Making Sense of Rework: Reflections from the Blunt and Sharp End in Projects

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Abstract

Rework is a chronic problem in complex construction, engineering resource (e.g. minerals and energy) projects. It is a significant contributor to cost and schedule overruns and can have an adverse impact on safety. Yet, there is a notable dearth of theory that adequately explains rework occurrence. This research narrows this knowledge gap by adopting a *retrospective sensemaking* perspective to determine how and why rework arises. Staff from organizations operating at the blunt end (e.g. clients and design engineers providing finance and information) and those at the sharp end (e.g. contractors at the 'coalface') of a project's supply chain were interviewed to make sense of rework that occurred. The analysis identified an overarching need for managers to de-emphasize the environment that prioritizes production over all other considerations. Rather, mechanisms and factors that shape the performance of people should be systematically examined to ensure that projects are delivered safely, on time, to budget and to the specified level of quality. Limitations of the research and the implications for managerial practice are also identified.

Keywords: Rework, error, offshore projects, retrospection, production pressure, learning

1. Introduction

Rework is a chronic and recurrent problem in construction, engineering and natural resource (i.e. oil, gas, mineral sands) projects which adversely impacts upon project performance, productivity and safety [1,2]. Surprisingly, rework has largely been ignored and deemed to be a normal function of operations [3], and often deliberately concealed [4]. As rework fundamentally pertains to correcting errors arising from unanticipated events, the question then is "How do we anticipate it when, by definition, its occurrence is unanticipated?" [5]. Rework costs are implicitly accommodated within a project's traditional cost contingency [6], yet an allowance for rework is unacceptable to clients as it is deemed to be something that should not occur. Indeed, contractual tenders that include cost, time and disruption due to rework render consultants and contractors potentially uncompetitive. With increasingly tighter profit margins and lower productivity rates being experienced, particularly in Australia[1], rework is untenable as business competitiveness is severely jeopardized. To prevent rework, various approaches are being promulgated and include visualization technologies, modularization, lean construction and

[1] Refer to www.gattan.edu.au,

relationship contracting [6]. Such approaches may yield some project performance improvement but merely abate rework, as human behavior is all too adept at concealing problems and committing errors [4].

People conceal rework from managers in a vain attempt to protect them from 'bad news' and/or present information that does not adhere to their beliefs [4]. This practice of hiding mistakes is institutionalized in many organizations [4]. In fact, Roth and Kliener [7] reported an inherent cultural mandate established within some engineering organizations of concealing problems unless accompanied by a solution. Thus, in this instance, concealment becomes standard practice [4]. In some ways this position marries with the notion of strategic misrepresentation (i.e. in effect, lying) to explain why projects experience cost overruns [8].

Those project team members that abrogate their direct responsibility and remain silent about problems do so to avoid a reprimand from their immediate manager. Moreover, team members collude to conceal knowledge of errors and/or omissions by revealing the issues that need to be addressed to the project manager [4]. Under such circumstances, project costs and the schedule apparently will remain the same and they avoid blame. However, if they reveal that errors or omission have been caused by others, this provides project managers with the opportunity to attend to them with other project team members being blamed for the cost and schedule overruns that may occur. However, should all project team members reveal all the known problems, project cost increases and the schedule slips - and all are apportioned blame from the management which results in a negative outcome for project team members concerned to produce a lose-lose outcome [4].

Failure to admit a negative outcome and pursue a course of action can contribute to rework [9]. This behavior is referred to as *defensive avoidance* [10]. Shaw [11] provides several reasons why such behavior materializes. First, people pursue a course of action in spite of negative feedback largely because of the negative feedback [11]. This argument suggests that people value tenacity and perseverance, and admire those who stick to their principles. It also suggests that people can adopt a valued characteristic of forsaking a more rational approach to difficult decision situations to ensure consistency?

Contemporary rework research has narrowly focused upon identifying specific causation factors [12-15]. This approach is however, counterintuitive as rework causation can only be understood by reviewing the whole project system in which it occurs and examining how variables dynamically interact with one another [16,17]. Within this context, an operational system, such as a construction, engineering or resource project, can be categorized as having 'blunt' and 'sharp' ends [18]. The 'sharp end' represents the project site where people are carrying out physical work associated with project delivery. Whereas the 'blunt end' encompasses the organization(s) that support, drive and shape the activities of the design and construction process. The 'blunt end' (which includes governments, regulatory bodies, financial institutions and clients) provides information to facilitate design and construction, but invariably introduces project cost and time constraints. Strategic decisions taken at the 'blunt end' can create, shape and stimulate opportunities for errors to materialize [18]. Too often, time constraints restrict design related activities and lead to incomplete tasks and/or inadequately prepared processes [19]. When rework occurs, and time constraints are imposed, and there is then a propensity for the formation of 'vicious circles'[2] to significantly increase [20].

There is a notable lack of theory to explain why rework occurs in construction, engineering and resource projects. Thus, the research presented here aims to contribute to narrowing this knowledge gap through the lens of *retrospective sensemaking* [21]. The adoption of retrospective sensemaking can facilitate a deeper understanding of issues that contribute to rework and provide a means to inform and direct actions to mitigate its occurrence. A detailed review of the normative rework literature is presented to provide a sense of the extant knowledge and associated gaps that the research aims to fill. Organizations operating at the 'blunt' and 'sharp' ends are interviewed to make sense of the rework that occurred on their projects. Understanding rework in this way provides the feedback required to develop a foundation for learning to occur.

2. Literature Review

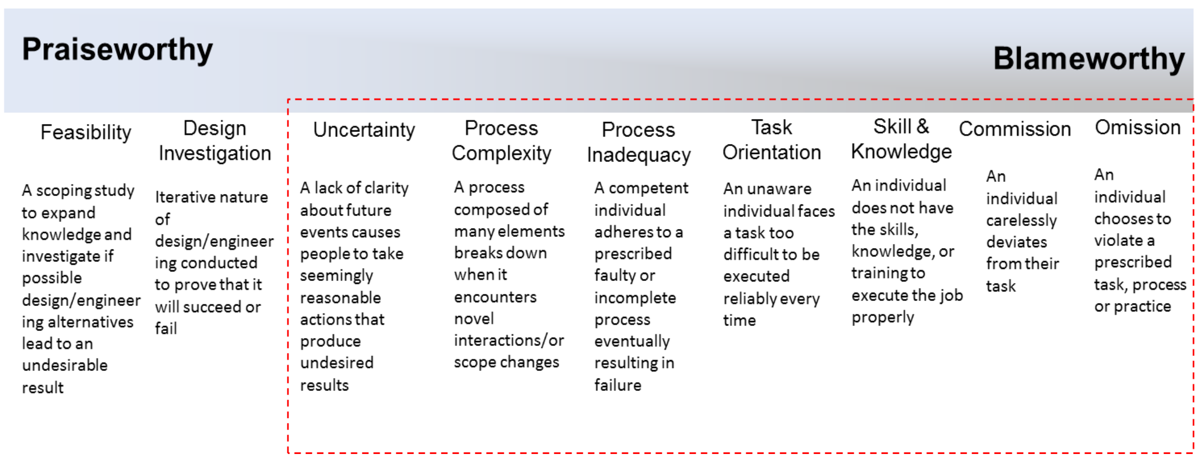
Terms such as quality deviation, non-conformances, quality failures, and defects are often considered to be synonymous with rework [22,23]. Because these terms are used interchangeably, a degree of ambiguity with regard to the definition of rework exists [24.25]. For example, the terms 'quality failure' and 'defects' were used to define rework or errors in the same study [26-29]. Put simply, rework can be defined as "the unnecessary effort of re-doing a process or activity that was incorrectly implemented the first time" [30]. The Construction Industry Institute [31] confine rework to the sharp end and defines it as "activities that have to be done more than once or activities that remove work previously installed as part of the project". However, it should be acknowledged that some activities or processes implemented correctly might require adjustment due to changes in client or end-user requirements [32].

Ultimately, errors occur due to the physiological and/or psychological limitations of humans [33]. However, whether individuals can justifiably be blamed for all errors is a contentious matter, as making mistakes is an innate characteristic of human nature [33]. Human errors occur for various reasons, and different actions are required to prevent or avoid them. Specifically, errors can arise due to mistakes of commission (doing something incorrectly) or mistakes of omission (not doing what should have been done or doing something out of sequence). An

[2] Williams *et al*., [73] state that "Increasing cross relations between concurrent activities increase activity duration, which under time constraints causes activities to become more parallel and hence increases cross relations" (p.151)

individual's training, experience or competence does not necessarily prevent errors or omissions [34]. Admitting errors can, however, lead to blame and may result in legal proceedings, which is why design professionals (e.g. engineers) and contractors have been unable or unwilling to fully realize the potential of learning from errors [35-36].

Edmonson [37] observed that executives, for example, are often faced with a false dichotomy, that is: "How can they respond constructively to failures without giving rise to an anything goes attitude. If people aren't blamed for all failure what will ensure they try as hard as possible to do their best work?" (p.50). Drawing upon Edmonson's [37] work, a continuum is presented in Figure 1 to determine those errors that are praiseworthy and blameworthy (i.e. denoted by the dotted line in Figure 1).



Adapted from Edmonson [37]

Figure 1. Error continuum

Commission and omission errors warrant blame but a lack of skill and knowledge is attributable to the organization which should ensure that individuals are occupationally competent. In the case of task orientation, an employee could be stressed and/or fatigued due to tight time constraints being imposed. In this case, the individual's manager is responsible for the employee failing. The key research question therefore is what circumstances lead to such time constraints being imposed? In this instance, an understanding of context is needed as it "binds people to actions that they must justify and it affects the saliency of information, and it provides the norms and expectations that constrain explanations" [17,38]. A key proposition of this research is that developing a rich understanding of rework causation and contexts can help avoid the 'blame game' and institute an effective strategy for learning to emerge.

Only the experience acquired from committing an error can engender learning and lower the risk of reoccurrence [24]. Yet, organizations with high reliability[3] may be anxious that errors or potential failures are embedded within ongoing activities. Especially as unexpected failure modes and the limitations of foresight may amplify the error [39]. For organizations participating in such projects trying to maintain a high reliability status they need to: i) continually make sense of their environment; and ii) learn from reports and identify the risks embedded within processes and systems at the project's operational, tactical and strategic levels. This task may be particularly arduous when contracts involve multiple organizations, each with potentially conflicting goals, objectives and organizational cultures. Within the realm of understanding human error, Dekker [18] suggests that (p.71):

- past situations should be reconstructed and documented by other people in a way that considers assertions about unobservable psychological mechanisms; and
- there are systemic connections between situations and behavior, that is, between what people did and what actually happened in the environment around them.

The connection between situations and behavior is bi-directional as people change the situation by doing what they do and by managing their processes [18]. Yet, an evolving situation also alters people's understanding and behavior, and allows changes to be undertaken. Under such circumstances, connections between the situation and behavior can be uncovered, investigated, documented and represented graphically [18,40] using techniques such as cause-effect, causal loop and fault tree [16,17,40-42]. To understand human error, knowledge of the individual's working environment and situation is required (which includes tasks undertaken, and tools and technology used). Answers to the question "what's the story?" are therefore addressed such that plausible answers gain their validity from subsequent activity [21].

2.1 Quantification: The Need for Context

Studies have typically quantified rework according to its cost as a proportion of contract value, its type (e.g. change, error and omission), or by subcontract trade and building element (e.g., substructure, superstructure, internal and external finishes and services) [43-46]. The Construction Industry Development Board (CIDB, 1989) in Singapore estimated that between 5% and 10% of total project costs are associated with doing things erroneously and rectifying them [47]. The CIDB concluded that adoption of an effective quality management system would reduce rework to anywhere between 0.1% and 0.5% of total project cost [47]. The Construction Industry Development Agency in Australia revealed that projects without a formal quality

[3] In this context, such as those involved in the construction of a Liquefied Natural Gas (LNG) Plant, where safety is the priority.

system in place (and procured using a traditional lump sum contract) experienced rework costs in excess of 15% of their contract value [48]. Contrastingly, an analysis of 260 construction and engineering projects revealed that rework costs did not significantly vary by project size (i.e. contract value), procurement method and project type adopted [49]. Hwang *et al*. [12] concurred with Love's findings [49] and found no significant differences for rework costs by project size, and work type (i.e. construct only or design and construct). However, Hwang *et al*. [12] identified an increase in rework costs between light industrial, heavy industrial and various buildings types - probably because of varying and increased design complexity.

The reported costs of rework identified within the extant literature vary significantly and range from 3% to 25% of a project's contract value [50]. Research suggests that this is primarily due to a lack of a standardized and robust methodology for its determination [50,51]. Some studies have excluded change orders and errors due to off-site manufacture that result in rework being undertaken [1,52] and increasing emphasis has been placed on simply determining direct rework costs. However, the intangible costs associated with disruption and schedule delays that arise have been overlooked as an additional cost [35]. Rework may also have a multiplier effect of up to six times the actual (direct) cost of rectification [53,54]. Yet, such costs are not apportioned to the client or contractor but rather 'forced' down the supply chain to subcontractors and suppliers. Such additional costs can adversely impact these firms' profitability and survival that are typically small-to-medium sized firms, dependent upon having a positive cash flow [54].

However, understanding the circumstances that form the setting in which errors and subsequent rework occurs is a critical part of the process of reducing their occurrence. Dekker [18] specifically states: "knowledge of context is critical to understanding error. Answers to why people do what they do often lie in the context surrounding their actions. Counting errors and stuffing them away in a measurement instrument removes that context" (p.68). The establishment of a context that focuses on 'retrospective decisiveness' should be stimulated, which, according to Weick *et al*. [21] is similar to learning in reverse (p.184). Through this process, people can learn from their errors or reconstruct a history that summarizes lessons learnt into a single narrative. Such an approach can increase an individual's confidence and enable them to act more decisively in the future. Weick (1995) suggests that confidence is a key determinant for 'environmental enactment', for instance, managers can utilize workplace systems and processes that they anticipate will reduce and contain the incidence of rework. This approach may trigger a process of unlearning that challenges the underlying concepts, paradigms, and the *Weltanschauung* that has determined their historical way of thinking.

2.2 Design and Construction: The Known and Unknown

Smith and Eppinger [55] contend that the proportion of money and time spent on rework in the product design phase can be significantly higher than the construction phase. This is because the design engineering process is inherently iterative as it strives to solve coupled problems with complex relationships. The situation within construction is the opposite as design costs are often less than one percent of the life-cycle cost of a project or less than 10% of the total construction value [56]. While design costs are minimal, it is the single most important influence on total project expenditure. It is during the design process that errors and omissions materialize (as contributors to rework), and occur due to embedded dysfunctional organizational practices, 'pluralistic ignorance', unreasonable cost estimates and schedule constraints being imposed upon the project team by clients [57]. Such unreasonableness may be attributable to clients' optimism bias and their inexperience with the project delivery process. This may well be expected as most clients only ever build once and even those who construct on a regular basis rarely use the same team to deliver their requirements [58].

A plethora of academic, industry and government reports produced have acknowledged the need for clients to change their approach to delivering projects in order to enhance productivity and performance. Yet, despite the persuasive arguments put forward, clients remain generally reluctant to embrace the recommendations proposed (e.g., shift away from the use of competitive tendering, the use of relationship contracting, and technologies that utilize aspects of Building Information Modeling) [6]. Regardless of 'value for money' aspirations, clients have a proclivity to steer themselves toward the lowest price, irrespective of the long-term financial consequences [58]. In some instances therefore, clients may subconsciously trade-off lowest price (i.e. both with consultants and contractors) with the possibility of scope changes to unconsciously create rework during construction - the extent of which remains unknown at the time of exchanging contracts.

The fixing of a project's governance, delivery strategy (including responsibility and risk allocation) and technology influences the ability to establish an effective generative project culture that focuses on accomplishing a common goal and good team performance (i.e. doing what everyone is supposed to do) [59]. On this point, Love *et al*. [58] examined the influence of strategic decisions at the formative stages of a project and proposed the following orthodoxy: "competitive tendering for selecting design consultants' projects establishes an environment where their services are reduced or omitted to maximize profit. The omission of critical tasks and practices such as design audits, reviews and verifications leads to contract documentation being erroneously produced and therefore increases the propensity for rework occurring during construction" (p.569).

Conventional project planning and monitoring techniques do not acknowledge or measure rework and tasks are either deemed 'to be done', 'in process' or 'done' [60]. In contrast, the *rework cycle* is best described as an archetypal dynamic structure [70,71]. The rework cycle is presented in Figure 2 and provides a description of workflow, which incorporates rework and *undiscovered rework*. Work rate is determined by staff skills, productivity and their availability; as project time advances, the amount of work remaining reduces. Work is completed (i.e. work done) or becomes undiscovered rework depending on the quality (the proportion of work undertaken completely and correctly). Undiscovered work contains errors that remain undetected and are perceived to have been undertaken. The quality of work produced may fall below the required standards and errors may still occur. Errors are often not immediately identifiable (latent) and only transpire after a period of incubation in the system [72]. As time progresses, these errors are eventually detected and rework is identified, snowballing staff workload [70,73].

The extent of rework required is dependent upon how long the latent error has remained undetected. For instance, a dimensional error or spatial conflict contained within the engineering design may not transpire until the project is physically constructed on-site. If the error necessitates a major change, the entire perceived progress prior to the error occurring may be considered wasted. Addressing the error not only generates more work for individuals but also increases the possibility of more errors being generated. This is denoted by the main cycle loop in the model, which is a reinforcing loop (indicated by *R*). Importantly, the balancing loops, denoted by *B*, should counteract the accumulation of work remaining. The gap between perceived and actual progress may be difficult to close; it may appear that all work is nearly complete, but the project can persistently remain at a frustrating 90 percent level of completion [73,74]. Poor progress rates occur mainly when staff involved with tasks either leave (staff turnover) or become unavailable and replacement staff are needed to complete the tasks.

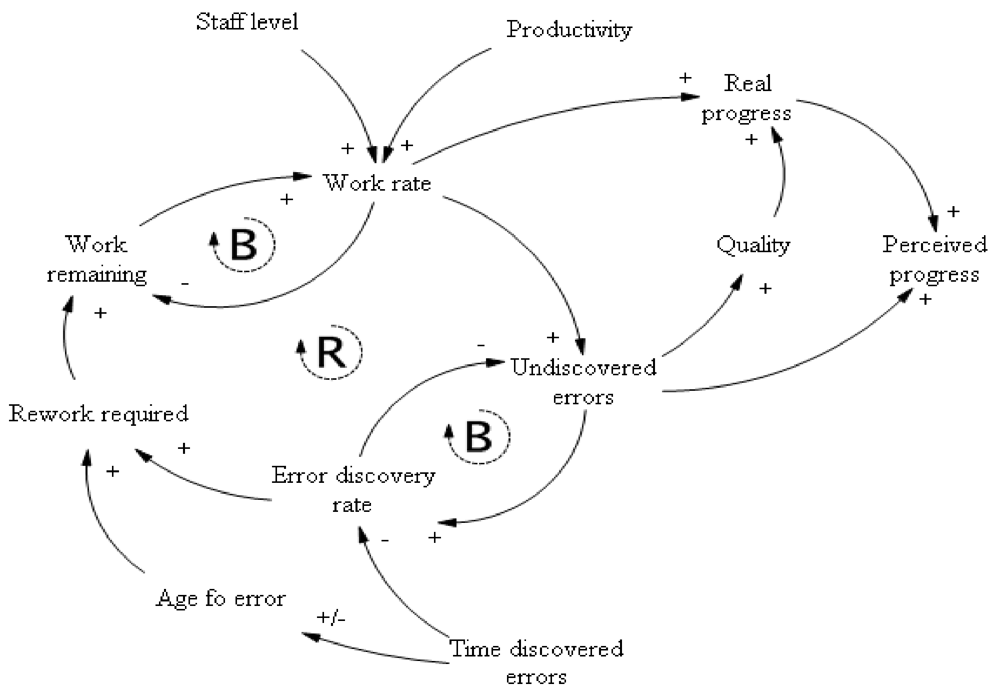


Figure 2. The rework cycle [74]

The discontinuity of design staff significantly impacts upon design process performance [73,74]. This is because the inherent project knowledge held by each staff member cannot be seamlessly transferred directly from one individual to another, even if a hand-over 'transition' period (and/or de-briefing) occurs. Even in-house staff recruited cannot acquire sufficiently detailed knowledge immediately after commencing work on site and so an initial project absorption period is needed. In practice, activities are executed at varying levels, depending upon the individual's skill and competence, and this can lead to compromises in quality. Within the rework cycle it is assumed that inexperienced people are more likely to commit more errors. This assumption may be true but Reason [75] contends that often, highly qualified and competent individuals commit most mistakes with the worst consequences. Cooper [70,71] suggests that the quality and the error discovery rate are important factors that should be considered. Purely bolstering a project with additional resources will not resolve fundamental problems; a more pre-emptive approach should be utilized to reduce the number of errors and the time taken over their detection [74].

The rework cycle provides a systemic overview of project behavior but it fails to contextualize rework causation for organizations to learn from experience. Rather, the underlying contextual conditions influence people's ability to learn from errors [76]. Dixon [77] notes that it is the ability to retrospectively find patterns in the continual flow of daily workplace activities that give those events meaning. When insights and knowledge are acquired about rework causation within a given context, changes to prevent and reduce its negative consequences can be implemented

[78]. A key obstacle preventing achievement of these goals has been the inability to understand how to specify the contexts in which rework might occur as previous research has tended to focus upon identifying a singular root cause.

3. Research Approach

To determine the systemic nature of rework the ontology of 'subjective idealism' is adopted due to the limited discourse in this specific field of research, particularly oil and gas projects [79]. For this approach, individuals construct their own views and opinions on the phenomena under investigation based upon their experiences; an inclination to truth and pragmatism is deemed to prevail. Sensemaking is used to underpin the ontology adopted, as meaning is given to experience, dialogue and narratives about events that have occurred through the process of retrospection [80,81]. The notion of 'retrospective sensemaking' is derived from Schutz's [82] analysis of 'meaningful experience' where events occur in a moment of time and can exist in pure duration and as discrete segments. Pure duration can be described as a "stream of experience" [83]. Experience is a singular construct that is a "coming-to-be and passing-away that has no contours, no boundaries and no differentiation" [82].

Experiences in this context, however, imply distinct, separate episodes [81]. The creation of meaning from experience(s) is reliant upon a temporal process of attention being directed backward to specific time periods; so whatever presently occurs will influence future discoveries when people analyze the past [21,81,84]. Furthermore, memories are events that occur in a given period of time, so anything that affects a person's ability to remember also affects the same sense that is made of those memories. With this in mind, Wieck [81] refers of Fischoff [85] states that 'creep determinism' can prevail, especially "when people who already know the outcome of a complex prior history of tangled, indeterminate events remember that history as being much more determinant, leading inevitably to the outcome they already knew" (p.28). Consequently, determinant histories can be reconstructed differently [81], which is akin to a postmodern cultural view, as one person may experience the same phenomenon differently from another [86,87]. For example, if an outcome is perceived to be bad, then antecedents are reconstructed to emphasize incorrect actions and inaccurate perceptions even if they were not influential or obvious at the time [81]. In this instance, retrospective sensemaking implies that errors and subsequent rework should be anticipated and reduced through a process of 'good project management'. The future is indeterminate, and the past is reconstructed knowing an outcome, thus past events are rarely accurately recalled. Reason [33] asserts that the "knowledge of the outcome of a previous event increases the perceived likelihood of that outcome" (p.91) which can lead people to overestimate their ability to influence future events. This phenomenon is known as the 'illusion of control' [88]. Organizations with a strong desire and willingness to reduce rework within projects require an interpretation of past indeterminacy that favors order and oversimplifies causality [33]. This approach facilitates a meaningful context as to ‘why’ and ‘how’ rework materialized and provides insights that help construct invaluable lessons on how to mitigate future rework.

3.1 Face-to-Face Interviews

The more complex the subject matter, the richer the communication medium needs to be, with the richest form being face-to-face interviews [40]. Face-to-face interviews provide more clues in terms of tone of voice, facial expression, and body language - all of which assist the interviewee to make informed adjustments about the topic of inquiry. For this reason, Dixon [77] recommends sensemaking conversations need to be held face-to-face, as do conversation invitations and the communication of results.

Using this approach interviews were undertaken with two organizations [an operator (i.e. blunt end) and contractor (i.e. sharp end)] that had extensive involvement and experience in delivering oil and gas projects in Australia. They were systematically selected for this research because they were market leaders and actively involved in the delivery of offshore projects. For the oil and gas operator, 23 in-depth interviews were conducted with a variety of personnel that had been involved with constructing off-shore floating structures such as Floating Production Storage and Offloading (FPSO) vessels, Tension Leg Platforms and Jacket Platforms. Interviewees included a general manager (1), operations managers (2), project managers (10), structural engineers (3), procurement managers (2), business managers (2), and engineering managers (3). The contractor was involved in the design, installation and commissioning of electrical and instrumentation (E&I) engineering systems. Interviews were also undertaken with the Managing Director, Business Development Manager, Engineers (8) and Draftsmen (6).

The research team collaborated with a direct contact point within the participating operator and contractor who had an interest in understanding ‘why’ and ‘how’ rework emerged in their projects. For reasons of commercial confidentially, specific details about the organization and individuals interviewed are not presented. All interviews were conducted at the interviewees’ offices for their convenience. Interviews were digitally recorded and subsequently transcribed verbatim to allow for finer nuances of the discussions to be documented. Handwritten notes were also taken during the interview to record any notable facial expressions, gesticulations, or other body language that could assist with the line of inquiry. The interviewees’ details were coded to preserve anonymity, although all interviewees were aware that their identities might be revealed from the textural narrative. The interview format was kept as consistent as possible and followed the emergent rework themes identified within the extant literature.

The semi-structured interview commenced by asking individuals about their experience within industry, and their current role within the organization. Interviewees were then invited to: select a completed project they had worked on; identify a particular rework incident that had occurred; and explain how and why it arose from their perspective. Phrases such as ‘tell me about it’ or ‘can you give me an example’ were asked at opportune moments when further information was required. These open questions allowed for avenues of interest to be pursued without introducing bias in the response. Interviewees were asked to identify sources of rework that occurred during the project’s construction phase and suggest appropriate rework mitigation strategies. Interviews varied in duration (between one to three hours) and sought to engender conversation while simultaneously creating a positive interpersonal rapport between the interviewer and interviewee. A copy of each interview transcript was given to each interviewee to check overall validity and accuracy. In conjunction with the interviews, documentary sources for each project discussed were provided.

3.2 Data Analysis

The textural narratives compiled were analyzed using QSR N5 which is a version of NUD*IST and combines the efficient management of non-numerical, unstructured data with powerful processes of indexing and theorizing. QSR N5 enabled additional data sources and journal notes to be incorporated into the analysis as well as identify emergent new themes. The development and re-assessment of themes, as the analysis progressed, accords with calls to avoid confining data to pre-determined sets of categories [89]. Kvale [90] suggests that ad hoc methods for generating meaning enable the researcher to access “a variety of common-sense approaches to interview text using an interplay of techniques such as noting patterns, seeing plausibility, making comparisons etc.” (p.204).

4. Research Findings

Transcript analysis obtained from the operator revealed that the interviewees had been involved with the same projects and coincidently identified specific rework events that had an impact on the project’s performance. The analysis also identified that interviewees had a different understanding of the events leading to rework. This was expected as a person’s sensemaking is a unique property of their physiology, self-consciousness and culture, experience and social and intellectual needs. The interviewees’ memories of the event were reliant on the context (which they sensed and interpreted), as well as the new context that they were in when attempting to remember details of the event. In the case of the contractor, the interviewees were all involved with the re-engineering of an FPSO’s ‘fire damaged’ safety control system.

Uncertainty, ambiguity and complexity were inherent characteristics associated with the design, engineering and construction of the projects identified in this study, but also oil and gas in general. The projects experienced time and cost overruns and operated in hazardous environments using high-end technology. The operator and contractor identified safety and the influence of operations on the environment as being paramount. Both organizations had a preoccupation with failure and had rigorous systems and processes to ensure a data-centric workflow was in place to track for lapses and errors. This was particularly the case for the operator when developing their Process Flow Diagram (PFD) and Process and Instrumentation Diagram (P&ID) in order to maintain data consistency with process information, line sizing data, and instrumentation and equipment definitions for their projects. For example, a 3D plant conceptual design model, plant design reviews, corrosion risk assessment and simulations formed an integral part of the pre-Front-End Engineering Design (FEED) phase. During FEED and construction, processes were in place for reporting near misses, process upsets and small and localized failures (e.g., HAZOP/Safety Reviews). Identifying errors was an organizational obsession, yet rework still occurred thus contributing to cost and schedule overruns, and poor productivity.

In many instances, rework was perceived by those interviewees at the 'blunt end' to be an expected 'norm' during the construction of projects despite an overarching organizational fixation with error mitigation. Interviewees of the operator indicated that project construction costs tended to be inflated by 5% to 7% due to rework which was perceived to be acceptable. One project manager stated: "if rework costs were kept at these levels then a project was deemed to be a good job". Conversely, the contractor viewed rework as unacceptable as it reduced profits and jeopardized safety. Nonetheless, if the rework arose due to a 'change' then the cost of rectification was invariably reimbursable. If a documentation omission or error occurred, then the contractor's likelihood of recovering additional costs (associated with productivity and rework losses) would be negligible even though such costs are significant. The contractor suggested that additional costs of 10% to 15% of capital expenditure (CAPEX) were often incurred due to erroneous engineering documentation produced in haste to commence production as early as possible. The operator's employees identified a number of offshore projects that had experienced significant rework and the most common example discussed related to a new-build FPSO, which is examined in this paper.

4.1 Blunt End: New-Build FPSO

The FPSO construction formed part of a major oil field development valued in excess of AU$1 billion. It was the operator's first new-build project and was commissioned to connect five subsea production wells, spread across two fields. The connected wells consisted of vertical, deviated and horizontal well bores with single-chrome completions. The FPSO's engineering design was undertaken by various consultants in Europe (e.g., Norway, Monaco, and the Netherlands) and Korea, with the operator's staff present in each location to provide design input. The original contract for the hull was awarded to a Korean shipyard, which was later assigned to a European consortium. The topside's contract was awarded to a European firm and constructed in two separate yards. The FPSO was integrated and constructed in Singapore and therefore, the hull had to be towed from Korea and the modules floated from Europe. It was estimated that rework experienced during the FPSO's construction was approximately 30 percent% to 35% of its CAPEX. Due to commercial sensitivity, the FPSO's final cost was not provided but interviewees openly and candidly conversed about the issues that they perceived to have contributed to rework being experienced. In Figure 3, four core themes emerged from the analysis of transcripts: (1) circumstance, (2) organization, (3) system and (4) task.

'*Circumstance*' is used to describe the situation or environment within which the project was operating. In this case, the operator had a bias towards production (i.e. early revenue creation) and established an unrealistic time period for commencing oil export even though there was a high degree of uncertainty associated with the size of the hydrocarbon reservoir. Producing and exporting oil efficiently would provide potential investors and shareholders with confidence that the operator was worthy of their investment.

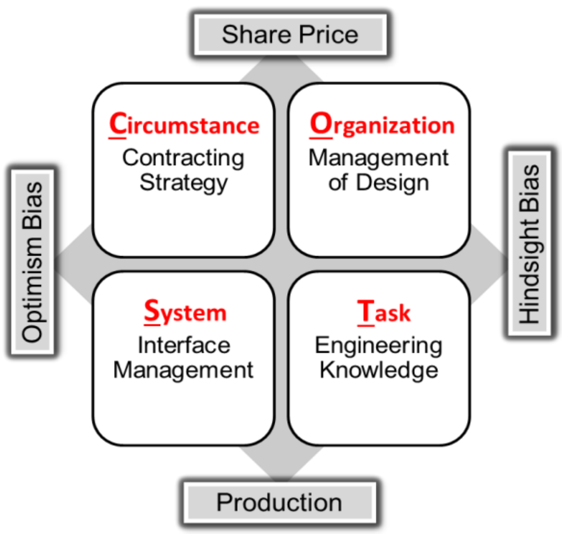


Figure 3. Blunt end themes

Fundamentally, the strong emphasis on production contributed to generating rework. This was the operator's first new-build FPSO project, albeit many employees had experience in the Gulf of Mexico, the North Sea, and West Africa. Despite this abundance of knowledge several fundamental design and engineering problems emerged during the FPSO's construction. This, in part, was attributable to the contracting strategy implemented and the operator commencing detailed design before the hydrocarbon reservoir's conceptual studies had been completed. This resulted in an oversized FPSO and anchorage system, and a significant increase in CAPEX.

Rather than adopting an established Engineering Procurement Construction (EPC) or EPC Management (EPCM) contracting strategy, the operator decided to manage and coordinate the contractors themselves. The choice of arrangement was chosen to reduce CAPEX and to ensure that the project's schedule would be met.

'*Organization*' denotes rework related issues that arose as a result of the project's organizational structure. The operator relocated dedicated staff to each of the contractors' offices to manage the project. With contractors working in different time zones, communication was paramount, yet the operator failed to provide them with a detailed project definition and milestones. When questioned about this issue an interviewee stated: "we just wanted to get the project going, and so developed the project's scope as we progressed and more information became available." This approach resulted in their contractors being supplied with information at different times, which hindered their ability to plan work. A severe lack of project definition manifested itself in rework; for example, climate data was not provided in the scope, and air-conditioning had not been included in the constructed FPSO.

Rework arose from the way the organizational '*system*' related to interface management (IM). Collaboration and the fostering of communication between organizations are pivotal for efficient IM. The inadequate provision of technical data and documentation juxtaposed with the engineering being undertaken out of sequence resulted in on-site rework occurring during the FPSO's construction, assembly, testing and commissioning. While the operator assumed responsibility for IM to reduce costs, their attempt to transfer responsibility onto the contractors created unnecessary conflict. For example, the hull contractor's contract was awarded based upon their specification. The operator fatally assumed at the award of the contract that their specification and the contractor's mirrored each other. As a consequence, during construction the operator realized that there were specification issues that were not being addressed. For example, the vessel was being constructed to accommodate 100 people and 30 additional temporary crews, yet the operator's specification required accommodation for 130 people. Changes were made at the operator's request, which required significant rework.

The '*task*' emerged from the engineers not having the appropriate engineering knowledge and/or experience. For example, lifeboats specified by the operator and installed onto the FPSO, failed international standards and so were removed and completely re-built. The absence of specified climate data also had significant ramifications in terms of rework encountered - hence, Norwegian engineers designed the FPSO based on North Sea climate specifications rather than those for the Timor Sea. Also, the helideck was designed to accommodate snow loading, and had been partly fabricated when this problem was discovered. An interviewee stated: "we had our own engineers in the office and we believed this sort of thing would not happen, yet they did." The schedule compression coupled with a lack of knowledge and experience that was placed on engineers was considerable because shareholders held expectations that the operator would deliver by a specified date. When under such pressure, people tend to take short cuts to meet a deliverable. It was perceived that the operator's staff in the Norwegian engineer's office had been overloaded and there were not enough resources allocated to managing the design and engineering process.

Key decision-makers, such as the operator's senior managers, are rarely, if at all, cognizant of how their decisions impact operations at the sharp end as they focus on establishing objectives that meet their immediate goals (i.e. the push for production and profit maximization).

4.2 The Sharp End: Upgrade to Safety Control System for an FPSO

In contrast to above, this case examines issues that occurred at the sharp end. In this instance, an FPSO's safety control system had caused frequent shutdowns, many of which were specious and led to oil production losses. To achieve a system with integrity and to enhance the production rate, the operator decided to upgrade the safety control system. However, due to a contractual dispute between the previous owner and the shipyard that was contracted to convert the tanker to an FPSO, many of the 'as built' drawings were unavailable.

For the organization that was contracted to undertake the safety control system upgrade, the work consisted of four parts: (1) engineering design; (2) on-site engineering; (3) hardware; and (4) system installation. The engineering design had three specific phases: (a) information interpretation from the existing design; (b) new system design; and (c) Programmable Logic Controller (PLC) programming.

The safety control system upgrade should have been a straightforward process, but a lack of available information created design rework. Although two weeks were originally scheduled to complete the physical works in a dry dock, document errors and omissions issued to the contractor hugely expanded this program to five months at considerable cost to the operator. The average production rate was 35,800 b/opd, and a total loss of production for five months resulted in a loss of 5.37M barrels of oil. Given the current price of crude oil, which was US$96/barrel (June 2013), the total capital loss equates to US$515.52 million. Decisions and work practices adopted at the blunt end can have adverse consequences at the sharp end. Figure 4 presents three themes that emerged from interviews held with an electrical and instrumentation (E&I) contractor who was operating at the coalface. From the contractor's perspective, errors and omissions contained within documentation issued hindered productivity and jeopardized the potential integrity of the safety control system. For example, a gas detector was designed to trip the Public Address and General Alarm System (PAGA) when it was detected at a 20 percent Lower Explosive Limit (LEL). However, the correct design should have been at a PAGA initiation of 10percent LEL for gas detection. As a consequence of this design error, the initiation of the PAGA was delayed and potentially endangered the safety of both the operators and equipment.

The contractor's engineers suggested that robust design audits and reviews would have identified this type of error. Errors and omissions were categorized as 'Practice' and arose due to people not executing their roles and duties adequately. While issues of commercial confidentiality restricted access to the operator, the contractor's engineers and draftsmen indicated that when the decision was taken to place the FPSO in dry-dock, the operator's dedicated project team 'panicked' as shareholders needed to be informed of production losses. In an attempt to address the problem, incomplete documentation was issued, envisaging that the contractor would identify any problems while on-site and subsequently raise Requests for Information (RFIs).

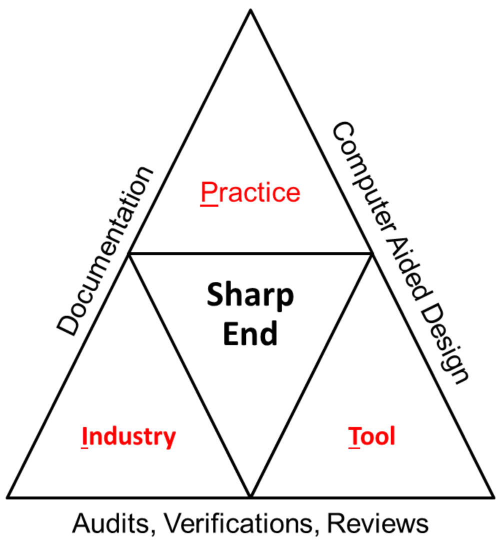


Figure 4. Sharp end themes

The term 'industry' was used to describe rework that arose due to the structural properties of the industrial environment, specifically how engineers performed their work. The E&I had been drafted in Computer Aided Design (CAD), and when errors, omissions or changes were required, a draftsman was required to manually amend all drawings where they occurred.

Noteworthy, when a change is required to a 2D CAD drawing, then the drawing and each corresponding view has to be manually updated. This can be a very time-consuming and costly process. Furthermore, as drawings are manually coordinated between views in 2D, there is a propensity for documentation errors to arise particularly in the design of complex electrical, control and instrumentation systems, which comprise of hundreds of drawings that are not to scale and have to be represented schematically. In this instance, information is often repeated on several drawings to connect each schematic together. Consequently, the time to prepare the schematics can be a lengthy and tedious process, especially as the design gradually emerges and individual documents are completed. Inconsistencies can manifest between the documents and therefore they must be re-edited and crosschecked before they can be issued for construction. For example, a heat detector specified in drawings had a 2ooN voting function, whereas in other contractual documentation it was 1ooN (one out of N). The issue was clarified through raising an RFI, but these inconsistencies adversely impacted workflow and productivity. Almost all the rework experienced arose from the design and documentation of the safety control system. The general perception among interviewees was that the operator had not devoted enough time to scoping their requirements and had grossly underestimated the extent of work required. The push for production had become the focal point, and the work that needed to be undertaken had almost become secondary.

Organizations operating at the sharp end are the closest to the errors and omissions that arise and are often left with the responsibility of identifying and resolving them before rework occurs. Involving organizations operating at the sharp end in the decision-making process during the project's formative stages can enable a systemic view of project performance. However, this requires organizations and people to challenge existing views and beliefs and not to accept that rework is simply an isolated incident in the system.

Views at both the blunt and sharp end acknowledge that rework is a common problem, which receives limited attention. Mitigating rework occurrence requires more than simply implementing additional procedures and compliance checks, but rather the unlearning of current beliefs and views about the prevailing system and the engagement in a process of learning and re-learning from acquired experiences.

5. Discussion

Learning from an operational failure such as rework, which is experienced by other organizations presents a number of important challenges and opportunities [91]. According to Hora and Klassan [92] the main challenge appears to result from a lack of information that is readily available after an event has occurred. Invariably only the consequences are identified rather than the contributory factors that led to rework thus creating causal ambiguity [17]. Self-confidence in an organization's own processes increases the likelihood of dismissing the possibility of project rework. Yet, despite these challenges, learning from organizations that have experienced rework provides an opportunity for others to acquire new knowledge in order to prevent reoccurrence. Examples presented within this research provide a context to understand the nature of rework. The findings clearly indicate that production pressure triggered an array of unintended dynamics, which unknowingly influenced rework and therefore when the pressure to produce increases there is often a tendency for the toleration of risk to be high [93]. Such a side effect can adversely influence an organization's ability to accommodate errors made during FEED and construction. This organizational misconception can be interpreted as 'organizational mindlessness' [84]. Goh *et al*. [93] assert that the danger of this dynamic is that it forms a vicious cycle that can continuously encourage a stronger management focus on production and further distortion of risk perception. Thus, it acts to deteriorate the organization's mindfulness in a cyclic manner. This vicious circle is arguably the core reason that provides fertile conditions for rework to manifest itself.

According to Reason [75], organizations that possess a bias towards production are more likely to experience organizational accidents. Previous research has revealed that when rework arises during construction there is a propensity for safety to be overlooked as there is an immediate focus on rectifying the problem at hand and minimizing its impact on the project's schedule [25]. It is noteworthy that the organizations participating in this study have impeccable safety records, but if rework occurs, then there is the potential for an accident to occur should the error not be identified. Supporting evidence for this claim is apparent within the significant number of engineering failures that have occurred due to design errors and omissions. For example, the collapse of I-35w Minneapolis Bridge (which killed 13 and injured 145) occurred due to gusset plates being incorrectly specified. Operators must have the capability to identify the systemic structure that promotes and gives rise to rework in order to adapt to increasingly complex project environments. An inability to see the broader system at play can lead to an organization possessing a 'learning disability' [94]. Such a disability often displays the following symptoms: a fixation on events (overemphasis on sudden and recent occurrences), an inability to notice subtle warning signs, and a delusion of learning from experience (lack of opportunity for trial and error).

5.1 Managerial Implications

To successfully curtail rework, managers who are charged with delivering complex projects (such as an FPSO) should adopt a systemic view during the formative stages when critical decision-making is undertaken. Managers are often faced with severe cognition challenges and are not in a position to make decisions that are rational and strategic [95]. In this situation managers tend to make decisions within familiar and relatively restricted boundaries formed by easily accessible information and available options [93]. The decisions made are rational within these familiar boundaries but not beyond. The dangers of decision-making within restricted boundaries can only be exposed if organizations are able to understand the broader systemic structure of projects within which they operate [93] and learn from acquired experiences [32]. Managers need to recognize that people's actions and behaviors are influenced by their environment; therefore changing it is a far more effective strategy than trying to alter the behavior of employees [95-97]. Thus, it is suggested that managers should openly de-emphasize the environment that places production at the top of its agenda to one that systematically examines the mechanisms and factors that shape the decisions and actions of people. This approach will ensure projects are delivered safely, on time, to budget and of the specified quality.

Learning from errors is a controlled and mindful activity [76]. Learning requires attentional, motivational and cognitive resources [95]. Motivational variables drive and direct the allocation of cognitive resources in terms of how much and how long they will be allocated for learning [98]. Thus, managers need to develop and harness an environment where people are motivated to learn, particularly through external (i.e. direct line manager) and task feedback. When design reviews and checks are not adequately undertaken, an organization should ask why people behaved the way they did, and examine their mental models and environmental factors that affect decision-making.

6. Limitations

The research presented is not without limitations. First, the findings are not generalizable as only two examples were examined and further research is therefore required. Second, hindsight bias may have been present, though the line of inquiry was not anchored to outcome knowledge. According to Hendrikson and Kaplan [99], investigations that are anchored to outcome knowledge run the risk of not capturing the complexities and uncertainties that people are confronted with at the sharp end and why their actions made sense at the time. Thus, important lessons may go unlearned if the exercise is merely to retrace someone else's decision landmarks. Interviews purposefully did not seek to find a specific cause as often no well-defined starting point exists to determine the essence of a causal chain. Furthermore, progressively working backwards through the causal chain is a time-consuming process and pragmatic considerations need to be taken into account such as resources and time constraints. Interviews undertaken did not attempt to establish where the organization or people went wrong, but rather tried to understand why their assessments and actions made sense at the time, if at all. And finally, retrospective analysis is limited, as systems are rarely static [100]. Organizations and the projects that they are involved with continually experience change, as adaptations are made in response to local pressures, short-term productivity and cost goals [101]. People adapt to their environment or change their environment to suit their purposes [94]. This propensity for systems and people to adapt over the life of a project reduces managerial effectiveness particularly when cost-efficiency and increased productivity governs its decision-making processes.

7. Conclusion

Previous rework related research has tended to focus on causal factors and identifying a specific root cause. Yet, rework arises due to human error, which is the effect of symptoms derived from a systems environment where tools, tasks, and operations are interdependent. It is impossible to identify a single cause for rework as a complex array of inextricably linked variables and conditions interact with one another to produce the event. In the cases studied, it was revealed that production pressure was an underlying latent condition that provided fertile conditions for influencing critical decision-making, and the behavior of people and organizations involved with FPSOs. In one case presented, the operator was an inexperienced organizational entity in delivering an FPSO, though its managers and engineers had extensive experience in their design and construction, which was acquired with previous employers. Despite such experience, rework still occurred, which resulted in cost and schedule overruns.

This study demonstrates that the pressure to produce oil focused management's attention onto production, which tended to distort their risk perception and lead to a further focus on production. This finding aligns with the current theory that has been propagated to explain organizational accidents. In the case of rework, the error or omission is identified before such an accident occurs. The danger is, however, if an error or omission is not identified the propensity for an accident or major catastrophe increases. It is irresponsible for managers and engineers to operate in (or even contribute to) unsafe environments, such as those offshore, to consider rework 'normal' under operating conditions. Notwithstanding the potential for loss of life and/or environmental damage due to failure of an offshore facility, there are implications for shareholders and those contractors working at the sharp end. For shareholders, there is the potential for dividends to be adversely impacted as production may be delayed. For contractors, a reduction in profit margins and productivity may be experienced, as they attend to rectifying problems that have manifested themselves from decisions made in the formative stages of the development process.

Causes are fundamentally constructed rather than found and so it is suggested that future research should focus on explaining people's behaviors to examine their mental models, environmental factors and other influences that affected their decision-making, which lead to errors and subsequent rework. To undertake such research effectively, it is suggested that emphasis should be placed on working backwards through the causal chain, particularly using causal maps, to obtain rich understanding of the context in which decisions and behaviors occurred.

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