Developments in the Built Environment 12 (2022) 100084

Contents lists available at ScienceDirect

Developments in the Built Environment

journal homepage: www.sciencedirect.com/journal/developments-in-the-built-environment

When 'less is more': The rationale for an adaptive toolbox to manage the risk and uncertainty of rework

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ARTICLE INFO

Keywords:
Adaptive toolbox
Construction
Heuristics
Rework
Risk
Safety
Uncertainty

ABSTRACT

Determining the risk and uncertainty of rework in construction has received limited attention due to a paucity of information about its frequency and causes. Errors made during construction, which may require rework, can go undetected, manifesting as an engineering failure during an asset's operation and thus jeopardise system safety. Therefore, this paper addresses the following research question: *How can practitioners make better decisions to mitigate the risk and uncertainty of rework during the construction of infrastructure assets and ensure system safety?* Using a mega-transport infrastructure asset as a case setting, we adopt an interpretative line of inquiry and examine people's experiences with managing the risk and uncertainty of rework under the auspices of a sense-making lens. Our analysis revealed that heuristics were being used informally to determine rework risks and uncertainties due to the absence of information, resulting in them becoming curiosities as the same mistakes were repeated and learning stymied. We suggest that developing an adaptive-box tool comprising heuristics can provide the much-need theoretical foundation to effectively manage the risk and uncertainty of rework. Such heuristics would be adaptable to different situations as they are fitted to the environment through evolution and/or learning by amending them successively in small steps.

1. Introduction

While constructing an infrastructure asset, unidentified errors can manifest during its operation, negatively impacting maintenance and simultaneously compromising system safety (Love and Matthews, 2020). Detecting and rectifying errors before an asset is operational provides a line of defence to ensure a constructed asset's system safety. During the construction of an infrastructure asset, the context of this paper, having to rework a task or process due to an error is an ever-present reality that continues to plague practice, despite efforts to mitigate its risks (Asadi et al., 2021). Performing rework during the construction of an infrastructure asset can be far-reaching, adversely influencing costs and schedule, productivity, the environment (e.g., contamination and pollution) and a construction organisation's reputation, profitability and stock value (Love et al., 2020).

Errors cannot always be prevented as they are a normal part of any work routine (Hughes, 1951). Emphasising the adage that to err is human, Reimer (1979) reminds us that "any work, regardless of routine involved, is faced with the probability of error" (p.123). Statistically, "the more times per day [a person] does a given operation, the greater [their] chance of doing it wrong sometimes" (Hughes, 1951: p.320). It is natural for construction organisations to prevent people from making errors as they are associated with negative consequences, such as performing rework or accidents (Frese, 1991). Thus, instinctively, construction organisations cultivate an error prevention mindset that assumes "errors can and need to be prevented" (Frese and Keith, 2015: p.666). Prevention is sought through "blocking erroneous actions (i.e., goal-directed behaviours and communicative acts)", by designing tools, procedures and systems and through training (individuals and teams) (Frese and Keith, 2015: p.665). When errors do occur, miscreants are blamed and reprimanded accordingly.

Such responses are in accord with the *Bad Apple Theory*, where there is a belief that the organisation would perform efficiently and effectively if not for a few "unreliable people" responsible for errors and any

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https://doi.org/10.1016/j.dibe.2022.100084
Received 10 July 2022; Received in revised form 29 July 2022; Accepted 4 August 2022
Available online 17 August 2022

failures (Dekker, 2006: p.1). In the case of rework, construction organisations have traditionally treated it as 'uncomfortable knowledge'[1] or a *zemblanity* (i.e., an unpleasant yet unsurprising discovery) (Love et al., 2019). The practice of hiding mistakes is institutionalised in some construction organisations as management does not like to hear bad news (Ford and Sterman, 2003). With mistakes being associated with bad news, project team members are often reluctant to document non-conformances (Love et al., 2018a). The resulting "wall of silence enables project team members to abrogate their direct responsibility, thereby preventing any form of reprimand from their immediate manager" (Love et al., 2016: p.2).

A focus on error prevention hinders the ability of construction organisations to contain (i.e., enhance detection and recovery from errors and minimise adverse consequences) and reduce (i.e., limit their occurrence) errors and therefore mitigate rework. Additionally, solely focusing on error prevention has contributed to stagnating safety performance, poor organisational and project performance, and ineffective learning and innovation (Love et al., 2018a).

Due to the drive to improve project performance and the safety of constructed assets, the spotlight is now being placed squarely on addressing error and assuring quality due to the 'Getting it Right Initiative'[2] campaign and initiatives in the United Kingdom (UK). By the same token, the former Level Crossing Removal Authority[3] (LXRA), now the Major Transport Infrastructure Authority responsible for delivering a mega infrastructure project in Melbourne (>$8 billion), recognised rework was a problem and organised a workshop in 2018 with its alliance partners to examine how it could be reduced and avoided.

Increased awareness of error, rework, and the likelihood of possible failure prevails more than ever in construction. Markedly, several construction organisations acknowledge rework is a problem and have been implementing practices to reduce its presence in projects (Love et al., 2022a; b;c). Such practices include communicating and sharing error knowledge and encouraging people to report their existence openly. Thus, we have seen the error culture in some major infrastructure projects subtly shift from an error prevention position toward error management. There is an acceptance that errors happen, and no blame for their occurrence ensues (Love and Matthews, 2022). An error management culture appears most notably in projects being procured using an alliance, where there is an advocacy for collaboration, a 'no-blame environment, and a 'gain-share/pain-share' incentive regime is in place.

While there is a wealth of research examining the proximal causes of rework in construction (e.g., Ye et al., 2015; Yap et al., 2020; Grag and Misra, 2021), limited attention has been placed on the conditions resulting in its occurrence, or managing its risk and uncertainty in projects. This situation has arisen because organisations explicitly avoid (besides non-conformances) documenting and analysing their error and rework events. The upshot is an inability to determine rework risks.

Armed with only limited information, project teams need to rely on heuristics to make judgements about rework. If we rely on heuristics, in the absence of information, then the "mind resembles an adaptive toolbox with various heuristics tailored for specific classes of problems—much like the hammers and screwdrivers in a handyman's toolbox (Gigerenzer, 2008: p.20).

Against this backdrop, our paper addresses the following research question: *How can practitioners make better decisions to mitigate the risk and uncertainty of rework during the construction of infrastructure assets and ensure system safety?* Using the lens of sense-making, we draw on documentary sources and the insights and experiences of practitioners involved in constructing a transport mega-project (>$1 billion), using an alliance delivery method, to examine how errors and rework risks are assessed.

Based on our interpretation and extraction of meaning from the data analysis, we show how an adaptive toolbox can be used in practice to help anticipate rework risks and manage their uncertainty. At this juncture, when describing risk, we need to consider how decisions are made when all the relevant alternatives, consequences, and probabilities can be *known* (i.e., this requires statistical thinking) (Gigerenzer and Selten, 2002). Contrastingly, in the context of uncertainty, attention needs to be given to how we should make decisions when some of the alternatives, consequences, and probabilities are *unknown* (i.e., this requires heuristics and intuition) (Gigerenzer and Selten, 2002).

We commence our paper by briefly examining the theoretical background of errors and the risk of rework during the production of an infrastructure asset (Section 2). Then, we present our research method and data collection procedure (Section 3). The emerging insights from our qualitative analysis and observations of practice are next presented (Section 4), followed by a discussion about the role of an adaptive toolbox in managing the risk and uncertainty of rework (Section 5). Finally, we present our conclusions and identify the contributions of our study (Section 6).

2. Theoretical background

Definitions of rework abound in the literature. For example, Robinson-Fayek et al. (2004) describe rework as 'the total direct cost of re-doing work in the field regardless of the initiating cause', which excludes explicitly change orders (variations) and errors caused by off-site manufacture (p.1078). A broader definition that encompasses change and quality-based sources of rework has been provided by Love (2002), who suggests it is "the unnecessary effort of re-doing a process or activity that was incorrectly implemented the first time" (p.19).

With so many different definitions underpinning studies of rework in the literature, a great deal of ambiguity surrounds its consequential effects on project cost and productivity (Love et al., 2022a; b). Likewise, as we mentioned above, there has been a predisposition to focus on identifying the proximal cause of rework (e.g., poor workmanship) rather than the conditions (i.e., latent conditions such as culture, management and supervisory shortcomings) resulting in its manifestation. In this instance, the "counterfactual fallacy" is ignored (Reason, 2008: p.138). If things had been different, then rework would not have been needed; *thus*, the absence of such differences caused the rework (Reason, 2008).

Putting aside scope and change orders that result in rework, which are readily identifiable, and their costs are generally reimbursable from those requesting them (Burati et al., 1992), another common causal trigger often ignored in the literature is human error. Fig. 1 provides an overview of the types of action error,[4] violation (i.e., a conscious intention to break a rule) and errors in judgment and decision making (i.e., cognitive biases and heuristics) that can lead to rework having to be performed.

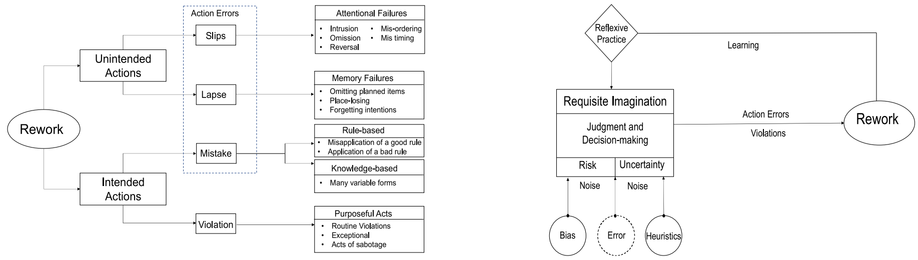
Action errors "imply the non-attainment of a goal and nonconformity to some plan," whereas judgment errors "are usually ascertained in relation to logical and statistical norms of rationality" (Frese and Keith, 2015: p.663). However, focusing on the logical and statistical norms of reality ignores the context in which decision-making occurs (Mousavi

[1] Four strategies to deal with un comfortable knowledge are (Rayner, 2012: p.107).: (1) denial - there is not a problem; (2) dismissal it is a minor problem; (3) diversion I am [we are] working on it; and (4) displacement -the model we have developed tells us that real progress is being achieved. Denial and dismal appear to be most common strategies embraced by project managers when dealing with rework.

[2] Details of the GIRI can be found at: https://getitright.uk.com/. Additional background information about the GIRI can be viewed at: https://www.youtube.com/watch?v=QreDy-TAuFg.

[3] LXRA Rework Symposium 4th November 2018, Docklands, Melbourne. Available: https://vimeo.com/301757104/a32e3fdab0.

[4] An action error is defined as the "unintended deviations from plans, goals, or adequate feedback as well as incorrect action that results from lack of knowledge" (Van Dyck et al., 2005, p.1229).



Adapted from Reason (1990: p.207)

(a) Rework: Errors and violations

(b) Judgement and decision-making

Fig. 1. Rework: Action errors, violations and judgement and decision-making Reason (1990).

and Gigerenzer, 2011). People react to "different representations of information differently", and thus the way information is communicated to decision-makers can "enhance or hinder sound judgment" (Mousavi and Gigerenzer, 2011: p.98). Nonetheless, people's judgments are not always equal and can be prone to variability, which Kahneman et al. (2021) refer to as *noise*.

If managers are to adapt, respond and learn through reflexive practice due to a rework event and improve their organisation's performance, then judgements and strategic decision-making toward managing errors across its projects need to be consistent. Achieving such consistency will require construction organisations to change their approach to decision-making to reduce noise by engaging in the process of *decision hygiene*.[5] Accordingly, organisations must understand the 'context' of their rework problem, specifically *how* and *why* it manifests in their projects and the decisions taken to manage its risks. As we mentioned above, it also calls for establishing an error management culture at all levels of a construction organisation and its projects to ensure that everyone is 'singing from the same hymn sheet' when making decisions about errors and rework.

Drawing on Reason's (1988) resident pathogen metaphor (i.e., latent conditions), Love et al. (2012) reveal that they provide the conditions for the manifestation of rework in projects. Akin to pathogens in the body that precipitate distress to their surrounding environment, they can take many forms in mega transport project systems manifesting as competitive tendering (i.e., focus on the lowest price), non-collaborative procurement, and an error prevention culture (Love et al., 2012). All stimulate behavioural and decision-making responses due to an absence of information symmetry, goal alignment, risk sharing, trust, collaboration and cooperation in projects. Whatever form pathogens take, when they combine over time, they break down the efficacy of project systems' defences and increase the likelihood of rework events.

While pathogens present in a system can be detected *a priori,* active errors (e.g., slips, lapses, mistakes and violations) that combine with them to result in a rework are difficult to predict and are often unearthed *posteriori.* Consequently, Love (2020), following Reason's (1988, 2008) insights on managing safety in high-performing systems, concludes that we should focus on detecting and eliminating pathogens instead of active errors, which has been a goal of construction organisations as they focus on error prevention.

Rework arising as a consequence of an action error, violation, or error in judgment and decision-making can have far more reaching consequences for construction organisations than those that occur from scope and change orders, providing the "raw material for tragic events and catastrophes" (Frese and Keith, 2015: p.663). Examples of errors in engineering design abound, with many going unidentified until emerging as failures during the construction and operation of an asset (Adam and Buitrago, 2018; Blaszcynski and Sielicki, 2019). In addition to the Mascot and Opal Towers identified above, the Champlain Towers South Condominium (Miami, Florida) is a pertinent high-profile example, where a design error went unidentified for 28 years before tragically resulting in the building collapsing, killing 98 people (BBC, 2021).

Transport projects, the focus of this paper, have also been prone to experiencing design errors. For example, in 2004, four people were killed when a cut-and-cover tunnel during the construction of the Nicoll Highway in Singapore collapsed (Ministry of Manpower Singapore, 2005). Evidence from an inquiry revealed the collapse was attributed to errors in the design of the steel struts, which yielded and failed. The steel struts had been connected to a wailing beam, which supported the excavation for the diaphragm walls. The client suggested that the contractor was reckless, dishonest and negligent (Myluis, 2005). An investigation revealed an inappropriate analysis of the existing undrained soil conditions by the contractor, and their in-house engineers misinterpreted the Singaporean building code (BS5950). Our research does not examine failures *per se*, but our intention here is to emphasise the importance of anticipating and identifying errors as early as possible and performing any necessary rework to mitigate their possible adverse consequences.

2.1. *Determining the risk of rework*

Due to confidentiality and commercial sensitivity issues, there is little access to real-life rework data from projects made available to researchers to analyze and develop project risk profiles and patterns (Matthews et al., 2022a). Thus, the focus of research has been to determine the cause and effect of rework and use this knowledge to alert practitioners of its risks in their projects.

2.1.1. *Ambiguity of perceptions*

Acquiring perceptions of rework risks using questionnaire surveys has been the mainstay for conducting studies into this phenomenon in construction (Ye et al., 2015; Yap et al., 2020; Grag and Misra, 2021); though, to a limited extent, interviews, direct observation and contract documentation have also ensued (Taggart et al., 2014; Zhang et al., 2021). However, using questionnaires to examine the phenomena of rework in construction often provides "ambiguous, irrelevant or misleading" results (Love et al., 2016; Einola and Alvesson, 2021: p.102).

The pre-construction questionnaire developed by Rogge et al. (2001) attempts to identify the variables that can predict rework in construction by developing a Field Rework Index (FRI). The FRI intends to eliminate rework that can emerge from engineering design, poor scope definition and pre-project planning. The FRI rates 14 variables, such as a design firm's qualifications, the degree to which the design schedule is

[5] Sibony (2021) describes the decision hygiene analogy as being "just like we cannot see every germ on our hands, we cannot identify every source of noise, but it doesn't mean the germ doesn't exist. The fight against noise, like the fight against germs, can only be fought through broad-spectrum prevention. Like washing your hands, noise reduction will prevent serious problems, although you will never know exactly which ones".

compressed and the commitment to constructability of the design and construction team on a scale of 1–5 to develop a score to determine the potential for rework to occur during construction. While the FRI may act as a barometer for the effectiveness of pre-construction activities, it shoehorns people into considering a limited number of variables negating their independencies, the prevailing error culture, project complexity and conditions beyond production pressure that can result in rework.

Similarly, using an online questionnaire, the Construction Industry Institute (CII, 2005) revealed that the average direct rework cost during construction was 5% of contract value. The costs provided were simply guesstimates and did not consider differences between change and quality-based rework. Then, without questioning, Hwang et al. (2009) repeated the CII's (2005) figure in their paper, as stated: "rework continues to affect both cost and schedule performance throughout the construction industry. The direct costs alone often tally to 5% of the total construction costs" (p.187). This figure of 5% has now been set in concrete and is often referred to as an industry baseline worldwide. But, with contractors' margins hovering around the 6% mark in Australia, for example, they would not be in a financial position to withstand and sustain such rework costs in their projects. Hence, we question the reliability of the CII's figure of 5%, primarily as changes requiring rework are reimbursable to contractors and may even increase their margins.

Rework studies using scales (e.g., Likert) to determine its causes are prone to be "subjected to linguistic and contextual misunderstanding or respondent carelessness", which is difficult to prevent and detect using statistical analysis (Einola and Alvesson, 2021: p.103). The consequence of researchers using questionnaires is to routinise "their ways of working and focusing on data", rarely questioning the meaning and reality of the statistical results that are being put forward. For example, Yap et al. (2020) computes a frequency index to rank rework causes with 'insufficient communication' and 'poor information flow', attributing values of 0.738 and 0.674, respectively, to these factors. These constructs are meaningless as they were obtained from a heterogeneous sample and do not relate to a specific project's culture.[6]

After all, when people generally commit errors that result in rework, their organisation's work culture sets the tone and influences the response and how information is shared. Yet, the research community in construction continues to use questionnaires, as there is a perception that they "can provide relevant, consistent and accurate information" (Scherbaum and Meade, 2009: p.637). However, "no statistical or methodological sophistication" can deal with a wicked problem such as rework (Einola and Alvesson, 2021: p.109).

2.1.2. *Social construction of reality*

Interviews and direct observation provide a context, awareness and understanding of the social reality within which rework occurs. For example, Love et al. (2018a), through their interpretative line of inquiry, revealed that the *modus operandi* of a construction organisation aligned with the practice of 'functional stupidity'[7] provided the environment for errors and rework to manifest. What is more, Love et al. (2018a) observed that "functional stupidity was explicitly linked to the 'power and politics' being played out in numerous projects" (p.1112). In these projects, managers attempted to discourage critical reflection that called into question prevailing organisational norms and values sanctioned under the auspices of a 'zero-vision'.

In some instances, this led to reinforcing stupidity self-management behaviour, whereby employees intentionally limited their critical reflection creating, resulting in what Love et al. (2018a) refer to as a "vicious zone of zemblanity" (p.1112). The corollaries in this instance are an inability to learn, engender innovation, and improve organisational and project performance. Love et al. (2018a) attest that the absence of a risk culture that enables and rewards individuals and project teams for taking the right risks in an informed manner has been a major issue stymieing progress toward containing and reducing errors and mitigating the need to perform rework in construction.

2.1.3. *Data disparity and disassociation*

As we mentioned above, non-conformances have been the primary documentary sources used to determine rework costs and causes, as they can be readily quantified (Love and Matthews, 2020). However, they only form part of the total rework required in construction.

Construction organisations have suggested that a considerable amount of rework may be overlooked, go unreported, or be documented in other formats, as no dedicated system exists in practice to consolidate events (Matthews et al., 2022a). However, information architectures and systems have been developed to measure and classify rework in the field but cannot accommodate the complexity of data sources and varying formats in mega-projects (Hall and Tomkins, 2001; Robinson-Fayek et al., 2004). As a result, construction organisations have been unable to effectively harvest data to manage rework risks (Matthews et al., 2022a).

2.1.4. *Just a piece of the jigsaw: non-conformances*

The analysis of non-conformances sheds some light on their costs and causes, providing managers with information to focus their continuous improvement efforts. For example, Abdul-Rahman (1995) revealed that non-conformances requiring rework accounted for 5% of a project's contract value. At face value, this figure is alarming, but a sense of perspective is needed here. When we examine Abdul-Rahman's (1995) findings, it can be seen that approximately 81.3% of non-conformance costs were attributable to subcontractors (e.g., poor workmanship), design (e.g., specification errors) and construction (e.g., setting-out, and mistakes) related issues. These issues do not necessarily increase the price a client pays for a project but instead impact the contractor's bottom line and its subcontractors. Furthermore, Abdul-Rahman (1995) reported that subcontractors and construction-related problems were the primary sources of non-conformances.

Continuing with the theme of non-conformance costs, Love and Li (2000) revealed that a sample of 14 projects delivered by a contractor ranged from 0.10% to 1.0% of contract value, with a mean of 0.42%. Similarly, Love et al.'s (2018b) analysis of 7082 rework non-conformances derived from 218 projects between 2006 and 2015 found their mean cost was 0.18% of contract value. Subcontract and contractor rectification costs accounted for 43% and 50%, respectively. Subcontract trades associated with concrete and structural steel elements were most prone to rework. The main contributors were the failure to adhere to Inspection Test Plans (ITP), lack of procedural compliance, work method error, or violations. In a study of a similar nature undertaken by Love et al. (2018c), who analysed a sample of 19, 605 non-conformance events derived from 346 construction projects delivered by a contractor between the years 2009 and 2015, a mean rework cost of 0.39% of the contract value was found. Over the analysis period, the contractor's mean yearly profit was reduced by a staggering 28% due to performing rework due to non-conformances.

While organisations understand the effects of rework issues, data around its causation and risks remains scant. Without such data, organisations cannot realise the benefits of utilising business analytics for strategic decision-making (Matthews et al., 2022a). However, some

[6] Culture is defined as "a pattern of shared basic assumptions learned by [an organisation] as it solved its problems of external adaptation and internal integration, which has worked well enough to be considered valid and, therefore, to be taught to new members as the correct way to perceive, think, and feel in relation to those problems" (Schein, 2010: p.18).

[7] Alvesson and Spicer (2012) define functional stupidity as the "inability and/or unwillingness to use cognitive and reflective capacities in anything other than narrow and circumspect ways. It involves a lack of reflexivity, a disinclination to require or provide justification, and avoidance of substantive reasoning". (p.1201).

headway is being made in this area, as studies have sought to make sense of people's experiences and craft narratives, combined with documentation of events, enabling learning to transpire (Taggart et al., 2014; Love et al., 2019). Here learning supports *requisite imagination* where practitioners can 'anticipate what might go wrong' before projects and activities commence (Westrum, 1993). Engaging in requisite imagination enables practitioners to cut across the fault lines contributing to errors, which may be "hidden, skirted, or only half-solved [understood]" (Westrum, 1993: p. 401).

All in all, a dearth of research has examined rework risk and uncertainties in construction. As mentioned above, construction organisations seldom formally assess rework risks before and during construction. Yet, the risk of rework is an ever-present reality that cannot be avoided in construction.

3. Research approach

To recap, our research question is: *How can practitioners make better decisions to mitigate the risk and uncertainty of rework during the construction of infrastructure assets and ensure system safety?* We apply our inductive approach as there has been limited research that has examined rework risks and uncertainty in construction to address our research question. Under the auspices of an interpretative case study, we use the epistemological lens of sense-making to form the basis of our qualitative approach enabling an understanding of how error and rework risks are assessed from an individual's perspective (Stake, 1995).

Our approach enables practitioners to attribute their rework experiences in the social world to a specific context or situation in a project. A central feature of interpretative research is to accept participants varying opinions as their truth forms the core of our inquiry. Our case study is instrumental as we seek to gain a broader appreciation of the conditions influencing rework and the decisions taken to mitigate its occurrence (Stake, 1995). The nature of our inquiry is to notice and bracket cues from a project's environment, interpret the information provided and then act to resolve issues surrounding the risk and uncertainty of rework through a process of sense-making.

3.1. Sense-making lens

Sense-making simply means "the making of sense" where people give meaning to their collective experiences (Weick, 1995: p.4). Various bespoke definitions and interpretations of sense-making in the literature align with varying human science philosophies, theoretical commitments and normative perspectives (Jones, 2015). 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 the context of this research, we are drawn to adopting a retrospective focus on the experiences of practitioners are captured to understand why rework materialised and decisions made to manage its risk and uncertainty. Hence, sense-making is defined as "the ongoing retrospective development of plausible images that rationalize what people are doing" (Weick et al. 2005: p. 409).

Our sense-making lens focuses on the individual within an organizational setting (i.e., project environment). It takes a hermeneutic approach to understanding practitioners' experiences and assessing the risk of rework in a transport mega-project (Dervin et al., 2003). As a result, we focus on understanding and promoting agency, enabling the individual and the researcher to engage in unfettered communication.

3.2. Case study

Our case study setting is a transport mega-project that comprises a program of works initiated by an Australian State Government to remove existing and construct new road and rail infrastructure throughout the metropolitan area of a major Australian city. The project is being delivered using a series of program alliances. For reasons of confidentially and political sensitivity, we cannot provide any more detail about the nature of the project. Notably, the rationale for the case's selection for this study is based on the authors' involvement in an alliance's continuous improvement initiative seeking to reduce *waste* (i.e., non-value-adding activities). To reiterate, this paper aims to determine if there is a rationale for developing an adaptive toolbox to mitigate the risk and uncertainty of rework. We need to understand prevailing practices to propose a new way to anticipate rework risks and be aware of and prepare for its uncertainty.

3.3. Data collection

We adopt Robinson-Fayek et al. (2004) definition of rework as it excludes change orders and focuses on human error within the confines and control of the project. In the context of this paper, we use a semi-structured interview approach to address our research question identified above, though we refer to project documentation (e.g., non-conformance reports, NCR) made available to us to bolster issues that are identified. As part of a study examining rework causation (Love and Matthews, 2022), we introduced leading questions to ensure dialogue remained within the bounds of the study. A copy of the questions used as the basis for interpreting and creating meaning for rework risks is presented in Fig. 3. 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 (Dervin and Naumer, 2009: p.879).

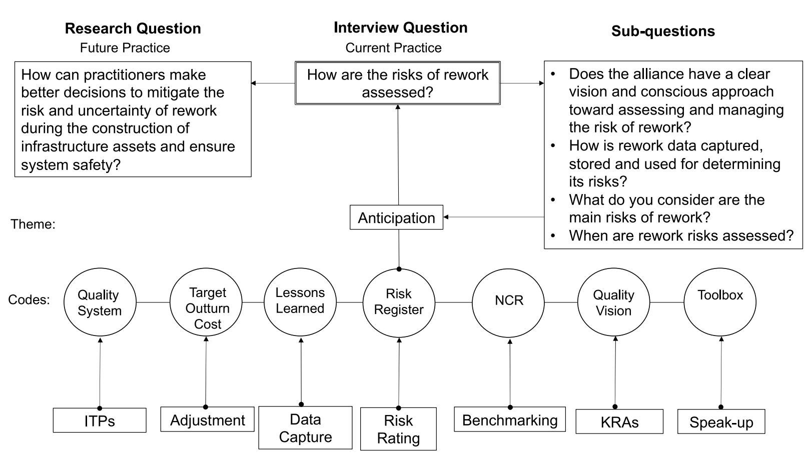


Fig. 2. Thematic analysis.

Table 1
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	Site 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**	**110,409**

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 were 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 within the agreed and allotted timeframe. Data saturation began to emerge as issues associated with risk assessment, and examples used in its management repeatedly came to the fore. Table 1 presents a list of interviewees that formed part of our study. Notably, we could not secure an interview with an operator representative who formed part of the alliance team. 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. They ranged from 26 to 60 min (totalling 12 h) and were digitally recorded and transcribed. We also had access to project documentation, which was used to cross-check issues raised during the interviews. In conjunction with the interviews, we attended fortnightly meetings with the alliance's continuous improvement team throughout 2021. We were provided access to various documentary sources such as site dairies, non-conformances, project plans and requests for information. Our observations and the documentary sources provide a context to understand and interpret the data obtained from the interviews. There were instances where interviewees repeatedly mentioned the same rework events, enabling us to identify the respective non-conformances and their descriptions in site diaries.

3.4. Analysis

We use thematic analysis to derive and interpret meaningful themes for rework risks. Thematic analysis is driven by our research question. We used a latent thematic approach to perform our analysis requiring us to focus on determining the underlying meanings of the data. The interview manuscripts were all inputted into *NVivo* Version 12 to organise and analyze patterns in the data. We used a reflexive thematic technique for coding as it provided us with the flexibility to change, remove and add codes as we worked through our data (Fig. 2). In the next section of this paper, interpret the data and add meaning to craft a narrative to enable us to address our research question.

4. Findings

The alliance commenced its program of work in 2015, and it is expected that the contract will not be complete until 2024 at the earliest. At the time of our study, the alliance had completed four projects, and another four were under construction. Errors and rework plagued the first project completed by the alliance, with a quality manager lamenting:

> "In the XXX project, there was lots of rework. It wasn't recorded as rework as it came from design changes. You see, we started construction based on design drawings to meet the project deadline and before the IFC [Issue for Construction] drawings, and so we were taking risks. When the program is driving you, risks are taken".

Procedures and systems for managing design and construction works are progressively amended (e.g., interdisciplinary design and construction (IDC) workshops) and fine-tuned in response to errors, inefficiencies and changing stakeholder requirements that arise during the delivery of projects. For example, the lessons learned process provides a mechanism to identify changes that can improve the performance of the design and construction process. A case in point was the introduction and development of the 'adopt, adapt and innovate' approach that aimed to reuse design details and components from one project, where possible, to the next, to not only reduce design changes but also as a response to the prevailing production pressure and meet agreed deliverables.

4.1. Quality: imperfect information

The alliance was aware it would be subject to production pressure but ill-equipped initially to assure quality as it ignored the risks of rework. A case of 'ignorance is bliss' prevailed. This was partly due to downplaying the importance of quality by not formally identifying it as a KRA within the Project Alliance Agreement (PAA) contract and developing a quality vision.

The rework materialising in the alliance's projects was attributable to quality-related issues and design and scope changes. However, after four completed projects over six years, the alliance decreased its design changes using its 'adopt, adapt and innovate' approach. The alliance also became better at managing its non-conformances because it established a robust quality system and effectively executed its ITPs,[8] sometimes referred to as a 'Quality Inspection Plan'. Likewise, the client developed a centralised system, enabled by *TeamBinder*, a web-based document management and collaboration solution, to capture and document non-conformances in a structured and coherent format. In addition, and described below, site management encouraged staff to report non-conformances to provide an opportunity for learning and benchmarking.

Notably, several engineers, safety managers and site superintendents had previously worked on the Barwon Water Alliance (BWA) project and had been involved in their 'Rework Prevention Program' and brought their experiences and knowledge to the alliance. However, they only joined the alliance after completing the first projects. Suffice to say, it was their influence and that of an independent consultant who had helped design and implement the BWAs 'Rework Prevention Program'. In doing so, people talked more freely and openly about errors and rework. The 'no blame' environment, an innate feature of alliancing, facilitated this dialogue, enabling a mindfulness of it being 'better to be hurt by the truth than comforted with a lie' to be cultivated within their projects. Specific details of the BWAs experiences with managing rework in their projects can be found in Love et al. (2022a).

[8] ITPs lay out a schedule of inspections at critical control points within a process to verify that things are progressing as planned.

4.2. Production pressure: time constraints

It was widely acknowledged amongst interviewees that production pressure often resulted in workplace stress, and on occasions, mistakes and shortcuts were made to make their work more efficient. Reinforcing these points, a senior project engineer made the following comment:

> "You see many people trying to cut corners when raising a non-conformance. It's tedious and time-consuming, filling in datasheets and things like that. A lot of the time, people don't follow the specification. I don't know why; perhaps they are careless and time-poor".

Focusing on specific areas where errors materialised during construction, the senior engineer noted that limited attention was given to inspecting reinforcement before concrete pours, as site staff were stretched, and project engineers were often deemed inexperienced. Referring to in-situ concrete pours, the senior project manager provided additional detail, stating:

> "Everybody should be checking things as we go, but we don't. We tend to leave things to the last minute for the final inspection. In one case, we performed a final inspection so the concrete pumps could be booked for the next day, and we picked up an error with the reinforcement layout. We didn't think it was a major issue as we'd previously encountered a similar problem. So, we could raise an NCR or an RFI [request for information], which we knew would be approved by the designers. We were willing to take the risk to get the pour done. We had to cancel the pour as we could not get approval and ended up pulling all the reinforcement out. So, two things happened here, people stop checking, and complacency".

Even after four projects had been completed, production pressure was felt by all those in the project supply chain. However, during Melbourne's 20 months of in-and-out of lockdowns due to COVID-19, the alliance's projects, at times, were only allowed to operate at approximately 30% capacity and adhere to strict health and safety guidelines. Even though the number of staff on-site was restricted, productivity was not adversely impacted. There was less traffic on the roads and trains, enabling the construction crews to work more freely and productively. The engineering design teams were required to work virtually. In doing so, some challenges were experienced, including technical problems at home with the speed of broadband connections. Contrary to expectation, a design manager indicated that COVID-19 and working from home had not adversely impacted productivity. Still, issues with engineering coordination did emerge as people could not communicate and share their knowledge face-to-face, particularly informally, through casual interactions.

While anomalies in design documentation were typically identified during IDC workshops, some errors remained and were included in the IFC documentation, resulting in rework being performed during construction. One such rework event was brought to our attention by a project engineer; in this instance, the architectural screens for a bridge were fabricated and installed in accordance with the design specified by the project's architects. Shortly after installation, they started to deflect severely during high winds and were deemed unsafe. Work had to stop on-site while the screens were removed, and a structural design review was undertaken. It was found that the connections were inadequately designed, unable to withstand the forces being placed on them by the wind. The screens were dismantled, refabricated and reinstalled at the cost of $½ million three months later. The issue arose due to a lack of interface coordination between the structural engineers and the architects. Reflecting on the rework event, the project engineer suggested that the risk of the connections failing may have been overlooked during the design review, stating:

> "It was a minor detail that everyone had sort of brushed over, but there were big consequences both program-wise and financially. Similar sorts of examples have happened, but not to this scale".

The contextual backdrop above provides a segue to create meaning from interviewees' insights and experiences on how the risks of rework are assessed and managed in the alliance's projects.

4.3. Assessing and managing the risk of rework: cognitive limitations

Our thematic analysis enabled us to create the theme of 'anticipation' to address how rework risks are assessed and managed. Table 2 presents examples of quotes extracted from the interviews that support this coding and theme. As shown in Table 2, there are instances where the coding is interdependent, particularly around sharing and communicating knowledge about non-conformances and rework events that had transpired. Developing an error management culture within the alliance facilitated a mindfulness to contain and reduce errors and mitigate rework. The ensuing dialogue about errors and rework events was facilitated by site management, forming part of a strategy to engender respectful, collaborative interactions within and between its project teams and subcontractors:

- *Trust*: People need to value and listen to the 'voice' of others and be willing to base their beliefs and actions upon them;
- *Trustworthiness*: People are encouraged to honestly report as a no-blame environment exists (e.g., errors, non-conformances, rework, safety incidents). As a consequence, others can draw upon and learn from reported observations to validate their beliefs; and
- *Self-respect*: People need to value their own beliefs and perceptions and aim to integrate them with others without disparaging them or themselves.

Site managers were conscious of rework and the added vulnerability to error-making due to production pressure. While site management strove to ensure work was completed 'right the first time', they were also focused on ensuring people's safety. As a result of the shared experiences from the BWA, a site superintendent was aware of the relationship between rework and safety incidents. Reinforcing this association between rework and safety, the site superintendent made the following statement:

> "We think more and more about NCRs with rework now. You see, you're probably 70% more likely to have an incident during rework. I think this [the likelihood of accident] sort of scares a lot of people. So, we have been looking at this closely."

To note, the alliance, at the time we conducted our study, had no data to support the site supervisor's supposition (i.e., representative heuristic). The daily toolbox meetings were used to reinforce the potential risks of rework and safety and openly discuss and share views about how everyday work is performed. During these meetings, 'bad news' that had previously happened in a project actively raised awareness and increased vigilance while performing operations (i.e., availability heuristic).

As we mentioned above, quality was not a KRA and rework was not identified as being a problematic issue until two projects had been completed. The absence of an explicit quality vision initially resulted in the normalisation of rework until it impacted the alliance's ability to meet its project's deliverables. The alliance's leadership and

Table 2
Example of quotes supporting the theme of 'anticipation'.

Code	Quote
Quality system	"From the outset, we just try to get it right the first time. Our quality management is probably best to do this as we have our construction execution procedure. Basically, this is a high-level document about how we are going to do the work" (No.1) "We have a really good quality team here. We spent quite a lot of time discussing it [quality] and assuring it since our first set of projects. What we build to the best of our ability is built right the first time and has a great quality system. I guess instead of a checklist, we rely on ITPs and the like to get everything right before we before we do it". (No.9)
Target outturn cost (TOC)	"Most of the risk is contingent on doing design rework. Our design includes risk. So, we have an optimistic outlook when we start the design and put the TOC together. Our assumption is not to do rework, but then obviously we have a contingency bucket as things do inevitably change whether through an omission on our part or whether a stakeholder changes their mind" (No.1) "If there are legislative changes, environment requirements, and the like, this is an adjustment event. We even may have an agreed pre-adjustment target, which we may allow for, such as a change in scope. It may result in rework, but we generally don't use adjustments for rework. We tend to share risks in the alliance such as those related to defects" (No.19). "We use actual facts and principles to calculate our contingency now rather than what is the usual practice of saying we want 7 or 8%. But I couldn't tell you how much rework costs us as a percentage of our TOC. I'd assume most would be to do with design and scope changes, maybe some would be covered by an adjustment event" (No.19)
Lessons learned	"They have come to a conclusion that they're [the alliance] not able to capture everything [rework], and lots of it is slipping through the net. It is obviously part of their continuous improvement. And looking at different ways of capturing it [rework] (No.13) "We need to improve the sharing of lessons learned. I think this is where we have failed to be honest. Even on XXXX, we are not sharing knowledge internally between different teams. It is part of the lessons learned stuff that maybe isn't being captured in things like NCRs" (No.14)
Risk register	"We had rework risk [risk opportunity] workshops, and we'd rank and discuss risks. We put processes in place and use our ITPs. We have a QA system in place and try to ensure everyone follows the process. (No.14) "Our design includes a risk-based around design rework. We run a risk register and are quite transparent about how we do it. There's quite a methodological way of working through risks. You know what your risk bucket should be as part of the design process, and we can put in defences to prevent the need for rework" (No.5).
NCR	"Sometimes, we ask what rework occurred today and have good discussions around it. These would be small events that don't end up as NCRs, but there are some that do. If we continue talking about it, people will think about it. So, we talk and discuss rework and NCRs" (No.9) "We do a fair bit of benchmarking early on when putting the budget together, and we do this for NCRs looking at potential risk areas that could impact the cost. This isn't formalised, but it forms part of the process of preparing a TOC" (No. 5)
Quality vision	"We consider rework risks now, but it's not been formalised. Our quality system and procedures ensure you don't have to do things twice. You know there is a contingency for scope changes, but no formal line item exists. From a commercial point of view, the expectation is that we eliminate it. So unofficially, it's probably built into some rates" (No.11). "I am not sure about the project's vision about rework. If there is one, then it's invisible to me. There some continuous improvements in place as we are always being asked how we can improve" (No.6)
Toolbox	"We have toolbox talks to inform everyone what is going on for the day and discuss potential risks. We now discuss about potential rework risks, near-misses, and that sought of stuff. We bring things out, and everyone learns. Sometimes we discuss how issues were solved" (No.4) "The daily 2.00 o'clock quality toolbox meeting with the construction team planning helps us identify the next day's work. What materials are coming and the support needed? How much traffic control is required? I guess we look ahead to anticipate and prevent rework by looking ahead (No.7).

management team had fallen afoul of the 'Fallacy of Centrality'[9] when preparing their TOC for their first two projects (i.e., confirmation bias). Even though the alliance became aware of its rework problem and implemented a dedicated continuous improvement initiative, referred to as the 'War on Waste', to examine the whys and wherefores of its occurrence, and develop approaches to mitigate its impact, only risks associated with change were incorporated into its commercial framework (i.e., anchoring bias).

In this case, events justifying a change in any targets in the commercial framework, particularly those related to design, are considered. So, its impacts are accommodated if a design or scope change requires rework. But, in the case of quality risks, they are expected to be shared by alliance members. Indeed, the risks of potential non-conformances are ranked and incorporated into the risk register, though there is an expectation that they are eliminated through the quality system. As well as people's experiences and insights, the lessons learned workshops provide feedback for establishing a project's risk register. While they are an essential source for learning, more emphasis is needed to capture rework events and the conditions resulting from their occurrence. Indeed, rework is recognised as a risk and on-site at the coalface of production, its negative impacts are realised.

The alliance has an increased alertness and awareness of errors and rework. But it has struggled to cultivate resilience to errors as they have been unable to prepare themselves to anticipate and develop a capacity to cope with the surprises rework brings beyond NCRs. To date, the alliance has also been unable to capture data to engage business analytics tools (e.g., statistical tools) required to develop foresight (i.e., predict risks), coping (i.e., prevent risks), and recovery (i.e., recover from an issue if it happened) strategies to build resilience to errors and abate rework. When we conducted our interviews, less than 300 NCRs documented across all four projects. Rework issues associated with installing reinforcement, determining the strength, pouring and placing concrete, and structural steelwork were common events. Despite being aware of its rework problem, the alliance's approach to capturing such data was fragmented and unstructured, resulting in an inability to make significant headway toward mitigating its occurrence (i.e., hindsight bias).

In sum, the costs of rework (direct and indirect) were indeterminable, its sources (e.g., change and quality) documented in an ambiguous format, and its consequences (e.g., impact on safety) only partly realised. Additionally, insights and experiences were not recorded and shared between projects, so the same mistakes occurred. Access to such information is necessary to identify patterns, derive risk analysis and decision-making insights, and implement rework mitigation strategies.

[9] The Fallacy of Centrality propagated by Westrum (1982) assumes that if people in a central position automatically know everything necessary to exercise effective leadership and decision-making. Similarly, it can be applied in a negative context: 'Because I don't know about an event, it must not be going on'.

5. Discussion

There is a general perception that we need access to extensive datasets to perform quantitative risk assessments. However, this is a strawman's argument. Instead, we need to focus on identifying the data required for prediction rather than using all available (Matthews et al., 2022a). Indeed, identifying the data necessary to assess rework risks possess many challenges, as noted in the case study we have examined and the literature (Matthews et al., 2022a; b). The uncertainty of performing rework within the alliance was addressed by increasing people's alertness and awareness by making the unthinkable cognizable and invisible during toolbox talks. But the alliance has still struggled to build its general response repertoires and competencies to cope with surprises and respond quickly to minimise their negative consequences. It has implicitly relied on trust and the ensuing dialogue between people to share insights and experiences in preparing for the (un)likelihood of rework.

Judgements and decisions on rework risks are made 'on the go'. Such decisions are cognitive shortcuts, commonly referred to as heuristics. Simply put, heuristics are "decision rules that allow one to make judgments without integrating all the information available" (Raue and Scholl, 2018: p.153). Notably, considerable debate surrounds the effectiveness of heuristics in judgement and decision-making and whether their use results in cognitive bias manifesting as systematic and predictable errors (Forbes et al., 2015). Despite the prevailing antipodal theoretical views surrounding judgment and decision-making, it is outside the scope of this paper to discuss their 'fors and againsts'.

Markedly, the alliance has no formal process to determine the risk of rework. It has been unable to collect, consolidate, and effectively share its rework data across projects. However, in the case of the uncertainties with rework, they "cannot be reliably hedged unless" they are reducible to risks (Mousavi and Gigerenzer, 2014: p.1671). Thus, "in making sense of uncertainty, the mathematics of probability that is used for risk calculations may lose relevance" (Mousavi and Gigerenzer, 2014: p.1671). Reinforcing this point, Love and Tenekedjiev (2022) remind us that applying probabilistic methods to predict 'wicked problems' such as safety incidents is unfitting. This is particularly pertinent in the context of this paper, as empirical research has demonstrated that safety incidents predominately occur while performing rework, which is also a wicked problem; so, if we reduce rework, safety performance will improve (Love et al., 2018d).

Relying on imperfect information to predict the occurrence of rework and making choices when outcomes are unknown are challenges that confront this alliance and construction organisations in general (Matthews et al., 2022a; b). Simon (1955, 1956) was the first to draw our attention to the constraints of environments with imperfect information and human processing limitations associated with making choices. In doing so, Simon (1955, 1956) propagated the idea of *bounded rationality*[10], which suggests we are unable to determine an optimal decision due to: (1) imperfect information; (2) time constraints; and (3) cognitive limitations.

The evidence we have unearthed in our case study explicitly indicates that bounded rationality is a reality of practice in construction, as perfect information and knowledge do not exist within the context of rework. As a matter of fact, this is also the case throughout an asset's life cycle. Reinforcing this point, Sorros (2009) and Stiglitz (2010) inform us that the idea of perfect information is only taken seriously within academic circles, not in the business world. Hence, decision-makers (e.g., site supervisors and engineers) need to work within their temporal and cognitive limitations and make choices to the best of their understanding and ability to anticipate and manage errors and rework. Considering it has been shown that in decision-making, often less is more, we need to keep decision-making, when examining the risks and uncertainties of rework, "simple, stupid" or "at least make it simple to avoid acting stupidly" (Forbes et al., 2015: p.199).

5.1. A way forward: the adaptive toolbox

As noted above, heuristics have been drawn upon for judgement and decision-making about the risks and uncertainty of rework in the alliance but have yet to be formalised. However, when heuristics are formalised, they can be "more accurate than standard statistical models that have the same or more information", with results referred to as the 'less-is-more effect' (Gigerenzer and Gaissmaier, 2011, p.453). But, the precision in this instance "is not enough to build a science of heuristics" as rules of thumb "may often look like curiosities in the absence of an overarching theory" (Gigerenzer and Gaissmaier, 2011, p.453). Three building blocks to support the theoretical underpinning to formulate heuristics are (Gigerenzer and Brighton, 2009):

1. *Search rules* specify the direction of the search and its space—for example, the type of data needed to decide the frequency of rework.
2. *Stopping rules* specify when the search is stopped—for example, in the alliance case, limiting the search for data from projects it has already completed.
3. *Decision rules* specify how the final decision is reached—for example, the choice of work practice to mitigate the likelihood of a rework event.

In conjunction with the core mental capacities that the building blocks utilise, the creation and accumulation of heuristics form the basis of an adaptive toolbox (Gigerenzer and Selten, 2002). Here core capacities, which can systematically vary between decision-makers, include "recognition memory, frequency monitoring, object tracking, and the ability to imitate" (Gigerenzer and Gaissmaier, 2011, p.456). When core capacities are in place, heuristics can be fast and frugal. Such heuristics are simple, task-specific decision strategies that form part of a decision maker's repertoire of cognitive strategies for solving judgment and decision tasks.

Fast and frugal heuristics work well in dynamic environments, where there is limited data, increasing the role of uncertainty, as opposed to risk, in characterising choice (Neth et al., 2014). In Table 3, we present sample heuristics and the environmental structures that make them ecologically rational. However, research is required to determine their applicability within the context of rework risks and uncertainties to develop a robust adaptive toolbox of ecologically rational heuristics. Needless to say, two common fast and frugal heuristics are: (1) *Recognition*, which exploits the absence of knowledge, and (2) *Take the Best*, which deliberately ignores information. Both heuristics can be applied to instances where choices need to be made and situations where a decision-maker has to determine if one object has a higher value than another on a quantitative criterion (Goldstein and Gigerenzer, 2002).

A particular heuristic that could form part of a decision maker's adaptive toolbox to determine the risk of rework is the Fast and Frugal Trees (FFT) (Table 3), which are graphical structures that ask one question at a time. They can create a family of simple heuristics, particularly in tasks where a binary decision or classification needs to be made and where a number of cues (or attributes) are available to make a decision. Typically, cues and decisions are binary (yes/no), and their relation can be framed as *if-then* statements. If the condition is met, the decision can be made, and the FFT is exited. If the condition is not met, the FFT considers the other cues, one after another, until the exit condition of a cue is met. The last cue of an FFT has two exits to ensure that a decision is ultimately made. The FFT is defined as a decision tree with $m + 1$ exits, with one exit for each of the first $m - 1$ cues and two exits for the last cue (Luan et al., 2011). An example of a simple decision tree

[10] Bounded rationality, a departure from perfect rationality, is a human decision-making process where we attempt to satisfice, rather than optimise. That is, we seek a decision that will be good enough, rather than the best possible one considering prevailing conditions (Simon, 1955, 1956).

Table 3
Sample heuristics and the environmental structures that make them ecologically rational.

Heuristics	Definition	Ecologically Rational if	Surprising Predictions
Recognition	To decide which two options are greater on some criterion, if only one option is recognised, choose one	Recognition is a valid cue (i.e., leads to correct decisions over half of the time)	Contradicting information about a recognised object is ignored; recognizing fewer options can lead to greater accuracy
Take The Best	As above, but if both options are recognised: 1. Search through cues in order of validity 2. Stop searching on the first discriminating cue 3. Choose the option favoured by this cue	Cue validities vary highly; moderate to high redundancy between cues	Can decide more accurately than multiple regression, neural networks and exemplar models when generalizing to new data
Tally (unit-weight linear model)	To estimate the criterion for some object, count the number of cues	Cue validities vary little, and low cue redundancy	Can decide accurately as multiple regression
Try-a-dozen (satisficing)	To select a high-valued option from an unknown sequence, set an aspiration level; at the highest value seen in the first 12 options, then choose an option that exceeds the aspiration	Unknown distribution of option values; no returning to previously options	Near-optimal performance over a wide range of sequence lengths (i.e., number of available options matters little)
Fast-and-frugal tree	Classify an object into two categories by: (a) searching cues according to their order; (b) stopping the search as soon as a cue allows to do so, and (c) choosing the object specified	Refer to the 'Take-the-Best' heuristic	Can predict accurately as or better than logistic regression

Adapted from: Todd and Gigerenzer (2007: p.168) and Raab and Gigerenzer (2015).

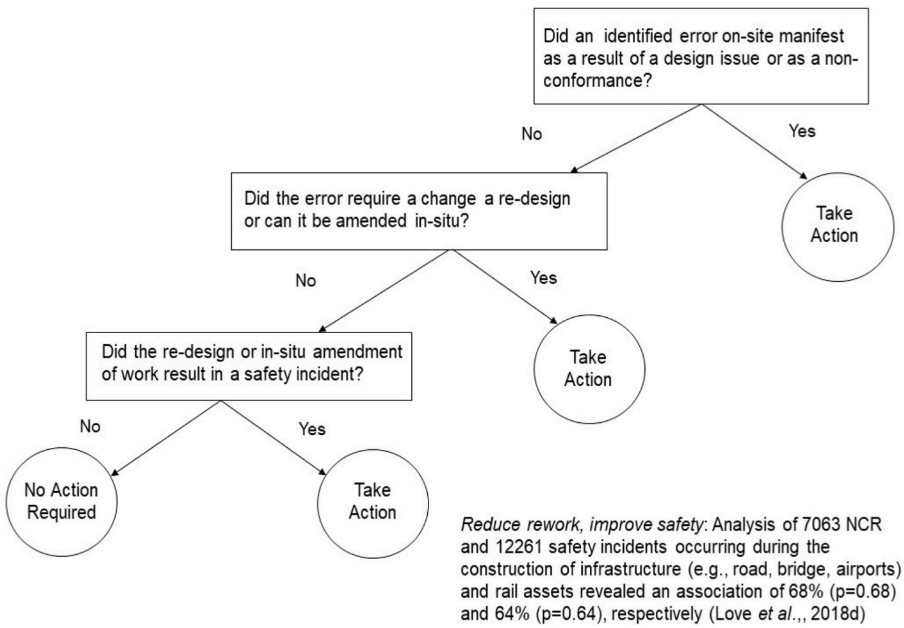


Fig. 3. A simple example of a fast and frugal tree for rework and safety.

drawn to determine if the quality or design-based rework results in a safety incident is presented in Fig. 3. The value of a heuristic in any decision-making context is the environment (Simon, 1990), and in this paper, it is the alliance we have examined. Thus, we need to adapt heuristics to the structure of their environment to ensure they are helpful and successful.

Ecological rationality is used "to bring environmental structure back to bounded rationality" by using heuristics in environments or circumstances where they can work well (Todd and Gigerenzer, 2012: p.13). The existence of multiple decision environments and strategies within the alliance and its projects poses a problem to decision-makers as they need to select the type of heuristic that fits and adapts to their circumstances. Evidence indicates that people are generally adaptive decision-makers and can respond to task and environmental characteristics (Gigerenzer and Selten, 2002).

So, by adopting the lens of ecological rationality, we can understand how and when people's reliance on simple decision heuristics based on 'smart data' can result in 'smart behaviour' in different contexts where rework manifests during the construction of an infrastructure asset. Thus, heuristics, in this case, can be *ecologically rational* with respect to the environment [e.g., the alliance] and the goals of the decision-maker, as they draw upon the adaptive toolbox at their disposal; that is, a set of evolved and learned rules that guide deliberate and intuitive decision-making (Gigerenzer and Selten, 2002; Todd and Gigerenzer, 2007).

The establishment of rules provides a much-needed theoretical underpinning to formalise heuristics for decision-making, enabling the effective risk and uncertainty management of rework and improving safety performance. However, future research is required to create an adaptive toolbox where its heuristics, based on building blocks (i.e., search rules, stopping rules and decision rules), are developed for specific conditions where errors and rework materialise.

By creating an adaptive toolbox based on project participants' collective and shared knowledge and experiences, cognitive biases (e.g., anchoring, confirmation, and hindsight) that may typically arise from taking shortcuts with heuristics can be mitigated. Awareness of the cognitive limitations of decision-making is critical for ensuring the best decisions are made.

6. Conclusion

The risk and uncertainty of rework during the construction of an infrastructure asset is an area of research that has received limited attention. Obtaining information for decision-making and formulating choices about appropriate risk and uncertainty management strategies to contain and reduce errors, mitigate rework, and simultaneously improve safety is a challenge. Organisations seldom recognise they have a rework problem, as it is often treated as uncomfortable knowledge.

As alliances become increasingly popular to procure transport infrastructure assets, due to their focus on collaboration, the pursuit of a 'no blame' environment and implementation of a 'gain-share, pain-share', we see rework being placed on their continuous improvement agendas, though quality is yet to be identified as a KRA in PAAs. As a direct result of being involved with a continuous improvement initiative of a mega transport infrastructure project being delivered using an alliance, we were afforded the opportunity to directly determine how the risk and uncertainty of rework are managed in practice and suggest ways to improve this process. Thus, we sought to address the following research question: *How can practitioners make better decisions to mitigate the risk and uncertainty of rework during the construction of infrastructure assets and ensure system safety?*

We adopted an interpretive line of inquiry using the lens of sense-making to address our research question. Semi-structured interviews were undertaken with various alliance members and subcontractors to understand their own experiences with assessing the risks of rework. Using thematic analysis, we developed the theme of 'anticipation' to encapsulate the alliance's organisational practices, awareness and alertness to errors and rework and their impact on safety. While possessing the attributes of an error culture and making headway toward building resilience to error, the alliance could not prepare itself to anticipate and develop a capacity to respond to errors and rework effectively.

Informally heuristics were being used to determine rework risks and uncertainties due to the absence of information. They were curiosities as the same mistakes were repeated and learning stymied. With the prevailing lack of information and the reliance on heuristics, we suggest a case for the creation of an adaptive toolbox whereby decision-makers with different domains of thought can draw on varying specific cognitive mechanisms to determine the risk and uncertainty of rework within a given environment (e.g., project or situation) instead of relying upon a strategy dominated by statistical methods that are unable to accommodate a wicked problem. To this end, the contributions of the research we present in this paper are twofold:

1. We bring to the fore new insights about the informal practices based on heuristics being used to manage the risk and uncertainty of rework during the construction of a mega transport infrastructure asset; and
2. Propose the creation of an adaptive toolbox comprising a set of heuristics that can be adapted to different rework situations as they are fitted to the environment through evolution and/or learning by amending them successively in small steps. The heuristics are fast and frugal, meaning we can make decisions quickly based on imperfect information.

Future research is required to create a repertoire of heuristics that can be drawn upon and utilised during the construction of transport infrastructure assets to improve the ability of organisations to manage the risk and uncertainty of rework. It is envisaged that such heuristics would also address rework during operations and maintenance of assets, though some re-calibration may be required for their building blocks.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors would like to thank the alliance and its contractors for participating in this research, as without their support, this work could not have been undertaken. We would also like to thank the Editor, Professor Pingbo Tang, and the *three* anonymous reviewers for their constructive and insightful comments, which have enabled us to improve the quality of this paper. Finally, we would like to acknowledge the Australian Research Council's financial support (DP210101281). This work involved human subjects. Curtin University (HRE2020-7385) and Deakin University (DUHREC2020-328) approved the ethics approval for this study.

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