Error Mastery in Alliance Transport Mega-projects

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***Abstract* –** Human error is a major source of rework, with a project's culture setting the tone for its response and how it cooperates and shares information. This article examines how a program alliance's error culture, which forms part of a transport mega-project, mitigates its errors and rework. We undertake a series of semi-structured interviews to make sense of the experiences of alliance participants about why and how rework occurs, its assessment, and if knowledge sharing occurs when it arises. Our analysis reveals that the alliance effectively utilizes elements of an error management culture to communicate and share knowledge. However, we find the alliance's learning capacity is constrained by its inability to capture and analyze rework-related knowledge, preventing it from building resilience to error. Consequently, we propose a collection of principles that an alliance can draw upon to create an error mastery mindset enabling it to manage its rework risks and unexpected events. The benefits of an error mastery mindset are threefold as it provides the ability to: (1) better support people's well-being; (2) anticipate what might go wrong; and (3) adapt and learn about circumstances where errors and rework occur and a mechanism to re-establish work practices after an adverse event.

***Index Terms* –** Alliance, error mastery, infrastructure, mega-project, transport, rework.

I INTRODUCTION

"There is more to curry than three pints of lager and a prawn vindaloo!" (Rick Stein, 2013)

Rick Stein, a celebrity chef, while filming his *Rick Stein's India* airing in 2013 on BBC 2 in the United Kingdom (UK), suggested that most people think it is relatively easy to cook curry associating it with having a few beers and a vindaloo at the end evening out by visiting an Indian restaurant. Rick Stein touring the Indian subcontinent, realized the complexity of cooking a curry, as the precise selection of spices was a matter of regional tradition, family preference and religious practice.

Indeed, there is more to cooking a curry than using commercially available curry powder and the traditional vindaloo, which the British are typically accustomed to eating. Understanding the subtlety and nuances between the different types of curry requires a mastery of complex flavours. While curries are complicated dishes to create, they are governed by three ingredients: spices, opinion, and garlic. Thus, garnering a mastery of these viands provides the basis for making a tasty dish. The ability to balance the flavour of curry is a perennial challenge akin to being able to offset a mega-project's time, cost, quality, safety, environmental objectives and stakeholders needs and requirements.

So, we draw on our curry analogy to provide a parallel with the complexity of the rework phenomena that plagues transport infrastructure mega-projects and contributes to their poor performance. Rework typically manifests due to errors and changes in design and construction [1]. 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 [2]-[5]. Notably, when change-orders are considered, rework costs substantially increase and range from 2.5% to over 20% of a contract value [1], [6], [7].

The industry-led ‘Getting It Right Initiative’[1] (GIRI), for example, has recognized the problem of error in construction, maintaining that “the annual spend due to error is estimated to be around seven times the total annual UK construction industry. When unrecorded waste, latent defects and indirect costs are included, the situation gets much worse with estimates of total costs of error ranging between 10% and 25% of project cost or between £10-25Bn per annum across the sector”. So, the consequences of errors and performing rework in construction can be adverse, resulting in increased organizational and project costs, a tarnished reputation, a reduction in stock value, losses in productivity, schedule delays, injuries and accidents, pollution, and contamination, to name a few [8].

Despite construction organizations being mindful of the consequences of rework, they have been unable to grasp an organizational mastery of the knowledge required to contain (i.e., enhance detection and recovery from errors as well as minimize adverse consequences) and reduce (i.e., limit is occurrence) errors that result in its manifestation. This situation has arisen due to the inability of construction organizations to balance competing demands[2], embrace an error management culture, and engage in the practice of reflexive learning [8], [10], [11]. Adding to this mix, construction organizations tend to institutionalize and legitimize an error prevention culture whereby emphasis is placed on “blocking error erroneous actions” and “communicative acts” in their projects [10]. [12: p.665].

Errors cannot be always be prevented as they are a normal part of any work routine in construction [13]. As a matter of fact, “any work regardless of routine involved, is faced with

[1] Details can be found at: https://getitright.uk.com/reports/call-to-action. Noteworthy, no empirical evidence exists to demonstrate the GIRI’s claims here, but errors requiring rework is a problem requiring attention.

[2] Competing demands are an innate feature of project management. According to Gaim *et al*. [9] “competing demands occur when management, depending on the use of limited resources or attention, requires more to be done than available resources suggest it is possible to do. Where competing demands are deemed to be of comparable importance for managers and decision-makers, tensions arise over resource allocation and prioritization” (p.1)

the probability of error" [14: p.123]. Statistically, "the more times per day [a person] does a given operation, the greater [their] chance of doing it wrong sometimes" [13: p.320]. While this axiom is well-understood, errors still have a negative connotation. Organizations, therefore, seek to exercise control over their performance by implementing a zero-vision and eliminating their source [15], [16]. However, the engagement of prevention and control-oriented practices hinders construction organizations' ability to learn as people are reluctant to report adverse events as they will be blamed for their incidence [12], [17]-[19].

If construction organizations can accept that 'errors happen' rather than considering that 'errors can and need to be prevented', they can be contained and reduced by cultivating an error management culture[3] and mastering its practices [20], [21]. Organizations' adept in error management are well-positioned to reduce their rework, improve their environmental and safety performance, and stimulate learning and innovation [20]-[24].

Using Van Dyck *et al*.'s [24] error orientation questionnaire, our previous research found that a 'program alliance'[4] that formed part of a major transport infrastructure mega-project[5] had unconsciously enacted practices associated with error management and, as a result, was able to reduce rework in its projects [27]. While Van Dyck's *et al*. [24] questionnaire displayed a high degree of content reliability and validity, the results from its administration *only* provided us

[3] Van Dyck *et al*. [24] conceptualize error management culture as norms and practices that encourage the detection and quick correction of errors to mitigate their adverse consequences, their communication, sharing of events, coordinating their handling and helping each other when they arise.

[4] A 'program alliance' incorporates multiple projects under an alliance framework, where the specific number, scope, duration and budgets of projects may be unknown and the same participants are potentially delivering all projects. These are usually longer-term arrangements, in the order of 5–10 years [26: p.35]. The alliance we examine in this article comprises four organizations: (1) rail operator; (2) two design engineering companies; and (3) constructor.

[5] Due to issues of confidentiality and political sensitivity we are unable to identify the project and provide specific details about its characteristics. However, the project exceeds AU$8 billion and will provide economic and social benefits to businesses and citizens. The project will help prepare the city's transport network for the future. The project also has the important, lasting legacies of improving safety, reducing congestion and mobility with the city.

with a yardstick to gauge the pattern of shared basic assumptions learned used by the alliance to adapt, integrate and respond to errors.

Put simply, we were only able to determine the alliance's error climate; that is, people's attitudes and perceptions toward error at a specific point in time and thus the prevailing mood. If an error climate is consistently positive over multiple points in time, it will inexorably impact error culture as positive behaviors and attitudes are reinforced. Likewise, the questionnaire results could not provide a context within which errors and rework occur, an in-depth understanding of the characteristics and nuances of the organizational error management practices that support its culture and implied assumptions in its projects. Moreover, individual respondents may have misinterpreted or misunderstood some of the questions presented in the questionnaire.

This article builds on our previous work [27] and aims to address the following research questions: (1) Why and how errors and rework materialize; (2) How are the risks of errors and rework assessed? And (3) How are organizational error management practices being used to facilitate the alliance's error management culture. Akin to Van Dyck *et al*. [24], we define action errors as "unintended deviations from plans, goals, or adequate feedback processing as well as an incorrect action that result lack of knowledge" (p.1229). In this instance, an error is an unintended behavior. Remedying errors during construction often requires rework, which is defined as "the total direct cost of re-doing work in the field regardless of the initiating cause and explicitly excluding change orders and errors caused during offsite manufacture" [28: p.1078].

We commence our article by describing the study's backdrop through the theoretical lens of *error management* [21]-[25] (Section II). Then, we the present our qualitative research approach, based on the epistemology of sense-making with the unit of analysis focusing on the situation (i.e., project) within which errors are managed (Section III). The emerging insights from our qualitative analysis are next presented (Section IV), followed by an in-depth discussion of the implications of the research to theory and practice (Section V). Finally, we present our conclusions and identify the contributions of our study (VI).

II THEORETICAL BACKGROUND

The literature is replete with studies that have sought to understand how people deal with the errors they make in their daily lives and workplaces [12], [20]-[22], [29], [30]-[32]. However, in construction, such an understanding is absent from the literature and in practice[6], which has contributed to the inability of organizations to redress the errors that require rework to be undertaken [34].

The insightful work of Love and Smith [3] summarizes the mainstream literature on rework causation in construction. Thus, we will not draw on their review and repeat what was has already been presented in their article. Instead, we examine the nature of errors, the precursor to rework, which has received limited attention in the context of construction. Of note, there has been a proclivity for the literature to focus on apportioning blame for rework in construction using negative undertones to describe its occurrence using terms such as 'poor workmanship', 'poor supervision' and 'poor site management' [35]-[37].

[6] The GIRI's mantra focuses on avoiding and eliminating errors through the development an error-free culture. They promote an error prevention (aversion) culture.

Attributing rework to such proximate [singular] causes is myopic as their interdependency is overlooked, stymieing our ability to understand the context and conditions that led to their occurrence [5], [8], [10], [11]. The absence of attention to and understanding of error-making in construction has resulted in the process of rework mitigation being subsumed in a *Kafkaesque* loop [27]. As a result, it renders construction organizations powerless to address this problem that continues to pervade practice.

To reiterate, we are concerned with action-based errors in this article rather than errors in judgment and decision-making (i.e., cognitive biases and heuristics) [23]. Besides judgment and decision-making, violations are also a form of error, though not considered in this research [12]. We must note that errors may interact with violations, failure and risk [12], [33].

A Defining Violations, Failure and Risk

A violation involves a conscious intention to break a rule [38]. How a violation is dealt with is dependent on the way people "construct the intentions that lie behind it" [39: p.38]. Non-malevolent violations, for example, will invariably be dealt with differently by an organization than those that take "on the form of recidivism" [39: p.42].

As for failures, these are adverse or undesired organizational outcomes that can be caused by a combination of errors, violations, risks, and uncertain conditions [12], [23], [33]. If errors are detected and corrected as soon as they are identified, a failure can be averted, generating "positive outcomes such as learning and innovation" [33: p.1317]. Risk is different to an error [12], [23]. Risk refers to the likelihood of "suffering, harm loss or danger and resides in an environment", whereas errors refer to acts people commit or through "interactions with others [33: p.1317], [40].

B Levels of Error

Errors in organizations have multi-level characteristics. They occur at an individual, team, and organizational level interacting with one another, as denoted in Figure 1 [29], [41], [42]. An organization's error culture influences organizational and managerial decision-making *via* social and workplace norms (Figure 2) [12], [43]. It also sets the tone and affects the organizational response to errors and how they cooperate and share information about them [44]. Indeed, errors are an effect or symptom of an organization, and in the context of construction, the project environment within which people work (Figure 2) [45]-[47]. To this end, Reason [47] cogently notes, "we cannot change (the) human condition, but we can change the conditions under which people work" (p.768).

1. Individual Level

At an individual level, an error is caused by an individual's sole actions without any participation from others [12], [33], [41], [42], [50]. Such actions can materialize due to mistakes, which can be *rule* or *knowledge*-based, as presented in the error taxonomy in Figure 2 [46]. In the case of ruled-based errors, "a practitioner may simply misapply a rule that worked in a previous situation" due to changed conditions [51: p.177]. Relatedly, an imperfect rule may have remained uncorrected and formed part of a practitioner's problem-solving toolbox [45]-[47]. In stark contrast, knowledge-based mistakes emerge when a practitioner "encounters a novel situation that lies outside the range of their learnt problem-solving routines" '[45]-[47] [51: p. 177], [58].

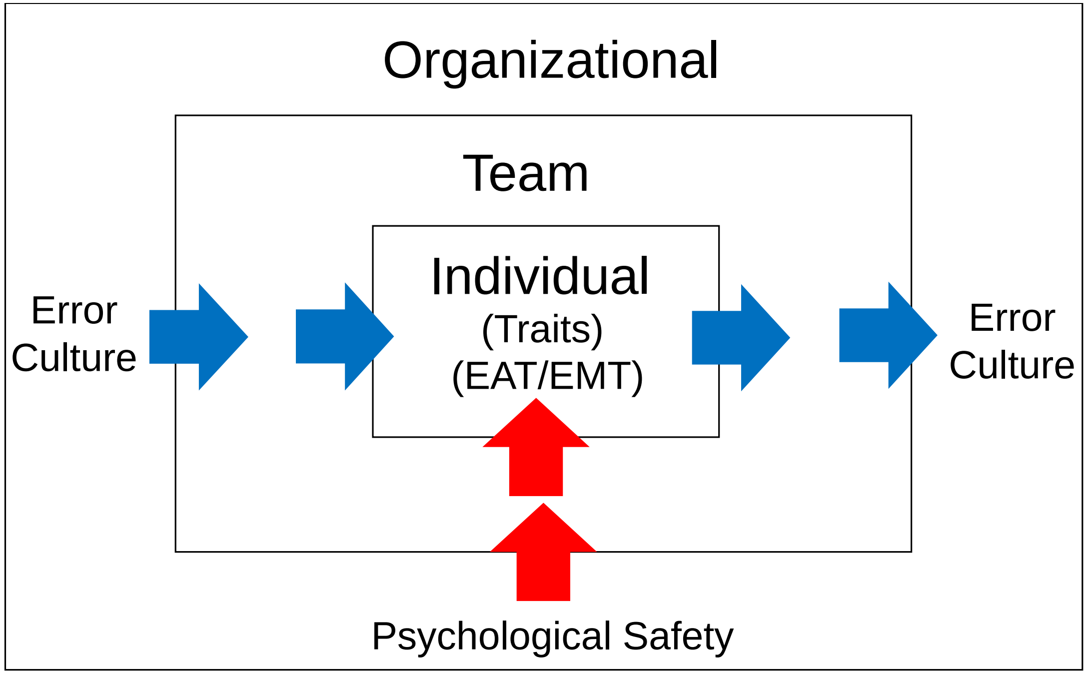
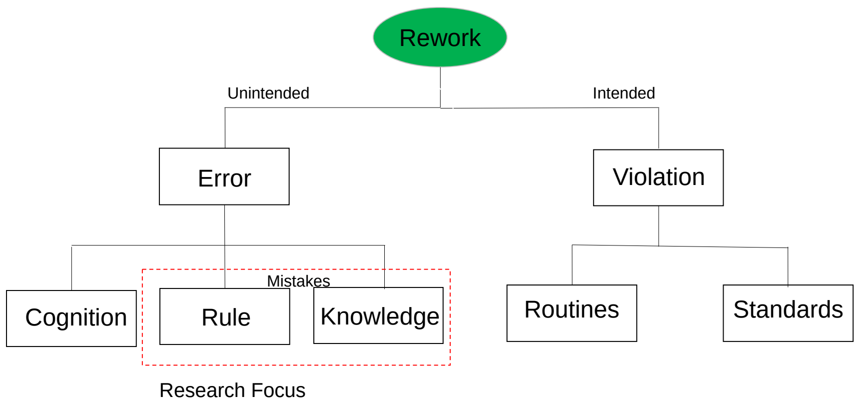
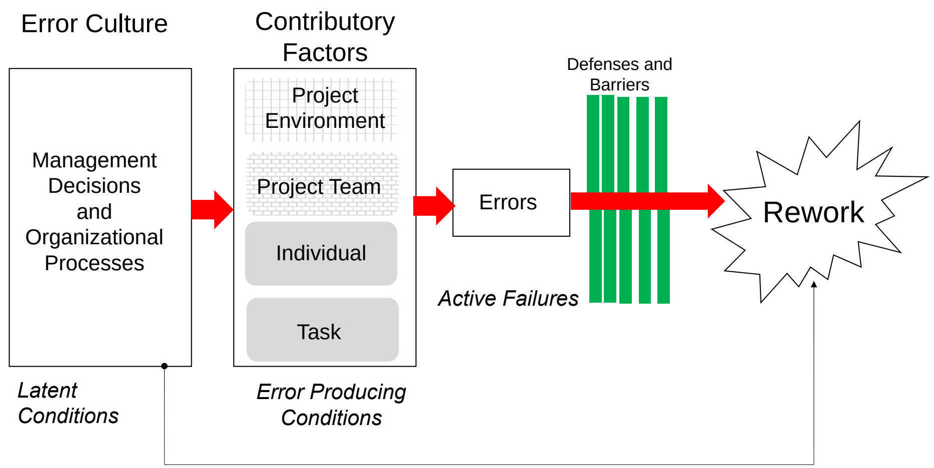


Figure 1. Interactions between individual, team, and organizational errors



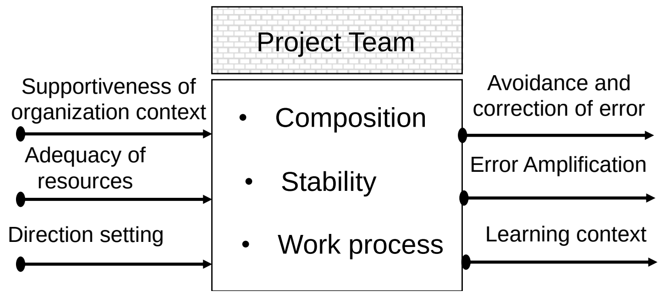
Adapted from Grabowski *et al*. [48]

(a) Error taxonomy for rework



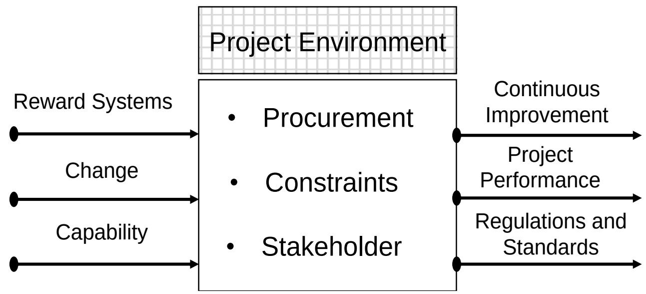
Adapted from Reason [46]

(b) Rework causation model



Adapted from Edmondson [49]

(c) Influences on project team and outcomes



Adapted from Edmondson [49]

(d) Influences on project environment and outcomes

Figure 2. Error causation and rework

Errors can also occur by impairing human cognition (e.g., slips and lapses of attention). The inability to engage and sustain attention is often a direct consequence of boredom [40], which arises when a person is either prevented from what they want to do or do not want to do [52]. Additionally, boredom may occur when a person cannot maintain attention or interest in any object or task [53].

Individual errors can be reduced and learning improved through the use of error training, which can take two forms [25], [30], [33] [41]:

1. *Error avoidance/prevention training* (EAT) emphasizes error-free performance and views them as adverse events that should be avoided. People are provided with precise instructions to prevent them from occurring.
2. *Error management training* (EMT) considers errors to be valuable feedback for learning and encourages people to learn from the errors they make.

While both these error training approaches have merit, EMT is more successful in the long term in handling errors in organizations. For example, EMT is generally more effective than EAT in helping people improve their task performance, deal with errors and learn from them [25], [31], [32], Though not all people benefit equally from EMT as their traits can play a moderating role in its effectiveness in reducing errors [33]. For example, those who are not open to experience (i.e., not adventurous and displaying a reluctance to explore) and afraid to error (i.e., anxious about erring) perform better under an EAT condition [54], [55]. Significant strides to addressing individuals' apprehensions to err can be overcome by providing a workplace environment where psychological safety[7] is promoted and enacted within an error

[7] Psychological safety "is a belief that one will not be punished or humiliated for 'speaking up' with ideas, questions, concerns or mistakes" [58: p.354].

management culture that can assist teams and organizations in learning [8], [56]. However, distinct differences between error management and psychological prevail in the literature [12].

Psychological safety is typically measured as climate in groups, similar to error management culture, but is distinct psychometrically [12]. It has also been linked to learning and positive organizational outcomes [12]. Indeed, psychological safety and error management emphasize organizational members responses to errors as predictors for learning [12]. The treatment of errors comprises forms *only* one of the seven dimensions considered by psychological safety [12], [56], [58]. Contrastingly, error management *solely* focuses on the treatment of errors. Additionally, psychological safety focuses on *what* individuals in teams experience emotionally, whereas error management culture emphasizes *how* individuals and teams act upon errors [12], [24]. [25]. In sum, error management, the focus on this paper takes a much broader and robust approach to the treatment of errors than psychological safety. However, highlighting differences between these theoretical constructs provides a segue to examine team level errors in the next section of this article.

2. Team Level

People tend to work in teams or groups in large complex systems, such as construction [63]. Team members have defined roles to ensure work is performed effectively and efficiently. While individuals are prone to error-making, teams can also make them [33], [42], [46], [47], [57] Thus, team errors "can occur as a result of the joint effect of antecedents across individual and team levels" [33: p. 1322].

Errors in teams tend to manifest due to mistakes (e.g., rules and knowledge) and lapses and arise in the "planning and thinking process and are more likely to be associated with group processes" [42: p.1]. Four types of team errors exist [42]: (1) independent individual errors; (2) dependent individual errors; (3) independent shared[8] errors; and (4) dependent shared errors. Additionally, the error-recovery process comprises three stages: (1) detection; (2) indication; and (3) correction and thus can take the following form:

- *Dependent shared error with failure to detect*: All team members cannot detect an error, and work continues to progress.
- *Independent shared error with failure to correct*: an individual commits an error, which goes undetected. The team *all* decides on a course of action, unaware of the presence of an error.
- *Independent individual error with failure to correct*: an individual error is detected, but the team decides not to correct it and continues their work.

A high performing team is able "to coordinate tasks, anticipate and respond to each other's actions" and work in unison [49: p.70]. For example, Love *et al*.'s [8] study of a program alliance responsible for delivering a wide range of water infrastructure assets realized that rework was an issue during the construction of its projects. The alliance and its contractors came together to develop an error management approach to contain and reduce its occurrence. Not only did the incidence of rework decrease, but surprisingly safety performance improved (i.e., fewer incidents and accidents). Errors that contribute to quality and safety issues are akin [11]. So, by the alliance responding to errors quickly, communicating and sharing knowledge about their causes, and members helping each other in error situations, significant improvements in quality and safety performance ensued [8].

[8] Sasou and Reason [42] state that shared errors that are "shared by some or all team members, regardless of whether or not they were in direct communication" (p.2)

The managerial effectiveness of a project team and the supportiveness of the organizational context (i.e., incentives, communication and leadership) influences their ability to deliver pre-determined outcomes and mitigate rework [8], [59], [60]-[62]. Construction projects comprise one-off project teams. Their error rates and rework levels may be explained by differences in the directional setting espoused by an organization's strategy (e.g., the management of competing demands and set margin levels), their configuration and the delivery method used [5], [8], [63]. While "individual and team antecedents may work in the same direction to increase or reduce errors", they can also have an opposite effect on one another [29], [33: p.1322]. To put it another way, individual antecedents can reduce team errors, and team antecedents can increase them or *vice versa*. For example, a site supervisor with highly specialized skills and experience may commit a limited number of errors. But in a team with a high degree of task interdependency and varying specializations (e.g., construction manager, project engineer, and contracts administrator), orchestrating their work with others can become a challenge and result in coordination errors.

The delivery method adopted (e.g., traditional *versus* alliance contracting or the Private Participation in Infrastructure) can influence the level of resources allocated by a contractor to a project due to the agreed contract type (e.g., lump-sum or cost-plus), complexity, size and type. Alternatively, in an overheated market, contractors often cannot acquire staff (e.g., engineers and supervisors) with the requisite skills and knowledge, which affect the adequacy of resourcing provided to a project. It stands to reason that, if there are an inadequate number of engineers and supervisors and the like, a project team may become stretched, requiring them to do more with less. This will result in an inability to identify or overlook mistakes that may have arisen in the design documentation and specification and/or the work performed by subcontractors.

3. Organizational Level

Organizational errors have been defined as the "actions of multiple participants that deviate from organizationally specified rules that can potentially result in adverse" outcomes (e.g., accidents, litigation, and reputational loss) for an organization, especially in high-stakes settings such as construction [41: p.154]. Thus, a rudimentary "feature of an organizational error is that multiple individuals deviate from the expected organizational practice" [41: p.154]. Construction organizations and their projects can be classified as "systems of interdependencies" [41: p.155]. Thus, "deviations can occur in activities within [an organization and its business units] and between" their projects due to varying contexts (e.g., teams, tasks, technology) [41: p.155]. Indeed, the environmental context within which a transport project is procured, the constraints of senior management (e.g., strategy, competing demands and expected margins) and stakeholders (e.g., clients, businesses and communities) establish the conditions for its delivery.

The culture of an organization influences error-handling throughout all its levels (Figure 1). An error management culture as opposed to a focus on error prevention, which, as we indicate above, has tended to be the mainstay of construction organizations, is pivotal for reducing the negative and promoting positive error consequences. All too often, construction organizations implement behavioral interventions to eliminate errors, but such initiatives tend to be ineffective as they eschew focusing on developing a culture that is attuned to learning [8], [64].

Learning from errors at an organizational level requires leaders to create an environment that supports psychological safety (Figure 1), which must also be reinforced and engendered in the projects of a construction organization [5], [8], [10], [56], [58]. Thus, psychological safety is enacted by fostering open reporting (e.g., non-conformances, defects, unsafe behaviors, and environmental hazards), active questioning (e.g., to understand why a course of action is being undertaken), and sharing of insights and concerns [33].

While construction organizations, mainly in Tier 1[9] contractors, understand and recognize the importance of promoting an environment of psychological safety, obtaining its benefits from trying to empower learning poses a challenge, particularly within the context of rework mitigation. This situation arises as psychology safety is incompatible with an error prevention culture and its zero tolerance for error [8]. In actual fact, an error management culture and psychological safety go hand in hand, providing the ability to address organizational errors through a process of ‘learning through’ (i.e., how to handle error) instead of ‘learning from’ as they enable error-correction mechanisms to be put in place [44]. Thus, rather than focusing on preventing errors, construction organizations need to consider them to be “ubiquitous and unpredictable”, requiring them to adapt and respond accordingly to changing environmental cues [65: p.120].

We cannot discount the role of error prevention altogether. It is natural for organizations to prevent people from making errors. However, it is the way that errors are construed by organizations that affect their ability to learn and avoid rework [27]; that this, they are viewed as being a nuisance, resulting in negative consequences [21], [22]. There is also a propensity to associate errors with poor performance and negligence and blame people for their occurrence. So, when people are caught making an error or admit it to them, they may ‘lose face’ [27]. Like organizations, people work hard to prevent errors [66], but no matter what we do, they cannot be wholly avoided [38]. Accordingly, Van Dyck *et al*. [24] maintain organizations may be able to benefit from simultaneously pursuing” both goals through the use

[9] Tier-1 contractors are the largest and have the capacity and capability to deliver major infrastructure projects (>$500 million)

of an error management strategy (p.1229). In fact, error management was developed to be an add-on to error prevention [21], [24], [25], even though "they differ in their underlying belief about errors and the mindset of acceptance or tolerance" [12: p.667].

As information about errors resulting in rework becomes available, organizations have to choose between *anticipation* "(i.e., sinking resources into specific defences against anticipated risks)" or *resilience*[10] "(i.e., retaining resources in a form sufficiently flexible – storable, convertible, malleable – to cope with whatever anticipated harms might emerge)" [65: p. 220]. Anticipation makes sense when we can predict and verify rework risks. For example, research indicates activities associated with concreting (e.g., its strength and placement, formwork and reinforcement), pre-cast concrete and structural steel are high-risk areas in projects and warrant attention [4], [5], [8]. Yet, despite this knowledge, construction organizations seldom give these areas of risk the attention needed to consistently assure quality in their projects as it is not subjected to legislative requirements such as safety [10], [11].

The risk of errors and rework may also be *speculative* in transport projects. Thus, it makes sense to embrace a resilience approach as "we cannot know which possible risks will" arise [41: p.163], [65]. In this instance, construction organizations can manage errors using a resilience approach, but in doing so, they will be required to commit and develop a 'capability for resilience' [68]. Fittingly construction organizations will need to "expand people's general knowledge and technical capabilities, their behavioral repertoires and skills to improvise and social and relational networks that can help compensate for lapses" [41: p.163]. An error management culture that promotes psychological safety enables organizations to adapt and

[10] Resilience "is the capability of a system to maintain its function and structure in the face of internal and external changes, and to degrade gracefully when it must [67: p.1034].

respond and develop vigilance and attentiveness to the context where errors and rework may occur in projects [4], [41], [69].

III RESEARCH APPROACH

An inductive approach is used to address our article's proposed research questions. We adopt the epistemological lens of sense-making, forming the basis of our qualitative approach, enabling an understanding of the nuances associated with treating errors and rework within the alliance's error culture to be acquired from an individual's perspective.

A Research Context

An alliance is a collaborative delivery method characterized by a culture of collaboration and cooperation between the parties delivering a project [26]. Risks (i.e., positive, opportunities – negative, threats) are shared through an incentive scheme (i.e., risk and rework model through a 'gain-share/pain-share' regime) between non-owner participants (NoPs) [26]. Key features of an alliance project are: (1) an integrated team; (2) a joint governance framework; and (3) decisions are made on a 'best-for-project' basis with a 'no-blame' culture. In a nutshell, a 'no-blame' culture involves a commitment from an owner participant (OP) and NoPs, "that where there is an error, mistake or poor performance under the alliance contract, the [OP and NoPs] will not attempt to assign blame but will rather accept responsibility and its consequences and agree on a remedy or solution which is best-for-project [26: p.19]. In the program alliance we examine in this article, the OP retained the risk for delivering each project and payment to the NoPs was made on a cost-plus basis.

The error culture questionnaire that we previously administered within the program alliance enabled us to obtain a snapshot of its prevailing error culture (i.e., environment) [27]. On the error culture continuum ranging from error aversion (i.e., prevention) to error management presented in Figure 3, our analysis of the questionnaire results revealed, on a five-point Likert scale ranging from '1' (Not at all) to '5' (Completely agree), the alliance received a mean score of 3.6 [27]. This score indicates that the alliance was implementing error management practices, contributing to errors being contained and reduced in its projects.

B Sense-making: An Individual and Hermeneutic Approach

Different perspectives on sense-making align with varying human science philosophies, theoretical commitments and normative perspectives [70]. Each perspective has different units of analysis, meanings of internal and external representations and interprets an observed outcome from an individual or collective viewpoint. In this article, our sense-making lens focuses on the individual within an organizational setting (i.e., program alliance). It takes a hermeneutic approach to understand their experiences with errors and rework within the alliance's established culture and how they are managed [71]-[74]. As a result, we focus on understanding and promoting agency enabling the individual and the researcher to engage in an unfettered communicative process.

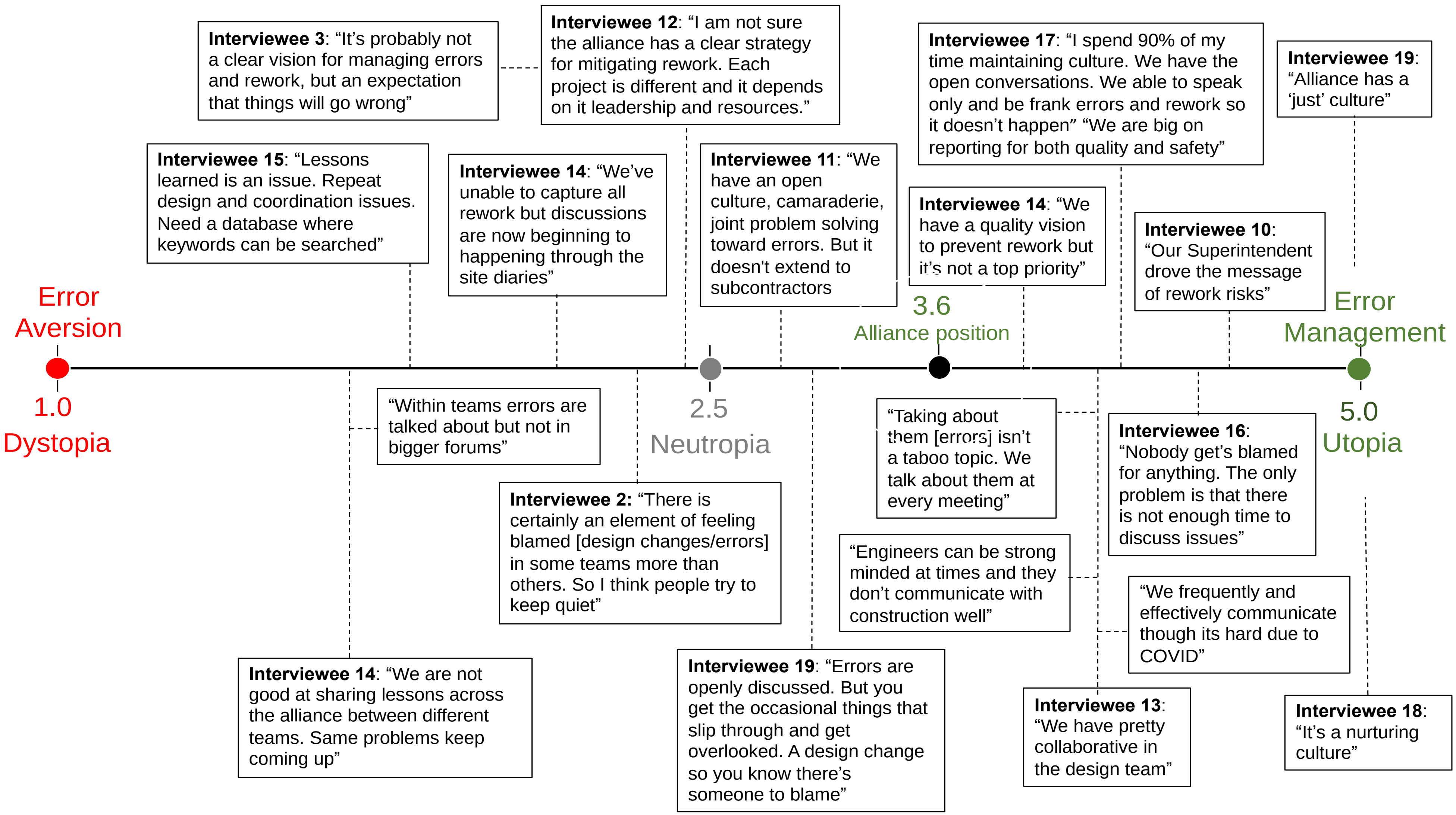


Figure 3. The error culture continuum: Mapping people's views of their project environment

Cognizant of the power relations in the alliance and how it can influence the management of errors, we formulated a *dialogic surround* [72]. Hence, the surround comprises multiple perspectives (i.e., to hear how others construct their world views), providing dialogue that enables a holistic understanding of the interactions between individuals concerns to be obtained. Hearing, in this instance, becomes "fodder for active sense-making" [73].

C Data Collection

We use a semi-structured interviewing process to address our research questions identified above (Table II). Leading questions we introduced to ensure the dialogue remained within the bounds of the study. The interviews aimed to stimulate a process of "spontaneous communication" and interrupt the hegemony of power assumed within the context of doing research by encouraging self-reflective communication [74: p.879]. As a consequence of the questionnaire, we had previously distributed to all members of the alliance, interviewees were aware of our study on error culture and rework.

Members of the alliance from its functional areas such as engineering and design, delivery, and commercial) along with the operator and subcontractors were purposefully selected and invited to participate in the research by being interviewed. Three months was set aside to conduct the interviews. A total of 30 interviewees were invited *via* email to participate in the study, with all agreeing to be interviewed. However, only 19 interviews were conducted within the time frame as potential interviewees could not find time in their busy schedules to accommodate an interview at the agreed and allotted time. However, data saturation, particularly within the context of rework examples identified, began to emerge. Therefore, it was decided not to pursue the additional interviews, even though they were willing to re-schedule them later.

Table I presents a list of interviewees that formed part of our study. Notably, we could not secure an interview with a representative of the OP. Two researchers jointly conducted the interviews. Due to the Coronavirus 2019 (COVID-19) outbreak, travel restrictions resulted in the interviews being performed using Microsoft Teams. Each varied in length from 26 minutes to 60 minutes and were digitally recorded and transpired. We also had access to the project documentation, and issues raised during the interview were checked to validate the presented narrative. Copies of the interview transcripts were made available for comment by the interviewees.

Table I. Sample of interviewees

No.	**Interviewee***	**Time (Minutes, seconds)**	**Transcript word length**
1	Project engineer	40:19	5615
2	Design manager	37:39	5561
3	Quality manager	60:14	9557
4	Project engineer	26:52	3585
5	Design manager	53:58	8653
6	Design coordinator	49:41	6257
7	Quality manager	41:39	5187
8	Project engineer	55:54	5321
9	Superintendent	36:01	5341
10	Project engineer	45:03	6776
11	Construction manager	26:21	3399
12	Subcontractor	48:24	6852
13	Planning manager	39:34	5485
14	Senior project engineer	31:40	4825
15	Engineering coordinator	43:49	7360
16	Planning manager	39:18	5015
17	Subcontractor	32:41	5159
18	Engineering manager	28:54	4333
19	Commercial manager	44:11	6128
	Total	**782:12** (Appox.12 hours)	**110,409**

* For confidentiality, a generic title of the interviewee is used

Analysis

We use thematic analysis to derive and interpret meaningful themes and topics from the interviews [75]. Thematic analysis is driven by the research questions proposed. We used both deductive and latent thematic approaches to perform our analysis. We primarily used a deductive approach to address our first question as prior knowledge and the existing literature were drawn to create themes (Table II). A latent approach required us to focus on the underlying meanings of the data. We relied on this approach to address our remaining research questions as it required us to interpret and not take at face value the data enabling us to theorize.

The interview manuscripts were all inputted into *NVivo* Version 12 to organize and analyze the data. We used a reflexive thematic technique to coding as it provided us with the flexibility to change, remove and add codes as we worked through our data [63]. To recap, our themes align with our research questions and topics to aid our analysis, with direct quotes being selected to reinforce the issues that arose during the interviews (Table II). Figure 4 presents an example of the themes and extracts from interviews. In the next section of this article, we use our data analysis to craft a narrative to address our research questions.

IV RESEARCH FINDINGS

We analyzed the interview data using our intuition and extensive knowledge of the subject matter. We made sense of the interviewee's views and insights about the alliance's error culture to craft a narrative aligned with our proposed research questions. To recap, these questions are: (1) Why and how have errors and rework materialized (i.e., the emergence of error and rework)? (2) How are the risks of errors and rework assessed? (i.e., the anticipation of risks) And (3) How are organizational error management practices being used to facilitate the alliance's error management culture (i.e., organizational error management practices)?

Table II. Research and interview questions, topics and thematic analysis

Research Questions	Topics and Interview Questions	Codes	Themes	Codes	Sub-Themes
Why and how have errors and rework materialized?	**The emergence of error and rework** Identify and describe an event that resulted in rework and its consequences? • What actions were undertaken to resolve the issue? • How long did it take to rectify the problem once identified? • Could it have been rectified quicker? • What was the response to the event from management? • What could have been done to prevent the rework? • Do you feel that you would be penalized/blamed for reporting a problem? • What continuous improvement initiatives are you aware of in the alliance, and have they, in your opinion, been effective? If not, why?	Sub-standard work Quality Defect Poor workmanship Concrete tolerance Reinforcement Structural works Temporary works Fabrication Compliance	Non-conformance	Controlling the program Design programme Staging of programme Decision-making at the coalface Rectification method RFI Unclear directions Immediate modification Adopt, adapt & innovate *	Production Pressure
		Repeat design issues Coordination Combined service route Pre-cast Detailed design The gap between design and construction Pedestrian bridge	Design Change	Stressful Staff turnover Exhausting A feeling of blame Quality system COVID-19 Skilled workforce	Resourcing
		Wrong size Non-Australian steel Combined services route	Design Error	Stakeholder coordination Changes Engineering design Interface coordination	Stakeholders
				Double-handling Early con. involvement Best-for-project	Sub/con

How are the risks of errors and rework assessed?	**The anticipation of risks** • Does the alliance have a clear vision and conscious approach toward assessing and managing the risk of error/rework? • How is rework data captured, stored and used for determining its risks?	Quality system Risk register Interface management Quality vision Workshops	Resilience	Expect things to go wrong Need a database Data capture Benchmarking Site dairies Toolbox Rework register Adopt, adapt and innovate* Skin in the game Key result areas Target adjustment event Target outturn cost People's well-being	Anticipation Preparedness** Awareness Flexibility Opacity
How are organizational error management practices being used to facilitate the alliance's error management culture?	**Organizational error management practices** • How would you describe the culture of the alliance? • How difficult or easy is it to talk about errors/rework? • What types of errors do people talk about? • How is error/rework information shared, communicated and handled? • How often after an event is rework talked about?	Different culture No-blame Just culture Nurturing culture Collaborative team Open-mindedness*** Trust*** A sense of purpose*** Ask questions *** Lessons learned Toolbox talks Informal discussions Message	Error Management Communication and Knowledge Sharing	Muck in together Site coordination meeting IFC drawings RFIs Design assurance Site dairies Repeat design Rework capture BIM Meetings Processes Design-change requests	Help in Error Situations Quick Detection and Damage Control Analyzing** Coordinating Handling

* Some codes applied to more than one theme (e.g., 'Adopt, adapt and innovate' design approach).
** Preparedness and analyzing errors are similar and share similar codes.
*** Align with psychological safety and no-blame culture

A Emergence of Error and Rework

Our first research question requires us to understand the conditions within which a project is delivered and how they influence people's work. The alliance's projects are subjected to considerable production pressure, with several interviewees suggesting that the programmes were overly optimistic. Needless to say, the alliance has been able to successfully construct its projects, with rework being perceived to be significantly lower than those procured using other delivery methods. Markedly, the number of rework incidents in projects has declined considerably since the completion of the first one several years ago and continues to do so as the alliance and its subcontractors learn together. Indeed, collaboration and trust are profound within the alliance underpinning its culture. Reinforcing this point, a commercial manager described the alliance leadership as being authentic, the project having a "Just Culture[11]" and "collective learning environment", enabling it to become "resilient to errors".

It was heartening to hear these contemporary terms associated with anticipating and treating errors in organizations, but they were only explicitly referred to during this interview. There is no doubt the alliance is striving to provide an environment where people can actively learn, 'speak up', cope and recover from errors, but it is falling short in achieving these goals due to the absence of a clear strategy to develop and implement practices to nurture an error management culture

However, the alliance's focus has been building a no-blame culture. In doing so, it has developed a genuine sense of camaraderie within the alliance and with its subcontractors. It has taken over five years for the alliance to establish its culture, and no doubt its leadership has

[11] A 'Just Culture' establishes an organization-wide mindset that positively impacts the work environment and outcomes [76]. It promotes a process where errors do not result in automatic punishment, but rather a process to uncover their source. So, a Just culture looks at 'what went wrong' rather than 'who caused the problem'

played a significant role here. Still, the role of the alliance’s leader was only referred to in passing. Many lessons have been learned requiring design and construction processes to be modified, procedures to be adapted and fine-tuned, and peoples’ skills and knowledge to be updated.

The alliance's strategy to mitigate the risks of production pressure was to use a ‘adopt, adapt and innovate’ design approach. It enabled them to adopt new and complex solutions according to existing knowledge previous resources. Designs from completed projects were re-used and modified, which contributed to gains in productivity and a reduced incidence of mistakes. Even though the ‘adopt, adapt, and innovative’ strategy has been an effective response to production pressure, an engineering coordinator informed us that “repeat design and coordination errors still occur even when we use this approach” (Figure 3).

With each new project and the drive to complete it quicker than previous ones, the ability of project teams to adapt and respond to the imposed stretched completion target and coordinate work becomes constrained. What is more, design engineers have been reluctant to listen and accommodate suggestions from supervisors, project engineers and the like working onsite at the coalface. A quality manager, in jest, used the following analogy to describe working with engineers as “like wrestling with a pig in mud” and went on to say that “they don’t like to be told something is wrong”.

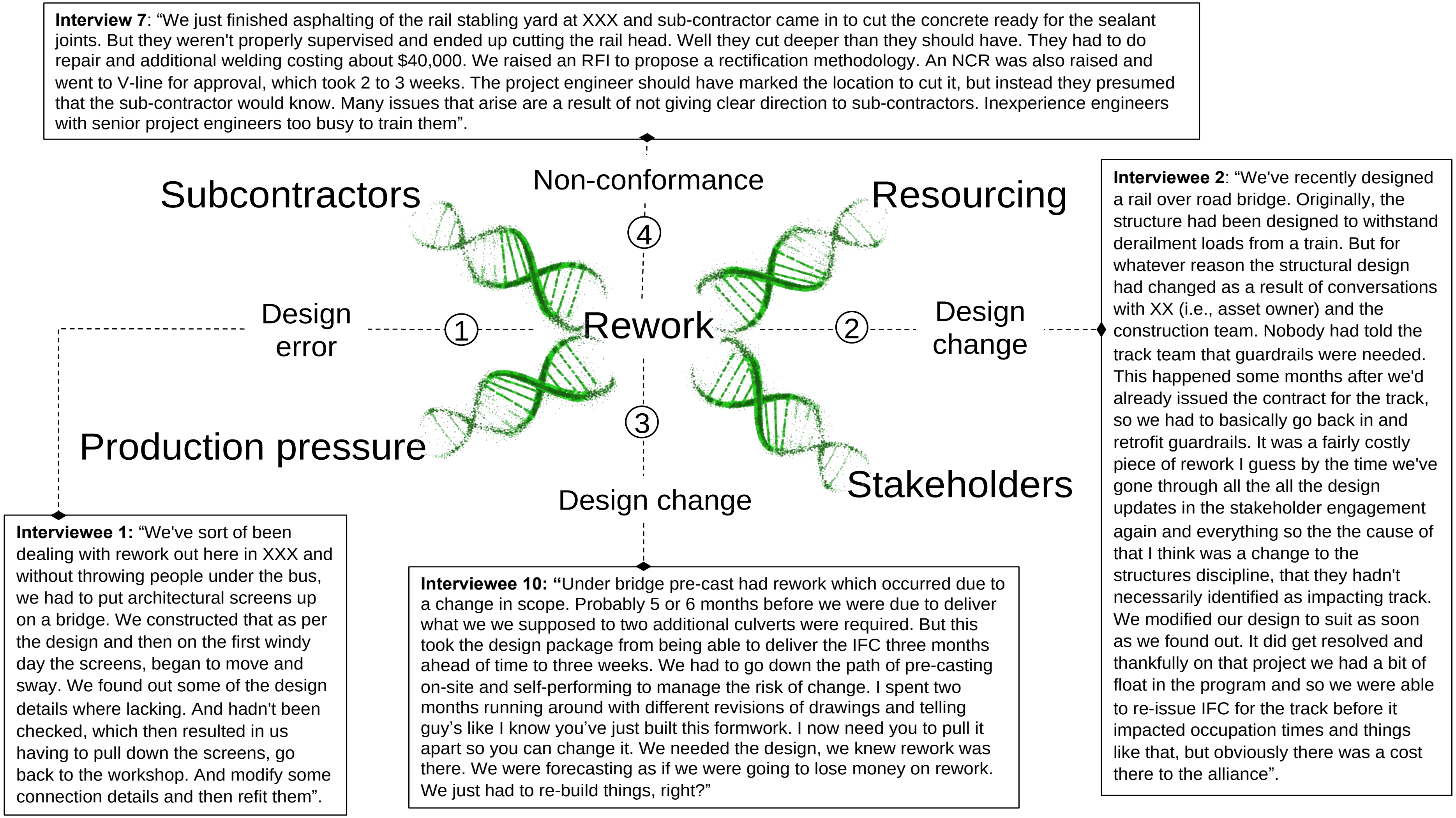
We can readily paint a picture describing how successful the alliance has been in containing and reducing its errors. However, this is not the intention of this article. Errors are still occurring, and rework impacts productivity negatively despite a continuous improvement strategy being in place.

Our active sense-making approach enabled us to understand the dialogue that emerged from the interviewees within the alliance context. We invited interviewees to describe a rework event they were familiar with to garner insights about the conditions within the alliance that influenced its occurrence. Examples of rework events emerging from interviewees are presented in Figure 4 and aligned with the themes as non-conformances, design errors and changes. Noteworthy, design changes were required due to mistakes contained in IFC drawings.

1. Production Pressure

As we indicated above, project deliverables were constrained by time, with several interviewees describing the working environment within the alliance as being "intense", "stressful", and "exhausting". Naturally, such a work environment impacts people's physical and psychological well-being, increasing their propensity for error-making. Stress and burnout are often outcomes of production pressure and may result in staff turnover, leading to further strain being placed on employees. While it was mentioned staff had resigned due to the pressures of workload and resultant job strain, those interviewed all emphasized there was workplace support enabling them to adapt, cope and learn with the demands imposed upon them. Affirming the supportive work environment of the alliance, a design manager made asserted:

> "The language we use in this project is collaborative. The culture is nurturing. You know there's a support network, and there is a sort of selflessness that comes through as a result of the culture. It is enjoyable to be in this culture where you know it's very supportive".



Key: IFC = Issue for Construction, NCR = non-conformance report, RFI = Request for Information

Figure 4. Classification of rework themes and examples

Interviewees were in the midst of a ‘lock down’ due to COVID-19 when our study was conducted. Design teams had to work virtually, hindering their ability to informally clarify and discuss engineering issues and obtain an immediate response to queries and problems. Virtual working required additional time and effort to synchronize the design and documentation of engineers to mitigate coordination errors. Acknowledging the difficulties of virtual working, an engineering manager stated, “we’ve had challenges with collocating, managing interfaces, issues with bandwidth, and coordinating design”, and as such “we’ve had the occasional slip-ups”.

Among the numerous rework examples provided, such as the architectural screen event highlighted in Figure 3, error-making (e.g., mistakes and lapses) due to time constraints was repeatedly identified during the installation of reinforcement. In essence, project engineers routinely focused on checking the quantity of reinforcement instead of paying limited attention to nuances of the design and what had been installed. Referring to one particular incident, a site supervisor made the following remark:

> “Engineers checked the quantity, but they didn’t check the actual cog (i.e., bend of the bar). It was the wrong length. The cage had to be amended, and the concrete pour was delayed”.

Seven pile caps needed to be checked, and six had been completed without an issue. So, it is was assumed the final pile cap would also conform, and a concrete pour was scheduled. However, before the concrete pour, the supervisor noticed a mistake in the reinforcement cog requiring work to be halted, resulting in rework and delays to works being incurred.

2. Resourcing

Several transport infrastructure mega-projects were being simultaneously constructed in the Eastern States of Australia. Skilled workforce shortages abound, impacting project costs and productivity. In the case of the alliance and its projects, there is an absence of knowledgeable and experienced project engineers capable of supervising works and understanding design and construction methods. According to a project engineer, the upshot is that "graduate engineers just don't have the support they should have", and they have to accommodate greater responsibility in their roles.

In the example non-conformance example that we present in Figure 4, the cost of performing rework due to a mistake by a junior engineer was estimated to cost AU$40,000. This incident, briefly described in Figure 4, occurred in the first project undertaken by the alliance. As a result of this event, considerable effort has gone into ensuring engineers communicate with one another and the site team concerning the process of rectifying non-conformances (e.g., 2.00 pm daily coordination meetings). Having access to an experienced and qualified workforce is an on-going issue facing the alliance; mistakes and lapses are being made by inexperienced people, which are being exacerbated by production pressure.

3. Stakeholders

The projects being procured by the alliance have multiple stakeholders. Managing their needs and requirements is a daily challenge, with an engineering coordinator lamenting, "we often are required to make changes, and constantly communicate with them". Changes to the engineering design due to mistakes, misunderstandings or misinterpretations of an operator's maintenance requirements were frequently required. Such changes tended only to be communicated to immediate discipline that was impacted and not others. For example, the operator created an engineering change requiring the structural engineer(s) to modify their drawings. The change directly affected the installation of the rail line, but this was not communicated to the track group. After the issue of the IFC, the error came to light requiring an additional three weeks to re-work the design and an additional Interface Design Coordination (IDC) workshop. So, why did the structural engineer(s) not inform the track group? The reasons put forward focused on resolving the immediate problem at hand and oversight brought about by pressures not to delay the design process.

4. Subcontractors

Despite the alliance working with the same specialist subcontractors for several years, their expertise is not drawn upon when designing and planning the construction works. A site supervisor and planning manager suggested that rework could be mitigated by using early contractor involvement (ECI) in the design process. However, they thought there would be resistance from engineers. Reinforcing the participative role that subcontractors can play in mitigating the need for rework, a construction manager stated:

> "We have an open culture, camaraderie and joint problem solving toward errors, but it doesn't extend to subcontractors. I think they have an important role to play, and we should consider their input in the design process" (Figure 3).

If specialist subcontractors had some input into the design process and a project's constructability, errors and rework would be reduced, and safety improved. Subcontractors were not provided with any form of financial incentive scheme (i.e., 'gain-share/pain-share' regime), like that underpinning the contract of NoPs. Even though specialist subcontractors had worked with the alliance for several years, they were required to bid for work and provide a lump-sum price. While the alliance aimed to select subcontractors on a 'best-for-project' basis and their ability to deliver value for money, on occasions, they awarded contracts to the lowest bidder.

On one occasion, this backfired, potentially having negative consequences, as the bid of a precast subcontractor who had regularly worked with the alliance was overlooked in place of the lowest price. The selected subcontractor's performance came into question, as they were unable to meet the standards and expectations of the contract in accord with their tendered price. On the day of the interview, the subcontractor that had been overlooked for the job and had established a "reputation, hit targets, did the work well and had a decent safety record" was "asked to come in and take over the piece of work". Naturally, the subcontractor agreed to complete the unfinished work, as they were committed to the alliance, but its quality (i.e., standards and compliance to regulations) had yet to be assessed.

B Anticipation of Risks

Our second research question aimed to examine how rework risks are assessed. Alliance members were cognizant that rework had been and continues to be a problem in their projects. At the same time, there was an absence of an explicit mission statement and organizational vision (e.g., Getting it Right the First Time) to address rework, though considerable effort and investment in developing a robust quality system to manage its risks had been made. Thus, the default for formally managing rework risks was adhering to and relying on the quality system and its procedure to capture non-conformances. However, when a non-conformance is identified, the process to record, monitor and close-out is time-consuming, resulting in project engineers, in some instances, considering alternative avenues (e.g., raising an RFI) to address queries or obtain solutions. Informally, rework risks are discussed during daily toolbox talks and superintendent coordination meetings, particularly their potential safety impact. The toolbox talks provided an informal medium to raise awareness and monitor potential problem areas, and determine if appropriate resources were available to respond accordingly. Bolstering these points and emphasizing the need to anticipate rework risks, a superintendent remarked:

> "You're probably 70% more likely to have an [safety] incident during rework. Realizing this sort of scared a lot of people. We need to start understanding this issue, and maybe we need to start looking more closely at rework."

Putting aside non-conformances, there is no mechanism to formally capture, consolidate, and analyse other rework events within the alliance, making it difficult to determine the actual costs and negative impacts on work activities. The absence of such explicit error and rework knowledge hinders the alliance's ability to anticipate its risks effectively. Notwithstanding, the alliance is making strides to address its rework and associated wastes. It has initiated a program of research and development to heighten its design and construction teams and subcontractors about error-making and handling. Emerging from our interpretation of the interview data is the theme of *resilience* as there was an underlying desire to identify and respond to errors and rework, but the absence of data was hindering its awareness and thus its ability to prepare for them.

C Organizational Error Management Practices

Our third and final question examines how organizational error management practices were being used to facilitate the alliance's error management culture. Our interpretation of the data led us to align our themes with the organizational error management identified by Van Dyck *et al*. [24] (Table III) (1) communicating about errors; (2) sharing error knowledge; (3) helping in error situations; (4) quick error detection and damage control; (5) analyzing errors; (6) coordinating error handling; and (7) effective error handling.

We use our interpretation of the interview data to denote the extent of implementation of the organizational error management practices identified in Table III. Our subjective interpretation was checked by members of the alliance's continuous improvement team comprising members from various functional areas and considered representative of practice.

Managers and supervisors encouraged people to 'speak up' within their design and construction teams and engage in open and constructive dialogue about errors within the alliance. Similarly, site management teams encouraged subcontractors to present their voice, no matter how trivial they may appear to be, about their likely issues or concerns. Despite promoting the importance of 'speaking up', fear of being caught and reprimanded for making mistakes remained an issue for some teams and individuals.

We often see people placing a lot of energy into concealing mistakes. Referring to a particular rework incident that arose with a water main issue, estimated to have cost AU$250,000, a commercial manager found that no one in the engineering team would take responsibility for not communicating and liaising with a public authority about its required specification. Instead, blame was deflected back onto the water authority even though the engineering design for a water main's sleeve had to be re-designed at a cost to the alliance as it did not adhere to the public authority's standards.

Table III. Illustrative interview quotes to support error management organizational practices

Organizational Practice	Example of a Quote	Extent of Implementation †
Communicating errors	**Interviewee 1**: "It gets frustrating having to do things more than once. We try to work through things that go wrong, but you don't go broadcasting your mistakes to everyone, but you speak to the relevant people and work together to get it [the errors] resolved. There is a big push in the alliance to communicate stuff-ups, especially at the end of a job". **Interviewee 2**: "A mistake requiring a change should always be communicated to the wider team, and we do it in this alliance. We have weekly meetings to make sure people are aware and identify those impacted". **Interviewee 4:** "Any problems [mistakes] we have or rework are brought up at toolbox meetings, and everyone learns from there. There is nothing to hide. We talk about it [errors and rework], and move on." **Interviewee 11:** "Everyone is fairly open to talking about rework; everyone is in the same office, and we chat about issues. We often talk about problems with concrete strength, crushed rock compaction and stuff like that."	****
Sharing error knowledge	**Interviewee 17:** "We often share our rework experiences with the alliance, and if we have a near-miss, we share this as well. We have established a relationship with them [the alliance] and have skin in the game, so we share our knowledge as it benefits us both" **Interviewee 9:** "I run a daily 2.00 pm coordination meeting with the entire site team, including subcontractors. We sort of run through the works of the day and discuss any problems [errors] and rework that may have happened or could happen. So, we have a look at how have we gone so far? And, what does tomorrow look like for the next couple of days". **Interviewee 17**: "Lessons learned from other jobs is important for us as we look to re-use solutions and methods. We're trying to create a sort of IKEA site type textbook, so we can meet programme and improve productivity."	****
Helping in error situations	**Interviewee 9**: "Everyone's work affects someone else. We're all on the same page, trying to get the job done. We all muck in together when a problem occurs, and	***

	everyone wins. It's not a blame thing here. We come from the same place of learning. So, stuff happens. I run a daily 2.00 pm coordination meeting with the entire site team, including subcontractors	
Quick error detection and damage control	**Interviewee 5:** "There is a risk of rework post the IFC of drawings, but we undertake a design assurance process before they are issued. If there is an issue, we will be informed by the construction team, and we will try to develop a solution as quick as possible. We evaluate solutions not to delay the project." **Interviewee 12:** "You have to do your prep work before the IFC drawings. We do temporary works but don't start works anymore before the IFC are given to use – we use RFI's when there are potential problems [mistakes].	***
Analyzing errors	**Interviewee 9:** "We are starting to capture rework [i.e., not documented as non-conformance reports or design-change requests] through site dairies to analyze the types of error. So, we'll have a record of things that are brought and discussed". **Interviewee 15:** "Repeat design issues are a problem and coordination errors. Concrete approvals are repeated in our projects, but we don't have any concrete registers that make it easy for construction [the team] can effectively use and approve. A lot of repeat paperwork, which I am looking at now. We need a database to search for keywords. You know concrete works are a potential rework problem. So, how can you prevent cracking? Do we need to change the design?"	**
Coordinating error handling	**Interviewee 2**: "You often don't think about how a change [due to a mistake] affects the wider team. This was a lesson we learned. Now, when a change is needed, it is communicated to the wider team, we have a weekly meeting where the issue is talked about". **Interviewee 2**: "Our reliance on BIM [building information models] allows us to attend to issues [errors and changes] from an interdisciplinary perspective. We can notify all affected by a problem."	**
Effective error handling	**Interviewee 19**: "Our processes for dealing with changes, non-conformances etc., have been evolving, and we can do this well now. We're always learning but are faced with time constraints, and so we deal with issues as effectively as we can."	**

†Key: ***** Very large extent, ****Large extent, ***Some extent, ** Minor extent, * Not at all

Although people in the alliance are openly encouraged to discuss errors within their respective design and construction teams in informal settings in large forums, such as ‘lesson learned’ workshops, this was not the case. A degree of hesitancy prevailed about ‘speaking up’ at formal events, particularly in front of unfamiliar members of the alliance. But, glancing over our interviewee data, we can clearly see that talking about errors and rework during these workshops increased awareness of their presence. However, from the insights obtained, it appears the alliance might not understand and know how to deal with errors and enact changes to practice to ensure they are contained and reduced effectively (Table III).

According to an engineering manager, lessons learned workshops were viewed as a “check box” exercise as “the same problems keep coming up, and we’re not learning”. Indeed, the alliance has made progress toward establishing an error management culture, though unconsciously under auspices of its ‘no-blame’ approach. Still, it needs to work on its coordination, analysis, and handling to develop the mastery of errors required to make the step-change improvements necessary to mitigate rework in its projects (Table III).

V DISCUSSION

The alliance, over several years, has been able to implement a series of organizational practices that have enabled it to make progress toward establishing an error management culture where error occurrence does not result in cognitive resources being wasted and, in its place, a focus on controlling their causes. The challenge for the alliance is to identify the controllable cause (e.g., the working conditions and practices) of rework as its systems and processes have not been specifically tuned to capture and document events and enable them to be analyzed [31].

Identifying rework causes and adjusting work practices has been typically *ad hoc* and over-reliant on learning from significant events. The identification and analysis of controllable causes provide the ability to determine risks and optimize processes and tasks within projects. Equipped with knowledge about the errors that result in rework, the alliance would be in a position to anticipate its risks and better cope and respond to unexpected events [4], [57]. Not all errors are controllable, especially cognitive ones (i.e., judgment and decision-making), though we have not addressed them in our study. However, we need to point out within the context of the alliance's work environment, which is characterized by high workload demands, a cognitive error can be exacerbated by a person's stress response, resulting in constrained thinking. The fear of making a different mistake compounds the issue at hand, creating repetitive thinking rather than problem-solving.

The decisions we make are all vulnerable to different forms of bias or error [12], [27], [33], [41]. With the benefit of hindsight, various explanations for the decision taken relate to embedded ways of thinking, such as the use of mental heuristics (e.g., rules of thumb and short-cuts). Such heuristics can be efficient and accurate in many situations but are sometimes predisposed to wrong decisions. A case in point is determining the alliance's project schedules, which have undoubtedly been subjected to optimism bias. Here there is a mistaken belief that adverse events (e.g., rework) can be addressed, and projects will be delivered on time. In fact, projects have been delivered on time but at a cost. The resultant production pressure manifests negative consequences, including increased job strain, a reduced capacity to effectively handle and coordinate errors, and learn and develop innovations.

To this end, drawing on the words of Winston Churchill's "When you're going through hell, keep going". Metaphorically speaking, we consider hell to be the on-going production pressure that confronts projects. The commitment, trust, collaboration and camaraderie within the alliance provides its various teams with the drive to ‘keep going’ and ‘muddle through’ their errors by enacting organizational practices of error management, though in varying degrees, enabling incremental changes to procedures and routines. Though only briefly touched upon, the authenticity of the alliance’s leadership team appears to have energized its design and construction teams' motivation to deliver their projects successfully. However, going forward, an error mastery mindset, which extends beyond error management to include resilience (i.e., an ability to transform lessons from the past into future success), should be developed within the alliance to accommodate better and balance the project’s competing demands [11]. In this instance, error mastery “entails a positive approach, optimally balancing the needs and possibilities for both error prevention and management (e.g., correction and learning) of errors” [25: p.429].

A Theoretical Implications

Studies examining error culture in mega-projects have been rare. Yet, their sheer size and length of time enable error cultures to be developed by establishing shared norms, values, and practices. Our previous research suggested that the program alliance culture, which we also examine in this article, displayed norms and values akin to an error management culture [27]. As we have mentioned, an alliance contract is built on a ‘no-blame’ culture and recognizes that errors will be jointly remedied, but no consideration is given to developing a mastery for error-handling and recovery, which is essential for learning to mitigate rework in projects [8].

The use of a ‘no-blame’ culture promotes open communication and collaboration. It, therefore, follows that communication and sharing of errors were prominent features of the alliance we have examined in this article. Over time, it has also begun to intuitively employ the organizational practices of error management. While a 'no-blame' culture goes some way to addressing error, the alliance in pursuing this approach was unable to benefit from simultaneously pursuing its goals of control (e.g., project schedule) and learning.

Yet, if an error management culture is wholly pursued and organizational practices effectively applied, errors can be quickly detected to control their damage, enabling minimal disruption to a project's schedule. In the case of learning, error management views errors as "learning opportunities encouraging exploration and experimentation" [24; p.1229]. In essence, an error management culture extends the 'no-blame' approach that alliances aspire to develop by moving beyond communicating and sharing errors. Error management can address the trade-off in "allocating resources between control and learning", therefore providing a much-needed approach to respond to the error-making resulting rework, which has permeated practice in transport mega-projects [11], [24: p.1229].

While cultivating an error management culture can improve the performance and productivity of alliances [8], its organizational practices are not well-positioned to 'anticipate what goes wrong' (e.g., rework beyond non-conformances). Thus, a new theoretic for error mastery emerges by building resilience and incorporating it into an error management culture. In doing so, we extend the 'no blame' approach used in alliances, enabling headway toward rework mitigation to be made. Two theoretical issues come to the fore requiring attention in the future to help operationalize the effectiveness of an error mastery mindset in alliancing, which include the:

1. Determination of the boundary conditions of the 'gain-share/pain-share' incentive regime and acceptable risk behaviors. Under the auspices of an error management culture, the

positive outcomes of learning through trial and error are promoted, but it can come at a cost to project performance if controls are not implemented.

2. Differences between the aetiology of errors and rework with varying consequences, and examining how people can be motivated to engage in reflexive practice, share knowledge to anticipate their risks.

Despite the need for clarification around the theoretical issues we have identified above, we present an operational framing to practically implement our error mastery theoretic in the next section of our article.

B Practical Implications

Like in the alliance we have examined, other projects repeatedly experience similar errors, though their consequences vary depending on how quickly they are identified and the degree of rework required. Indeed, providing individuals with EMT and nurturing their ability to cope (e.g., build vigilance and improvisation skills) and 'learn through' errors can be beneficial [32], [55]. However, it is the organizational and team errors that tend to be the most disruptive, producing adverse outcomes in projects.

Most error-making conditions are controllable, and some will be unexpected. Yet, how an alliance *understands, embraces* and *adapts* to their projects conditions and complexity will determine its ability to respond and recover from errors and build resilience. The context within which program alliances and their projects operate produces organizational and team errors. By context, we refer to the setting of the alliance's contract and deliverables (e.g., key result areas), which can shape processes and behaviors through the interactions between project participants. Based on our sense-making study and previous studies in this area [5],[8], the principles we present in Table IV, akin to the key ingredients of a curry, can support program alliances to create an error mastery mindset and improve their performance.

Unquestionably, an error mastery mindset will enable alliances to support their people better, anticipate what might go wrong, enable them to adapt and learn about circumstances where errors and rework occur and re-establish work practices after an adverse event [4]. What is more, we suggest specialist subcontractors performing critical works can also be incorporated into the alliance as an NoP. In doing so, they would be provided with the benefit of a 'gain-share/pain-share' regime and an incentive to become actively involved in the alliance's error management approach as part of an ECI strategy.

C Limitations

Our suggestions for improving practice are confined to program alliances. Despite this limitation, they are now popular delivery strategies to procure complex infrastructure projects by the public sector and have relevance for practice [78]. Moreover, our collection of principles creates an error mastery mindset, which can be readily adopted, moulded and integrated into the fabric of mega-projects delivered using other forms of collaborative delivery (e.g., Integrated Project Delivery).

Another limitation of our study is that we have only examined action errors and not considered violations and errors in judgement and decision-making and the conditions within which they occur. Errors and violations may interact, and when they do, the consequences can be disastrous, as in the cases of the Tay Bridge collapse (1879), Westgate Bridge collapse (1970), and Charles de Gaulle airport collapse (2004), to name a few.

Table IV. Creating an error mastery mindset in alliance transport mega-projects

Error Mastery Principles	Explanation	Strategy
Alliance Leadership and Management Teams (ALT/AMT) Commitment	ALT and AMT demonstrate commitment towards people's well-being and performance	ALT/AMT regularly visit and walk-around project sites and establish a working committee to look at risks of error/rework and anticipate unexpected events.
Error Management Culture	A belief that errors are inevitable, potentially damaging, and can be turned into something positive. Involves coping with errors to avoid their negative consequences. Violations (e.g., culpable acts) are not tolerated and are dealt with separately	Establish a clear vision regarding errors. Quality, for example, to be included as a key result area. Implementation of organizational practices such as communicating about errors, sharing error knowledge, helping in error situations, and quickly detecting and handling errors.
Psychological Safety	Supports team members to report and 'speak up' about issues without feeling embarrassed, their voice rejected, and they will be punished.	Support and encourage people to 'speak up' during meetings lessons learned workshops. Establish communities of practice to identify problems and propose solutions/innovations
Awareness	Data gathering and providing management with insights about the performance of people and project(s) to determine the extent of problems (e.g., rework) and the current state of defences	Routinely monitoring people's well-being. Also, issues such as rework and its consequences (e.g., associated wastes, costs, delays, environmental and safety, incidents)
Preparedness	Alliance actively anticipates the impact the workplace demands and constraints can have on people's performance and prepares for them to *understand*, *embrace* and *adapt*	Foresight (i.e., predicting risks), coping (i.e., preventing risks) and recovering (i.e., recover from an issue if it happens) strategies are identified and integrated, and work practices amended accordingly
Flexibility	The ability of the alliance to adapt new or complex problems in ways that maximise their ability to solve problems without disrupting work	Allowing specialist subcontractors to have' skin in the game' and become an NoP. Their involvement can help improve constructability (e.g., 'adopt, adapt and innovate' design approach), quality, safety, productivity, and reduce costs.
Opacity	Alliance is aware of the financial, workload, production, quality, safety, and environmental pressures and where effort needs to be invested in ensuring defences are not degraded	Monitoring workplace pressures (e.g., programme) so that strategies can be developed to ensure standards and project deliverables are met

Adapted from Jeffcott *et al*. [77: p.258]

Research has shown that people tend to commit violations as a "result of a well-intentioned desire to get the job done" [79: p.77]. Thus, people breaking rules may not understand how they function and unintentionally underestimate risks they are taking [4], [12], [38], [57], [79]. We often see violations occurring in projects when there is a trade-off between low-priority and high-priority goals while production pressure is present [11], [12], [79]. Moreover, we need to be cognizant that violations only occur as rules exist but have tended to evolve "as a reaction to errors on some prior occasions" [12: p.679]. Hence, Frese and Keith [12] propose using violation management akin to error management in treating violations. In this instance, violation management commences "after a violation has occurred" and aims "to avoid its negative consequences altogether" or reduce its negative consequences [12: p.679]. However, violation management has yet to be examined within the domain of project behavior.

VI CONCLUSION

The mitigation of rework in construction presents itself as a wicked problem. Previous studies have overlooked the complexities and nuances of errors that result in rework. We, therefore, drew on Rick Stein's experiences with Indian curries, where he believed that people under-appreciated the complexities associated with their creation. The quest to address rework in construction is mirrored here, as attention has been focused on singular causal factors rather than the conditions that influence the occurrence of errors.

Our previous research revealed that the alliance we have examined in this article and forming part of a major transport mega-project displayed the attributes of an error management culture, enabling it to progress toward combating its rework problem [27]. This study extends our erstwhile research by garnering an understanding of the context within which errors and rework and the organizational practices within the alliance are used to contain and reduce them. We, therefore, sought to answer three research questions: (1) Why and how errors and rework materialize; (2) How are the risks of errors and rework assessed? And (3) How are organizational error management practices being used to facilitate the alliance's error management culture?

In accord with our quantitative results, [27], we can confirm the error culture of the alliance aligns with that of error management, with emphasis placed on communication and sharing error knowledge. Actually, this is not surprising considering an alliance operates under the umbrella of a 'no blame' environment. Additional error management organizational practices were at play, though not to the same extent, such as helping in error situations. Practices focusing on the analysis and quick correction of errors to mitigate their adverse consequences were also left wanting. As a result, this has hindered the alliance's adeptness for learning as it has experienced episodes of 'Groundhog Day' where repeated rework events have become leitmotivs of practice. Compounding this situation has been the alliance's inability to *understand*, *embrace* and *adapt* to production pressure, stakeholders, resourcing (e.g., competing demands) and their specialist subcontractors' constructability knowledge.

We should acknowledge that the alliance recognizes the problems associated with rework and strives to learn from its occurrence. But it has seemingly stalled and needs to do something different to obtain step-change improvements in performance. So, taking heed of the wise words of Einstein, "once we accept our limits, we go beyond them". Error training can provide an individual's awareness and increase skills. It may also improve their motivation to perform well. Still, a focus on organizational error management and practices and building error resilience is needed to enable the alliance to mitigate its rework and improve its performance beyond its current levels.

We, therefore, propose a collection of principles that the alliance can draw upon to create an error mastery mindset so it can manage its rework risks and unexpected events. The error mastery principles we present in this article form the basis of our contribution. The benefits of an error mastery mindset are threefold as it provides the ability to: (1) better support people's well-being; and (2) anticipate what might go wrong; (3) adapt and learn about circumstances where errors and rework occur and a mechanism to re-establish work practices after an adverse event. Future research is required to test and validate the proposed error mastery mindset, particular the creation of the format and structure data to be collated to support our 'awareness' principle and the development of business analytics to support the 'preparedness' one.

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