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The symbiotic nature of safety and quality in construction: Incidents and rework non-conformances

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ABSTRACT

Safety and quality performance share a symbiotic relationship. Despite the extensive amount of research that has provided quantitative assessments of the financial impact of rework, there have been limited studies that have examined the relationship between safety performance (i.e. in terms of the number of incidents arising) and rework that occurs from the issue of non-conformances (NCRs). Using an exploratory case study approach, the statistical characteristics of incidents ($n = 16{,}885$) and NCRs ($n = 2885$) requiring rework experienced by a tier one Australian contractor over a 31 month period are analyzed and their relationship determined. A significant association between incidents and rework NCRs was revealed ($p < 0.05$). The skewness and kurtosis values of monthly incidents and NCRs are computed to determine if the empirical distribution of the data follows a Normal distribution. The Kolmogorov–Smirnov, Anderson–Darling and Chi-Squared non-parametric tests are used to determine the 'Goodness of Fit' of the selected probability distributions. An Inverse Gaussian probability function is found to be the best overall distribution fit for the monthly incidents and used to calculate the probability of their occurrence. A Lognormal probability function was found to be the best overall distribution fit for the NCRs and also used to calculate their likelihood of occurring. Ascertaining the best fit probability distribution from an empirical distribution can produce realistic probabilities of incidents and NCRs, which should then be incorporated into a contractor's risk management and continuous improvement strategy.

1. Introduction

A symbiotic relationship exists between safety and quality performance (Das et al., 2008; Pagell et al., 2014). They are interdependent 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.

In construction, an examination of this symbiotic relationship has been limited (e.g., Hatush and Skitmore, 1997; Hoonakker et al., 2010; Wanberg et al., 2013), despite the extensive amount of research that has provided quantitative assessments of the financial impact of rework on project performance (e.g., Burati et al., 1992; Barber et al., 2000; Love, 2002; Love and Edwards, 2004). Loushine et al. (2006) have specifically noted that there have been limited empirical studies that have examined the impact of rework on safety performance. Taking into account this paucity of empirical assessment of the relationship between quality and safety outcomes, Wanberg et al. (2013) demonstrated a significant correlation exists between recordable injury rate and rework and the number of defects. Despite this single case providing an indication of the relationship between rework and incidents, the lack of empirical research to date may be attributable to having limited access to data due to its commercial sensitivity or as noted by Behm et al. (2007) it not being documented at an organisational level

Against this contextual backdrop, the aim of the research presented is to examine the symbiotic relationship between safety and quality performance within a tier one contractor in Australia and determine their probability of occurrence. By understanding this relationship and probability of quality impacting safety and vice versa, contractors can better prepare themselves for possible

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'unplanned' work. Uniquely, the contractor provided access to their database encompassing projects nationwide over a 31-month period giving an unprecedented opportunity to examine the relationship between safety and quality performance. For the purposes of this paper, safety performance is defined in terms of the number of incidents arising and quality is measured as rework that occurs from the issue of non-conformances (NCRs). An incident is an unplanned event that can cause injury, illness, environmental damage, or property loss. ISO 9001 defines non-conformance (NCR) as a non-fulfilment of or deviation from the agreed specifications or requirements, and requires to be addressed by a corrective action.

A common probability distribution used by risk analysts who rely on Monte Carlo, for example, is the Normal (or Gaussian) Distribution (Hubbard, 2009). Such a distribution is used as it appears to 'fit' observed phenomenon from an array of data often found in manufacturing and actuarial science. Moreover, its use is also assumed to apply to *Options Theory* (e.g., Black and Scholes, 1973; Merton, 1973) and *Modern Portfolio Theory* (Markowitz, 1952, 2005). Yet Hubbard (2009) has argued that the use of Normal Distribution does not necessarily reflect what actually arises in reality. As the Normal Distribution is symmetrical and not skewed, the mean is in the middle. Thus, the standard deviation represents a unit of uncertainty around the mean (Hubbard, 2009). Yet not all datasets are Normally Distributed and bell-shaped and therefore it is important for risk analysts to determine the tails of distributions and identify the best fitting distribution to determine appropriate probabilities of occurrence. Thus, the statistical characteristics and the relationship between incidents and NCRs for the sample provided are examined. Then to determine the likelihood of incidents and NCRs arising in the future for the contractor, the empirical distribution of the data is computed and the 'best fit' probability density function (PDF) is assessed so that correct probabilities of occurrence for incidents and NCRs per month can be determined. The case study presented offers a learning opportunity for other contractors to examine their incidents and NCRs and develop lead indicators so as to improve their performance and productivity. In addition, the aggregated cross-sectional data presented in the paper can be used as a platform benchmarking their safety and quality.

2. Safety and quality

To understand the interplay between safety and quality in the construction industry, it is necessary to examine these constructs. The American Society of Safety Engineers (ASSE) defines safety as the "state for which the risks associated with the work area are acceptable and tolerable in the setting being considered" (Manuele, 2008: p. 30). While quality is defined as the sum of attributes for a product or service that enables it to meet the requirements or specified need of the customer (Harris and McCaffer, 2013). Safety is typically the more easily understood concept, as most people are able to grasp the concept of 'worker well-being' and statistics associated with injuries and/or worker illness are readily recordable (Sing et al., 2014). In the case of quality, however, there is a lack of consensus about definitions and measurement indicators, especially within the construction industry. The Construction Users Roundtable (2005) has identified rework as the typical indicator of construction quality, as it measures the activities required to repair defective products and satisfy customer requirements. Love (2002) also identified various forms that may require rework such as quality deviations and failures, nonconformance, and defects. This followed the earlier work of Love and Li (2000) that the identified primary causes of rework, or quality failures, were changes initiated by the client or end user and errors and omissions in documentation. Notably, several studies have consistently found rework or quality failures arise from design and engineering stages of a project (Burati et al., 1992; Love and Li, 2000; Barber et al., 2000).

Frequently the areas of safety and quality overlap, especially as clients often specify safety related elements in their requirements to contractors. Thus, if contractors are to meet requirements so as to provide a quality product or service, they must also fullfil the safety requirements for a given project. The shift in client, engineer, and contractor attention toward safety is due to the fact that protecting the health and safety of workers is one of the most fundamental elements of the social component of sustainable production (Pagell et al., 2014).

Behm (2005) established a link between fatalities and poor design. In light of the push toward safety and the established link between the need for effective design and safety, engineers have developed the skills to design production and distribution systems that protect workers against injuries (Gambatese et al., 2005, 2008; Manuele, 2008; Schulte et al., 2008; Pagell et al., 2014). Akin to quality and rework, safety originates in the design stage and has the potential to be mitigated across various stages in a project.

Even though engineers are capable of designing systems that protect workers, safety incidents and unsafe behaviors still regularly occur on construction sites. As noted by Pagell et al. (2014), to accommodate why such incidents occur, researchers have hypothesized that when workers are faced with decreased slack in their schedules or task overload, they are then forced to take shortcuts (otherwise known as procedural violations or omission errors) and thus place themselves at risk of injury (McLain, 1995; Barling et al., 2002; Goh et al., 2012). The shortcuts taken by overloaded workers can also harm quality outcomes (Das et al., 2008). Contrastingly, Hasle et al. (2012) reveal that quality practices that reduce the slack in a workers schedule, such as lean construction, have been linked to increased injuries and illness (Hasle et al., 2012). Such findings are contradictory to those reported in Hoonakker et al. (2010) who found that contractors identified safety as being a potential benefit to quality management systems.

To better understand and address the link between safety and quality, Wanberg et al. (2013) undertook to empirically examine their relationship. Wanberg et al. (2013) examined data from 32 construction projects of varying size, scope, and location within the United States. On the basis of the empirical and opinion-based data analysis, they identified a correlation between safety and quality performance. Their empirical data suggests that the Occupational Health and Safety (OSHA) recordable injury rate is positively correlated to rework and the first-aid rate is positively correlated to the number of defects on a project. Thus, Wanberg et al. (2013) fundamentally conclude that a project with poor quality performance has a higher likelihood of injuries. However, this is a single study conducted in the United States and further empirical studies will help shed further light on the relationship between safety and quality. Thus, further research is required to ascertain the strength of this relationship, particularly the determination of their likely occurrence.

3. Research approach

Exploratory research is undertaken to examine a problem that has not been clearly defined and invariably relies upon secondary data (Shields and Rangarjan, 2013). 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 of incidents that arose during construction and NCRs that resulted in rework for a tier one contractor with an annual turnover in excess of AU$1 billion per