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Reduce Rework, Improve Safety: An Empirical Inquiry into the Precursors to Error in Construction

Abstract: A positive association between rework and safety events that arise during the construction process has been identified. However, empirical lines of inquiry to determine the precursors to these events have not been forthcoming. In addressing this gap, this paper presents knowledge to begin to fill this void. In-depth semi-structured interviews with operational and project-related employees from an Australian construction organisation were undertaken to examine the precursors to rework and safety events. Analysis of the interviews enabled the the precursors of error to examined under the auspices of: (1) People; (2) Organisation, and (3) Project. The analysis also revealed that the precursors to error for both rework and safety incidents were similar. With this in mind, a conceptual framework to simultaneously reduce both rework and safety incidents during construction is proposed. It is acknowledged that there is no panacea that can be used to prevent rework from occurring, but from the findings presented it is suggested that a shift from a position of 'preventing' to 'managing' errors is required to enable learning to become an embedded feature of an organisation's culture. As a consequence, this will contribute to productivity and performance improvements being realized.

Keywords: Error, error prevention, error management, learning, rework, safety

Introduction

For several decades, rework has been identified as a significant and recurring problem in construction projects (e.g., Burati *et al*., 1992; Abdul-Rahman, 1995; Willis and Willis, 1996; Barber *et al*., 2000; Hwang *et al*., 2009; Love *et al*., 2016a). The adverse consequences of rework have been widely espoused, including damage to reputation, loss of productivity, and reduced profitability. Anecdotally, it has been observed that the underlying conditions that contribute to the occurrence of rework in construction projects have been recognised as the main contributors to safety incidents (Love *et al*. 2016b).

If rework can be reduced, then significant improvements in safety performance can be achieved. Considering the amount of rework causation research that has been undertaken, Love *et al*. (2016a) has suggested that its likelihood can be reasonably predicted based on the pathogenic influences that exist. This view aligns with the National Academy of Engineering in the United States (US) which has suggested that the precursors can contribute to predicting fatalities and disabling injuries. Here precursors are defined as "a reasonably detectable event, condition, or action that serves as a warning to a fatal or disabling injury" (cited in Alexander *et al*., 2017a).

Precursor analysis aims to model historical data to predict potential accident scenarios (Alexander *et al*., 2017a;b). Wu *et al*. (2010) have identified a series of precursors for scaffolding operations, such as wearing fall protection and missing scaffolding boards. The precursors included the immediate and latent conditions related to scaffolding work. Similarly, Zhou *et al*. (2014) have identified a series of causal factors that lead to subway collapses. According to Alexander *et al*. (2017a) precursor analysis remains in its infancy, specifically as there is no comprehensive codified list of causal factors that can be used to deterministically predict safety incidents. The determination of the precursors for rework and safety incidents is a novel new line of inquiry.

With this in mind, a sensemaking approach (Weick, 1995) is used to identify the precursors to error for rework and safety incidents from a series of semi-structured interviews undertaken with an Australian contractor. Analysis of the interview transcripts enabled the precursors of error to be clustered into three themes of People-Organisation-Project (POP). These constructs are used to propose a conceptual framework and recommendations to reduce rework and improve safety

performance in construction. The developed conceptual framework provides the basis to better understand the interdependency that exists between precursors to error for rework and safety incidents (i.e. (i.e. unsafe acts and workplace injuries[1]). In addition, it serves as an avenue for further research in this unexplored and potentially fertile area.

Theoretical Framing of the Research

The etymology and etiology of errors have been widely discussed in industrial and organisational psychology, construction, engineering and safety literature (e.g., Blockley 1985, Melchers 1989; Paté-Cornell, 1990; Dekker, 2001; Van Dyck *et al.*, 2005; Hofmann and Frese, 2011; Hong and He, 2015). They can be classfied as: (1) action errors (i.e., goal orientated behaviour 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) violations, which are a conscious intention to break rules or not conform to a standard (Hofmann and Frese, 2011); and (3) judgment and decision-making which arise due to cognitive biases and heuristics (Weber and Johnson, 2009).

Errors in judgment and decision-making (cognitive biases and heuristics) are difficult to contextualise. Mousavi and Gigerener (2011) have stated that "human judgments are usually considered erroneous when measured against logical and statistical norms of rationality" (p.97), as the context within which a decision is being made is not considered and given sufficient meaning/recognition. The research presented in this paper is confined to examining errors of action and violations, as they imply non-attainment of a goal and non-conformity and therefore peoples' experiences are drawn upon to derive meaning and understanding of these non-conformities. Moreover, the paper does not examine those errors that lead to an engineering failure and the adverse consequences that may arise.

Instead, the research examined failure to conform to specifications or requirements resulting in a non-conformance (NCR) being issued, which then requires corrective actions to be undertaken.

[1] An injury or illness that is work-related whereby an event or exposure in the work environment either caused or contributed to the resulting condition or significantly aggravated a pre-existing injury or illness.

Inexorably, additional work is required to rectify the non-conforming product to ensure it complies with the required specifications unless the NCR is classified as a deviation that is within the acceptable threshold stipulated within the specifications. The rectification process of an NCR is referred to as *rework*. A consequence of rework is that safety incidents can materialize (Wanberg *et al*., 2013; Love *et al*., 2018).

Numerous definitions of rework have been propagated in the extant literature. Love (2002), for example, has defined rework as the "unnecessary effort of redoing a process or activity that was incorrectly implemented the first time" (p.19). This definition is all-encompassing and includes design changes and errors that result in the rectification of works during construction. Contrastingly, Robinson-Fayek *et al*. (2004) refer to rework as the 'total direct cost of re-doing work in the field regardless of initiating cause' and specifically excludes change orders and errors due to off-site manufacture (p.1078). For the purposes of the research presented in this paper, the rework definition proposed by Robinson-Fayek *et al*. (2004) is adopted as the influence of design changes and errors are not considered.

Figure 1 presents a conceptualisation of the causal chain for rework. Here precursors are aligned with Reason's (1990) concept of pathogens, which are the strategic and economic decisions that can influence the way in which a construction organisation processes information. These precursors like pathogens emerge as a result of people, the organisation, and project (POP) actions and decisions and therefore impact the way risk is managed. Moreover they create an environment for errors to happen (Reason, 1990; Reason, 2008). Before these precursors become apparent, individuals, site management teams and organisations often remain unware of the impact that particular decisions, practices and procedures can have on a project's performance and productivity (Busby and Hughes, 2004). The conditions that reside within and between organizations that participate in the construction of a project can influence individual and organizational errors (Reason, 1990; Goodman *et al*., 2011). The creation of these conditions will vary from project to project, but will tend to revolve around strategic decisions made at their outset (Love *et al*., 2009). Such strategic decisions may create latent errors, which can reside in a period of incubation; when they are combined with active failures the prevention mechanism that may have been put in place in projects are often disregarded (Reason, 1990).

At the individual level errors that occur are attributable to one person whereas two or more people share those of a team or organizational nature. Pivotal to abating error is a project team's ability to openly communicate (Sasou and Reason, 1999). Thus, individuals (people) teams (project) and organisations (organisation) can hinder or assist error detection depending upon their ability to keep the channels of communication open. (Sasou and Reason, 1999: cited in Frese and Keith, 2015:p.664):

- *Organizational rules or standards may determine the type of errors that can appear*: For example, Reason (1990) observed that when 'checklists' are put in place, people make errors in those areas that are not regulated. Yet, when checklists are not adhered to, there is a tendency for errors of omission to arise;
- *Team members can help to determine the occurrence of error cascades:* Team members may detect or even correct errors, reducing the tendency to escalate into more errors. For example, with the advent of Building Information Modelling (BIM) project team members can learn to detect errors through the process of clash detection, communicate them to the affected party and observe a protocol for handling them. On the negative side, some parties may increase the amount of errors that are experienced as they may not have the skills and experience to deliver the level of detail required within a BIM environment and thus rely on others to identify and possibly fill the information gaps; and
- *Teams or organizations do not always correct individual errors*: When people work together in teams there is a propensity for *social loafing* (i.e., the phenomenon of people exerting less effort to achieve a goal when they work in a group than when they work alone) to arise (Latane *et al*., 1979). As a result, some team members place reliance on others to achieve the goals that have been established. Working in teams may produce an atmosphere where people can lose sight of their responsibilities so they do not make the necessary observations or share fully collective decisions or actions. Moreover, if people are not provided with sufficient information through communication, then they are unable to detect errors (i.e. individual and shared). This has led Sasou and Reason (1999) to suggest that how people communicate is important, and leads to the question why only selective aspects of information are actually communicated. Reasons for this proffered by Sasou and Reason (1999), include: people are too busy performing their daily tasks, over-stimulation due to the

seriousness of the event, or simply not being aware of the importance of the task or observation. Having access to inadequate resources and being subjected to time constraints not only creates errors but can also hinder their detection.

Communication and sharing knowledge within project teams is essential for detecting and preventing errors. Within construction, the barriers to effective communication have been a source of contention since the publication of the report on the United Kingdom construction industry by Banwell (1964) over fifty years ago. Enabling effective communication within construction principally requires collaboration and the establishment of trust, which needs to be engendered through leadership and a culture that is attuned to learning.

Quality and Safety Performance

While human error is a common denominator for rework and safety incidents, an examination of the relationship between these constructs has been limited (Wanberg *et al*., 2013; Teo and Love, 2017; Love and Teo, 2017). In Wanberg's *et al*. (2013) study, data from 32 projects (a combination of commercial, residential and civil projects) was used to examine the association between quality and safety performance; though only 18 projects were used in the analysis. The following safety performance data were obtained from each project: (1) recordable injury rate (i.e., number of recordable injuries per 200,000 worker-hours); and (2) first-aid injury rate (i.e., number of first-aid injuries per 200,000 worker-hours). Wanberg *et al.* (2013, p.4) defined recordable injuries as "any injury that results in death, days away from work, restricted work or transfer to another job, medical treatment beyond first aid, or loss of consciousness", and first-aid injuries as minor injuries that require one-time treatment. Wanberg *et al*. (2013:p.9) research revealed that:

- recordable injury rate per 200,000 worker-hours and number of worker-hours related to rework per US$1 million project scope (n= 9, r^2 is 0.937, and *p*-value is 0.032);
- recordable injury rate per 200,000 worker-hours and the number of worker-hours related to rework per 200,000 worker-hours (n=9, r^2 is 0.977, and *p*-value is 0.011);
- first-aid rate per 200,000 worker-hours and number of defects per US$1 million project scope (n=15, r^2 is 0.548, and *p*-value is 0.009); and

- first-aid rate per 200,000 worker-hours and number of defects per 200,000 worker-hours (n=16, r^2 is 0.722, and *p*-value is 0.0011).

Wanberg *et al.* (2013) concluded that the recordable injury and first-aid rates were positively correlated to the number of rework hours and defects respectively; thus, a project with a poor quality performance has a higher likelihood of injuries. Although the findings by Wanberg *et al.* (2013) provided valuable insights, the sample size of the study was relatively small (with *n* ranging from 9 to 16) and comprised a heterogeneous mix of projects (from the United States and other countries). Using data provided by a contractor for the period 2007 to 2015, Teo and Love (2017a) replicated the research of Wanberg *et al*. (2013) using a larger homogenous dataset comprising 569 projects. A total of 19,314 cases of NCRs were recorded with 47% (n=9,098) being classified as 'rework', 48% (n=9,229) as 'used-as-is', 3% scrap (n=540), and 2% (n=448) were not classified. The mean number of NCRs per project was 92.

Of the 569 projects that were examined by Teo and Love (2017), 456 reported injuries, and a total of 17,783 injuries were recorded. Injuries were further categorised into four main types: (1) lost-time injury (LTI), (2) first-aid injury (FAI), (3) alternate work injury (AWI), and (4) medical treatment injury (MTI). Teo and Love (2017) analysis of the 456 projects revealed that the Pearson-*r* values (0.007-0.317) and coefficient of determination r^2 (0-0.100) were low indicating a weak association between quality and safety rates, which were contrary to the results presented in Wanberg *et al*. (2013). The *p*-values did not indicate any significant association between first–aid and quality rates, except for the injury rate and rework frequency per million scope, which yielded an *r*-value of 0.307 and *p*-value 0.046 that were significant at 0.01 level.

Apart from the limited nature of Wanberg *et al*.'s (2013) sample size, another issue pertained to the determination of correlation between ratio variables with a common divisor (e.g. *x/z* and *y/z*), which was personnel hours. In addition, in Wanberg *et al.'s* (2013) research, the recordable injuries, FAIs, and rework were expressed as a ratio per million worker hours and per US$ million project scope. Love and Teo (2017) observed that the use of correlation coefficients of ratios with a common divisor can lead to spurious results. To prevent the aforesaid issues, Love and Teo (2017) undertook correlation analysis between the frequency of quality and safety incidents for

their sample of 456 projects. The results revealed a significant association between frequencies of injuries and quality incidents. The Pearson-r values ranged between 0.653 and 0.896 and the r^2 ranged between 0.426 to 0.803, which demonstrated a significant association. In particular, the association between injuries and rework was significantly strong (r^2 =0.701, p = .000).

Love and Teo (2017) used linear regression to predict injuries from the frequency of rework incidents and the number of person hours worked. The regression results demonstrated that there was a significant association between injury, and rework and personnel hours [$F(2,186) = 202.500$; p = .000]. Both predictors accounted for 68.2% of the explained variability in injury frequency (R^2 = 0.682, and R = 0.8285). The regression coefficients can be used, instead of injury rates, for the purposes of benchmarking and as lead indicators for safety.

Love and Teo's (2017) results provide empirical evidence that there is a positive association between the frequency of quality and safety incidents; that is, the occurrence of unplanned work that can materialise from NCRs, defects or rework, is strongly associated with safety incidents. Although this was a large sample size and it has shed light on the association between rework and safety incidents, further research is required to determine their precursors if rework and safety are to be better managed.

Research Method

To acquire an ameliorated understanding of the relationship between rework and safety incidents, a sensemaking approach is used to comprehend the ambiguity that surrounds the causal relationship between these constructs. Sensemaking is defined as "how people make sense out of their experience in the world" (Klein *et al*., 2006: p.70). In doing so, the process of creating an awareness and understanding situations of high complexity or uncertainty in order to make decisions is enacted. The use of sensemaking is suitable when there is an explicit goal to improve the practices and processes that exist within the workplace.

Due to the complex and dynamic nature of the relationship that prevails between quality and safety, the researchers were cognizant that there would neither be an explicit beginning nor conclusion to the study. Previous research has demonstrated that understanding improves as information

becomes increasingly available, but when presented with additional information and saturation arises, this can hinder the ability to extract meaning (Oskamp, 1965; Omedi *et al*., 2005). However, more often than not, people's confidence continues to increase with additional information being made available and there is then a proclivity to become over-confident rather than gradually accept the phenomena being examined (Klein *et al*., 2006). Naturally, it would be assumed that the sensemaking process follows the progression of data, followed by information, knowledge, and lastly understanding; this is also known as the *waterfall model of cognition* (Ackoff, 1989). However, this may not be the case or applicable in all instances (Weick, 1995; Klein *et al*., 2006); for instance, poor processing of information can lead to inconsequential data being massaged by inferential operations which then materialises as new knowledge. Furthermore, this process can also be misleading as sensemaking does not have a clear beginning and end. In this instance, the waterfall model of cognition runs counterintuitively to the empirical evidence presented for decision-making (Klein *et al*., 2006). Keeping an 'open mind' appears on face value is a way to address the issue, but according to Rudolph and Morrison (2007) a balance between exploration and exploitation (i.e., speculation) of known dynamics is needed to draw appropriate conclusions. These known dynamics were derived from the statistical analysis of the 569 projects.

Data Collection

To derive some form of understanding and meaning about the issues that surround rework and the cause of workplace injuries, a series of semi-structured interviews were undertaken with an Australian contracting organisation's staff. The contractor had previously afforded to the researchers access to their quality and safety data for 569 projects, which were subjected to detailed analysis with results presented in Love and Teo (2017) and Teo and Love (2017). Building upon this quantitative analysis, interviews were undertaken to try and make sense of the association between rework and safety incidents.

Semi-structured interviews were carried out to enable the process of exploration and exploitation. Semi-structured interviews are an appropriate method to collect contextual data when there is limited opportunity to undertake follow-up interviews. This approach provides a clear set of instructions for interviewers and can provide reliable, comparable qualitative data. The inclusion

of open-ended questions also provides an opportunity for identifying new ways of viewing and understanding the imminent topic.

A total of 16 interviews were undertaken with staff in Safety, Quality and Environment (SQE) roles (n=9) and those in project-based (n=6) roles. Each interview ranged from 40 to 75 minutes and was digitally recorded and transcribed verbatim. For the purposes of anonymity, specific role types and projects that interviewees made reference to during the interview were suppressed. The research instrument used to examine rework and safety incidents and their relationship can be found in the Appendix.

Data Analysis

Content analysis was used to analyze the interview data. This process can be undertaken manually or by using computer software such as *NVivo*. This analysis was undertaken manually as the researchers felt that by immersing themselves within the rich content provided would enable them to recollect and reconnect with the dialogue that had occurred. Noteworthy, the transcribed manuscripts resulted in excess of 80,000 words of text being analyzed. Essentially, content analysis is a research method used to determine the presence of certain words or concepts within texts or sets of texts. The presence, meaning and relationships of such words and concepts were quantified and analysed, and inferences were made about the messages within the texts, including the interviewee(s), the audience, and even the culture and time can be included in the analysis. In conducting the content analysis, the text was broken down into manageable categories on a variety of levels – word, word sense, phrase, sentence, or theme – and then examined.

Research Findings

The analysis revealed that there was not only a unanimous view that there was a relationship between quality and safety, but the underlying precursors to error were similar. In addition, these precursors were generally interdependent, and so the occurrences of NCRs and unsafe acts are not the effect of an individual uni-dimensional factor. Interviewees all vociferously called for more attention to be paid to issues surrounding quality, as they deemed rework to be a recurring problem. Surprisingly, not all the costs of rework were known - they were measured in several projects, but not all. Moreover, it was suggested that there was no uniform policy and procedure in place to

determine the costs associated with rework. In this instance, rework costs were simply calculated based on costs associated with product NCRs that required rectification. Although rework is acknowledged as being a problem, there was a perception that it was not being addressed by senior management.

A degree of optimism about the need to actively address rework within the organisation came to the fore. There was an overt acknowledgment that the nature of rework costs needed to be understood and quantified as an interviewee explained:

> "So at the very end of the last job, we sat down with the construction director, the environmental manager, and the safety manager, and agreed on a format for capturing costs. We also agreed on what we believed was all the various costs that needed to be captured. So not just the direct, but also some of the indirect stuff, and we'd sort of set that out. But as I say, we were so sort of far into the project by the time we actually got round to doing all this we just decided it's too late, this one's bolted. But, for the next project we'll be implementing it from the start and we'll be making the project managers, and then the construction managers who sit above them, accountable for reviewing this data and making sure that it is accurate, because they would, at the end of the day, have to sign off, "Yeah". That is what we believe is a fair and truthful estimate of the cost."

While lessons learnt were deemed to be regularly undertaken and a dedicated database established to share knowledge, seldom, if ever, were projects examined to understand 'why' and 'how' they were delivered successfully. It was, in the opinion of the interviewees, that the lessons learnt exercise did not, to their knowledge, result in explicit changes being made at the organisational level to improve the way the future projects were delivered. Instead, individuals with an appetite for 'excellence', usually directors or managers, led this charge in their specific projects. As a result, there was a general consensus that quality and safety performance levels significantly varied between them: that is, as an interviewee stated "when the A team is put on a project, you know you'll hit your targets, make margin and there will be minimal rework and safety incidents".

Rework and Safety: Vignettes

Each interview commenced by asking each interviewee to identify a rework event that they were familiar with or had been actively engaged with resolving. Below are a sample of vignettes that were retrospectively identified and for the purposes of confidentiality the projects where the incidents arose have been concealed:

Vignette One: The face of the XX wall was being constructed and subcontractors were progressively working from the base upwards using a scaffold. Reinforcement was being installed, and concrete poured. As the formwork was being stripped, honey-combing of the concrete was observed due to inadequate vibration. The structural integrity of the wall was therefore jeopardized. The schedule was tight, and despite being aware of this problem, it was decided to keep going with casting the XX wall, and recorded an NCR and attend to the issue at a later date. The decision to meet programme timeline, rather than attend to the problem at hand immediately, resulted in a significant safety incident to occur during the rectification process. The interviewee found it perplexing as to why the work was not rectified immediately, as the safety incident would not have occurred.

A temporary hoist had to be erected so that the rectification works to the dam wall could be undertaken. Two men were then hoisted down the face of the XX wall. The rectification works required drilling and re-grouting of a number of sections of the dam wall. An item fell from the scaffold, and a person slipped, though fortunately no major incident occurred as the worker was secured by their safety lanyard. The incident was recorded as a 'near miss'.

As the interviewee was recalling this incident, they perceived this event to be akin to a choice between 'production versus protection' issue. In fact, the interviewee went further and made the following comment "for me, this example spoke profoundly of what typically happens across…or, in most

cases across our industry and our business. This constant short-term thinking, production pressure, just almost speed at any consequence, almost literally".

Vignette Two: A bridge over a railway line required work. The subcontractors that had been appointed to undertake the project were not experienced with working in rail corridors. They were, however, deemed to be very professional civil engineering subcontractors with considerable experience at constructing bridges, but not over rail tracks. The supervision of the work was undertaken by the contractor. As work was being performed, the contractor's supervisor, for some unknown reason, left the site without informing their colleagues. This resulted in the subcontractor being unsupervised while they went about their work. An employee of the subcontractor was seriously injured and the regulator was required to carry out a full investigation.

The subcontractor feared that if they had admitted to what had happened, there would have been serious repercussions. The subcontractor refused to take responsibility for the incident and stated to the contractor: "I don't know what happened. I was working on a ladder, a train went past, I heard a noise, looked over, and Y had his nose bleeding." However, the contractor's staff knew exactly what had occurred, even though the subcontractor denied any knowledge about how the incident had occurred. The ladder was placed incorrectly in the rail corridor, which was confirmed by the train driver and its camera. The worker dismounted from a ladder holding a piece of a reinforcement and was startled by the train passing them. As the worker turned away, the train struck the reinforcement bar, which then hit the worker in the face. What had transpired was that the subcontractors had been having difficulty inserting a reinforcement bar into a shutter box, and had to replace it prior to a concrete pour for the abutments of the bridge.

> The contractor's supervisors were reprimanded and counselled about the incident. The interviewee stated: "There was counselling. I'm a big fan of accountability, and it's not always the big stick, but I think people fear rework because they think, "Well, if we have a significant amount of rework then we'll be punished." For me it's about, well, let's try and learn why it happened, so we can stop it from happening on the next job". The interviewee stated: "I think in general our organisation is pretty good with supervision. We're very hard on our own people. We don't want subcontractor supervision because we've got a set way of doing things. But, as the bridge incident showed, even our own guys can sometimes lapse, and in the end we almost…we could have killed someone".

Issues surrounding supervision and time constraints were recurrent themes that were identified and discussed, which often led to risky behaviour occurring; that is, the taking of short-cuts. The relationship between poor (or lack of) supervision and taking short cuts was emphasized by an interviewee who drew from an example where bored piles that were too long, had been delivered to site. As a result, the subcontractor decided to 'trim' their toes on-site. However, the toes had additional helical sections of reinforcement, which were cut-off. This then impacted the piles strength at their toe. In explaining the reason for this issue and taking responsibility for the incident, the interviewee stated:

> "It was just the quickest, simplest solution as far as the sub-contractor was concerned. We weren't managing them well enough to say, "Guys, if you want to make a change, whatever it is, you come tell us and we will tell you whether we're happy that you do that".

The rework did not result in a direct safety incident that was officially recorded, but a series of unsafe acts (e.g., not wearing safety glasses and gloves) were identified during the trimming process. The examples of rework incidents where safety issues generally arose were in the following areas: (1) piling; (2) concreting; (3) structural steel; (4) temporary works; and (5) associated rail works.

Precursors to Error

A detailed examination of the transcripts confirmed that three underlying themes that engendered the enactment of errors: (1) People; (2) Organisation; and (3) Project (POP). Notably, there is a degree of subjectivity surrounding this classification, but it provides a basis to understand the precursors of errors within project environments (Lopez *et al*., 2010). Moreover, the use of a POP acts as a mechanism to contextualise and provide meaning to the latent pathogens that may prevail. From the rework and work place injury examples that were drawn upon by the interviewees, mistakes and violations that manifested from the strategic decisions taken at the POP levels were identified as the recurrent issues.

Figures 2 and 3 summarize the key themes that emerged from the interviews. It can be seen that the issues that contribute to rework and safety are almost identical. More detailed findings are presented in Figures 4 to 6 under the POP nomenclature. Noteworthy, a high degree of interdependency exists between the emergent constructs, for example, between the constructs of 'risk behavior' and 'schedule pressure', and 'social distance' and 'knowledge and skills'. Social distance among workers refers to seniority, age and social norms where the experiences of older workers were ignored or overlooked while undertaking a task (Alexander *et al.,* 2017a). For example, younger (or those less experienced) workers ignore the advice from their peers with regard to hazards or how to correctly perform a task.

Insert Figure 2. Precursors of error for rework

Insert Figure 3. Precursors of error for safety incidents

People

The adoption of 'risky behavior' by subcontractors was considered to be driven by pressure of time and cost constraints (Figure 4). However, 'not getting it right the first time' placed even more pressure on subcontractors, which had been observed to lead to further risky behavior. While several interviewees suggested that from the many instances of rework that they had observed or managed, the issue of subcontractor's skills and knowledge, and their ability to perform work was often raised. There appeared to be no vetting of the subcontractor's workforce and the

responsibility of ensuring work could be performed to the required standards and safety levels, was being placed on their management. In cases where safety incidents occurred due to 'risky behavior' there was a general consensus it was due to violations, which tended to occur when there was limited or no supervision being provided by the contractor.

Insert Figure 4. Examples of 'people' precursors to error

It was noted that during a project's start-up, resources were minimal and considerable pressure was placed on the contractor's site staff to award contracts, implement systems and procedures, and ensure availability of plant and equipment and procurement of materials. During this period, substructure works are typically undertaken and temporary works installed. This is a vulnerable period in a project and was identified as being prone to experiencing rework which could potentially lead to unsafe acts occurring. Supervision at this point in time is therefore imperative. There was a general view that to prevent 'risky behavior' from occurring and becoming a norm within a project, there was a greater need for education, and open and honest dialogue between the contractor and their subcontractors about their needs and requirements.

Organisation

At the organisational level, a number of issues were identified as being precursors for error (Figure 5). Schedule pressure was repeatedly identified by the interviewees as a key contributor to both rework and safety incidents. For instance, schedule pressure was exacerbated by a lack of resources, which resulted in less supervision, and people adopting 'risky behavior' leading to rework and safety issues, and reducing profit margins for the organisation. This is, however, contrary to the general perception that projects were under-resourced so as to maximize their organisation's margins. In fact, minimizing resources had created the opposite effect caused by rework and safety issues. Moreover, the established programmes for project delivery were generally perceived to be overly optimistic and it was suggested that more attention to detail was needed in the planning of the execution of projects. In short, be more realistic.

Insert Figure 5. Examples of 'organisation' precursors to error

Issues surrounding how the function of quality was being managed within the contractor's organisation were identified as another key concern. There was a perception that the quality function was no longer given the recognition that it deserved. For example, the interviewees considered that there was no commitment by their senior management to reduce the occurrences of rework. There was a general feeling that management were only concerned about safety and environmental issues.

Yet, in terms of the safety function, the organisation had only placed emphasis on *lagging indicators*, which were deemed not to be useful mechanisms for preventing safety issues. In fact, an interviewee expanded further on this point by stating "we're not very good at learning from other jobs particularly safety issues and assessing the risks of having to do additional work that's not been planned". Here a call was being made for the development and use of *leading indicators* that could be used to 'anticipate' the likelihood of rework and safety issues. Not all unplanned works will result in an unsafe act being committed. But, there is a possibility, and therefore it needs to be anticipated and managed so that mechanisms can be put in place to alleviate this likelihood.

Project

A lack of managerial commitment to quality at the organisational level had been transferred to projects. This became apparent during the interviews as it was identified that policies and procedures were being applied differently and inconsistently across projects; strategic disconnection had been manifested. Even though there was a strategy in place to ensure and maintain quality, those project managers who were driven to achieve their margins had only 'paid lip service' to it (Figure 6). There was a general perception that the reporting of NCRs was frowned upon by senior management and as a result had been blatantly discouraged by some project managers. On the other hand, there was only one interviewee who stated that they had been encouraged to report rework in a project, with the expectation that continuous improvement would be initiated. However, staff soon became cognizant that there was no commitment to engage with any form of continuous improvement as site management preferred the comfort of *status quo*.

With increased emphasis being placed on safety due to legislative requirements, the importance of quality had seemingly diminished within the contractor's organisation. Dedicated quality roles

were being gradually eroded and incorporated within the remit of safety and environment, which had resulted in structural change occurring within the organisation. However, quality is pivotal for engendering and managing change and improvements to business processes. While there were examples where quality excelled, it was only being enacted in those projects where staff were being led by project directors/managers who strove for and promoted a willingness to learn from previous experiences/failings.

Insert Figure 6. Examples of 'project' precursors to error

From the interviews, it was observed that within the contractor's organisation emphasis was placed on the prevention of errors; essentially, a zero-tolerance prevailed. This was noticeable, given the limited evidence of counselling that was provided after a rework and/or safety incident had occurred (with the exception of vignette two example presented above). But, rather than providing additional training, and as described in several rework and safety incidents, offenders committing an unsafe act were severely reprimanded or even lost their jobs (Figure 6). This does not create an environment conducive to their immediate reporting.

Discussion

Reducing and containing errors that contribute to rework and safety incidents is a complex and challenging task. The conditions that contribute to people making errors are often highly interdependent. There is no 'silver bullet' that can eradicate such conditions, but acknowledging that they exist and putting in place mechanisms to mitigate their impact as well as learning from their experiences will provide foundations for improving quality and safety performance.

Every organisation in the construction industry will be confronted with errors. Yet, the mere existence of errors is often shunned by construction organisations, as they are associated with failure (Lopez *et al*., 2011). In many instances, errors can be corrected without significantly affecting people's daily routines and tasks, but some, as identified from the findings, can lead to an increase in the likelihood of safety events occurring. In the case of the contractor organisation, there is a need for them to openly acknowledge that errors can happen, if they are to improve their performance.

Skilled and routine tasks are regularly carried out on-site reliably, but the potential for error and biased decision-making significantly increases in novel situations, such as when unplanned work arises. In these instances, people's ability to process information is hindered, especially when they are subjected to time and cost constraints. At times of stress and uncertainty, the probability of mistakes increases, no matter how conscientious the person is. So, when an error is committed there is no point reprimanding the person, as there is no intention whatsoever to cause the error in the first place. But, the fear of being chastised results in people not reporting errors.

What can be gleaned from the interview findings is that a culture of *error prevention* prevailed within the contracting organisation. This approach assumes that errors can and need to be prevented; yet this view highlights the fragility of human beings, as errors will undoubtedly occur. Within the contracting organisation, errors have had a negative influence on the quality and safety performance of their projects. This clearly has been confirmed from the interview findings and was previously demonstrated in many of the 456 projects that were initially examined between 2007 and 2015 (Teo and Love, 2017; Love and Teo, 2017).

While individual errors have contributed to rework events and safety incidents, the interviews indicated that 'organisational errors' were also at play. In essence, organisational errors refer to the actions of multiple participants who deviate from specified rules and procedures, which may result in adverse outcomes for the contractor in their projects (Goodman *et al.,* 2011). For example, 'supervisors' failed to carry out an inspection or check items prior to installation due to a lack of resourcing; the basic feature of an organisational error is when multiple individuals diverge from the expected practice/standards required by the organisation.

Moving Toward the Mitigation of the Precursors to Error

Figure 7 provides a conceptual framework of the key issues that may need to be considered simultaneously to reduce rework and improve safety within the contracting organization. It is suggested that changes are required in people's behavior, the organisation's culture (i.e. shared norms and values and a set of common practices) and leadership at both the corporate and project levels if quality and safety performance is to improve in the context of the case organisation. This view also marries with the views identified by van Dyck *et al*. (2005) and Frese and Keith (2015).

Such changes would require the contractor to 'offload some of their existing organisational baggage' by stimulating a process of unlearning, so that old routines and beliefs can be supplanted by new ones. To engender the change that is needed to improve quality and safety performance will require a 'champion' who possesses authentic leadership traits, which include (Walumbwa *et al*., 2008):

- *Self-awareness*: An on-going process of reflection and re-examination of their own strengths, weaknesses, and values;
- *Relational transparency*: Openly sharing their own thoughts and beliefs, balanced by a minimization of inappropriate emotions;
- *Balanced processing*: Solicitation of opposing viewpoints and fair-minded consideration of other viewpoints; and
- *Internalized moral perspective*: A positive ethical foundation adhered to in their relationships and decisions that is resistant to outside pressures.

Such a leader would place emphasis on building their legitimacy through honest relationships with followers, who value their input and are built on an ethical foundation. Generally, authentic leaders are positive people with truthful self-concepts who promote openness. Changing organisational and project culture is a mammoth undertaking and would be an impractical proposition to the contracting organisation. Therefore, under the guidance of a 'champion' it is suggested that the contractor would need to shift toward adopting an *error management* approach as it provides an environment to learn from experience. This is "an approach directed at effectively dealing with errors after they have occurred, with the goal of minimizing negative and maximizing positive error consequences" (Frese and Keith, 2015: p.661). In this instance, error management can be used to supplement existing routines and practices, though the contractor would be required to ensure 'no blame' becomes an explicit part of its mission and vision.

Insert Figure 7. Mitigating the precursors of error

The fostering of an open, 'no blame' equitable culture is pivotal to ensuring employees can report and share their experiences without fear of being reprimanded. Subtle, but distinctive changes can

be introduced to modify the behavior of people, such as the introduction of knowledge sharing forums (i.e. openness to errors) that are undertaken on a regular basis with the aim of stimulating a self-perpetuating cycle of learning. Accordingly, a *process of socialization* can be used enact new routines and practices; that is, "the way we do things around here" (Love and Smith, 2016)

Error Identification and Recovery

Error management is essentially the process of detecting and responding to threats and errors, and to ensure that the ensuing outcome is inconsequential; that is, the outcome is not an error, further error or an undesired state. Error consequences are avoided by engaging in an 'error process' comprising of: detection, explanation, handling and recovery (Frese and Keith, 2015). In this instance, every effort is made to mitigate the negative consequences of an error and reduce its occurrence in the future (secondary error prevention).

Detection of errors is the most important aspect of error management (Sellen, 1994; Zapf *et al*., 1994). It is imperative for those charged with leading and managing a project to reinforce a no-blame environment through their advocacy. Error detection is defined as knowing, either consciously or subconsciously, that an error has occurred (Sellen, 1994). There are two stages of evaluation (Van Dyck *et al*., 2005),: (1) *error identification*, which is knowing what was done wrong and what should have been done; and (2) *error recovery*, which involves knowing how to undo the effect of the error and achieve the desired state.

Encourage Responsibility

Individuals should be encouraged to take responsibility for errors that they commit (Van Dyck *et al*., 2005; Frese and Keith, 2015; Love and Smith, 2016). As noted above, blaming an individual for an error is simply unproductive, but is also unconducive to learning; this not only applies throughout the contractor's organisation, but also to their subcontractors. Blaming an individual, consultants or subcontractors involved in the action can damage relationships that have been fostered and may even result in tarnishing the organisation's image in the marketplace. It should be acknowledged that forgiveness for action errors (which are unintentional deviations from goals, rules and standards that had been stipulated by the contractor) was evident in some examples. Understandably, there was limited tolerance by the contractor with respect to violations that had

been incurred, especially in the examples provided by interviewees, which more often than not led to blame being apportioned and to people losing their jobs.

Learning

The process of learning from previous actions and events forms the core of an error management approach. The process of learning and the initiation of change to processes and procedures as a result of rework was perceived to have been avoided by the contracting organisation. Making sense and being mindful to continually learn from acquired experiences about the actions that created the error appeared to be absent from almost all those interviewed. When an individual and the organisational mindset that accepts errors arise, then the motivation to minimize them and their impacts can be bolstered. The accumulation of experiences and views derived from the interviews suggest that:

- there is a need to cultivate a culture of mindfulness so that individuals and project teams are able to improvise and handle errors that impact quality and safety so that they are not repeated;
- all members of the contractor's project team including subcontractors (and consultants where applicable) need to be able to learn and understand each other's goals, roles and responsibilities; and
- being prepared for errors and using procedures and systems to shield and screen them out is not acceptable. In this instance, individuals and project teams should try to determine non-routine solutions to mitigate against them.

It should also be noted that when an organisation possesses a 'zero vision' (i.e., striving for no defects and fatalities/injuries), it generally leads to unsatisfactory quality and safety outcomes (Dekker, 2013). Such an attitude stifles an organisation's ability to change and innovate as learning and knowledge are controlled by existing routines. Only one interviewee identified the need to have a zero vision, but there was no evidence presented that this attitude was being exercised within the contractor's organisation.

Coaching

The process of coaching (i.e. unlocking a person's potential to maximise their performance) provides the mechanism to enable the transfer of learning from the individual to the organisational level (Whitmore, 1996). Essentially, coaching can be used by the contractor to enact the new behaviors that are required to initiate and implement an error management culture.

Emphasis is placed on learning by doing, role modelling and explicitly sharing experiences and learnings (Swart and Harcup, 2012). The aim is for peers to emulate each other and therefore a coaching or mentoring style of management is adopted within projects. This type of management style leads to *coaching the coach* and learning through coaching (Swart and Harcup, 2012). As a result, a feeling of commonality is engendered, which can enable the coach to facilitate the absorption of tacit and explicit knowledge about quality and safety issues (Love *et al*., 2015). The learning that emerges can then be embedded into the new routines, procedures and practices. Moreover, such knowledge can provide the contracting organisation with an ability to 'anticipate what might go wrong' (i.e. taking sufficient time to reflect) in their projects, particularly in terms of future quality and safety outcomes.

The use of after-an-action (AAR) discussion, which is a formal conversation but less formal than a review, of an event can enable project members with similar or shared interests to discover for themselves what and why events occurred, and how to address future issues that may arise (Crowe *et al*., 2017). Therefore, project participants are supporting the ability to 'anticipate what might go wrong'. According to Scott *et al*. (2013) AARs provide an environment where informal discussion between individuals results in enhanced by learning and sensemaking in groups and teams takes place. The process of coaching can be used to engender a higher attention to detail due to the mindfulness that is nurtured within the organisation and its projects. Therefore, the mindset that is created enables individuals to collectively recognise and respond to error signals that are being incurred within their projects (Allen *et al*., 2010). The elements of a good AAR, which can be utilized by a coach, have been identified to positively enhance safety norms and climate within organisations (Crowe *et al*. 2017). These are presented in Table 1, and have been modified to accommodate issues that also involve rework.

Limitations

The research has a number of limitations that need to be acknowledged. The sample was restricted to 16 interviewees who had a diverse range of roles within their organisation. There was notably an absence of interviews with people who are operating at the 'sharp-end' of a project and had direct contact with the subcontractors who are prone to committing errors. Therefore, understanding from a subcontractor's perspective the conditions that lead to rework and safety incidents would provide a basis to develop strategies to mitigate their future occurrence.

Taking information out of context by selecting and combining it in hindsight, can also be misleading. This is because the original context and meaning may have become redundant and a new sense is adopted. The social construction of a rework/safety incident cause depends upon the experience and views of all those who were involved with the event, and not solely an individual. The research also did not focus on cognitive failures of individuals (i.e., slips and lapses) with respect to understanding their actions/inactions, however, this is an important area that requires further research.

Conclusion

A symbiotic relationship exists between quality and safety. However, quality was not given the importance it rightly deserved within the contracting organisation that participated in this research. Examples were drawn upon by interviewees to make sense of rework and safety incidents. Drawing on the views and experiences of the interviewees, the underlying precursors of error were identified, which were revealed to be similar for NCRs and safety incidents.

To reduce rework and improve safety, there is a need to move from a position of focusing on error prevention to adopting error management. In this instance, error management can be used to supplement existing routines and practices. The nurturing of a 'no blame' equitable culture is pivotal to ensuring employees can openly report and share their experiences so that learning can occur. The shift towards embracing error management, however, should not be viewed as being transformative, but in the case of the contracting organisation, an evolutionary process to simply re-calibrate its cultural orientation. To cope with the change that is required to improve quality and safety performance, it is necessary to develop new knowledge and skills as well as the ability to

apply integrated ways of thinking. Here the process of coaching can be used to enhance goal attainment, encourage development and support operational and project employees to embrace the change process and shift toward error management.

Further research is required to determine the generalisability of the precursors for rework and safety incidents identified in this paper. The presented work has provided the building blocks to further explore the relationship between quality and safety. Research of this nature should aim to understand the context and focus on developing strategies that can enable organisations in construction to transition from being focused on the prevention to the management of errors. If construction organisations are able to achieve this during the operation of their projects, they will without doubt experience productivity and performance improvements.

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Appendix – Research Instrument

1. Ask the interviewee to select a project that you have been involved with.

2. Can you think of any specific rework event that has occurred in the project that you have selected?

3. Would you be able to describe what you consider to be the events that lead to it occurring and how and why do you think if (they) occurred? What were the consequences of this event?

4. Did any safety event occur? What class of incident outcome or potential occurred? In your opinion, why and how did the incident occur?

5. Was there any form of counselling/additional training provided to those parties who were involved in the safety incident?

6. If violations are identified, then ask the interviewee about the events that lead to people adopting this risky behavior? Again, what were the consequences and was there counselling/training provided after the event?

7. On the project selected ask the interviewee if people were encouraged to openly report rework/incidents/'risky behaviors' (i.e. violations)? If not why?

8. To what extent were rework events and safety incidents, specifically those involving both, were shared with the construction team on-site/subcontractors?

9. Was there any analysis of rework/safety incidents/injuries for the purpose of encouraging learning within the project? If not why? If so, how was this undertaken?

10. When rework was identified what additional precautions were put in place to ensure the safety of people?

11. To your knowledge did you know of incidences where 'near misses' were not reported? Why do you think people did not report near misses on this project?

    a. What system do you have in place to report rework?
    b. What type of system would you like to see in place to report rework?

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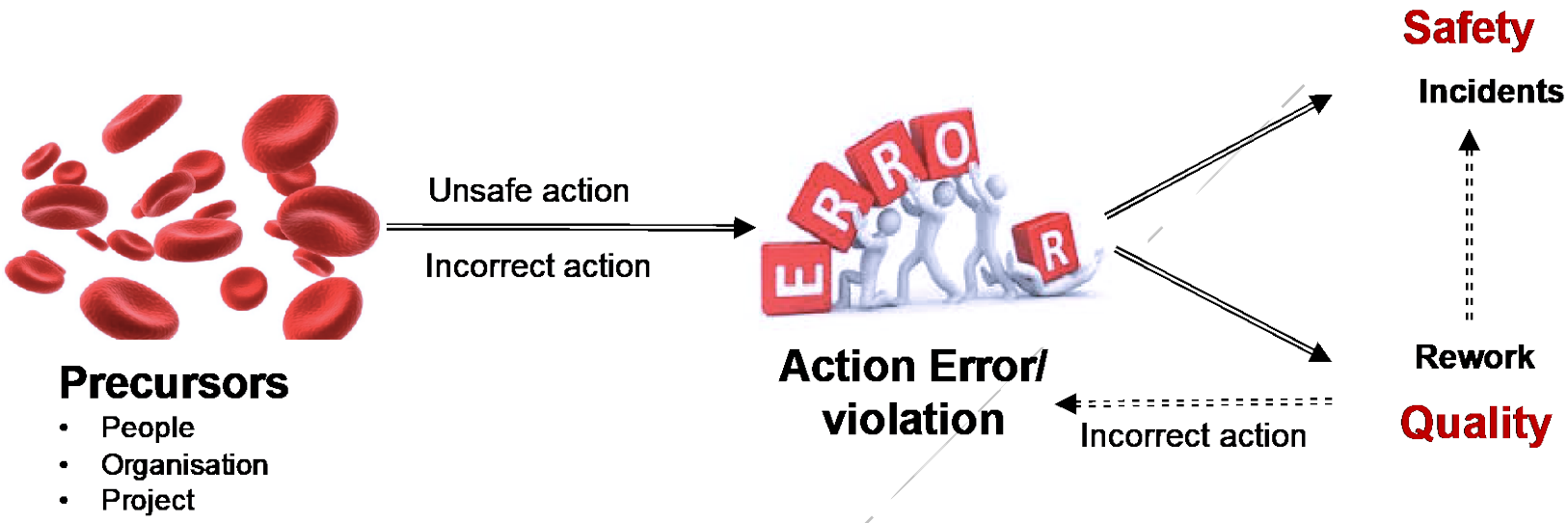
Table 1. Issues to consider in an 'after-action-review' for rework and safety incidents

Issue	Definition	Example
Respect/Safe Environment/Do it Right First Time'	Showing respect for other members of the project team. This can involve emotional respect, active listening and demonstrating empathy for others.	Respect different opinions and versions of events
Requesting Timely and Honest Feedback	Project team members 'openly' discussing issues amongst each other and with subcontractors (S/C).	Seeking ways to improve and new ways of doing things
Accepting Responsibility	Upon recognition of mistakes, focus on what was wrong, not being bad or incompetent allowing criticism to be less personal, allowing a correction of problems	Admitting mistakes and being accountable
Affirmation/Praise	To state or assert a positive manner. Project team members including S/C should be praised for reporting and recognizing error signals	Discuss what went right and why
Sharing Observations and Experiences	Project team members as well as S/C contributing practiced and observed behaviors in a meeting setting	Discussing what has been learned
Specificity	Being precise about what actually contributed to the event happening	Detail account of the event
Prompt	Ensuring the AAR commences on time and does not over run. It needs to be targeted at the specific event that occurred	Should be undertaken as soon as possible after the event
Humor	Any mention of jokes, laughing or comedy	Identifying any funny things that had or may have occurred

Adapted from Crowe *et al*. (2017: p.86)



Insert Figure 1. Theoretical framing of the research (Adapted from Love *et al*. 2011)

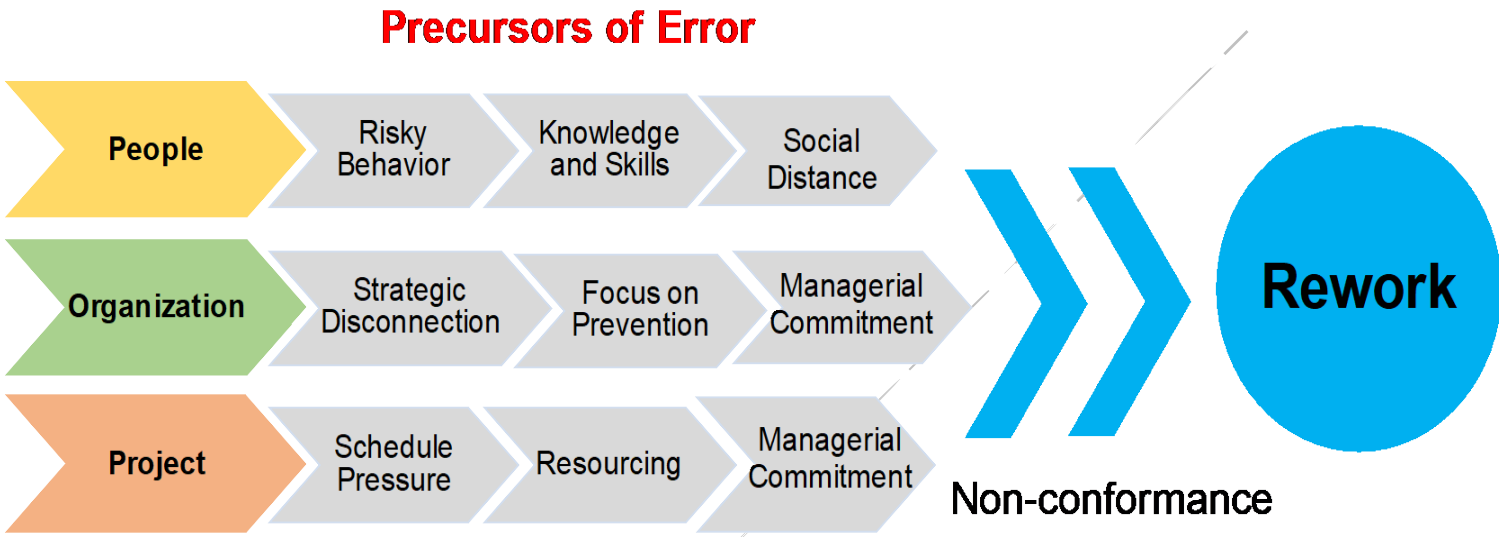


Figure 2. Precursors of error for rework

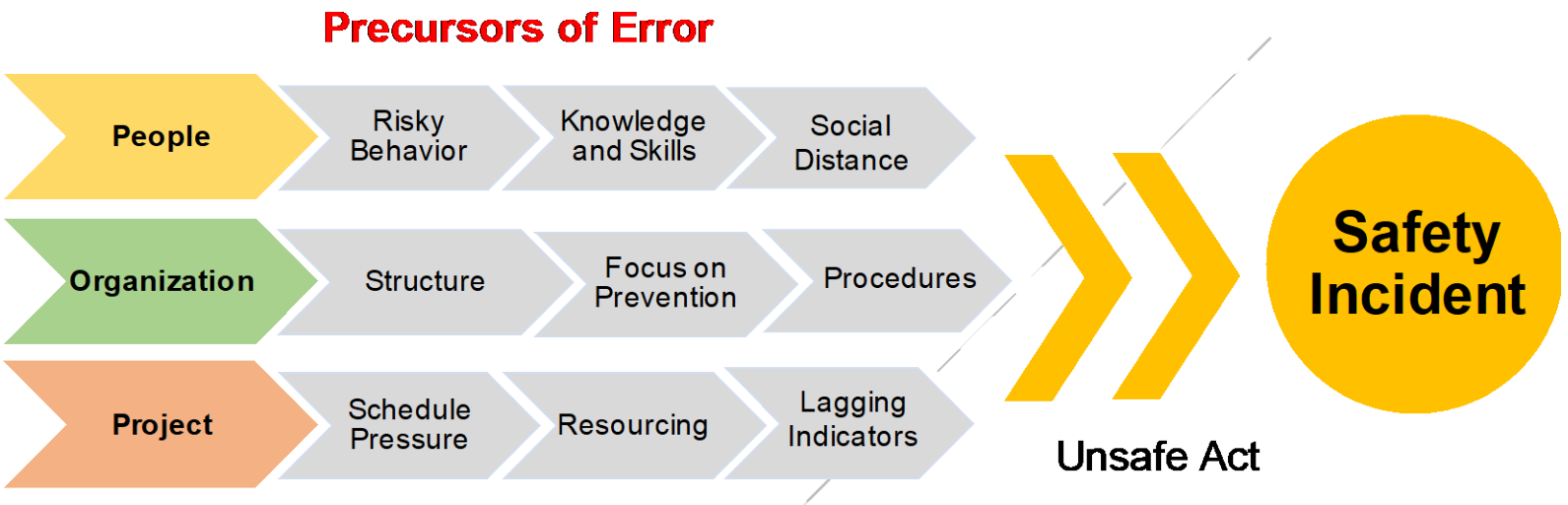


Figure 3. Precursors of error for safety incidents

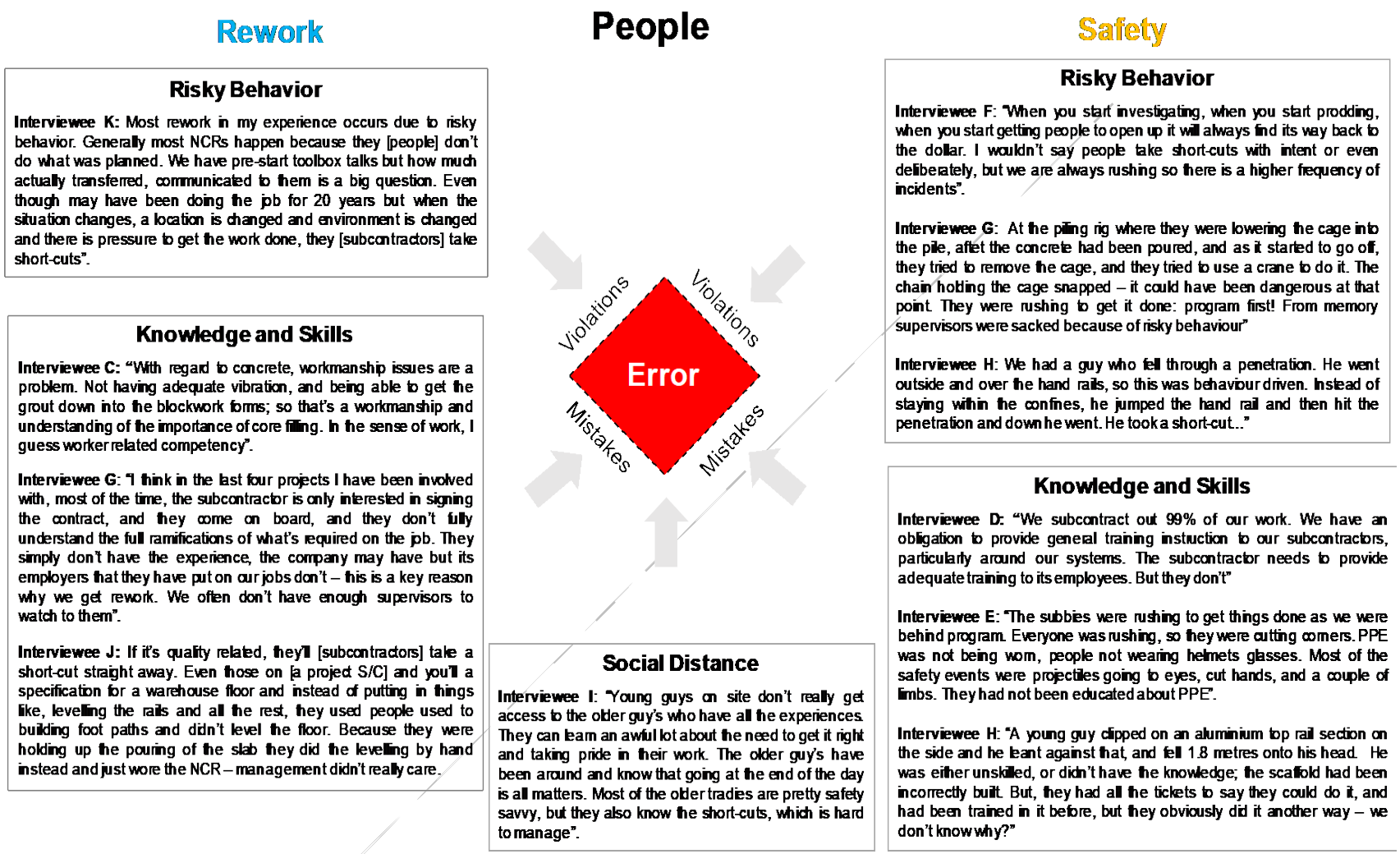


Figure 4. Examples of people 'precursors' to error

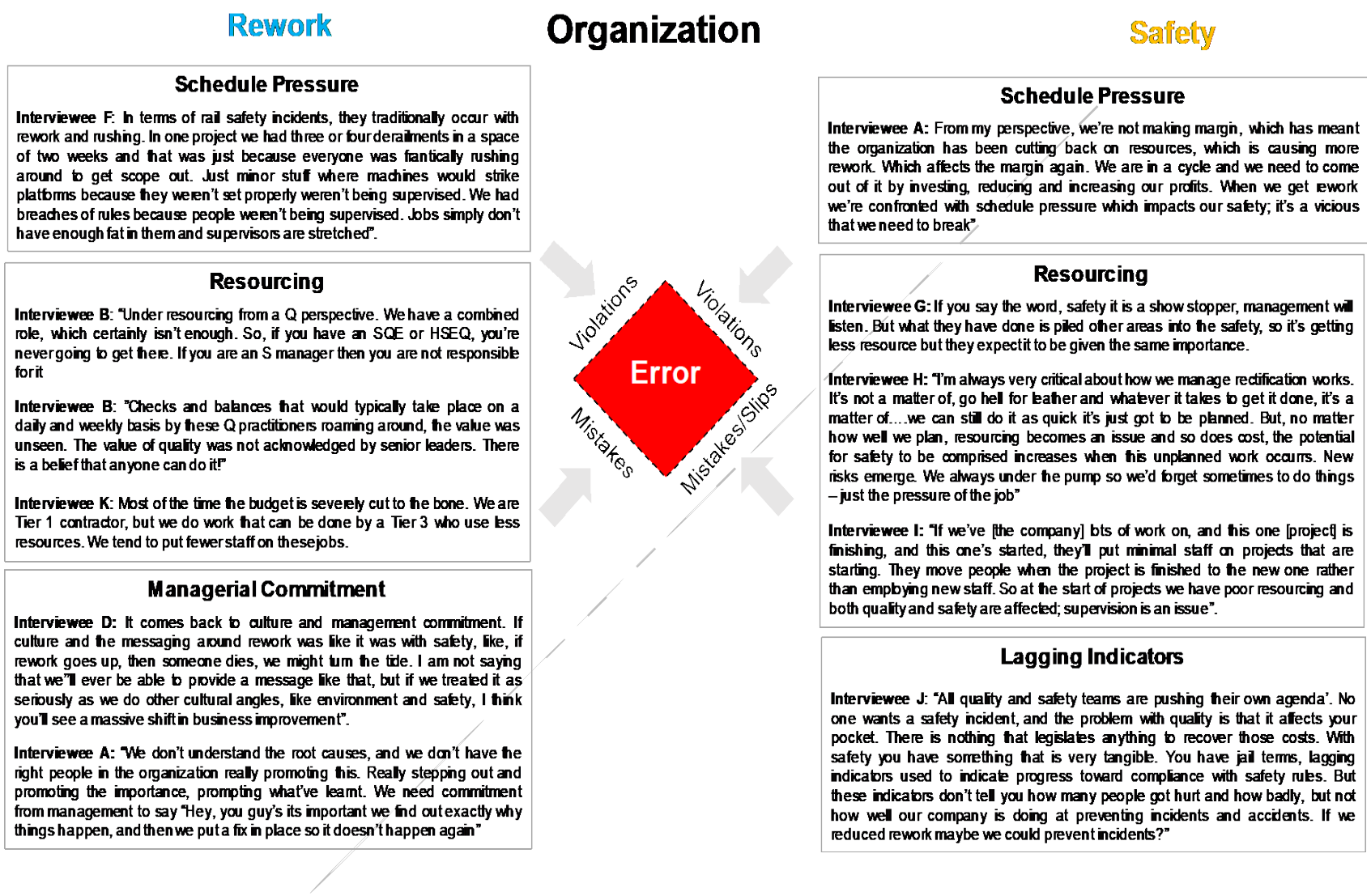


Figure 5. Examples of organization 'precursors' to error

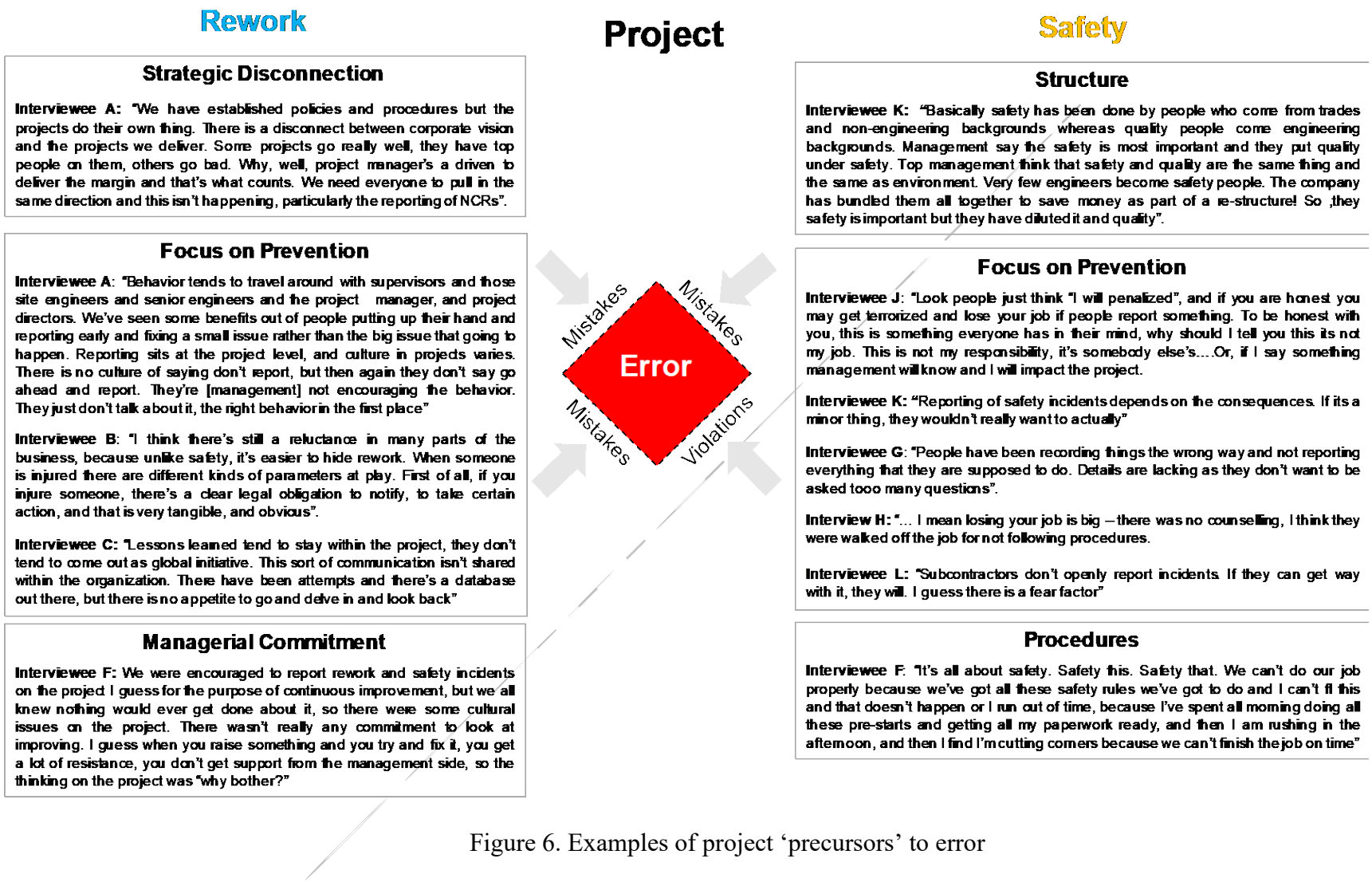


Figure 6. Examples of project 'precursors' to error

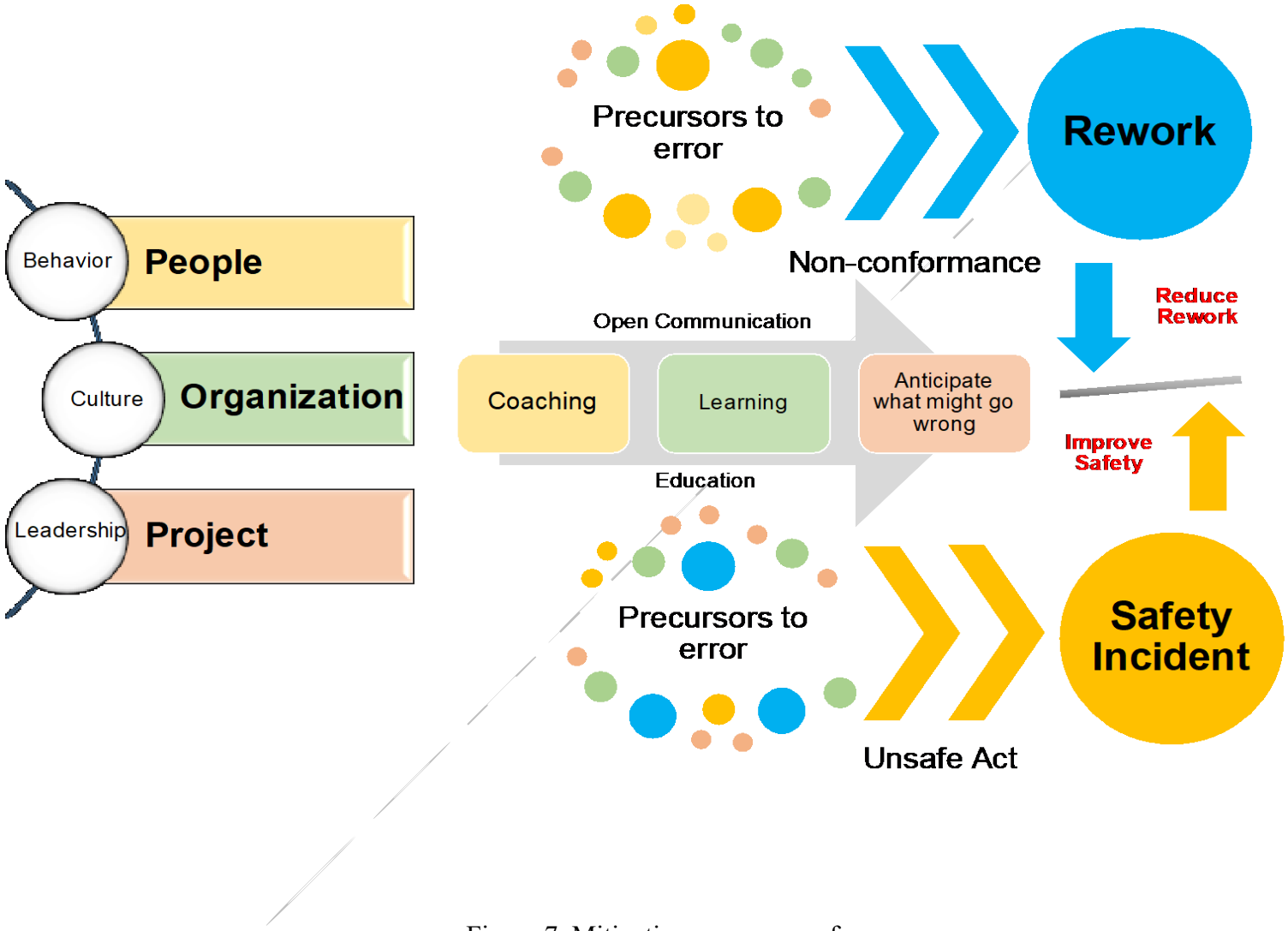


Figure 7. Mitigating precursors of error