projects.

The number of injuries and NCRs were aggregated and organized in a monthly format (over a period of 106 months) and categorized by 'Project Type'. Correlation were again used to test the relationship between injuries and NCRs and the results are presented in Table 14. Spearman rho values demonstrate that there is a significantly strong positive association between injuries and NCRs for 'Infrastructure' and 'Building' at 0.01 level.

Figs. 1–6 present scatterplots of injury and NCR/rework frequency for each project type. In Fig. 1 it can be observed that 'Building' possess the highest rho value (0.642). Thus, in this instance there is a 64% likelihood an injury will occur when an NCR is being attended to in 'Building' projects. Similarly, in Fig. 5 it is revealed that rework is the major NCR event that is contributing injuries within the 'Infrastructure' projects. This positive relationship may be explained due to additional 'unplanned work' caused by having to undertake rework.

The evaluation of safety in construction is often based on the frequency of incident rates, calculated using the number of incidents per million personnel-hours. This may lead to misleading results, as a linear relationship between injury frequency and exposure in personnel-hours and a normal distribution are assumed. Research undertaken in traffic safety studies, for example, acknowledge this issue and revealed that this relationship is non-linear and exponential (e.g., Lord, 2006). Injuries are shown here to have a positive association with quality indicators, such as NCRs and rework, across project types at both the project and aggregated levels.

The analysis has established a positive association between rework and safety. Though, the Spearman's rho is sufficiently robust in ascertaining the monotonic trend, but is not able to provide a quantitative measure regarding the strength of the association between NCRs and injuries. Despite unearthing this association, it should be made explicit that this does not indicate causation, but instead implies that poor quality performance is associated with higher levels of injuries. Having established an association between quality and safety, the implications of the research findings are discussed particularly the underlying

Table 14
Association between injury and quality indicators by project type based on aggregated monthly data over 106 months.

Project type	Safety indicator	Quality indicator	Spearman's rho, ρ	p-value
Building	Injury	NCR	0.642**	.000
Infrastructure	Injury	NCR	0.579**	.000
Rail	Injury	NCR	0.445**	.000
Building	Injury	Rework	0.585**	.000
Infrastructure	Injury	Rework	0.616**	.000
Rail	Injury	Rework	0.342**	.000

** Correlation is significant at the 0.01 level (2-tailed).

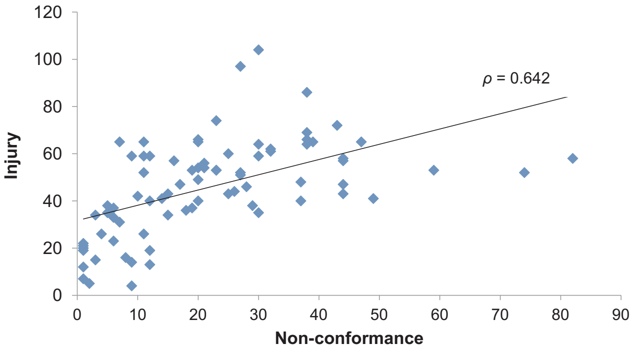

Fig. 1. Building: Injury and NCR frequency.

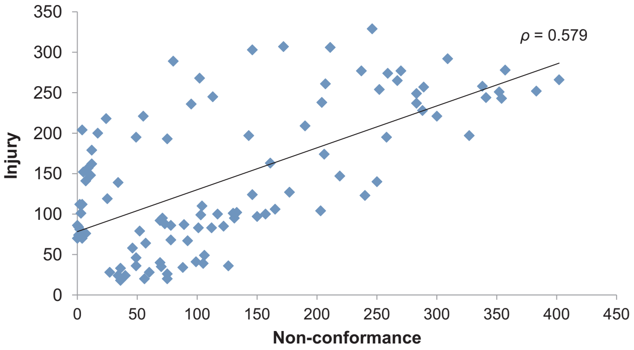

Fig. 2. Infrastructure: Injury and NCR frequency.

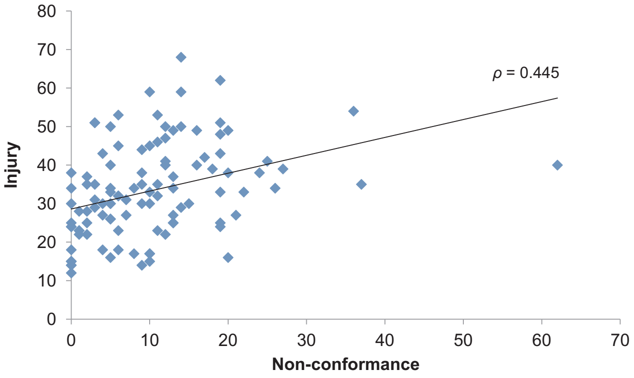

Fig. 3. Rail: Injury and NCR frequency.

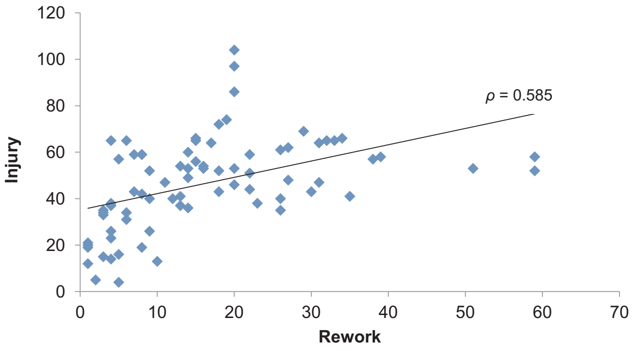

Fig. 4. Building: Injury and rework frequency.

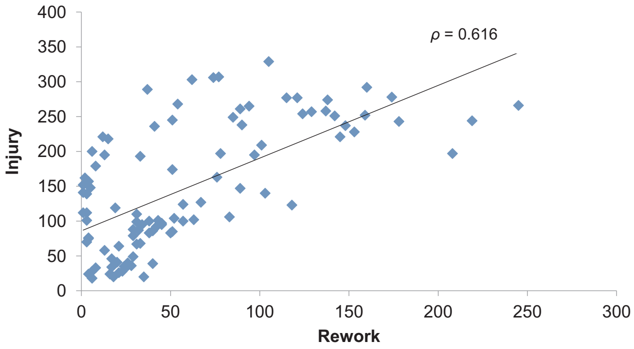

Fig. 5. Infrastructure: Injury and rework frequency.

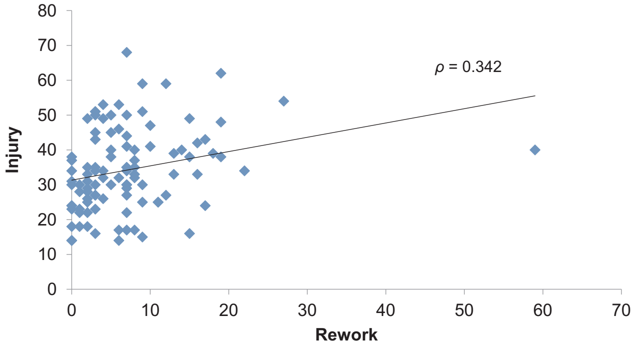

Fig. 6. Rail: Injury and rework frequency.

factors that are common to both constructs.

4. Discussion and implications

There have been significant reductions in the numbers and rates of injuries and fatalities in the Australian construction industry over the last ten years (WorkSafe Australia, 2015); however safety risks remain high. Notably, the mean injury frequency rates of the construction organization that were presented were comparable with the national average. While the findings are not generalizable they do provide a reference point for benchmarking to take place, which may spur process improvement initiatives to be adopted. Explicitly, NCRs, such as rework, are risks that adversely impact safety and therefore they need to be reduced and contained within projects. While injuries and fatalities have been clearly declining in Australia, these rates can be reduced at a greater rate if NCRs are minimized.

Typically within construction, the raising and issuing of NCRs is considered to be a problematic issue; by doing so a contractor admits that they did not do what they should have done and that they have to rectify it or even change the way they do things on site. This came to the fore during several informal conversations with personnel from the case study organization and therefore raising of NCRs were generally frowned up by senior management. If contractors can prevent NCRs being issued then they invariably will do so, as they do not like to recognize that they did not perform and manage tasks or processes in accordance with what was contractually required. Moreover Love and Smith (2016) have suggested that a 'blame culture' often resides when NCRs arise, specifically when rework is required, as it has often has financial implications. More often than not, however, organizations involved with the event try to deflect the responsibility for the additional costs that may be borne on to others.

4.1. Human error

As an NCR is an 'unplanned' activity and are unanticipated. Bearing in mind the examples presented in this paper, which have provided a context for the statistical analysis, an undeniable feature that contributed to both NCRs and safety incidents was human error; the fragility of human beings inexorably ensures that errors will occur. In acknowledgment of this, Love and Teo (2017) have suggested that there is therefore a need to 'anticipate what might go wrong' and accommodate the likelihood of errors occurring when undertaking a risk analysis prior to the commencement of construction. Yet, rework emanating from errors that are committed, for example, is often ignored and seldom, if at all, are its causes determined and costs measured (Love and Li, 2000; Moore, 2012). With tighter profit margins and reduced workload, some contractors have begun to realize that there is an urgent need to find ways to curtail their rework, if they are to remain profitable. By attending to rework, some contractors have obtained additional benefits as they have observed that their safety has also improved, though anecdotally (Love et al., 2016b).

Putting in place mechanisms to reduce and contain errors (e.g., coaching, error management, and lessons learned forums) rather than simply preventing them, has been identified by Love et al. (2016a) as key strategy to simultaneously improve quality and safety in projects. At this juncture, it is necessary to identify types of error that have been found to both contribute to rework and safety incidents (Love et al., 2016a,b); (1) *action errors* (i.e., goal orientated behavior that is consciously regulated or via routines), which are unintentional deviations from goals, rules and standards (Frese and Keith, 2015). Such errors comprise of mistakes (a wrong intention is formed) and slips and lapses (failure of execution) (Reason, 1990); (2) *judgment and decision-making*, which arise due to cognitive biases and heuristics (Weber and Johnson, 2009); and (3) *violations*, which are a conscious intention to break rules or not conform to a standard (Hofmann and Frese, 2011).

4.2. Production pressure

It was outside the scope of the research to determine the types of errors that were incurred, but it was observed from the quality and safety reports that violations were common occurrences. When rework was required, for example, it was noted that people tended to take 'short-cuts'; this has also been previously observed by Love et al. (2016a). An incident may arise during rework as the original workface may have significant changed and there may no longer be equipment in place that supports a safe work environment; for example, scaffolding may have been dismantled after an NCR had been identified. Rather than waiting for the scaffold to be re-erected, a worker may simply try to use a ladder to minimize their delay and/or to reduce their costs of having to repeat their work.

An example of where violations in quality and safety have come to fore, and resulted in a major accident being experienced has been reported at the Muskrat Falls hydroelectric project in Labrador, Canada (McCabe, 2016). Seven workers had to receive first aid treatment on-site when formwork collapsed during a concrete pour. The project has been plagued with a series of quality and safety problems and as a result of this accident, the leader of the New Democratic Party (NDP), stated "there should be a review of all contractors at Muskrat Falls and all of the employees overseeing work there to make sure they are doing what they should be doing, particularly when it comes to safety" (McCabe, 2016). The NDP leader further stated "There's a push, push, push for production and a lack of a kind of safety-first basis for doing things. And people have said they feel it's only a matter of time before someone is killed down there, which is a pretty serious statement. Too many shortcuts". The project has been significantly delayed and is significantly over budget; it was originally forecasted to cost $5 billion in 2010 and in 2014 $7.6 billion, and will no doubt further increase.

According to Frese and Keith (2015) violations tend to occur when low priority goals are sacrificed in favor of those of a high-priority (i.e. goal conflicts); for example, Guo et al. (2016) observed that in one case labor on-site ignored warnings to enter an area where heavy plant was operating as they had not completed a specific task, which resulted in a serious injury occurring. Conventional wisdom holds that having a mass of rules in place often renders work impractical, so there is a tendency for people to ignore them to ensure they can complete their allotted tasks (Lawton, 1998; Beus et al., 2010; Hale and Borys, 2013). As construction organizations become overregulated, 'violation management' then becomes an issue; its aim is to avoid or reduce the negative consequences people's actions, which is akin to 'error management' (Frese and Keith, 2015).

4.3. Organizational errors

While on face value individual errors may have been perceived to have contributed to rework events and incidents, there is a possibility that 'organizational errors' may have also been at play. Organizational errors refer to actions of multiple participants that deviate from specified rules and procedures, which may result in adverse outcomes (Goodman et al., 2011). For example, on many occasions it was reported that items had been installed incorrectly across a wide range of projects and sometimes repeatedly on the same project. In this instance the 'supervisors' may have omitted to carry out an inspection or check an item prior to its installation. This situation could have arisen due to a lack of resourcing, which more often than not, materializes as a by-product of competition and operating in an environment where low profit margins are the 'norm rather than the exception'. In fact, requests from site personnel for additional resources were identified on several large infrastructure; whether such requests went unheeded or not, were not made available to the researchers.

To explain organizational errors, the processes that cause multiple individuals to engage in a common pattern of behaviors/deviations need to be examined in detail, in particular what causes their amplification within an organization. Contrastingly, individual errors involve actions (deviations) that differ from those of others within the organization. So, to explain individual errors, the factors that are idiosyncratic to them need to be considered.

Dekker's (2006) view of 'human error' is drawn upon to provide a stimulus for improving both quality and safety. Hence, it is proffered that construction organizations should not view errors as a cause of failure, but as an opportunity to learn and perhaps modify their work practices. Errors are an effect or symptom of the project environment within which people work. They are not random acts, but are systematically connected to aspects of people's tools, tasks and their milieu (Dekker, 2006). Essentially, people ensure quality and create safety while having to negotiate with multiple system goals; for example, the economic pressures that a contractor's on-site staff have to deal with include schedules, selection of plant and equipment, determining the method and sequencing of construction, selection of subcontractors and suppliers. Thus, the trade-offs that have to be made with quality and safety and other goals are chosen under conditions of uncertainty and ambiguity.

Errors that contribute to quality and safety issues can be viewed as an organizational problem; they invariably arise as a result of the way that people work. According to Dekker (2006) it is necessary to understand the organizational context within which people work if errors are to be reduced. In particular, Dekker (2006) points to three key issues that can explain an organization's work setting and how errors may occur (p.159):

1. *Procedural drift:* Arises when there is a mismatch between procedures and practice. Over time this mismatch can increase, which increases the gap between how the system was designed and how it actually works (Dekker, 2006; p.161). For example, rules can be overly designed and rigid rendering it difficult for people to attend. To accommodate multiple goals, people may depart from routines to make work more efficient, which may subsequently become routine.
2. *Production pressure:* Having multiple goals also results in conflicts for

contractors and their subcontractors. A typical example is the trade-off between quality/safety and schedule. Within construction, safety is almost always identified as the overriding goal of organizations. In reality, however, this is not their only goal, otherwise there would be no reason for the organization to exist (Dekker, 2006; p.161). So, goal trade-offs may need to be engendered by the nature of the work to be undertaken in projects, and the sort of safety required and associated risks that will be encountered (i.e. threats); and those of the organization (e.g., the importance of project and the establishment of working relationships).

3. *Safety culture:* Management commitment and their active involvement in their projects, employee empowerment, incentive structures and report systems are common ingredients of a healthy and vibrant 'safety culture'; without these elements in place the propensity for people to commit errors will significantly increase. It is imperative that management are receptive to hearing about problems that could potentially materialize as well as those that have occurred so that effective mitigation strategies can be initiated to minimize the negative consequences of an event.

An atmosphere of openness, willingness and commitment to learn is required to improve quality and safety (Love et al., 2016a). To improve business performance, organizations should unequivocally acknowledge that rework, for example, is a recurrent problem that needs to be addressed (Love et al., 2016b). The process of learning commences by challenging the basic underlying assumptions, beliefs and values of an organization's culture and then by identifying and acknowledging the sources of vulnerability that exists within its daily operations and the processes used to deliver its projects.

5. Conclusion

The statistical analysis presented in this paper has provided empirical evidence to unearth the interplay that exists between quality and safety. The nature of NCRs and safety incidents experienced in 569 construction projects delivered by a contractor over an eight year period was discussed and analyzed. To provide a context to the statistical analysis, examples of NCRs and safety incidents that arose were also presented. Primarily, it was revealed that a positive association existed between NCRs and safety incidents, but more specifically rework was identified as having the strongest association ($p < .01$).

The safety statistics of the construction organization involved in this research mirrored the national average. However, there are no national statistics regarding quality measures, specifically NCRs. The analysis provides essential information for organizations to benchmark themselves, which can provide the impetus for reflection and a basis to commence initiatives to simultaneously address quality and safety issues, particularly rework reduction and containment. While the findings presented in this paper may not be generalizable, they do serve to demonstrate that quality and safety issues need to be considered in unison.

Human error is the primary contributor of quality and safety issues, but the environment within which people work provides the conditions for them to occur. People make mistakes, but organizations make it possible for them to be really serious. Data gleaned from quality and safety reports identified that violations were a prominent feature, though the classification and determination or error types was outside the scope of the research. Reasons for this are abound, but a mismatch between procedures and practice, and a series of organizational errors may provide an explanation as to why they occurred. It is suggested, therefore, that future research should focus on trying to explain why, how and where errors emerge and their causation. There is a paucity of understanding within the construction about the nature of error and the impact it has on operations. The research presented in this paper provides the foundation to further examine how errors influence on rework and safety incidents, particularly those that are organizational in nature.

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