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Case Study

Quality and Safety in Construction: Creating a No-Harm Environment

Peter E. D. Love, Ph.D., D.Sc.[1]; Pauline Teo, Ph.D.[2]; John Morrison[3]; and Mathew Grove[4]

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Abstract: There have been limited studies that have examined the relationship between quality and safety performance. In addressing this issue, this paper examines a project-lifecycle safety, quality, and environment (SQE) strategy, which was supported by a behavioral and accountability initiative, and its effect on reducing the number of safety incidents in an AU$375 million program alliance that delivered 129 water infrastructure projects over a 5-year period. While the SQE program proved to be effective, the alliance also recognized that rework had become an issue and thus developed a rework prevention program as part of their continuous improvement process. Thus, this paper describes the nature of these programs and provides statistical analysis to demonstrate their combined effectiveness in reducing safety incidents. It is suggested that the alliance's approach and experiences in simultaneously addressing quality and safety provide learning opportunities for those organizations that are seeking to ameliorate the performance of the projects that they are charged with delivering.
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Introduction

Poor quality and safety performance can adversely influence the cost and schedule of a project. When rework occurs during construction, there is an increasing propensity for safety incidents and/or accidents to occur (Wanberg et al. 2013). Explaining incidents and accidents in an appropriate context helps in understanding the importance of safety in project success. Safety incidents are undesired or unexpected events, while accidents are unplanned or unanticipated events that cause injury, illness, damage, or loss. The quality and safety literature is replete with studies that have examined how and why rework (e.g., Josephson et al. 2002; Hwang et al. 2009), incidents, and accidents occur (e.g., Choudhry and Fang 2008; Jitwasinkula and Hadikusumoa 2011). However, there have been limited studies that have sought to examine the relationship between rework and safety incidents. According to Love and Edwards (2013), the causal natures of rework and of safety incidents are akin, and therefore strategies to contain and reduce their occurrence share a symbiotic relationship. The causes of rework and safety incidents can be traced back to organizational influences, unsafe supervision, preconditions for unsafe acts, and the unsafe acts themselves (Reason 1997). Fundamentally, however, there is a proclivity for an array of pathogens to trigger these events.

Pathogens are latent conditions that lay dormant within a system until an error comes to light. Before they are apparent, team members often remain unaware of the effect upon project performance that particular decisions, practices, or procedures can have during construction. Pathogens can arise because of strategic decisions taken by senior management or key decision makers. Such decisions may be mistaken, but they also may be deliberate in the form of *strategic misrepresentation*. Latent conditions can lay dormant within a system for a considerable period of time and thus become an integral part of everyday work practices. Meanwhile, once they combine with active failures then omission errors can arise and their consequences may be significant. Active failures are essentially unsafe acts committed by people who are in direct contact with a system. Such acts include slips, lapses, mistakes, and procedural violations. Active failures are often difficult to foresee. As a result, they cannot be eliminated by simply reacting to the event that has occurred. Latent conditions, however, can be identified and remedied before an adverse event occurs.

This paper aims to examine a safety, quality, and environment (SQE) program, supported by behavioral and accountability initiatives, and its effect on reducing the number of safety incidents in a program alliance. Openly recognizing safety incidents and rework had become a problematic issue, so the alliance changed its underlying culture to one that focused on *error management*. Love et al.'s (2015a) erstwhile research examined how the program alliance was able to engage project team members' individual learning to become collective in nature to simultaneously ameliorate quality and safety. The research presented in this paper complements (Love et al. 2015a) and examines the influence of a project-lifecycle SQE program, particularly the effect that its rework prevention program had on improving safety performance.

Quality and Safety: Symbiotic Relationship

The relationship between quality and safety has been typically implied and supported anecdotally in the construction literature. A number of studies, however, have demonstrated that quality and safety management processes and practices share similar

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characteristics, and they proposed the integration of both management systems for a more efficient allocation of resources (e.g., Pheng and Shiua 2000; Loushine et al. 2004, 2006; Veltri et al. 2013). Loushine et al. (2004) and identified a relationship among several characteristics of quality and safety management such as employee involvement and management commitment. Similarly Husin and Adnan (2008) have revealed that a significant relationship exists whereby safety leads to quality and vice versa. Given this relationship, quality and safety can create a synergistic effect, thereby improving their mutual effectiveness (Hoonakker et al. 2010). Thus, Husin and Adnan (2008) promulgated that a dedicated *zero defects program* could lead to zero accidents being incurred. Despite the established theoretical relationship, the quantitative examination of quality and safety outcomes remains unexplored (Veltri et al. 2013; Pagell et al. 2014). Recognizing this gap in knowledge, Wanberg et al. (2013) demonstrated that a significant correlation existed for

- Recordable injury rate per 200,000 worker hours and the number of worker hours related to rework (i.e., per US$1 million scope of project completed and per 200,000 worker hours); and
- First aid rate per 200,000 worker hours and the number of defects (per US$1 million scope of project completed and per 200,000 worker hours).

The empirical results provide quantitative evidence that there is a direct positive relationship; and nonconformances, defects, or rework have an effect on the rate of safety incidents occurring. In this instance, there is a greater chance of safety incidents occurring when unplanned work such as rework is being undertaken.

Active failures, which include unsafe acts and rework, can be triggered by a wide variety of conditions such as production pressure (Goh et al. 2012), schedule pressure (Love and Edwards 2013), personal distractions (Hinze 1996), and cognitive dissonance on safety (Das et al. 2008). In particular, Love and Edwards (2013, p. 1128) have suggested that unrealistic schedules to complete tasks adversely "affect an individual's cognitive functioning and increase their propensity to commit errors, or omit tasks to meet organisational and project demands" (p. 1128). Similarly, distractions such as hazards can also affect the cognitive presence of an individual and reduce the ability to make correct judgements (Hinze 1996). Distractions can also be in the form of personal life events such as divorce, celebrations, and illnesses (Peckitt et al. 2004). Such causes may well result in unintended errors and violations and contribute to the misalignment of safety perceptions between employees and their managers.

According to Das et al. (2008), "when employees are faced with a situation where their perceptions of their own safety at work differ from the perceptions, statements, and actions of the management, employees will respond in ways that are likely to reduce the effectiveness and quality of their work" (p. 532). Consequently, Das et al. (2008) concluded that when there is an increasing disconnect with safety, its climate deteriorates and product quality deteriorates, which invariably results in further incidents and rework. In addressing this problem it has been suggested that instead of only focusing on human error as the causes of safety and rework, the performance variability of a system under different conditions needs to be better understood (Love et al. 2015b).

Research Approach

As there has been limited research that has simultaneously examined the relationship between quality and safety outcomes, an exploratory case study was undertaken. A program alliance was selected, as it had been able to significantly improve its quality and safety performance as a result of implementing a project-lifecycle SQE program in conjunction with a dedicated rework prevention program. As a result of implementing these initiatives juxtaposed with establishing a cooperative learning culture (Love et al. 2015a), the National Safety Council of Australia (NSCA) bestowed the Pinnacle Award for excellence in workplace health and safety, as well as the award for Best Safety Leadership Program in 2013, to the alliance.

The program alliance was charged with delivering 129 water infrastructure projects over a 5-year period at a value of AU $375 million. The program alliance went about reducing safety incidents and rework through a process of context-specific learning that was engendered by authentic leadership, engagement and empowerment, and a strong focus on continuous improvement. Specific details about how the alliance developed and implemented the rework prevention program can be found in (Love et al. 2015a).

To acquire an understanding of the context and subsequent effect of the program alliance's project-lifecycle SQE program, a triangulated approach was adopted to overcome problems associated with bias and validity (Patton 1990). Cohen and Manion (2000) define the process of triangulation as an "attempt to map, or explain more fully, the richness and complexity of human behavior by studying more than one standpoint" (p. 254). Thus, multiple viewpoints were obtained from the alliance team and contractors to obtain a balanced understanding of the effectiveness of the SQE program and the change that was initiated. Interviews and observations were undertaken by three researchers and findings were compared and contrasted, which enabled them to overcome intrinsic biases and problems that may arise from a single observer. The research process commenced with a series of interviews and then with observations (e.g., on-site, meetings, workshops), which were supplemented with documentary sources. The data obtained from documentary sources were then used to undertake a statistical analysis to examine the effectiveness of the SQE program in reducing incidents.

Data Collection

In this case study unstructured interviews; documentary sources (e.g., lessons-learned database, workshop notes, and reports); and nonparticipant observation, which involved site visits, formed the cornerstones of the data collection process (Yin 2009). A total of 26 unstructured interviews were conducted with a variety of personnel such as the alliance manager, design manager, SQE manager, commercial manager, site supervisors, and contractors. Purposeful sampling was employed to select the interviewees from various functional areas (e.g., commercial, design, delivery, and project support) who were actively involved in initiating and implementing the process and technological changes undertaken within the alliance. Interviews were used as the mechanism to examine why change was initiated and how the alliance initiated process improvement through implementing a lessons-learned initiative to improve quality and safety performance. Interviews were conducted at the interviewees' offices and on-site. They were digitally recorded, and then transcribed verbatim, to allow for any finer nuances to be detected. Interviews were kept open using phrases such as "Tell me about it" or "Can you give me an example?" The open nature of the questions stimulated avenues of interest to be pursued as they arose without introducing bias in the response. Additional notes were taken during interviews to support the digital transcription process to maintain validity and safeguard against the digital recorder's failure. Each interview varied in length from 45 minutes to 2 h and a conscientious effort was made to break down any barriers that may have existed between the interviewers and interviewee.

Data from workshops conducted by the alliance team members with contractors were made available for analysis. Moreover, the researchers acted as nonparticipant observers during several of these workshops and recorded their observations, particularly ideas and the emergent discourse that arose from participants interacting with the facilitator. Data pertaining to safety incidents that arose from 2010 to 2014 were derived from the alliance's database. These data contained the following information: the type of incident, date of occurrence, classification of the severity, time of occurrence, body parts injured, and a narrative about the event that had occurred.

Case Study

The program alliance was established in 2009 to deliver 129 water infrastructure projects, comprised of pipelines, water treatment plants, pump stations, tanks, storages, and channel works throughout a regional area of Victoria in Australia. After an extended period of drought in 2008/2009 and significant growth in the region, the demand for water increased. As a result there was a need to upgrade existing and construct additional infrastructure to meet this demand. The alliance team was comprised of three organizations: the owner participant (OP), who was responsible for delivering water to its customers over an area of 8,100 km^2 to five municipalities and 275,000 customers; an engineering consultancy who provided design, environmental, and stakeholder management expertise; and a contractor who provided commercial and construction capabilities. The program of works to be undertaken was AU $375 million over a 5-year period. At the onset of the alliance, a set of core values were established: safety, teamwork, respect, innovation, vibrancy, and excellence (STRIVE). These were later aligned to a set of key results areas (KRAs): environment (noncompliance criteria) 15%, delivery 30%, functionality 15%, regional benefit 15%, people and well-being 15%). These KRAs had a total of 21 key performance indicators (KPI). In 2014, the program of works was transitioned to the OP, as it was always intended that during the alliance's life, both the engineering consultancy and contractor would provide the knowledge and capability to enable them to continue with their projects alone.

In 2011, approximately 2.5 years into the 5-year program, the alliance leadership team (ALT) and alliance management team (AMT) became aware that a number of projects were incurring unnecessary cost and time delays because of rework and issues relating to safety. This coincided with the first batch of projects, which reached the end of their 2-years asset proving period (i.e., defects liability). An average of a 3-week delay per project was being experienced because of rework issues, which at the time equated to in excess of AU$1 million in costs to the alliance alone (e.g., management and supervision). Over the life of the program, *ceteris paribus*, the costs that would have been incurred by the alliance were estimated to be in excess of AU$3 million. The costs borne by contractors as a result of this rework were estimated to be at least five times this estimation. The costs of rework did not vary between the project types. Yet, the number of product quality nonconformance reports (NCRs) formally raised and reported by contractors was zero, although it was clearly known that this was not a reflection of reality, primarily because of the fear of blame and damage to the organization's reputation. Moreover, rework was deemed to be a norm and thus business as usual. It was not until the contractors became aware of the problem that they began to work with the alliance to prevent its future occurrence.

The ALT and AMT knew that there were quality issues as a result of their inspections, but at the time they felt that the alliance lacked the systems, contractual power, relationships, and culture to support and enable the contractors to identify errors and mistakes that could lead to rework. A concerted effort had been made within the alliance to report safety and environmental incidents, which improved over time, but the existing processes in place were inadequate to equally capture quality assurance (QA) and potential rework. Furthermore, no effort had been made to account for rework, as there was a perception that it was a result of poor work practices and demonstrated failure. The ALT/AMT recognized that safety was being jeopardized as a result of a number of rework incidents. On average, 10 incidents/near misses (of all types) were occurring per month, particularly during the months of November and December when 30 incidents/near misses occurred as a result of several issues such as fatigue and stress. In fact, it was propagated that the likelihood of a person being injured while attending to rework was nine times greater when compared to normal work activities (Cumming 2014). This was of great concern to the alliance as it was contradictory to their underlying value system that had been developed at the onset of the project. Responsively recognizing the problem at hand, the ALT and AMT, collectively with the nonowner participants (NOP), embarked on a targeted safety and rework improvement program to alleviate significant SQE issues that had been consistently emerging.

Creating a No-Harm Environment

Striving to create a no-harm environment the alliance began to engender a mindset that harm, damage, and rework could be prevented. However, a major challenge that confronted the alliance was delivering a large range of projects, over a range of locations, utilizing regional contractors with mixed capabilities (Cumming 2014). To address these challenges and ensure incidents and rework were reduced (i.e., measures designed to limit their occurrence) and contained (i.e., measures designed to increase their detection and accelerate recovery, as well as to minimize their adverse consequences) a project-lifecycle SQE risk management system was implemented and supported by a behavioral and accountability program.

SQE Risk Management

The SQE risk management process (Fig. 1), akin to Reason's (1997) Swiss Cheese Model, was tiered so as to reduce the likelihood of an incident occurring (Cumming 2014). Standard project risk assessments (PRA) were undertaken for each project type and were regularly updated as lessons were learned for each project. As a project was initiated, a risk profile was established with the aim of removing as many risks as possible through the design process; essentially the alliance was designing for safety during construction. The PRA was undertaken at designated milestones throughout the design phase with representatives from the alliance's design, construction, operations, estimating and management, commercial, and environmental teams.

The risks that could not be removed were transferred to the workplace risk assessment (WRA) and were monitored during the construction and operational phase. An activity method statement (AMS) was developed for those activities that were identified as being medium to high risk. The AMS ensured that the most appropriate work method, equipment, and resources were provided to reduce risk during construction and operations to an acceptable level prior to the commencement of works on-site.

Safe work method statements (SWMS) and standard operating procedures (SOPs) were used to then break down the activities into logical sequences for work crews as well as assign responsibilities for tasks. Here the work crews were required to produce a sketch and plan as an initial step in developing the SWMS. In this instance the work crews were empowered to develop the SWMS rather than the supervisor; this approach follows the principles embedded

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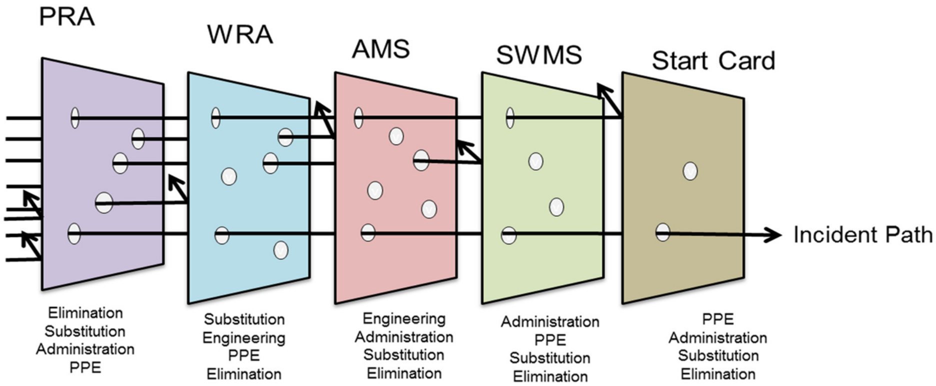

Fig. 1. Alliance's SQE risk management process

within the *Last Planner* (Ballard 1994). Finally, a Start Card was required to be completed by each individual crew member as a final check before commencing and conducting work. Here individuals completing the works were required to undertake a final check to ensure all hazards had been identified and controlled.

An example of the effectiveness of the SQE risk management process was realized in a pipeline project, which required the installation of a deep pipeline in soft soils in a sensitive coastal environment. During the PRA process, the risks associated with trench collapse and environmental risks were identified as high. Consequently, this led to a different construction method from using an open cut approach to undertaking two 1.9-km horizontal directional bores. Notably, specialist contractors were engaged in developing the solution and the design process to ensure that risks were reduced during construction. No incidents were reported, and the project was delivered at a lower cost, on time, and with a significantly reduced environmental impact.

Accountability and Awareness

The SQE risk management process had proved to be an effective mechanism for reducing incidents and rework, but as part of the alliance's goal to continuously improve the effectiveness of its systems and people, a number of initiatives were implemented. Specifically, the AMT/ALT aimed to address issues surrounding accountability and awareness and in doing so sought for team members to answer the following key questions: (1) What am I accountable for? (2) What are the key risks and controls? and (3) How do I know the controls are in place and effective? Two initiatives were implemented to augment individual accountability:

1. Process clarity: Procedural manuals, which were seldom referred to and deemed difficult to understand, were replaced with customized web-based process flowcharts (Fig. 2). These flowcharts were a dynamic tool that was interfaced and regularly updated by team members as lessons from projects were learned and improvements identified.
2. Individual accountability: Every person working on the alliance was required to sign on to the Code of Conduct. By doing so, individuals were committing themselves to the alliance's vision of "No Harm" and to operate within a set of fundamental principles for any activity, which were (1) assess the risk, (2) develop a plan and follow it, and (3) only do what you are competent to do. On the Start Card, it was made explicit that "No Harm, is a belief that harm, damage or *rework* can be prevented." If anyone did not adhere to the specific requirements, they were given a warning. However, if an individual was found to have blatantly committed an action identified on the Start Card they would be immediately removed from site. Moreover, the Start Card explicitly stated that if NCRs were not reported then individuals could be dismissed (Fig. 3).

Risk and Controls

Knowledge of the key risk areas is required to understand the risks and controls that were required for an activity. The accumulation of this knowledge by alliance project staff was a central tenet that influenced the alliance's ability to learn and initiate continuous improvement. Key initiatives that were established to transfer knowledge included:

1. Behavior-based inductions: Every individual in the alliance was required to undergo a behavior-based induction program that focused on establishing expectations on-site based on SQE planning and engagement. The induction included a series of case studies and risk assessment exercises from recently completed projects the alliance had undertaken. Lessons learned and the experiences of those involved with events or incidents were shared in a workshop environment with individuals who were being inducted. Teams were established within the workshops and encouraged to work together to develop safe work plans for typical project tasks.
2. SQE leadership training: At the early stages of the alliance program, the ALT identified that their good-performing projects had project managers (PM) and/or supervisors who provided effective SQE leadership. Based on this observation, training was provided for PMs and supervisors on how to create and maintain a proactive SQE culture on-site. The training was provided on an on-going basis to minimize disruption to the construction process. Each AMT member was also required to visit a site each month with a specific focus on site team engagement, planning, risk, awareness, controls, change management, and accountabilities.
3. Team selection: A risk profile was established for each project based on the type of works and the competency of the site team and subcontractors who were appointed to deliver the project. The alliance project team was then selected to match the established risk profile to ensure that less experienced members were married with those who had experience, which provided the ability for mentoring and the establishment of improved capabilities.
4. Team based planning: Site planning prior to construction was considered a high priority within the alliance and required all project members to be involved. To facilitate the planning process a two-stage planning board system was developed. In the first stage, a 2-week look-ahead planning was conducted by the alliance's PM and site supervisor and the subcontractors and their supervisors. These processes enabled effective

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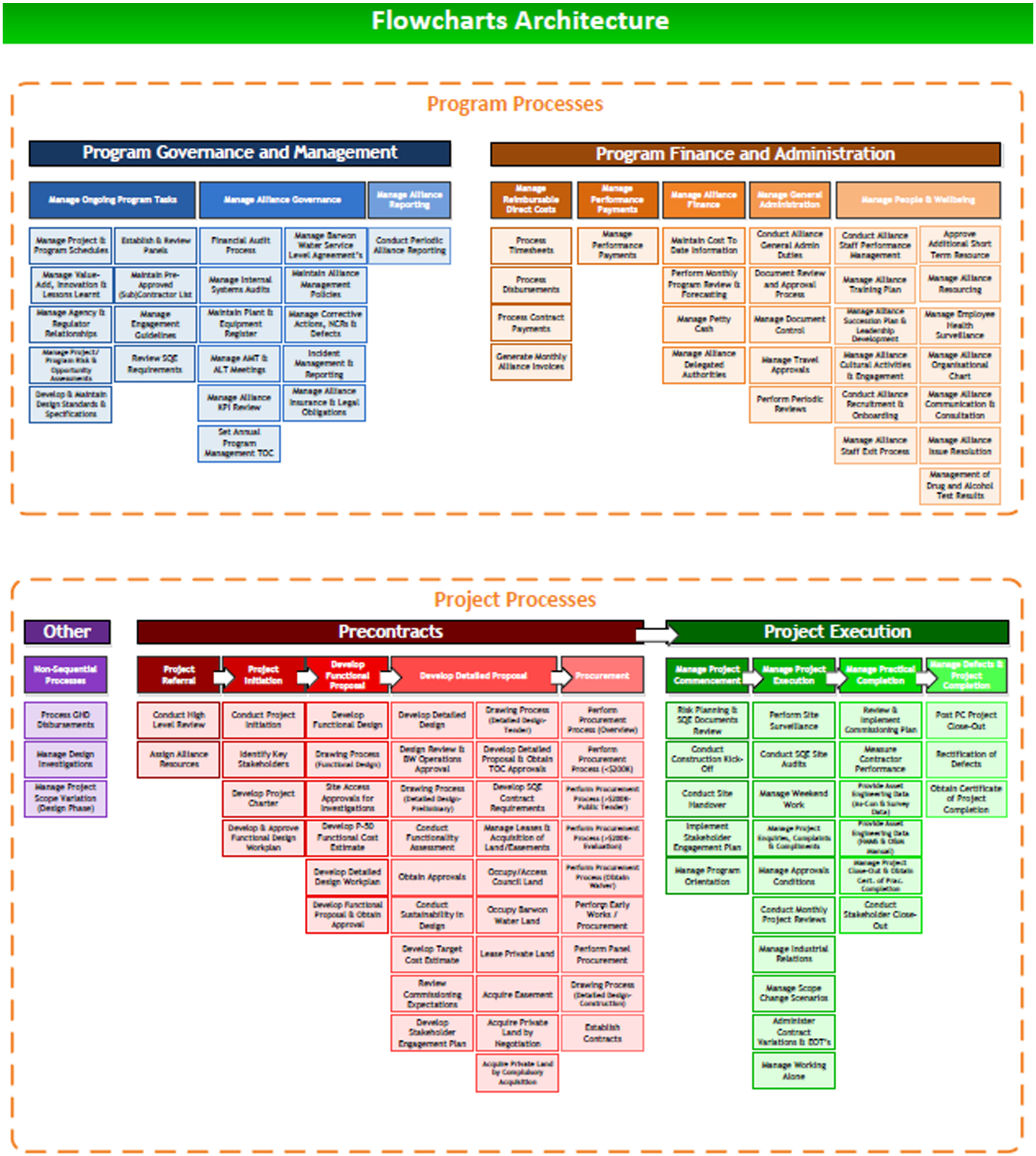
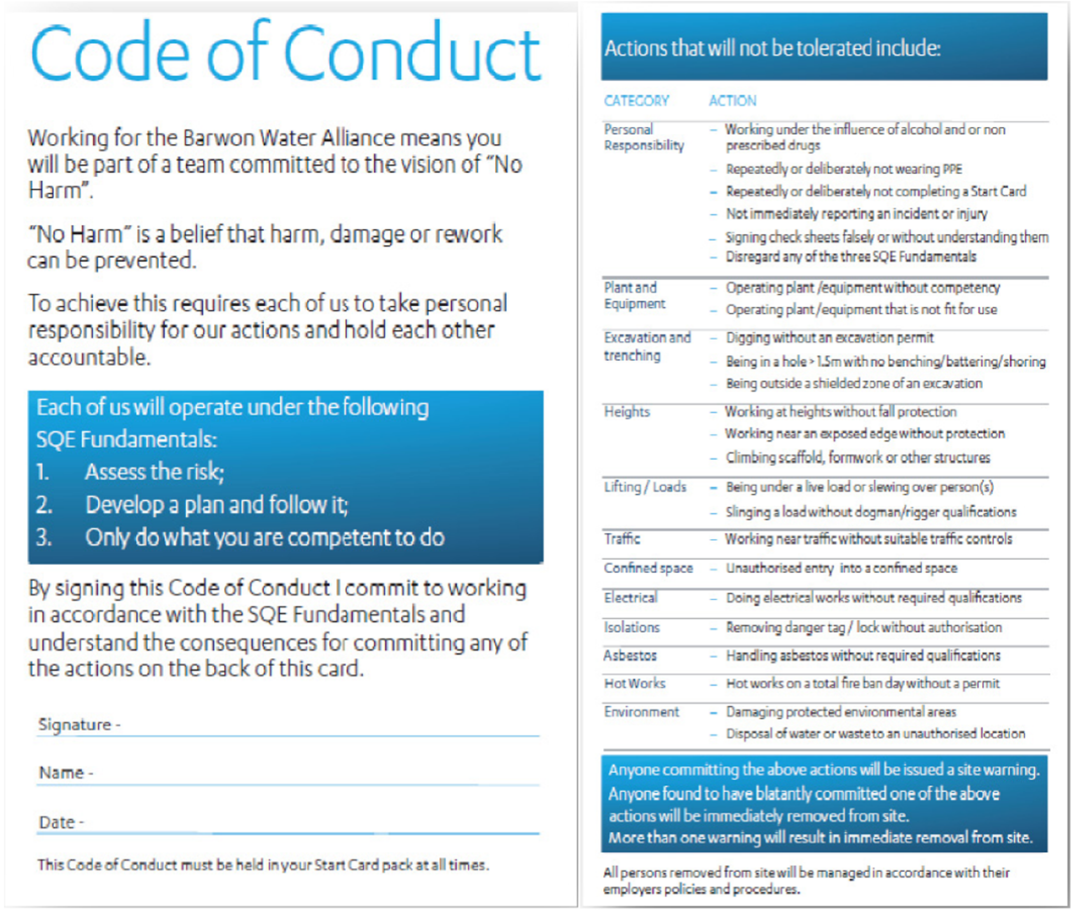


Fig. 2. Flowchart architecture

communication of the project's risks and early identification of SQE inputs. Furthermore this process led to the AMS and SWMS being examined and therefore ensured that a feedback process was undertaken. Information from the planning board system was then translated into a team-planning board that explicitly defined the tasks to be undertaken and by whom.

Monitoring and Control

To ensure that effective controls were in place, a monitoring scheme was introduced. Throughout the design and tendering process for each individual project, approval was required from SQE, operations, and construction teams. Prior to the commencement of works on-site, a kick-off planning workshop was undertaken to review strategic project risks with all team members. Inspections,



Code of Conduct

Working for the Barwon Water Alliance means you will be part of a team committed to the vision of "No Harm".

"No Harm" is a belief that harm, damage or rework can be prevented.

To achieve this requires each of us to take personal responsibility for our actions and hold each other accountable.

Each of us will operate under the following SQE Fundamentals:
1. Assess the risk;
2. Develop a plan and follow it;
3. Only do what you are competent to do

By signing this Code of Conduct I commit to working in accordance with the SQE Fundamentals and understand the consequences for committing any of the actions on the back of this card.

Signature -

Name -

Date -

This Code of Conduct must be held in your Start Card pack at all times.

Actions that will not be tolerated include:

CATEGORY	ACTION
Personal Responsibility	– Working under the influence of alcohol and or non prescribed drugs – Repeatedly or deliberately not wearing PPE – Repeatedly or deliberately not completing a Start Card – Not immediately reporting an incident or injury – Signing check sheets falsely or without understanding them – Disregard any of the three SQE Fundamentals
Plant and Equipment	– Operating plant /equipment without competency – Operating plant /equipment that is not fit for use
Excavation and trenching	– Digging without an excavation permit – Being in a hole > 1.5m with no benching/battering/shoring – Being outside a shielded zone of an excavation
Heights	– Working at heights without fall protection – Working near an exposed edge without protection – Climbing scaffold, formwork or other structures
Lifting / Loads	– Being under a live load or slewing over person(s) – Slinging a load without dogman/rigger qualifications
Traffic	– Working near traffic without suitable traffic controls
Confined space	– Unauthorised entry into a confined space
Electrical	– Doing electrical works without required qualifications
Isolations	– Removing danger tag / lock without authorisation
Asbestos	– Handling asbestos without required qualifications
Hot Works	– Hot works on a total fire ban day without a permit
Environment	– Damaging protected environmental areas – Disposal of water or waste to an unauthorised location

Anyone committing the above actions will be issued a site warning.
Anyone found to have blatantly committed one of the above actions will be immediately removed from site.
More than one warning will result in immediate removal from site.

All persons removed from site will be managed in accordance with their employers policies and procedures.

Fig. 3. Code of Conduct: "No Harm"

audits, and reviews were undertaken regularly to ensure compliance and continuous improvement. Information obtained from audits, inspections, and reviews was collated in real time using an iPad/web-based system so as to provide instant corrective/preventive measures. The acquired information was inputted into a lessons-learned system, which was made available to all project team members. The architecture for enabling the process for stimulating lessons learned is presented in Love et al. (2015a).

Leadership

The ALT recognized the importance of SQE to ensure improved quality and safety outcomes. Openly recognizing that safety incidents and rework were problematic issues was initially difficult because of the underlying negative connotations that reside within the construction industry with these issues. Challenging existing norms required the ALT to embrace change and adopt an authentic style of leadership that engendered integrity, open communication, and trust and allowed learning to take place (Love et al. 2015a).

Rework Prevention Program

Rework can arise for a plethora of reasons but research to date has not been able to provide empirically based solutions that demonstrate how it can be reduced in construction projects. Within the alliance, rework was a prevailing issue, which was openly recognized by the alliance and its subcontractors. Instead of simply correcting an action to solve or avoid a mistake, the alliance recognized that it needed to correct the underlying causes behind the problematic action if it were to learn and subsequently improve its performance. As a result, it developed a rework prevention program to complement its project-lifecycle SQE strategy.

This program emerged as a result of rework-related issues that an alliance construction manager had observed and subsequently discussed at a contractors forum. Such forums were used to exchange knowledge and experiences with regard to SQE matters. The discourse that emerged led to dedicated rework forums being implemented that were used to identify and discuss recurrent rework issues and identify strategies for its prevention. The forums were facilitated by an external consultant and were designed to be interactive. Issues identified from the forums contributing to rework are presented in Fig. 4. Openly acknowledging the need to address rework, a dedicated rework prevention actions register (including KPIs and responsibility) was developed by the alliance project team for the following areas: project referral; functional and detailed design; commercial and project tendering; project support and delivery; and SQE planning, commissioning, and hand-over.

Information contained within this register was uploaded to a lessons-learned system that had also been developed by the alliance. All project team members had access to the lessons-learned system and alerts about rework events were regularly distributed to contractors to highlight emergent issues. As part of the SQE program's approach to continuous improvement, the Code of Conduct, identified in Fig. 3, was amended to accommodate rework and the importance of reporting NCRs. As a consequence of acquiescently embracing the notion of rework informally through narratives in workshops and formally through new processes and procedures (e.g., lessons learned, Start Card), it was observed that safety also began to improve. The interdependency between quality and safety

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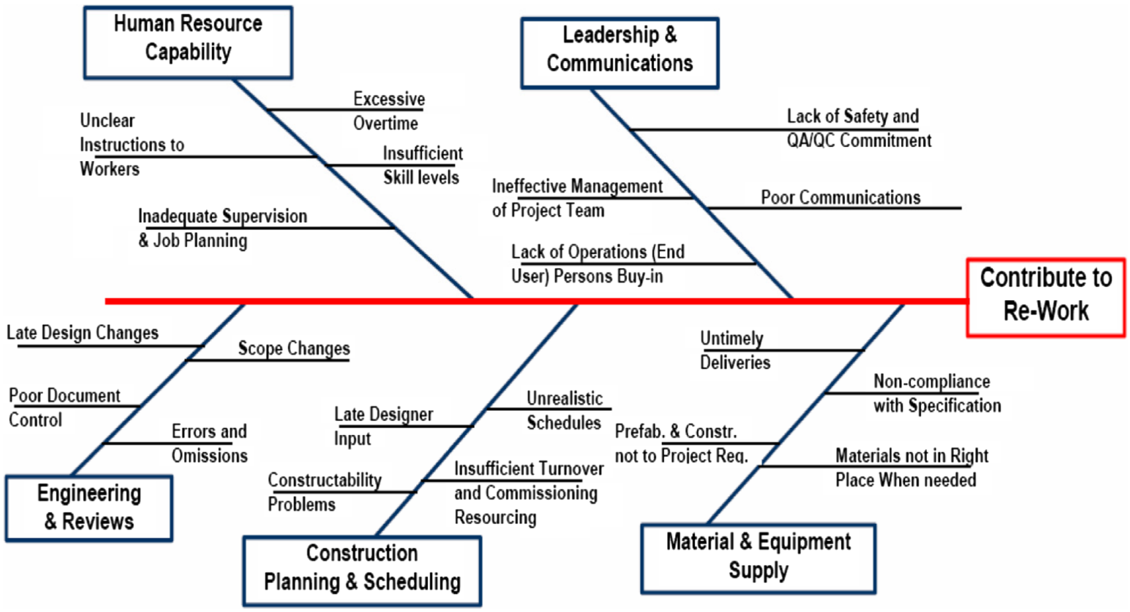

Fig. 4. Cause and effect of rework in the alliance

had come to the fore, especially as they had similar documentation, improvement, standardization, and decision-making processes within the alliance. The effects of the rework prevention program in conjunction with the continuous improvement approach of the SQE program is examined below.

Effects on Safety

A total of 380 incidents were identified in the 129 projects that were delivered by the alliance. Fig. 5 identifies that hand (35%) and leg (13%) injuries to the body accounted for a significant proportion of those that were incurred. In addition, the major types of incidents that arose were damage to services (19%), environmental incidents (17%), damage to property (14%), and first aid injuries (14%), which were deemed to be of low severity (Fig. 6). Injuries of low severity were those that inconvenienced individuals such as minor cuts or sprains, but allowed a person to continue with their or alternate duties for one full shift or more.

Human injuries of higher severity, that is, alternate work injury (AWI), lost time injury (LTI) and medical treatment injury (MTI), comprised of only 3% of total incidents incurred. Notably, 22% of total incidents involved only the reporting of unsafe acts or conditions. A total of 43.5% of the incidents occurred between 1000 and 1200 hrs. and 1500 and 1600 hrs. At 1000 hrs., site workers tend to have their morning break and therefore may have become distracted and lost their concentration. In addition, there is a propensity for site workers' blood sugar levels to drop at this time of day because of the physical demands of the work that they undertake, which may contribute to a loss of concentration (e.g., Reeves et al. 2015).

A chi-square test (χ^2) was undertaken to determine if there was a significant difference between H_0 (i.e., a null hypothesis that assumes there is no relationship between two measured phenomena): (1) incidents occurring during/not during breaks = 0; and (2) the alternative hypothesis H_2 that assumes there is a relationship. From the results, it was revealed that a significant difference between incidents occurring during break time and nonbreak time $[\chi^2(2, n = 360)] = 142.379$, $p = 0.00$, at 99% significance. Furthermore, a

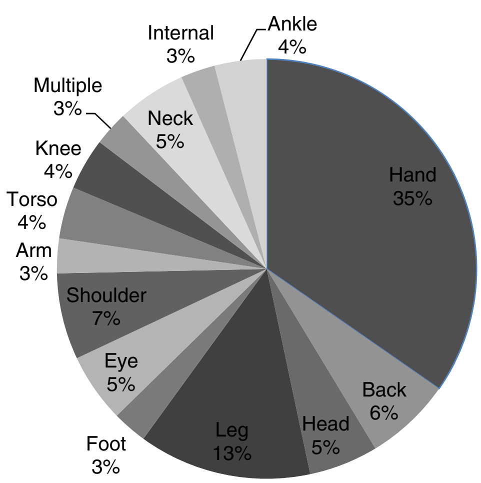

Fig. 5. Proportion of body parts injured

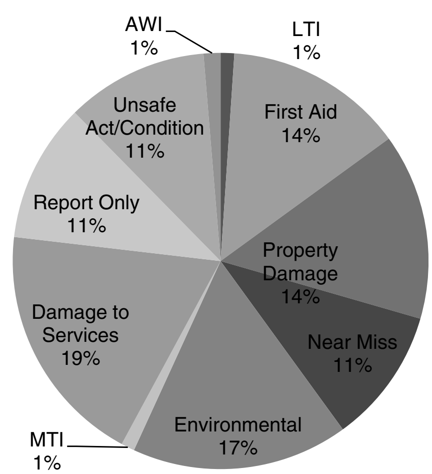

Fig. 6. Proportion of incident types

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Table 1. Percentage of Incidents Occurring during Rework

Incident type	Rework (%)	Nonrework (%)
Actual injuries	39	61
Unsafe acts/conditions and near misses	35	65
Property damage	32	68
High potential incidents ($1p/2p$)	42	58
Low potential incidents ($3p$)	28	72
Total incidents	29	71

greater rate of incidents occurred during break time (157 incidents in a 3-h period) than nonbreak time (203 incidents in the remaining 5-h period).

Effects of Rework Prevention Program on the Frequency of Incidents

A specific rework prevention program was instigated in May 2013, as part of the ALT's commitment to continuous improvement. Table 1 identifies the proportion of incidents by type that occurred when the rework was being undertaken. However, there were no significant differences between the type of incidents and rework at $p = 0.00$, at 99% significance.

As a result of implementing the rework prevention program, the mean number of incidents decreased from approximately eight incidents per month to five (Table 2). Fig. 7 highlights the fluctuation of incidents over the 5-year period and after the introduction of the program. Furthermore, statistical analyses reveal that the difference in the occurrence of incidents between the period before and after the program is significant. Both the independent samples' t-test and Mann-Whitney U test were carried out to determine if the rework prevention program had a significant effect on the frequency of incidents.

Independent Samples t-Test

One of the important assumptions of an independent samples t-test is the homogeneity of variance, and Levene's test is used to determine if this assumption is violated. As shown in Table 2, the p-value of Levene's test 0.127 is greater than 0.05 and the group variances can be treated as equal. In other words, the assumption of the t-test is not violated and the result of the t-test is valid. With equal variances assumed, the p-value of the t-test is less than 0.05 [$t(56) = 2.150$, $p = 0.036$], and therefore the H_0 that there is no difference in the number of incidents occurring per month before and after intervention is rejected. The results of the independent samples t-test demonstrate that there is a statistically significant difference in the number of incidents per month before and after the introduction of the program. The test results indicate a negative direction and significance at 95% two tailed.

Mann-Whitney U Test

As the independent t-test assumes normality and independence of observations, the Mann-Whitney U test, which does not assume normality, is carried out to further corroborate the results obtained from the t-test. The Mann-Whitney U test is the nonparametric alternative of the t-test. From Table 3, the preintroduction period had a higher average rank of 32.50, as compared to the postintroduction period that had an average rank of 21.63. From Table 3, the p-value is less than 0.05 ($u = 210$, $z = -2.202$, $p = 0.028$), and H_0 is rejected. Therefore, it is concluded that a lower number of incidents

Table 2. Independent Samples t-Test

	Descriptive statistics					Levene's test for equality of variances			t-test for equality of means					95% confidence interval	
Intervention	Total number of incidents	Number of months	Mean incidents per month	SD	Standard error mean	Equal variances	F	Significance	t	df	Significance (two tailed)	Mean difference	Standard error difference	Lower	Upper
Pre	304	42	7.24	4.264	0.658	Assumed	2.399	0.127	2.150	56	0.036	2.488	1.157	1.170	4.806
Post	76	16	4.75	2.864	0.716	Not assumed	—	—	2.559	40.482	0.014	2.488	0.972	0.524	4.453

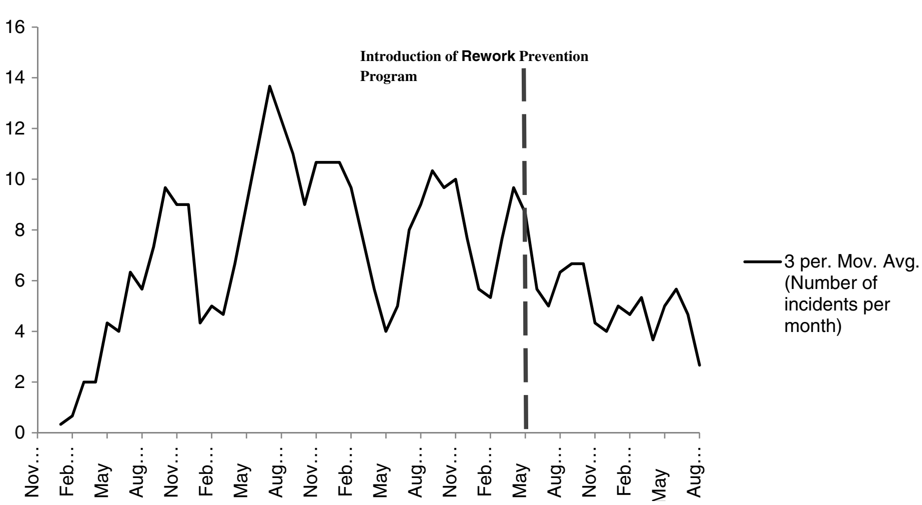

Fig. 7. Effect of the rework prevention program on incidents per month

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Table 3. Mann-Whitney U Test—Test Statistics

Test statistic	Incident occurrence
Mann-Whitney U	210.000
Wilcoxon W	346.000
Z	−2.202
Asymptotic significance (two tailed)	0.028

per month occurred on average after introduction than before introduction at a 95% significance level two tailed.

Comparison of before and after Rework Prevention Program

A nonparametric Spearman's correlation test was undertaken to determine if there was a significant relationship between the number of incidents occurring before and after the introduction of the rework prevention program. The Spearman's correlation coefficient prior to the introduction of the program, rs, is 0.438, and statistically significant at a 99% level ($p = 0.004 < 0$). This indicates a significant positive relationship between the month/year and number of incidents prior to the introduction of the program; that is, the number of incidents was increasing as the project progressed. However, in the postintroduction period, the correlation coefficient, rs, is −0.329, and $p = 0.213$. The results indicate no significant relationship (though in a negative direction). This suggests that the rework prevention program has altered the increasing trend of the frequency of incidents that occurred in the program alliance.

Developing Lead Indicators

Research undertaken by Love et al. (2015b) has suggested that the collation of safety incidents records can be used to develop lead indicators for risk assessment. The mean (M) number of incidents per month was 6.5, with a minimum of 0 and maximum of 15. The number of incidents per month was observed to be not normally distributed. The probability distribution was found to have a skewness 0.13229 and kurtosis −0.7964. Determining the best-fit distribution enables the probability of their occurrence to be established and allows the OP to develop lead indicators (preincident measures) for their future projects and therefore provides a basis for assessing the condition of their SQE (Love et al. 2015b).

The Kolmogorov-Smirnov (K-S) test revealed a D-statistic of 0.0883 with a p-value of 0.71628 for the 380 incidents that occurred over the 58-month period for the water infrastructure projects. The KS test accepted the H_0 for the sample distribution's best fit at $\alpha = 0.2$, $\alpha = 0.1$, $\alpha = 0.05$, $\alpha = 0.02$, and $\alpha = 0.01$. A continuous uniform distribution was found to be the best fit. This distribution is derived from a family of symmetric probability distributions such that each member possesses intervals of the same length for the distributions that are equally probable. The support is defined by the two parameters, a and b, which are its minimum and maximum values. In this instance, the parameters were found to be $a = -0.26316$, $b = 15.253$. The PDF is expressed as

$$f(x) = \begin{cases} \frac{1}{b-a} & \text{for } a \le x < b \\ 0 & \text{for } x < a \text{ or } x > b \end{cases} \quad (1)$$

The CDF is expressed as

$$F(x) = \begin{cases} 0 & \text{for } x < a \\ \frac{x-a}{b-a} & \text{for } a \le x < b \\ 1 & \text{for } a \le x < b \end{cases} \quad (2)$$

The probability, for example, that the alliance in this case would incur less than a mean of 5 incidents per month is $[P(x < x_1) = 0.38]$. In other words, the probability of the alliance experiencing between 5 and 10 incidents per month is 38% $[P(x_1 < x < x_2) = 0.38]$.

The most popular measures of safety are frequency rates and severity of accidents based upon personal injury such as lost time injury frequency rates (LTIFR). These indicators are often used by the construction industry to compare companies' performance with one another and thus identify those with poor safety performance records (Love et al. 2015b). The incidents were analyzed to develop a PDF, which can be used to determine their likelihood of occurrence. Thus, a lag indicator (i.e., measurement collected after an incident occurs) in this case can be used to develop a form of lead indicator (i.e., preincident measures) that can be put in place to improve safety performance.

Conclusion

Rework had been causing significant delays to this alliance water infrastructure project, which were much needed by the communities that they serviced. The project-lifecycle SQE strategy underpinned by the rework prevention program focused on changing the culture and behavior of alliance members and the contractors that were delivering the various types of water infrastructure projects. New processes and procedures were established and alliances members and contractors were encouraged to openly share their knowledge and experiences about the rework events that had occurred. Lessons-learned workshops focusing on rework were regularly held with alliance team and contractors.

While rework was explicitly reduced, the significant effect that the program had on safety performance was unexpected. In demonstrating the effect of the rework prevention program, the statistical characteristics of frequency incidents prior to and after its introduction were examined. A continuous uniform distribution was found to be the best overall distribution fit for the monthly incidents, which can be used to calculate the probability of their occurrence and used as a lead indicator in future water infrastructure projects that are delivered by the alliance. It was revealed that as a result of implementing the rework prevention program, there was a statistically significant difference in the number of incidents per month before and after the introduction of the program. Moreover, the analysis revealed that the number of incidents was increasing as the project progressed prior to the introduction of the program. Thus, the introduction of the rework prevention program significantly decreased the rate of incidents, which resulted in an improvement in safety performance.

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References

Ballard, G. (1994). "The last planner." *Northern California Construction Institute Spring Conf.*, Lean Construction Institute, Monterey, CA.

Choudhry, R. M., and Fang, D. (2008). "Why operatives engage in unsafe work behavior: Investigating factors on construction sites." *Safety Sci.*, 46(4), 566–584.

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Cohen, L., and Manion, L. (2000). *Research methods in education*, 5th Ed., Routledge, London.
Cumming, S. (2014). "Striving for 'No harm' in capital works delivery through implementation of whole of life project risk management." *Ozwater 2014—Australia's Int. Water Conf. and Exhibition*, Southbank Convention and Exhibition Centre, Brisbane, QLD, Australia.
Das, A., Pagell, M., Behm, M., and Veltri, A. (2008). "Toward a theory of the linkages between safety and quality." *J. Oper. Manage.*, 26(4), 521–535.
Goh, Y. M., Love, P. E. D., Brown, H., and Spickett, J. (2012). "Organizational accidents: A systemic model of production versus protection." *J. Manage. Stud.*, 49(1), 52–76.
Hinze, J. (1996). *Construction safety*, Prentice-Hall, Upper Saddle River, NJ.
Hoonakker, P., Carayon, P., and Loushine, T. (2010). "Barriers and benefits of quality management in the construction industry: An empirical study." *Tot. Qual. Manage. Bus. Excellence*, 21(9), 953–969.
Husin, H. N., and Adnan, H. (2008). "Management of safety for quality construction." *J. Sustainable Dev.*, 1(3), 41–47.
Hwang, B., Thomas, S. R., Haas, C., and Caldas, C. (2009). "Measuring the impact of rework on construction cost performance." *J. Constr. Eng. Manage.*, 10.1061/(ASCE)0733-9364(2009)135:3(187), 187–198.
Jitwasinkula, B., and Hadikusumoa, B. H. W. (2011). "Identification of important organizational factors influencing safety work behaviors in construction projects." *J. Civ. Eng. Manage.*, 17(4), 520–528.
Josephson, P.-E., Larsson, B., and Li, H. (2002). "Illustrative benchmarking rework and rework costs in Swedish construction industry." *J. Manage. Eng.*, 10.1061/(ASCE)0742-597X(2002)18:2(76), 76–83.
Loushine, T. W., Hoonakker, P. L. T., Carayon, P., and Smith, M. J. (2004). "The relationship between safety and quality management in construction." *Proc. Human Factors and Ergon. Soc. Ann. Meeting*, 48(16), 2060–2064.
Loushine, T. W., Hoonakker, P. L. T., Carayon, P., and Smith, M. J. (2006). "Quality and safety management in construction." *Tot. Qual. Manage. Bus. Excellence*, 17(9), 1171–1212.
Love, P. E. D., and Edwards, D. J. (2013). "Curbing rework in offshore projects: Systemic classification of risks with dialogue and narratives." *Struct. Infrastruct. Eng.*, 9(11), 1118–1135.
Love, P. E. D., Teo, P., Ackermann, F., and Morrison, J. (2015a). "From individual to collective learning: A conceptual learning framework for enacting rework prevention." *J. Constr. Eng. Manage.*, 10.1061/(ASCE)CO.1943-7862.0001013, 05015009.
Love, P. E. D., Teo, P., Carey, B., Sing, C.-P., and Ackermann, F. (2015b). "The symbiotic nature of safety and quality in construction: Incidents and rework non-conformances." *Saf. Sci.*, 79, 55–62.
Pagell, M., Dibrell, C., Veltri, A., and Maxwell, E. (2014). "Is an efficacious operation a safe operation? The role of operational practices in worker safety outcomes." *IEEE Trans. Eng. Manage.*, 61(3), 511–521.
Patton, M. Q. (1990). *Qualitative evaluation and research methods*, 2nd Ed., Sage, Newbury Park, CA.
Peckitt, S. J., Glendon, I., and Booth, R. T. (2004). "Societal influences on safety culture in the construction industry." *Construction safety management systems*, S. Rowlinson, ed., Spon Press, Taylor and Francis Group, London, 17–54.
Pheng, L. S., and Shiua, S. C. (2000). "The maintenance of construction safety: Riding on ISO 9000 quality management systems." *J. Qual. Maintenance Eng.*, 6(1), 28–44.
Reason, J. (1997). *Managing the risks of organizational accidents*, Ashgate, Aldershot, U.K.
Reeves, S., Huber, J. W., Halsey, L. G., Villegas-Montes, M., Elgumati, J., and Smith, T. (2015). "A cross-over experiment to investigate possible mechanisms for lower BMIs in people who habitually eat breakfast." *Eur. J. Clin. Nutr.*, 69(5), 632–637.
Veltri, A., et al. (2013). "Understanding safety in the context of business operations: An exploratory study using case studies." *Saf. Sci.*, 55, 119–134.
Wanberg, J., Harper, C., Hallowell, M., and Rajendran, S. (2013). "Relationship between construction safety and quality performance." *J. Constr. Eng. Manage.*, 10.1061/(ASCE)CO.1943-7862.0000732, 04013003.
Yin, R. K. (2009). *Case study research: Design and methods*, 4th Ed., Sage, Thousand Oaks, CA.

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