From Quality-I to Quality-II: Cultivating an Error Culture to Support Lean Thinking and Rework Mitigation in Infrastructure Projects

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***Abstract* -** While lean thinking may help tackle waste, rework remains an ongoing problem during the construction of infrastructure projects. Often too much emphasis is placed on applying lean tools rather than harnessing the human factor and establishing a culture to mitigate rework. Thus, this paper proposes the need for construction organisations to transition from the prevailing *error prevention* culture (i.e., Quality-I) that pervades practice to one based on *error management* (i.e., Quality-II) if rework is to be contained and reduced. Accordingly, this paper asks: What type of error culture is required to manage errors that result in rework and support lean thinking during the construction of infrastructure projects? We draw on the case of a program alliance of 129 water infrastructure projects and make sense of how it enacted, in addition to lean thinking, a change initiative to transition from error prevention to an error management culture to address its rework problem. We observed that leadership, psychological safety and coaching were pivotal for cultivating a culture where there was an acceptance that 'errors happen' and effort was directed at mitigating their adverse consequences. The contributions of this paper are twofold as we provide: (1) a new theoretical underpinning to mitigate rework and support the use of lean thinking during the construction of infrastructure projects grounded in Quality-II; and (2) practical suggestions, based on actual experiences, which can be readily employed to monitor and anticipate rework at the coalface of construction.

Keywords: Culture, error, lean, psychological safety, quality, rework

1.0 Introduction

The process of rework has been widely addressed in the manufacturing and process-based industries (e.g., Agnihothri and Kenett, 1995; Flapper *et al*., 2002; Flapper and Teuner, 2004; Biswas and Sarker, 2008; Wee and Widyadana, 2012; Ullah and Kang, 2014; Goerler and Voß, 2016; Chen, 2017). Lean production[1], a product of Shingo and Ohno's Toyota Production System (Ohno, 1988), whose goal is "to get the right things to the right place at the right time, the first time, while minimising waste and being open to change" has provided the theoretical setting for organisations in such industries to address rework (Biswas and Sarker, 2008: p.6585).

Manufacturing and process-based industries share similarities with the production of artefacts in construction (Gann, 1996; Crowley, 1998; Meng, 2019). The upshot is adopting lean principles by construction organisations to counteract the 'waste'[2] that often materialises in projects and adversely impacts their performance and productivity (Egan, 1998; Koskela *et al*., 2019; Meng, 2019). Indeed, lean tools such as Value Stream Mapping (Freire and Alarcón, 2002; Michaud *et al*., 2019), Six Sigma (Beary and Abdelhamid, 2005) and the Last Planner® (i.e., based on Kanban) have been shown to "improve workflow and engender a social network among contractors, which enhances coordination" (Priven and Sacks, 2015). Despite these valuable insights, the mainstay of studies has been unable to demonstrate the benefits of lean tools and techniques empirically (e.g., 5S, Andon, Poke-Yoka and Single-Minute Exchange of Dies). A similar experience has occurred in both manufacturing and service organisations where the use of lean has "not been as successful or sustainable as their architects had planned" (Hines *et al*., 2020: p.389).

[1] Defined as "an integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimising supplier, customer and internal variability" (Shah and Ward, 2007: p. 791)
[2] The concept of lean thinking aims to remove waste from work processes. In the context of construction these wastes COSTMORE: (1) Capability under-utilised; (2) Over-processing; (3) Stoppage; (4) Transportation; (5) Motion; (6) Overproduction; Rework; (7) and (8) Excess inventory.

In the context of rework[3], however, the take up of lean thinking by construction organisations has done little to thwart its occurrence. It remains a significant problem (Love and Matthews, 2020). The application of lean principles in construction has focused on managing "the physics of production" using prescriptive operational tools (Howell and Ballard, 1999: p. 33). Consequently, the behavioural and cultural interventions needed to cultivate the process changes required to mitigate rework have been effectively discounted (Love, 2020).

The critics of lean construction point out that it "is confined to the limited domain of instrumental rationality[4]" (Green, 1999: p.21) and shows "little recognition of social and politicised" issues that should be considered during its implementation in construction (Green and May, 2005: p.498). The adoption of lean, a complex and challenging task, entails significant organisational change (Scherrer-Rathje *et al*., 2009; Martinez-Jurado *et al*., 2014). Like any organisational change initiative, people are crucial to its success. However, when implementing lean production, too much emphasis is placed on applying tools and techniques (*hard side*) instead of harnessing the human factor and establishing a culture[5] (*soft side*) to sustain its diffusion (Liker and Hoseus, 2010; Hines *et al*., 2020).

We do not discount the espoused benefits of lean production; it has a valuable role to play in addressing waste and engendering continuous improvement, particularly in construction (Meng, 2019). However, despite the calls by Egan (1998), over 20 years ago, for the construction industry to embrace lean production, the culture that resides within organisations and projects has failed to deliver its purported benefits. Markedly, within construction, an error prevention culture prevails (Love and Smith, 2016). As Frese and Keith (2015) note, "most lay

[3] We define as "redoing work in the field regardless of the initiating cause," which expressly excludes change orders and errors caused by off-site manufacture (Robinson-Fayek *et al*. 2004, p. 1078).
[4] The pursuit of any means necessary to achieve a specific end, especially the elimination of waste in the case of lean.
[5] `

people and scholars think error prevention" is an effective culture to have in place "as it seems right" to prevent errors[6] from occurring (p.665). Contrary to popular belief, however, having such a culture in place hinders an organisation's ability to learn since there is a reluctance for people to report adverse events as they will be blamed for their occurrence (Angelis *et al*., 2011; Dora *et al*., 2013; Frese and Keith, 2015).

So, if headway is to be made to contain (i.e., enhance detection and recovery from errors and violations[7], as well as minimise their adverse consequences) and reduce (i.e., limit its occurrence) rework, then construction organisations need to engender a process of enculturation and socialisation whereby 'learning from mistakes' becomes the norm (Love *et al*., 2019b). After all, rework during construction generally arises due to human errors and violations (Love, 2020). This very failure to acknowledge the role of the human element in containing and reducing rework and the related absence of a learning culture has made it an innate feature of construction practice (Love and Matthews, 2020).

With a burgeoning interest to contain and reduce rework in practice, we, therefore, ask: *What type of error culture is required to manage errors that result in rework and support lean thinking during the construction of infrastructure projects*? If we are to redress rework in projects effectively, we need to understand people's work norms and practices. After all, it is generally the errors committed by people that result in rework, with an organisation's work culture setting the tone and influencing its response and how they cooperate and share information (Westrum, 2014; Love, 2020)

[6] Characterised by Van Dyck (2005) as "unintended deviations from plans, goals, or adequate feedback processing as well as an incorrect action that results in a lack of knowledge" (p.1229). Errors in judgment and decision-making (cognitive biases and heuristics) may result in the performance of rework. However, there have been no studies to date that examined the link between judgement, decision-making errors, and rework. In sum, rework is the consequence of an error or violation. Similarly, a failure is a consequence of an error (Frese and Keith, 2015)

[7] Violations involve a "conscious intention to break a rule or to be nonconforming to a standard; in contrast, errors are unintentional deviations from goals, rules, and standards" (Frese and Keith, 2015: p.663)

Considering the symbiotic relationship between quality and safety (Das *et al*., 2008; Wanberg *et al*., 2013), we take inspiration from the safety literature. Safety thinking has witnessed a positive shift from Safety-I concerned with 'what goes and could go wrong' to Safety-II preoccupied with 'what goes right' in industries such as aviation, health, and nuclear (e.g., Amalberti, 2001; Hollnagel, 2010; Hollnagel, 2013; Dekker, 2014; Hollnagel, 2014). Likewise, we propose a move from a Quality-I, where the focus is on error prevention, to a Quality-II mindset centred on error management.

We commence our paper by providing the theoretical underpinning for the research and outlining the backdrop for our case study (Section 2). The meta-theoretic assumptions of our case-based research method are then described (Section 3). Next, we present the background details for our selected case and explain how it was able to change its culture to better support its socio-technical system and approach to implementing lean (Section 4). Then, we identify our research's theoretical and practical contributions (Section 5) before concluding our paper (Section 6).

2.0 Meta-Theoretical Framing

Construction projects are high risk and complex environments designed, managed, constructed, and regulated by people who interact with technology (e.g., plant and equipment). Consequently, such projects can be classified as *socio-technical systems*. When an activity or process deviates from what has been planned during the production of an artefact in construction, it is then left to people (e.g., engineers and site supervisors) to rectify the problem and mitigate any possible adverse consequences. Thus, a project's success or failure is ultimately dependent on people and how they are led and managed (Walker, 1995). Accordingly, we need to play to people's strengths and effectively provide them with a 'voice' to achieve success in projects (Macomber and Howell, 2004). Suggestions for improvement, especially from organisations that operate at the sharp end of construction, can then be acted upon (Love *et al*., 2019a;b). Thus, drawing on the sage of a contractor's subcontractor is a *sine qua non* condition for containing and reducing rework.

There has been a tendency for studies to identify singular causal variables that explain rework (e.g., Hwang *et al*., 2014; Ye *et al*., 2015; Yap *et al*., 2020). These studies fail to acknowledge the complex and interdependent underlying dynamics that result in rework occurring (Cooper, 1993; Rodrigues and Bowers, 1996; Han *et al*., 2013). What is more, rework often results in the materialisation of waste, such as stoppages (e.g., idle time), transportation (e.g., unnecessary moving of materials) and motion (i.e., unnecessary movements of people), which may occur simultaneously.

When rework takes place, it adversely affects project costs and the profit margin of contractors and subcontractors (Hwang *et al*., 2009; Li and Taylor, 2014; Alexander *et al*., 2019). The determination of rework costs has bedevilled organisations as they lack a systematic approach to trace both the direct and indirect impacts (Robinson-Fayek *et al*., 2004; Love *et al*., 2019a). The costs of rework during construction, excluding change-orders and offsite manufacturing issues, can range from 0.14% to 5% of a project's contract value (Love and Li, 2000). Notably, when change-orders are considered, rework costs substantially increase and can range from 2.5% to over 20% of a contract value (Barber *et al*., 2000; Forcarda *et al*., 2017).

2.1 Old and New Views of Quality

As mentioned in the introduction, we have seen a subtle shift in safety thinking away from *Safety-I* to *Safety-II over the last two decades*. As a result, improvements in safety performance have occurred in several industries. However, in construction, a different story unfolds as safety rates have become asymptotic (Love *et al*., 2019c). Evidence indicates that this plateauing has arisen due to tensions between the ‘competing demands’[8] of quality and safety. These tensions have materialised as construction organisations seek to adhere to safety legislation (Love *et al*., 2018). Of course, safety must be a priority for organisations. Nevertheless, at the same time, quality cannot be downplayed as we know that a significant amount of safety incidents arise while performing rework (Love *et al*., 2019a;b;c). It then follows that if we can reduce rework in projects, then safety performance may improve. Therefore, in line with the shift in safety thinking toward Safety-II, we call for a move from a *Quality-I* to *Quality-II* mindset to ensure alignment with Safety-II but, more importantly, to contain and reduce rework.

Strides towards the dual goals of ‘reducing rework and improving safety’ can be made by construction organisations. Table 1 presents the old and new views of human errors based on Dekker’s (2006) work on safety, which led us to our Quality-I and Quality-II meta-theories. These views provide a context for the case study that we examine in this paper and the basis for its established project culture. The relationship between behaviour and culture is admittedly complicated. However, it can be explained through the lens of *reciprocal determinism*, whereby an individual’s behaviour influences and is influenced by both the social world and personal characteristics (Bandura, 1986). In effect, behaviour determines culture, which drives behaviour. As mentioned above, an error prevention culture prevails in construction projects and thus shapes behaviours toward safety and quality (Love *et al*., 2019a). Concomitantly, it influences the treatment of rework.

[8] This occurs when management, depending on the use of limited resources or attention, requires more to be done than the resources that are readily available (Gaim *et al*., 2018)

Our Quality-II meta-theory is broad and forms part of an “interdisciplinary trend” connected to “the Zeitgeist” (Hjørland, 1998: p.607) that is striving to improve quality in construction after significant building and engineering disasters such as the Grenfell Tower, London (Moore-Bick, 2017), Oxgang Primary School, Edinburgh (Cole, 2018), and Opal Tower, Sydney (Unisearch, 2019) to name a few.

2.2 Quality-I

Behaviour-Based Quality (BBQ) focuses on what people do, analyses the way they do it, and applies an intervention strategy to improve work practices. A behaviour-based program is operationalised by setting goals (e.g., zero defects), putting in place observation techniques, recording and analysing the causes of an adverse event (i.e., using standard approaches such as root cause analysis, incident reporting, failure modes, and effects analysis), and creating an effective communication system (Smith and Valenta, 2018). Markedly, BBQ rewards behaviours that result in ‘getting it right the first time’ and supports the implementation of a lean philosophy in construction (Geller, 2001; Spencley *et al*., 2018; Gomez *et al*., 2020).

Quality, in this instance, is measured by the absence of negatives. Thus, quality performance is high when the number of non-conformances, defects and the like is low. The drive for quality is then epitomised by “zero errors, zero defects, zero rework and zero surprises” as there is a need for perfection at every level of the production chain (Spencley *et al*., 2018: p.1). Cogently, however, implementing a zero-vision goal “can reduce operational knowledge, lead to manipulation of [quality] figures and restrict organisational learning” (Dekker, 2017: p.125).

Table 1. From Quality-I to Quality-II

What Goes Wrong?		**How to Make it Right?**	
Old View (Quality-I)	**New View (Quality-II)**	**Old View (Quality-I)**	**New View (Quality-II)**
Human errors/violations are a cause of poor quality in projects	Human errors/violations are a symptom of problems that reside in an organisation/project (e.g., competing demands, production pressure and procedural drift).	The perception that poor quality and rework are one-off events in projects. Safety (and environment) takes precedence over quality.	Poor quality (e.g., rework) will always be a risk in projects. Key performance indicators in projects are improved, such as programme, safety and environmental performance.
To explain why poor quality prevails (e.g., non-conformance); ascertain why people made errors (e.g., mistakes, slips, and lapses) and committed violations.	To provide an explanation as to why poor quality occurred and *do not* find out where people went wrong	People are unreliable, inconsistent, and undermine defences, rules and procedures of the organisation and its projects	For the construction organisation, projects are a trade-off between competing demands (e.g., quality and efficiency).
Determine the inaccurate assessments, wrong decisions and bad judgments made by people	Instead, determine why people's assessments and actions made sense at the time, given the circumstances that surrounded them	Restrict the human contribution by automating, implementing tighter procedures and controls and supervision to improve quality (e.g., reduce rework) in projects	People have to create an environment for 'getting it right the first time' (and safety) and engage in the process of *collective learning* at all levels (e.g., contractor and subcontractors).

Adapted from Dekker (2006: p.xi)

Behavioural approaches for quality and safety (i.e., Behaviour-Based Safety (BBS)) have been widely proselytised in construction (e.g., Choudhry, 2014; Guo *et al*., 2016; Spencley *et al*., 2018; Gomez *et al*., 2020). Notably, they aim to discourage people from engaging in risky behaviours to prevent errors and violations. The BBS approach widely adopted by construction organisations falls under the auspices of the Safety-I paradigm. Accordingly, it concentrates resources "on rare events, linear causality and individual culpability" (Smith and Valenta, 2018: p.671). However, adherence to a Safety-I mindset has resulted in intractable improvements in construction safety performance (Love *et al*., 2019c).

Suffice it to say, there is a rapprochement between BBQ and BBS (Spencly *et al*., 2018). However, BBQ shares the same shortcomings as BBS. It has been acknowledged, for example, that the Safety-I orthodoxy, akin to BBS, is fundamentally flawed as it is "predicated on individual culpability with errors and adverse events mainly attributable to incompetence, negligence and individual personality deficits such as carelessness, forgetfulness or recklessness" (Mannion and Braithwaite, 2017: p.686). Supporting this orthodoxy, construction organisations engage in error prevention intending to shun the negative error consequences (e.g., rework) "by avoiding the error altogether" (Van Dyck *et al*., 2005: p.1228). While putting 'blame' on employees is not the intent of a BBQ, it is difficult to separate the actions and behaviour that result in a poor-quality outcome. Inexorably, people are therefore blamed for their actions.

Recognising that most applications of the lean production philosophy have been unable to utilise the human element effectively, the principle of 'respect for people' has been incorporated to improve value delivery in construction (Gomez *et al*., 2020). In support of the drive for value delivery and reducing rework, and improving safety, Gomez *et al*. (2020) suggest lean is conceptually aligned with BBQ and psychological safety[9] (Figure 1).

As we denote in Figure 1, BBQ and psychological safety are antipodes and thus "intrinsically paradoxical" (i.e., prevention/adaptation, blame/no-blame, silence/vocalisation, untrustworthy/trustworthy, and vulnerability/invulnerability) (Giustiniano *et al*., 2020: p.2). Navigating the implementation of these paradoxical tensions under the umbrella of lean presents organisational challenges, which can be best surmised using the following Chinese proverb: "When the winds of change blow, some people build walls and others build windmills" (Giustiniano *et al*., 2020: p.1). Here, the adage of 'building windmills' amid the winds of change illustrates how construction organisations can acquire the benefits of psychological safety by giving employees a 'voice'. As a result, employees can get the confidence and support to 'speak up' without fear of admonishment for their errors.

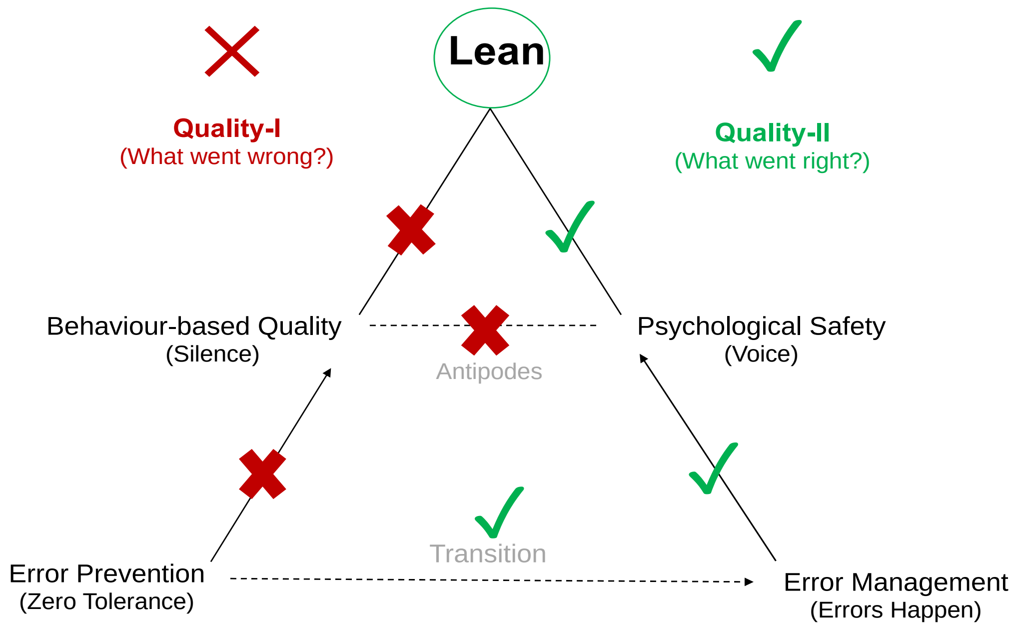


Figure 1. Conceptualising the link between lean and Quality-II

[9] Defined as "being able to show and employ one's self without fear of negative consequences of self-image, status or career" (Kahn 1990, p. 708). Similarly, Edmonson (1999) defines the concept as a shared belief that the team is safe for interpersonal risk taking.

In this regard, organisations become alchemists as they turn something negative into positive. This positive mindset manifests in the form of learning and stimulating innovation. Simultaneously, having a BBQ strategy in place will generate resistance (building walls) to engendering a ‘voice’, as there is a focus on negatives (e.g., non-conformances and performing rework). Accordingly, people will be constrained from interpersonal risk-taking and learning. As a corollary, they may become disheartened from engaging in the process of innovation. In sum, Gomez *et al*.’s (2020) conceptualisation of a link between BBQ and psychological safety as an attempt to support the use of lean is a ‘damp squib’.

2.3 Quality-II

Quality-II, like its Safety-II counterpart (Hollnagel, 2014), challenges organisations to shift away from engaging in change when an adverse event arises or when there exists a risk that is deemed unacceptable in a project. Moreover, Quality-II assumes that people no longer are required to follow specified rules and procedures to ensure quality and prevent rework. Instead, people are deemed flexible and constitute an integral part of the solution to the quality problem (e.g., containing and reducing rework), as they understand the nature of the work. Hence, they can continually adapt and adjust their performance to the prevailing conditions. In this instance, Quality-II needs people to be proactive and anticipate uncertain events (Love and Matthews, 2020).

Given the ability to imagine and “visualise possible worst-case scenarios”, people can make a tangible representation of quality risks and better accommodate uncertainty (Fruhen *et al*., 2013: p.972). However, assessing visible risks and determining their probability of occurrence only forms part of the jigsaw that depicts the quality landscape in construction. Cultivating an environment of psychological safety is also needed to ensure the ‘voice’ of all project team members is heard, no matter how immaterial their concerns may appear regarding quality-related risks (Love *et al*., 2019b; Love, 2020).

Akin to Safety-II, Quality-II questions the underlying assumption that compliance (i.e., conformity to plan) is required to produce quality outcomes. We acknowledge that rules and procedures provide invaluable direction about how work should be performed, but there may be instances where they are incomplete or unavailable (Dekker, 2014; Hollnagel, 2014). Additionally, non-conforming work, particularly when it requires rework, arises due to error (i.e., deviation from the plan).

When attention focuses solely on error, it creates a need to determine the causes of 'what went wrong' and the elimination or inactivation of the suspected cause-effect links (Hollnagel, 2013). Hence, this tends to result in counting how many fewer things go wrong and formulating the 'hypothesis of different causes' (Hollnagel, 2013). In this instance, "the causes or 'mechanisms' of adverse events are different from those of favourable events. If that were not the case, the elimination of such causes and the neutralisation of such 'mechanisms' would also reduce the likelihood that things could go right and hence be counter-productive" (Hollnagel, 2013: p. 4). Put simply, the things that 'go wrong' and those that 'go right' have the same mechanisms and tend to occur in a similar manner, irrespective of the outcome.

Ensuring that information flows freely in an organisation is critical for enabling Quality-II and thus providing quality outcomes in projects (Love *et al*., 2018). Acknowledging the role of information flow in cultivating culture, Westrum (2004) points out that we "can get an idea of how well people in the organisation are cooperating and also, how effective their work is likely to be" (p.58). Hence, when information does not flow, it can adversely affect the functioning of an organisation. For this reason, there is a need to create and nurture a culture and climate[10] whereby people actively seek information, are willing to share it, welcome new ideas, engage in a reflexive practice, and are rewarded accordingly (Westrum 2014). It stands to reason that communication is pivotal for facilitating a conducive climate to manage and ensure quality outcomes at both an organisational and project level (Westrum, 2004; Van Dyck *et al*., 2005; Love, 2020). By placing an overarching emphasis on culture and climate, organisations can enact a Quality-II mindset as consideration is given to their peculiar context and projects as a whole rather than the idiosyncratic experiences of individuals (Ehrhart *et al*., 2014).

2.3.1 Error Management

Error management can be used to create a culture that acknowledges that 'errors happen' and are "a recurring fact of organisational life" (Lei *et al*., 2016: p.1315). Thus, it is "futile to attempt to prevent all errors from occurring" (Frese and Keith, 2015: p.665). People are prone to making errors throughout their daily routines, and they cannot be entirely prevented. In recognition of the pervasiveness of error-making, we have seen a wealth of studies examining why and how individual, team and organisational errors materialise (e.g., Norman, 1981; Reason, 1990; Sasou and Reason, 1999; Goodman *et al*., 2011; Zhao, 2011; Lei *et al*., 2016). It is, however, beyond the remit of this paper to address these questions. Notwithstanding, a comprehensive explanation as to why and how errors and rework arise in construction projects can be found in the studies of Love *et al*. (2018) and Love *et al*. (2019a;b). A cursory look at the literature reveals that there is a consensus that "culture develops by consecutive dealings with past errors and mistakes that lead to new problems" (Frese and Keith, 2015: p.662). In

[10] Defined as "the shared meaning organisational members attach to the events, policies, practices, and procedures they experience and the behaviours they see being rewarded, supported, and expected" (Ehrhart *et al*., 2014).

this instance, it is the very nature of mistakes that enable people and organisations to learn and innovate (Frese *et al*., 1991).

Error management was developed by Frese (1991) as a strategy to cope with errors and as an "add-on" to error prevention (Frese and Keith, 2015: p.665). While error *prevention* focuses on "blocking erroneous actions" and "communicative acts", error *management* commences after an error occurs and aims to mitigate its adverse consequences or "reduce their negative impact through design or training" (Frese and Keith, 2015: p.665). Organisations with an error management culture in place actively deal with errors by fostering clear communication about errors, coordinating error handling, initiating quick error detection, and damage control (Van Dyck *et al*., 2005). In sum, error management aims to *expect* and detect and control errors as quickly as possible. This aim is achieved by (Hofman and Frese, 2011):

- *Controlling the potential damage of errors*: Damage control aims to reduce the negative consequences of an error as quickly as possible (Dörner, 1996; Frese and Keith, 2015). The time taken to detect the error is thus critical. Two scenarios can materialise. A short-time period can provide immediate feedback, but an individual or organisation needs to be prepared as error handling strategies must be immediately enacted. If, however, errors remain undetected for a long-time period, then an absence of instant feedback prevails. But this longer time frame enables the "active development of early warning signs" (Frese and Keith, 2015: p.669). It has been widely acknowledged that latent errors often reside in organisations (Reason, 1990; Reason, 1997; Ramanujam, and Goodman, 2003) and construction projects (Love *et al*., 2009). The longer latent errors remain undetected, the more likely they are to interact with local conditions [i.e., those within a project's environment], resulting in the need for rework and safety incidents occurring (Love *et* *al*., 2019a;b;c). Therefore, it is important that individuals have a 'voice' to openly discuss errors, no matter how trivial. Fittingly, managers can then be provided with error signals and the information to mitigate their ramifications and engender learning.

- *Reducing the potential of error cascades*: In this case, an error leads to another error occurring– a knock-on-effect materialises (Goodman *et al*., 2011). This observation has been reinforced by Frese and Keith (2015), who state that "error cascades imply a crescendo of errors on top of each other" (p.669). Cognitive overload has been identified as a major reason for error cascades occurring (Reason, 1997). This is further exacerbated when people perform several tasks simultaneously, as they are likely to commit more errors than if they focused on a single task (Oberauer and Kliegl, 2006). Having to perform rework lends itself to an error cascade. Though, it may also be the case that the rework is required due to a series of errors. When there is a need to perform rework, contractors, for example, are often subjected to a changed workface, schedule pressure, cost constraints and stress, which can compromise their safety (Love *et al*., 2019a). Thus, when errors occur, people adjust their routines by engaging in a "conscious level of regulation" (i.e., effortful and active cognitive processing) (Hofman and Frese, 2011: p.52). Actions at this level involve active processing and consideration of overall goals and "how sub-actions need to be organised to accomplish the goal" (Hofman and Frese, 2011: p.30). This level of regulation is enacted during the development of new patterns of action "as well as when individuals are confronted with novel and unfamiliar situations" (Hofman and Frese, 2011: p.30). As a result, individuals may plan a behavioural response by drawing on their conscious and analytical reasoning based on stored knowledge (Reason, 1990). The burdensome and sequential cognitive processing at this level is measured, and feedback is interpreted step by step. So, reducing the error strain placed on individuals by creating a positive mindset toward errors may help control error cascades (Frese and Keith, 2015).

- *Facilitating secondary error prevention (i.e., prevention of similar errors in the future):* As individuals learn and familiarise themselves about why and how errors arise and their consequences, they have a habit of preventing them from happening again in the future. Individuals often learn that they tend to make more errors when performing specific tasks. In doing so, people develop strategies to catch their errors more quickly. The secondary gains of error management, therefore, can result in improved error prevention and handling.

It has been shown that an error management culture is positively related to an organisation's profitability (Van Dyck *et al*., 2005) and safety performance (Fruhen and Keith, 2014). Thus, be it writ large, error management will also improve a construction organisation and their projects' quality performance. In the next section of this paper, we examine how a program alliance, which was utilising lean tools to manage its schedule and workflows, transitioned from error prevention to an error management culture and thus improved its quality by containing and reducing rework.

3.0 Research Approach

To recap, our research question is as follows: *What type of error culture is required to manage errors that result in rework and support lean thinking during the construction of infrastructure projects*? To tackle this question, we adopt an inductive qualitative method, particularly a sense-making approach based on our meta-theories of Quality-I and Quality-II matched with error prevention and error management cultures, respectively. The sense-making methodology we employ to address our research question provides a frame of reference for understanding how peoples experience make sense of the phenomenon being studied, in and on their terms (Dervin, 1992).

Following such a line of inquiry lends itself to the adoption of an interpretive case study (Creswell, 2009) as we aim to provide novel and profound insights into the economic, social, cultural and political influences that compelled the transition from error prevention (i.e., Quality-I) to an error management (i.e., Quality-II) culture to take place within a project context. Additionally, we utilise a case study approach to bring about a broader understanding of the organisational processes used to reduce rework and provide a basis for improving quality in practice.

Our approach to sense-making rests upon the assumption that people make sense of their workplace (i.e., project) at all times. How they do so and how they think and speak about making sense of it reflecting on their behaviour and the prevailing project's organisational culture in practice (Dervin, 1998). Our assumptions are informed by methods used to elicit and analyse project processes based on people's experience. By adopting a sense-making approach, we can regulate "the cacophony of diversity and complexity without homogenising it" (Dervin, 1998: p.36).

3.1 Case Selection

Case selection is the "primordial task" of case study research as it establishes the framing of a phenomenon to be studied (Seawright and Gerring, 2008: p.294). The case we have selected for this study was based on pragmatic considerations (i.e., its availability and access) and theoretical prominence, which are "legitimate factors in case selection" (Seawright and Gerring, 2008: p.295).

Representatives of the XYZ Water program alliance in Australia contacted us as they learned that we had received government funding to examine the nature of rework causation and its consequences in project settings. The alliance was tasked to deliver 129 water infrastructure projects over five years at a total contract value of $375 million. This capital investment program was the largest ever undertaken by XYZ Water (i.e., the owner participant, OP), the largest regional urban water corporation in the State.

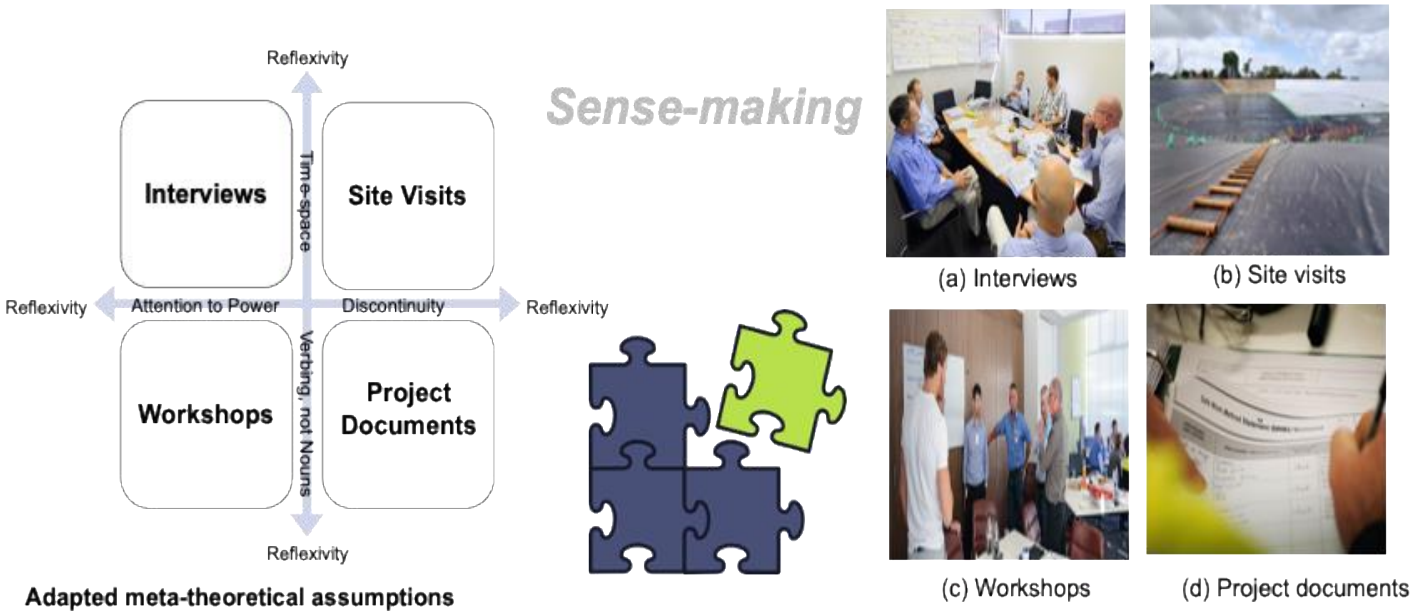
Going against the grain of common practice in construction, the alliance openly recognised it had a rework problem and sought to tackle it actively. Consequently, it embarked on implementing a change management initiative, which had made significant inroads in reducing its occurrence in its projects. As a result, we received an invitation to make sense of the alliance's approach to combating rework. In essence, the alliance had a desire to share their knowledge and experience with us and the broader industry about how they successfully leveraged a change in their orientation toward error and rework mitigation. Thus, with a rare opportunity to experience firsthand as scholars, with rich and meaningful data and insights, how rework is reduced in practice, we accepted the invitation from the alliance.

3.2 Data Collection

Before commencing our data collection with the alliance, we were cognisant of the need to orient and inform our line of inquiry with people's views and experiences using interviews and observations of practice. Therefore, our sense-making approach required us to embrace a series of meta-theoretical assumptions adopted from Dervin (1992), concerned with the contextual gaps between 'perceived' and 'actual' reality, which we present in Figure 2. Overall, this case study's data collection efforts include various sources: (a) 26 interviews with a range of alliance team members; (b) workshop and group meeting observations; (c) six site visits before completion and three site visits after completion along with informal discussions; and (d) pre-contract and post-contract documentation.

More specifically, the alliance sent us a copy of their contract and information so that we could familiarise ourselves with the allocation of risk and responsibilities of the OP (i.e., XYZ Water) and Non-owner Participants (NoP) (i.e., engineering consultancy and 'Tier one' contractor). Additionally, the alliance granted us access to pre-contract and post-contract documentation to enable us to grasp an understanding of the project execution process and triangulate our findings. Figure 3 presents a process flow chart that displays the activities and associated documents used to deliver a project. Additionally, the organisational structure of the alliance is illustrated in Figure 4.

The semi-structured interviews were digitally recorded. Then, they were transcribed and distributed to interviewees to check their veracity and provide them with an opportunity to clarify and amend the issues raised (Table 2). Our questioning initially focused on understanding rework causation and then moved on to how the alliance implemented its change initiative. We specifically used a 5W (who, what, when, where and why) line of questioning to make sense of the alliance's social embeddedness to institutionalise learning and remedy its rework. Moreover, as non-participant observers, we attended one of the many dedicated workshops organised for alliance members and their contractors to communicate and share rework knowledge and discuss mitigation approaches.



- *Discontinuity*: Is an aspect of reality and where gaps exist between people, things, spaces and time. So, gaps exist between what is 'perceived' and 'actually' happens. Thus, we are concerned with the subjective construction of reality (Neill, 1987);
- *Time-space*: We acknowledge that as people move through space and time their situation and context change. We acknowledge the uniqueness of individuals and their circumstances and thus were interested in identifying the commonalities in the 'change' processes they experienced.
- *Attention to power*: Individuals in the alliance are embedded in a social context, which shapes their experiences and views. Issues of power and constraint comprise influences and player's external to an individual's process of cognition. We therefore sought to understand 'how' the individual understood this context in the alliance and prevailing dynamics
- *Verbs not Nouns*: Individuals are conceptualised as actors navigating moments of situation-facing rather than nouns ascribed with chosen adjectives. Thus, we move away from focus static to a dynamic focus. Our sense-making approach is then process-oriented; and
- *Reflexivity:* We rely on our experiences, biases, understandings, to make sense of individuals experiences and views associated with the work practices in the alliance.

Figure 2. Data sources and meta-theoretical assumptions

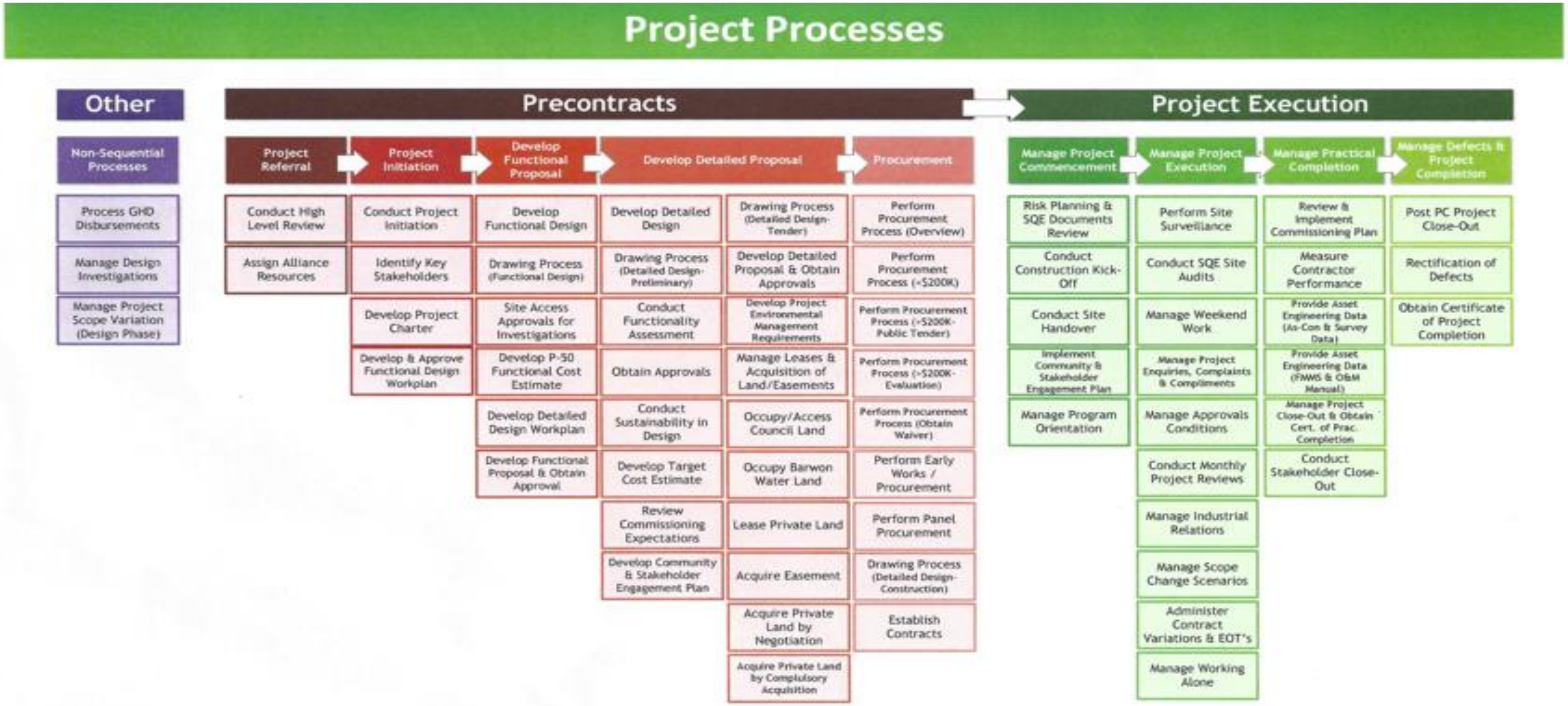


Figure 3. Processes to procure projects

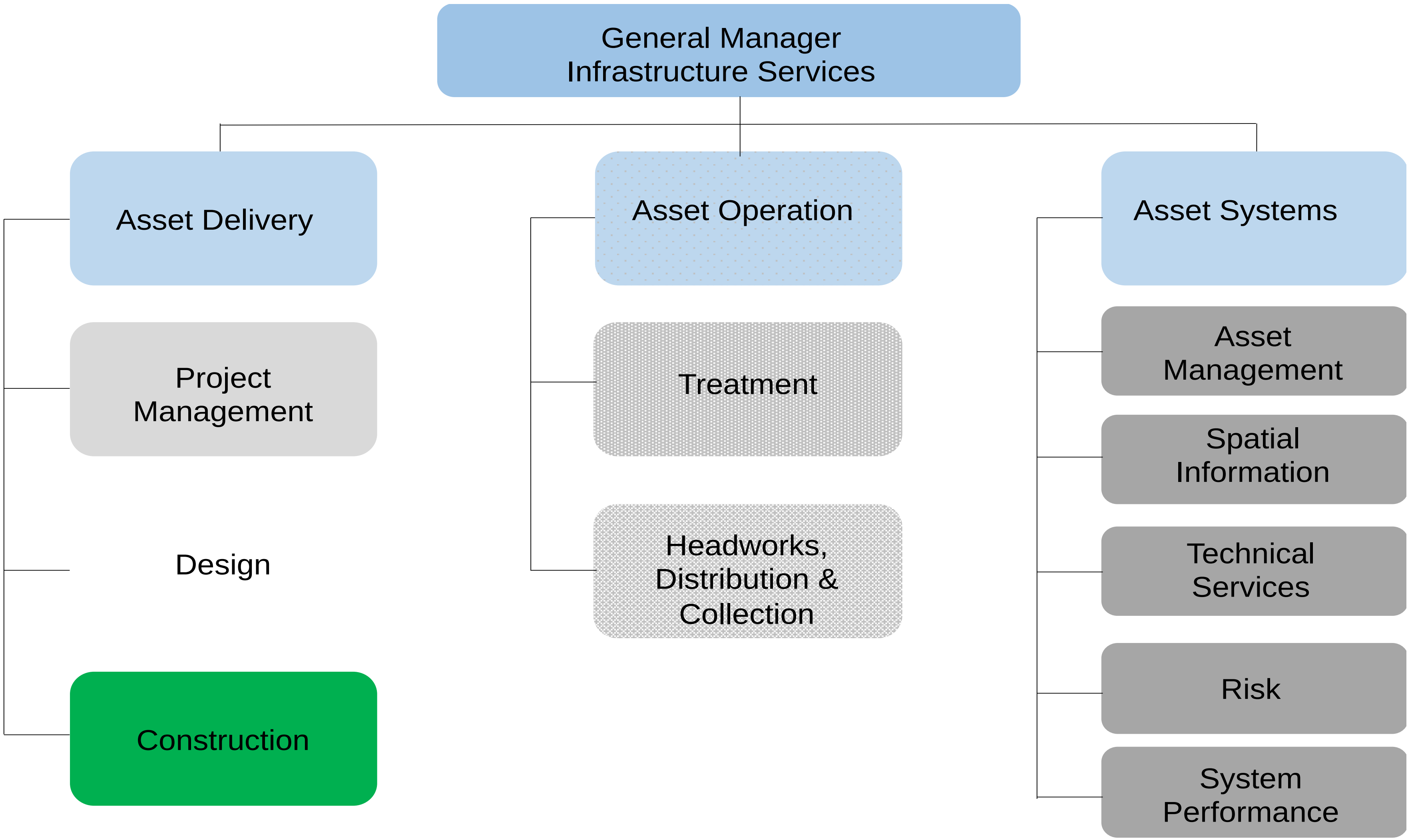


Figure 4. Structure of the alliance

Table 2. List of interviewees and workshops

Data Source	Functional Area	Length (hh:mm)
Alliance		
Alliance Manager	Alliance Leadership Team	0:42
Project Director	Alliance Leadership Team	0:52
Chairman	Alliance Leadership Team	0:20
Design Manager (n=2)	Design	1:06
Delivery Manager	Project Management	0:24
Design Team Leader	Design	1:18
Commercial Manager (n=2)	Project Management	1:19
Systems Engineer	Asset Systems	0:24
Risk, Quality and Support Team Leader (n=2)	Asset Systems	0:37
Safety, Quality and Environment (SQE) Manager (n=2)	Construction	0:31
Construction Manager	Construction	0:25
Project Managers (n=6)	Project Management	3:21
Project Engineer	Construction	0:25
Site Managers (n=2)	Construction	0:29
Site Supervisor	Construction	0:25
Foreman	Construction	0:44
Contractor Rework Forum (35 participants from the alliance, consultants and contractors)	Alliance Management Team, Design, Project Management, and Construction	1:30
Post-Completion		
+ 6 months – Group meeting with XYZ Water Staff which included Infrastructure and Operations Manager, Systems Engineer, three Site Supervisors and external consultant	XYZ Water	2.05
+ One Year – Group meeting with key XYZ Water Staff, which included two Site Supervisors, Project Manager and Operations Manager and external consultant	XYZ Water	1:46
+ Two Years (Workshop, non-participant observer included four contractors, engineering consultants, site supervisors and XYZ Water Project Management team. A total of 35 participants with 1 ½ hrs x 8 of audio data)	XYZ Water and Project Team	12:00*

* This workshop formed part of a separate study, but we draw on some findings to highlight issues raised post-alliance.

We conducted six site visits over two days to observe works being performed and informally discuss with site management and contractors' issues associated with rework and the changes that had occurred to curb its adverse impact on the alliance's performance. These informal discussions ranged from 45 to 80 minutes on each of the sites we visited and provided an invaluable context to the issues that arose prior to and after change management had been implemented to deal with errors and rework. After all, it is at the coalface of construction that errors are often made and rework is needed.

3.2.1 Post-Completion

On completion of the alliance, XYZ Water began to self-manage the delivery of its new infrastructure projects. We, therefore, visited the organisation on three separate occasions (i.e., after six months, a year and two years) to determine if the transference of experience, knowledge and learning accumulated within the alliance was put to use during the delivery of its projects. In this paper, we share these findings to highlight the pervasive challenges confronting the cultivation of a project culture that aims to contain and reduce the adverse consequences of error and rework.

3.3 Data Analysis

The data from our study was organised and analysed in *NVivo Version 11* to obtain insights from interviews and documentation. We applied a flexible coding process using common terms (e.g., rework, standardisation, visualisation, non-conformances, responsibility, and reporting) that were derived from the literature (axial) and the case study, with additional words being added as the research progressed (e.g., quality toolbox, root cause and [pre-construction] site walks) (emergent) (Saldaña, 2013).

The descriptive first-cycle of coding enabled portions of the data contained within the transcripts to be summarised (Miles *et al*., 2014). The second-cycle coding provided the basis for inferences from documentation to be determined and patterns regarding rework events to be established (Miles *et al*., 2014). However, these inferences are not considered in this paper as they have been analysed and documented in previous works (Love *et al*., 2019a;b). As a reminder, this paper focuses on how the alliance (i.e., its construction projects) was able to change its culture and orientation toward the management of errors and rework and simultaneously utilise its lean tools to support its drive for continuous improvement.

4.0 Research Findings

We now make sense of the data we collated by stitching together a narrative for the changes to the alliance's project culture and continuous improvement drive, which resulted in the mitigation of rework. The meta-theories of Quality-I and Quality-II that we have outlined above provide us with a frame of reference to make sense of how the alliance managed its rework throughout its life (Table 1).

We have therefore divided the presentation of our research findings into three distinct phases, as noted in Figure 5: (1) error prevention culture; (2) error management culture; and (3) organisational re-learning. The transition from error prevention to error management was not a fluid process as people's norms and behaviours had to be recalibrated not only to align with the alliance's core values (i.e., Safety, Teamwork, Respect, Innovation, Vibrancy, and Excellence) and Key Result Areas (KRA) but also develop a 'growth mindset'. The OP and NoP team members had acquired learned behaviours from working in conventionally procured projects where an error prevention culture had tended to reside. Furthermore, the OP and several NoP members had not been involved with an alliance delivery model previously. As a result, the relationship-style arrangement of an alliance required team members to switch their cognitive setting from a ‘them and us’ position to one of ‘we’ where collaboration became the focus.

Within the alliance, the OP and NoPs were required to work together to deliver the project, jointly manage risks and share rewards. Key features of the alliance included good faith and trust provisions with a ‘no blame, no dispute’ philosophy, the joint development of an agreed target out-turn cost, decisions made unanimously on a ‘best-for-project’ basis rather than ‘best-for-the-individual’, performance-based remuneration (based on direct costs with a margin/fee and a ‘Gainshare/Painshare Regime’ and the implementation of lean tools to plan and manage construction. These features, akin to those embedded within *Lean Integrated Project Delivery* (Walker and Rowlinson, 2020), provide a foundation for engendering a ‘voice’, but this was not necessarily the case for managing quality. We believe the contract may have somewhat reinforced the downplaying of quality as there was an absence of a financial incentive for NoPs within the ‘Gainshare/Painshare Regime’.

Within the ‘Capital Program Alliance Agreement Schedule’ document, for example, quality had not been identified as a gain-share modifier[11]. Needless to say, the following was explicitly stated in regard to safety and environmental compliance in the ‘Capital Program Alliance Agreement Schedule’:

[11] “Used for project objectives that have significant downside risk such as a no-harm outcome in the safety or environmental context. If significant adverse events occur under these headings, the entitlement to gainshare is reduced by a fixed percentage. Gainshare modifiers only modify the gainshare” (Hayford, 2010).

- “The intention of the modifiers is to replicate commercially the sense that the program would not be successful if there were major, systemic or repeated failures in these performance areas.
- This type of modifier works by adjusting the ‘Gainshare Entitlement that the NoPs can earn from other KRAs.
- The principle to be satisfied by these modifiers is that they must reflect the impact of both positive and negative behaviour and outcomes concerning safety and environment on the value to [the OP]”.

Safety and environmental compliances were fundamental commitments and requirements of the OP and thus were not directly incorporated into the ‘Gainshare/Painshare Regime’. Ultimately, safety and environmental compliance formed an innate feature of the alliance’s core values. In this instance, performance was absolute and therefore did not require financial incentives. Thus, the modifier regime was applied when performance differed from the minimum standards of satisfaction with respect to safety and environmental incidents. In essence, the contractual conditions shaped people’s behaviour, influencing a project’s climate and culture. In this case, a zero-vision became a product of the project’s culture. Attention was therefore directed at preventing safety incidents and adverse environmental impacts by implementing rigid controls and procedures (e.g., work method statements and a specific code of conduct for safety) overseen by site supervisors.

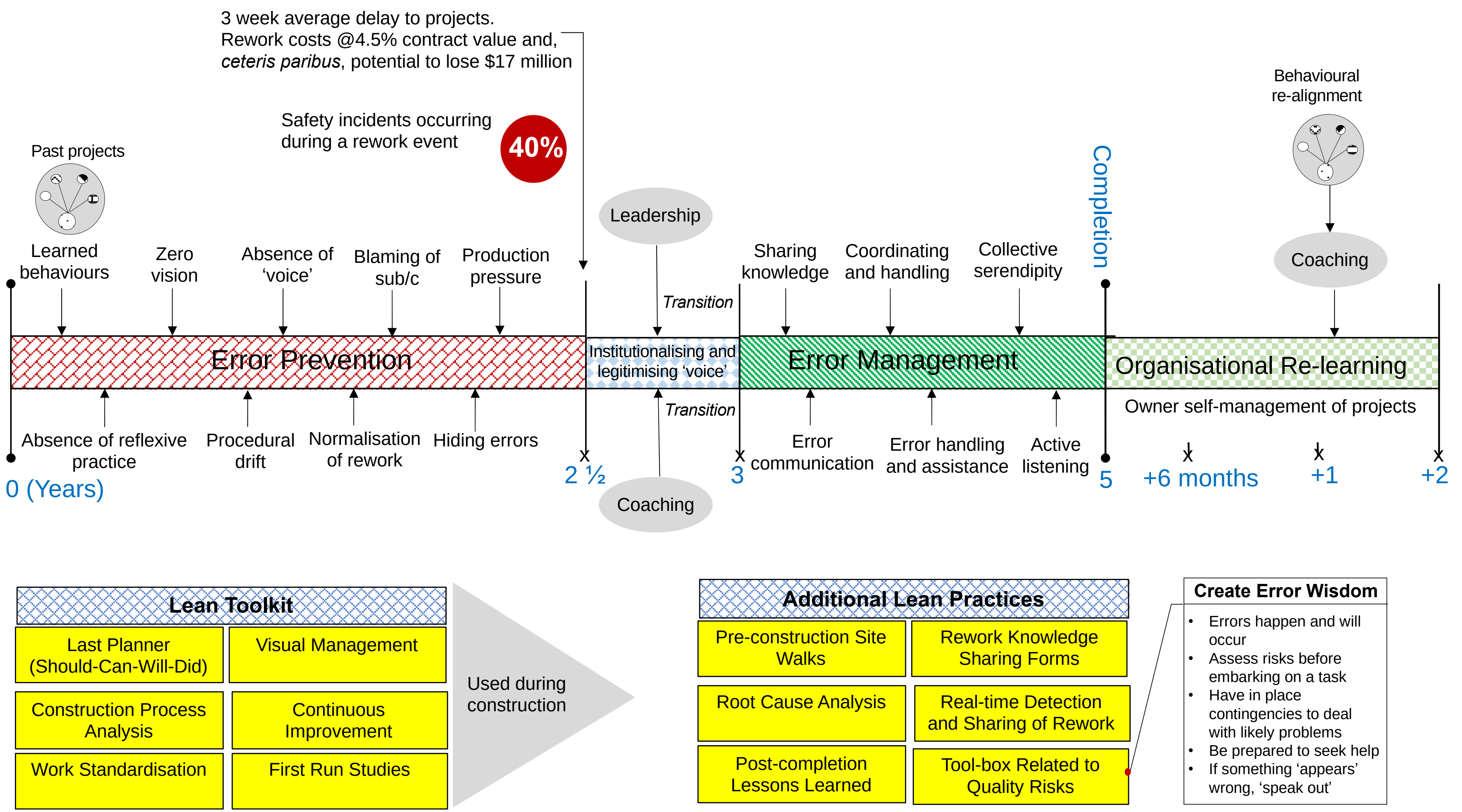


Figure 5. Making sense of the transition from error prevention to error management culture

4.1 Error Prevention

As we show in Figure 5, the XZY alliance had in place an error prevention culture before it realised that there was a need to engage in a process of change. The ‘learned behaviour’ acquired from erstwhile projects hindered the NoPs and contractors from not reporting non-conformances and mistakes that materialised. There had been an overriding perception that non-conformances were a measure of poor quality, which had been indoctrinated by the NoPs contractor’s parent organisation. What is more, the reporting of non-conformances was deemed a time-consuming and laborious process. The rules for documenting non-conformances were considered overly designed by the contractor and rigid, resulting in procedural drift occurring. That is, people departed from their required routine to make their work more efficient. In so doing, this drift subsequently became their new practice.

For contractors operating at the coalface, having to perform rework was normalised and indeed formed part of everyday practice, with a supervisor commenting: “it is what it is, and you just get on with the job”. The acquiescence to non-conformances and rework as well as the absence of a ‘voice’ was encumbering the alliance’s performance and productivity, even though it had in place useful lean tools for planning, standardising work and processes, visualising workflow and engaging in continuous improvement.

While look-ahead planning and workflow visualisations on-site were useful tools for understanding ‘what needed to be done and when’, there had been a reluctance by the contractor to consider the likely occurrence of rework. Rework was not even being measured during construction, despite the considerable attention placed on the unnecessary movement of plant, materials and equipment, optimising inventory, double-handling material and minimising punch-lists.

“Nobody enjoys having to do things twice” was a storyline that reverberated throughout our interviews and discussions with people within the alliance team and contractors. As a result, the alliance leadership and management team (both comprising OP and NoP representatives) worked tirelessly to promote and instil its values by encouraging positive language and behaviours and emphasising continuous improvement efforts, particularly with respect to safety and environmental performance.

When errors, near misses and critical incidents happened, however, people’s first reaction was to distance themselves so that they were not blamed; this was a *learned behaviour*. Additionally, there was a reluctance to provide feedback (e.g., express disagreement or offer dissenting views) about the effectiveness and efficiency of work practices and processes, despite calls from the alliance’s leadership and management. As a consequence, this hindered the alliance’s ability to stimulate learning through a process of reflective and reflexive practice. Confirming this observation, an SQE manager made the following comment: “we’ve struggled to close the loop and so it [rework] had been allowed to be repeated. We needed to change our systems to ensure we could capture lessons and close the loop”. Design errors and omissions were occurring in every project, with a commercial manager emphasising their manifestation by stating, “Every job. Every job. Every Job”. Queried as to why this was the case, the following comment was made: “they have [engineering consultants] checklists at different stages of the design process. But I guess problems [referring to errors] are one-off, and they didn’t get added to future lists. So, we didn’t learn”.

During a workshop organised to report on the progress of projects, a site supervisor vocalised their concerns and demonstrated, using data that they had acquired, that rework was delaying projects, on average, by three weeks. Furthermore, the supervisor having undertaken a 'back of the envelope analysis of the projects that they were responsible for, stated, though anecdotally, that the likelihood of a person being injured while attending to rework was nine times greater when compared with normal work activities. Moreover, from an economic standpoint, if changes to practice were not made, then the alliance, based on an average rework cost of 4.5% of contract value from projects completed, could have potentially lost $17 million (Figure 5).

4.2 Error Management

The site supervisor's 'truth' became a light bulb moment for the alliance leadership and management team. The supervisor was highly respected and had considerable knowledge and experience of construction. Tackling the learned behaviour was a priority for the alliance and required them to re-examine its values and KRAs. After all, its original values and KRAs had not been aligned to accommodate quality, rendering it potentially vulnerable to failure. But in response to this immediate problem, the alliance leadership vocalised the importance of quality intending to stimulate positive attitudes, beliefs, and behaviours about its importance and performance.

We describe the leadership style within the alliance as being authentic. An independent study of the same alliance conducted by Walker and Rahmani (2016) also confirms the interpretation of its leadership trajectory. Within the alliance leadership team, self-awareness was evident as they sought feedback from people and reflected on the issues contributing to errors and rework. Relational transparency was also apparent, as there was a genuine commitment to engage in continuous improvement to redress its poor quality and be open and honest about why and how they would confront their rework problem. From the alliance's onset, there was a drive to "do the right thing" by keeping project costs down, improving safety, and minimising the environmental impact of its projects. In light of the immediate problem facing the alliance, the leadership team realised it needed to re-prioritise its actions to focus on mitigating the adverse impacts of its incumbent and future rework.

To help the leadership team foster a 'voice' and better engage with the alliance members and its contractors, the alliance engages in the process of 'learning-by-doing' (i.e., making sense of their experience and practice), which was enabled by coaching at an individual, team and project level. An independent external coach was appointed to work with the leadership team to re-shape the alliance's culture with an emphasis on creating a 'voice' and ensuring the transferring of learning. Daily meetings over six months were also undertaken with the various areas of the alliance team to discuss issues and acquire ideas about changes to practice, if needed, to ensure quality was given an equal footing so that that rework could be contained and reduced in its projects. Fundamental changes to practice to enhance quality included:

- A new interactive governance and project management framework. The existing manual-based system was deemed cumbersome. The newly developed process chart is presented in Figure 3. The interactive system empowered teams and forced people to think about what they did and how they interfaced with the alliance members. The framework provided the alliance team members to inform each other in real-time of NCRs and errors that required rework; and
- Performed lessons-learnt reviews with the alliance and contractors. The lessons learnt were fed into the asset planning process, particularly to improve constructability and operations. For example, the design engineers were required to undertake pre-

construction site walks with site supervisors and contractors to ‘anticipate’ likely issues resulting in rework being required.

Equally, the coach regularly visited sites to talk through issues with contractors and reiterated the need to ‘speak up’ about quality issues, particularly when rework was required. The coach acted as a quasi-counsellor who actively listened to the subcontractor’s concerns about what was going right, which were relayed to the alliance team and used to amend practices, if necessary. Additional lean practices were also introduced, as we note in Figure 5, such as the introduction of a ‘quality toolbox’ to create an increased awareness of errors. All in all, by providing those working at the coalface of construction with ‘error wisdom’, it was possible to anticipate, contain, and reduce rework. Non-conformances were reported by the alliance team and seen as a learning opportunity rather than a blunt measure for poor quality. Encouraging contractors to draw upon their ‘error wisdom’ resulted in what Love (2020) refers to as the exhibition of ‘collective serendipity’. In this instance, by focusing on quality, unexpected significant positive safety outcomes occurred, which were a win-win for the alliance and its contractors.

The dialogue engendered through coaching increased people’s *contextual awareness* (i.e., their role and systemic importance in the alliance) and increased *motivation* (i.e., willingness to learn and share knowledge of errors and rework). The impact and efficacy of enacting a coaching strategy came to the fore during ‘knowledge sharing’ workshops where contractors freely engaged in coopetition. We observed at a ‘knowledge sharing’ workshop that the coach and the alliance leadership team had secured the trust of their contractors, and the spirit of collaboration could be sensed as there were productive disagreements, a free exchange of ideas, and a sharing of rework experience.

To this end, the alliance was able to cultivate organisational mindfulness, whereby its team members and contractors were able to improvise and handle errors. Moreover, the alliance's leadership's continued reinforcement for the need to 'speak up' and voice concerns ensured meaningful discourse and provided the foundations for engendering learning and continuous improvement. Therefore, we observed that the alliance's organisational processes of error complemented its lean practices, as denoted in Figure 5.

4.3 Organisational Re-learning

The error management culture created within the alliance was unique. Several members of the NoP expressed their reservations about going back to the 'old view' of quality (i.e., Quality-I) that has been bolstered throughout their parent organisation. When the alliance disbanded, the OP returned to self-managing its projects. It had been envisaged that the culture and work practices developed would be replicated and used to procure its future projects. However, the transition posed several challenges as several employees that had been in the alliance had resigned, and others were no longer required in the infrastructure services' section of the organisation.

Rework started to raise its ugly side, and the blame-game occurred in a project, resulting in a contractor entering into liquidation. The memories of the alliance's culture were ever-present within XYZ Water. So, once again, they adopted a coaching strategy. Still, this time, it was to re-familiarise the organisation and its subcontractors, who had worked on the alliance, about the need to accept that errors happen. A process of organisational re-learning materialised, which initiated the re-birth of error management that reinforced people having a 'voice'. XYZ Water is a project organisation and is regularly required to maintain existing assets and deliver new projects. For XYZ Water to remain resilient, it will need to maintain and continue to nurture its psychological safety with its project staff, particularly at the coalface of the construction and with contractors charged with maintaining its assets to assure their safety, quality, and environmental performance.

5.0 Discussion

An organisation’s culture shapes its response to problems (Westrum, 2004). In the alliance we have examined in this paper, the implementation of new organisational processes shaped the response to rework even though the lean tools and continuous improvement approach had been in place. Learned behaviours from previous experience in projects initially contributed to stymieing continuous improvement efforts. Thus, we view the alliance’s culture before engaging in its transition process as being “analogous to the personality of the individual” due to people’s varying response patterns and reactions to rework (Westrum, 2004: p. ii22). Patterns of thought, emotion and action are innate features of culture (Putman, 1993), and thus, people’s response to errors naturally consists in engaging in practices that prevent them. As we previously mentioned in Section 2.3, the blocking of errors thwarts information flow and communication and the ability to engage in the process of learning. Institutionalising and legitimising a ‘voice’ through a process of coaching engendered communicative action and enabled a Quality-II mindset underpinned by an error management culture to foster and flourish throughout the latter end of the alliance’s life.

In the case of lean, we note that it is not merely a toolbox that can be put into use, though in construction, this has been the case more often than not. The task, therefore, when implementing lean in projects is “to create an aligned organisation of individuals who each have the DNA of the organisation and continually learning together to add value to the customer” (Liker, 2004: p. 290). Getting people to learn together in a construction project that is being conventionally procured is a challenge due to varying commercial interests and drivers, aside from their ephemeral nature.

In the case of large-scale infrastructure projects (e.g., >$300 million), which have longer durations and are generally delivered using Private-Participation in Infrastructure (e.g., Public-Private Partnership) or relational approaches such as alliancing, there is an opportunity to stimulate collective learning. However, construction organisations need to transition from a Quality-I to Quality-II mindset, as did the alliance we investigated if headway is to be made to contain and reduce rework and acquire the benefits of lean thinking in projects. Moreover, if construction organisations deliver outstanding projects, a culture and mindset that emphasises achievement, excellence, problem-solving through autonomy, inventiveness, and learning is needed. Error management under the auspices of Quality-II then provides a 'new view' for tackling the waste that has adversely affected productivity and performance in construction.

5.1 Theoretical Contribution

Drawing on the work of Dekker (2006) and Hollnagel's (2010; 2013; 2014) Safety-I and Safety-II theories, we have proposed a new conceptualisation of quality in construction, focused on the difference in mindset between Quality-I and Quality-II. While our proposed Quality-II meta-theory aligns with psychological safety and an error management culture, we note that difficulties persist with sustaining the 'new view' as rework began to re-emerge in XYZ Water's projects after the alliance completion. Errors are a natural part of life and projects, and people need to be re-assured through a process of vocalisation that 'errors happen', and attention needs to focus on addressing their negative consequences as quickly as possible.

Our meta-theories of Quality-I and Quality-II have enabled us to make sense of and interpret the actions and experience of an alliance's cultural transformation. We acknowledge that people may have created different systems of meaning that impose socially and culturally meaningful constraints on the infinite array of interpretations about the change process enacted. Thus, no theory will provide a 'true' representation of the social reality of a construction project. Nevertheless, as our work explains, our meta-theories of quality offer a stereotypical view of what occurs in projects. Their core assumptions demonstrate that people are malleable, but they provide a clearer picture about 'what goes wrong' and 'what goes right' and how an error management culture can help address errors and rework in projects.

5.2 Practical Contribution

While this paper portrays a single case, several invaluable lessons for practice can be gleaned from its findings. First, as research has previously shown, a symbiotic relationship exists between quality and safety, and a reduction in rework has a positive influence on safety (e.g., Wanberg *et al*., 2013). However, in this case, safety was an unexpected though an overtly embraced outcome. Thus, contractors' equal attention and resources need to be given to both quality and safety when delivering construction projects. Moreover, in the specific case of an alliance contract, quality should be considered part of a 'Gainshare/Painshare Regime'.

Second, alliances, particularly with a program of works, provide a sound environment for applying lean thinking due to their collaborative characteristics. Still, a culture that supports the free flow of information and encourages communicative action is needed to support collective learning. For construction organisations, this is straightforward, and it requires them to provide their employees and subcontractors with a 'voice'. Making it simple to raise and report non-conformances may enable a process of benchmarking and the ability to assess the risks of waste (e.g., scrap and rework). Third and last, we recommend that contractors collaborate with subcontractors to incorporate quality into daily-tool box talks to take advantage of their 'error wisdom' as they operate at the sharp end of construction (Figure 5).

6.0 Conclusion

Rework has been consistently identified as being a problem during the construction of infrastructure projects. Unfortunately, rework continues to pervade practice presenting itself as being 'uncomfortable knowledge' to construction organisations or is explained away as being a one-off event. Rework has financial consequences for an organisation and a project; it can also negatively impact safety and environmental outcomes.

While lean thinking has been espoused as a philosophy to counteract rework in construction, it has generally had a minimal impact. This is not to say that lean thinking has had an ineffective role in mitigating rework, quite the opposite. However, the traditional view of error-making in construction resides within the realm of an error prevention culture, which we have referred to as our meta-theory of Quality-I. Thus, we sought to address this research question: *What type of error culture is required to manage errors that result in rework and support lean thinking during the construction of infrastructure projects?*

Drawing from the experience of a program alliance case that delivered 129 projects over five years, we made sense of how it redressed its rework problem. We observed that the alliance successfully transitioned from error prevention to an error management culture grounded in a Quality-II mindset. The transition was enabled by the alliance's leadership, which enacted psychological safety and coaching, thereby complementing effectively the lean tools employed as part of a continuous improvement process. A collective learning environment transpired and thus supported the drive to eliminate waste (e.g., rework, transportation, and stoppage). Thus, in addressing our research question we conclude that an error management culture is required to support lean thinking to contain and reduce errors and rework in infrastructure projects. To this end the contribution of this paper to theory and practice is twofold: (1) a new theoretical underpinning to mitigate rework and support the use of lean thinking during the construction of infrastructure projects grounded in Quality-II; and (2) practical suggestions, based on actual experiences, which can be readily employed to monitor and anticipate rework at the coalface of construction.

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