SYSTEMIC REWORK RISK CLASSIFICATION FOR OFFSHORE PROJECTS

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Rework arises due to errors and omissions, and significantly contributes to project cost and schedule overruns in offshore projects. To acquire an understanding of the causal nature of rework in offshore projects, twenty three in-depth interviews with leading oil and gas industry practitioners were undertaken. The dialogue and narratives obtained from the interviews enabled the underlying dynamics of rework to be determined. A risk classification matrix is developed that can be utilized as a frame of reference to mitigate future rework. If rework risks are not given due consideration then there is the potential for latent conditions to become embedded within organizational and project systems and processes. Consequently, the likelihood of failures, accidents or even catastrophes increases.

Keywords: dynamics, errors, offshore projects, rework, risk.

INTRODUCTION

Offshore installation environments are among the harshest in the world and most hazardous to operate in. The hazards associated with offshore projects such as the Deepwater Horizon have been identified as being similar to space exploration where the ‘tyranny of depth, distance and darkness’ prevail (Bea, 2010; Bea *et al*., 2010). Natural hazards presented by the pressures, forces, and movements of water, and by extremely low and high temperatures of the deep ocean provide an environment where there is minimal, if any, tolerance for errors to occur (Deacon *et al*., 2010). Considering the environment of offshore projects, their engineering, procurement and construction (EPC) becomes more technically challenging and complex. This is further exacerbated by the shift to deliver projects in remote and hostile regions where logistics and economies of scale are difficult. Projects in remote regions are difficult to plan and control, and have a 50:50 probability of failing (McKenna *et al*., 2006). Between 1993 and 2003 one in eight major offshore developments with a capital expenditure (CAPEX) ranging from US$1 million to US$3 billion were deemed to be a financial disaster (Merrow, 2003a). These projects exceeded cost and/or schedule growth by 40%, or within the first year of operating were producing less than 50% of production capacity. Furthermore, more than 40% of capital offshore projects in excess of US$1 billion overran budget by more than 10% (Merrow, 2003a,b). A factor found to significantly influence cost and schedule overruns is rework, which is

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often attributed to errors (Love *et al*., 2009). While rework is deemed prevalent, there is limited knowledge to date about its causal influences in offshore projects. To reduce the probability of cost and schedule overruns, rework risks need to be identified and classified before they can be assessed, managed, and mitigated. A series of unstructured interviews with leading industry practitioners was undertaken to acquire knowledge about their experiences with rework in projects that they had been involved with. The dialogue and narrative provide valuable insights about the dynamics of rework. From the findings a systemic classification risk matrix was developed, which can be used as a frame of reference to mitigate future rework.

REWORK

Rework has been defined by Love (2002) as "the unnecessary effort of redoing a process or task that was incorrectly implemented the first time" (p.18). It has been identified as an endemic problem in construction and engineering projects and a major contributor to cost and schedule overruns (Love *et al*., 2010) Rework, on average, contributes to 52% of a total cost overrun incurred and can increase schedule overrun by 22% (Love, 2002). Rework costs have been found to range from 5 to 20% of contract value in construction and engineering projects (Love, 2002; Love *et al*., 2010). To date, there is limited knowledge available about costs, causes and associated risks of rework in offshore projects. A major contributor to rework is error, which can arise due to slips, lapses, mistakes and violations (Reason, 1990). When an error is identified, it often requires rework to be undertaken. Rework has been attributed to latent conditions that reside within the organizational and project systems (Love *et al*., 2009). Reason (1997) states that "latent conditions are to technological organizations that which resident pathogens are to the human body" (p.10). For example, at an organizational level this may include insufficient training, resourcing levels and lack of a quality management focus. At a project level, lack of supervision, competitive tendering, and contracting strategy have been found to provide the conditions for errors to manifest themselves (Love *et al.*, 2009). In effect, latent conditions lay dormant within a system until an error comes to light. Invariably, they arise as a result of strategic decisions taken by senior management, government, regulators, designers and key decision-makers. The impact of these decisions spreads throughout an organization and project, shaping their culture and creating error-producing workplace factors that become part of their projects (Goh *et al*., 2011).

Evaluating the probability of human error for a specific project related task is an arduous task. Swain and Guttman's (1983) Technique for Human Error Rate Prediction (THERP) for common tasks performed under general conditions and obstacles has provided the foundations for such an assessment to take place. Error probabilities that have been developed are intended to be associated with a range of conditions and barriers. Techniques for assessing the probability of human error include: Paired Comparisons (Hunns, 1982); Absolute Probability Judgment (Seaver and Stillwell, 1983); Success Likelihood Index Method (SLIM) (Embrey *et al*., 1984); Human Error Assessment and Reduction Technique (HEART) (Williams *et al*., 1986); and Justification of Human Error Data Information (JHEDI) (Kirwan, 1994).

The probability of a major error in structural analyses has been found to range from 2x10-4 to 90x10-4 (Paté-Cornell, 1990; Trbojevic *et al*., 1996). The causes of human errors have been found to be associated with task familiarity, stress, time constraints, distractions and impairments (Love *et al*., 2009). Error detection probability varies depending on which person (i.e. their qualification and experience) is performing the review and the severity of error (Paté-Cornell, 1990). Schneider (1997) has revealed that 32% of errors can be detected through rigorous design checks. In addition, if an independent third party is used then as much as 55% of design errors could be accounted for. While design checks and verifications are useful for identifying errors, their usefulness is restricted if lessons are not learnt from previous projects and appropriate training and skill development implemented (Kvitrand, 2001).

Structural failure, for example, was identified as being a significant factor in the Alexander Kielland (North Sea, UK) accident (Ersdal, 2002). The degradation of steel structures due to gross errors has been identified as the starting point for the collapse of several offshore structures. Calculation and drafting errors and installations not fit for purpose are the main contributors to structural failure. Design failures can materialize as deficient or excessive resistance. Fabrication imperfections (such as cracks and plate misalignment) are also affected by resistance and influenced by human actions (Moan, 2005). A fatigue failure of a brace and a lack of design checks contributed to the collapse of the Alexander Kielland platform. The Ocean Ranger collapse (Newfoundland, Canada) occurred due to the crew having not received adequate training with the ballast valves. In fact, the ballast valves had not been designed to account for the prevailing extreme weather conditions within the platform’s vicinity. Omission errors, for example, arise due to economic and schedule pressures placed upon individuals and their organization. It has been suggested that 25% of inspection and maintenance expenditure during the operating life of an offshore installation results from the defects that occur during the fabrication stage (Karunakaran, and Wilson, 2009). Such defects are related to materials, corrosion protection and coatings, welds, and quality assurance /quality control (QA/QC) aspects. Accidents can be caused by inadequate engineering practices such as lack of knowledge (or ability) to cope with new situations as they arise. For example, phenomena such as ringing and springing of Tension Leg Platforms (TLPs) and degradation failure of flexible risers have been discovered on several off-shore structures in recent times before any major accident has occurred.

Several risk reduction strategies to reduce errors have been suggested for offshore structures. These include increasing the safety margins of Upper Limit State (ULS) and Fatigue Limit States (FLS) with respect to structural components, improving the skills and competence of individuals, QA/QC for design, and regular inspection of the structure and Accidental Collapse Limit States (ALS) (Moan, 2005). Since the structural damage characteristics and their behaviour depend on the type of accidents, it is not straightforward to establish universally applicable structural design criteria for the ALS. For a given type of structure, design accident scenarios and associated performance criteria must be determined through thorough risk assessment. Changing a platform’s functional use during operation (perhaps moving the platform to a different field) may require its service life to be extended, extensive design checks and an assessment of ALS. Such changes may require a degree of rework, which will not have been predicted during the platform’s initial design.

RESEARCH APPROACH

An interpretative research approach was adopted to determine the systemic nature of rework. A similar approach has been advocated by Goh *et al*. (2011) who examined the systemic causes of organizational accidents. As limited research has addressed rework in offshore projects ‘subjective idealism’ was adopted (Farrell, 1996). In this instance, subjects construct their own views and opinions on the phenomena to be investigated based upon their experiences; an inclination to truth and pragmatism is deemed to prevail. This approach is similar in nature to Weick's (1988) 'sensemaking' where meaning is given to experience, dialogue and narratives about events that have occurred through a process of retrospection.

Data Collection

Twenty three in-depth interviews were conducted over a four month period with a variety of personnel including operations managers, project managers and engineering managers who were working for a major international oil and gas operator. The sample consisted of: operations managers (3), project manager (10), structural engineer (3), procurement manager (2), mechanical manager (2) and engineering manager (3). Interviews were chosen as the primary data collection mechanism as they are an effective tool for learning about matters that cannot be observed (Kvale, 1996). The firm was selected as the research team had a direct contact point within the organization that had an interest in understanding 'why' and 'how' rework emerged in projects. For reasons of commercial and individual confidentially, specific details about the organization are not presented. Personnel involved with the procurement of projects within the organization were invited to participate in the research and interviews were conducted at the offices of interviewees for their convenience. Interviews were digitally recorded and transcribed verbatim to allow for finer nuances of the interview to be documented. The interviewees' details were coded to allow for anonymity, although all interviewees were aware that it might be possible to identify them from the content of the text.

The interview asked individuals about their experience within industry, and their current role within the organization. Interviewees had to select a completed project they had been involved with and identify a particular rework incident that had taken place. The interviewees' perspective on how and why they thought it arose was explored. Phrases such as 'tell me about it' or 'can you give me an example' were used when further information was required. Open questions allowed for avenues of interest to be pursued as they arose to prevent bias in the response. Interviewees were asked to identify the main sources of rework that occurred in offshore projects that they had been involved with and to suggest strategies that could be used to prevent it from reoccurring in the future. Notes were taken throughout the interview to support their digital recording to maintain validity. Interviews varied in length from one to three hours and sought to stimulate conversation whilst simultaneously breaking down any interpersonal barriers that may have existed between the interviewer and interviewee. Each interview was transcribed and a copy given to each interviewee for comment to check overall validity and accuracy. In conjunction with the interviews, documentary sources for each of the projects were provided.

Data analysis

The text derived from the interviews was analysed using NVivo 9. This software tool enabled additional data sources and journal notes to be incorporated into the analysis as well as identify themes. The development and re-assessment of themes as analysis progresses accords with the calls for avoiding confining data to pre-determined sets of categories (Silverman, 2001). Kvale (1996) 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). Using NVivo facilitated an organic approach to coding because it enabled triggers or categories of textural interest to be coded and used to monitor emerging and developing ideas (Kvale, 1996). These codings can be modified, integrated or migrated as the analysis progresses and the generation of reports, using Boolean search, facilitates the recognition of conflicts and contradictions.

FINDINGS

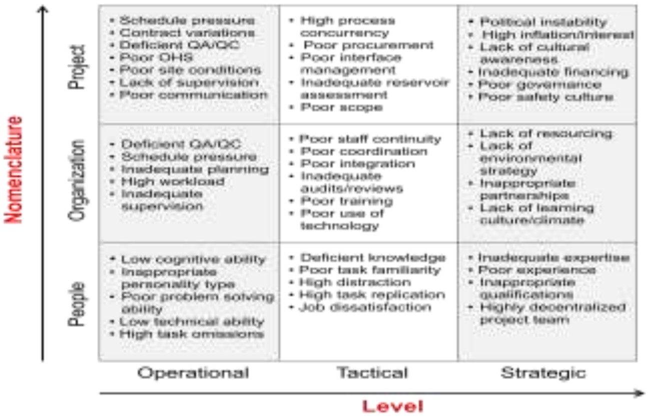
Each interviewee held views as to the reasons rework occurred in projects that they been involved with, though a high degree of consensus emerged as to the underlying causes and risks that needed to be taken into account to reduce its materialization in projects. Narratives from completed projects that interviewees had been intimately involved with from different parts of the world were described. This led to a rich representation of the dynamics and risks associated with rework to be attained. The sharing of dialogue and narratives is pivotal for learning, though there is a proclivity for it to occur at different levels within organizations. Many interviewees had worked on the same projects. In addition, several had worked on the same projects, but with different companies in the Gulf of Mexico and North Sea. The general causes contributing to rework are identified in Figure 1. The nomenclature of project, organization and people were found to be common causal attributes of rework that emerged from the data analysis. The causal attributes of rework are represented in a matrix presented in Figure 1. The factors identified are deemed also to be risks that can be taken into consideration during the formative stages of a project. Examples of errors and rework identified by interviewees are presented hereinafter.

Uncertainty associated with the behaviour of the hydrocarbon reservoir

Data, for example, obtained from the sub-surface was given to the facilities engineer to develop the project's specification; the specification was then used to procure a Floating Production Storage and Offloading (FPSO). A single firm was awarded the contract for the design and the construction of the vessel, however, the Topside facility contract was awarded to a different firm. The design engineers were unsure of the number of risers and umbilicals that would be required to interface with the drill centres. The engineers proceeded to design the FPSO based on the initial specification provided and their experience without enough consultation with the operator. Work had commenced at the subsea level to determine the number of oil production wells and establish the field layout requirements (e.g., Christmas Trees and Manifolds). Work had to stop due to the uncertainty associated with the oil reservoir; a design freeze occurred. Simulation and modelling of the field was completed and a degree of confidence was obtained regarding the production capacity that could be attained. The subsea layout needed to be rectified, which resulted in rework occurring.

Geographical dispersion of the project team

Errors in the hull and Topside design emerged in an FPSO. The hull's stability was brought into question. An unstable hull would significantly influence the propensity for green water loading to occur. The design error was not noticed until the vessel was being constructed in its dry dock. Engineering was undertaken in two locations: the Northern and Southern Hemispheres. To expedite the design schedule, the engineering and construction firm decided to use design teams in two separate time zones. When one team finished for the day, unfinished tasks were then handed over to the other team to progress with. The vessel's construction team had two different points of reference to seek clarification about engineering queries. There appeared to be limited communication between the engineering and construction teams within the same firm and this was further exacerbated by the need to also integrate works with the Topside contractor.



	Operational	Tactical	Strategic
Project	• Schedule pressure • Contract variations • Deficient QA/QC • Poor OHS • Poor site conditions • Lack of supervision • Poor communication	• High process concurrency • Poor procurement • Poor interface management • Inadequate reservoir assessment • Poor scope	• Political instability • High inflation/interest • Lack of cultural awareness • Inadequate financing • Poor governance • Poor safety culture
Organization	• Deficient QA/QC • Schedule pressure • Inadequate planning • High workload • Inadequate supervision	• Poor staff continuity • Poor coordination • Poor integration • Inadequate audits/reviews • Poor training • Poor use of technology	• Lack of resourcing • Lack of environmental strategy • Inappropriate partnerships • Lack of learning culture/climate
People	• Low cognitive ability • Inappropriate personality type • Poor problem solving ability • Low technical ability • High task omissions	• Deficient knowledge • Poor task familiarity • High distraction • High task replication • Job dissatisfaction	• Inadequate expertise • Poor experience • Inappropriate qualifications • Highly decentralized project team

Figure 1: Classification of rework risks

Construction and installation before the engineering is complete

In the case of a TLP, the hull and Topside were constructed into different locations as engineering being complete. The number of rigid risers and dry trees had not been determined prior to construction. This was surprising considering that they typically need to be determined in the pre-engineering stage. When the number of risers was finally determined, significant alterations had to be made to the Topside causing a six month delay to be experienced. In another example, process and utility equipment had only been preliminary designed when construction of the Topside commenced (e.g., injection compressors, gas turbine generators, HVAC). During installation clashes and dimensional errors were identified which required modification and rework on-site.

Inadequate interface management

An engineering team, for example, from Northern Europe designed an FPSO to operate in the Southern Hemisphere where the climate is far hotter and more humid. Air conditioning was not included in the design. This design error only became evident when the FPSO had commenced operations on-site. If design checks and coordination with the Topside contractor had been undertaken then it was perceived that this error would have never arisen.

Coating failures

A number of causes of coating failures were identified which included poor attention to surface preparation, coating application, inspection and component design. A typical problem identified was the welding of gusset plates to I-Beams. As a result the edges of the gusset plate were often not coated properly, which led to them being re-painted. In another example, a platform in the Gulf of Mexico experienced excessive galvanic corrosion. Stainless steel bands attached to stainless steel tubing punctured the paint coating. Corrosion progressed, and if it had not been detected and rectified the vessel shell may have pitted. This was a clear case of poor design as the painters and coating used was not deemed to be the problem.

A SYSTEMIC APPROACH TO REWORK MITIGATION

A high degree of interdependency exists between many of the factors identified in Figure 1 and the examples presented. A systems perspective is used to explain the relationships and dynamics between factors (Goh *et al*., 2011). The interrelationship between key variables is presented an influence diagram presented in Figure 2. The arrows that link each variable indicate a place where a cause and effect relationship exists, while the plus or minus sign at the head of each arrow indicates the direction of causality between the variables. The development of Figure 2 enables the complexity and dynamic behaviour associated with rework to be visualized and therefore provide managers with an insight as to how decisions they make can influence errors and rework. Defining project scope remains an on-going problematic issue within offshore projects. Not so much in what needs to be constructed and installed, but the capacity, type, and contracting strategy required to deliver and produce oil and gas most effectively and efficiently. The use of Front End Engineering Design (FEED) should, in theory, mitigate rework during EPC. But it is the latent conditions, as noted above, that become entrenched within project and organization systems and processes that provide the environment for errors to manifest. In the examples presented in this paper, stage gate reviews and FEED were seemingly inadequate in capturing the errors. An ameliorated understanding of scope and acknowledging that rework may occur will improve the likelihood of more accurate forecasts of project cost and schedule, as denoted by negative feedback loop structure in Figure 2. Specifically, contracting strategies that utilize alliances, where risks can be shared, have been demonstrated to improve integration between team members and the organizational interfaces, which in turn, can address problems associated with coordination and communication that often are experienced in projects (Love *et al*., 2011). Additionally, the use of ‘design/engineering alliances’ during concept design and FEED can be beneficial in determining salient rework issues that may arise.

Risk identification and management is pivotal to delivering successful organizational and project outcomes. The techniques used for assessing and mitigating technological, environmental and safety risks within the oil and gas industry are sophisticated as the consequences of not managing and preventing likely events can be catastrophic. Yet, a dichotomy exists between the ‘individual’ and ‘organization’ in relation to rework. Informally, individuals know and even expect rework to occur considering the complexity and uncertainty that exists within projects, but the organizational rhetoric denies it exists or will occur. With this mindset in place, a ‘learning disability’ can exist if errors remain undetected despite efforts to improve the performance of processes. Decisions taken by senior managers at an organizational level, which are often influenced by the demands imposed on them from their environment, can determine the extent that policies and procedures are adhered to as well as the resourcing capacity for a project. Decisions that are made by individual organizations can increase or decrease the likelihood of rework. Each participating organization has differing goals, objectives and learning capacity, which may further exacerbate problems that become embedded within project systems and processes (Love *et al*., 2004). The contracting strategy adopted for a project therefore needs to ensure that goal alignment can be ensured. The current use of an EPC contracting strategy inhibits goal alignment between participating project organizations, especially when competitive price determination becomes a driver for the selection of their services (Love *et al*. 2011). Instead, as noted above, alliances with an in-built learning capability and performance incentives should be used to establish a project culture that is able to drive the behaviour of organizations to achieve a successful project outcome.

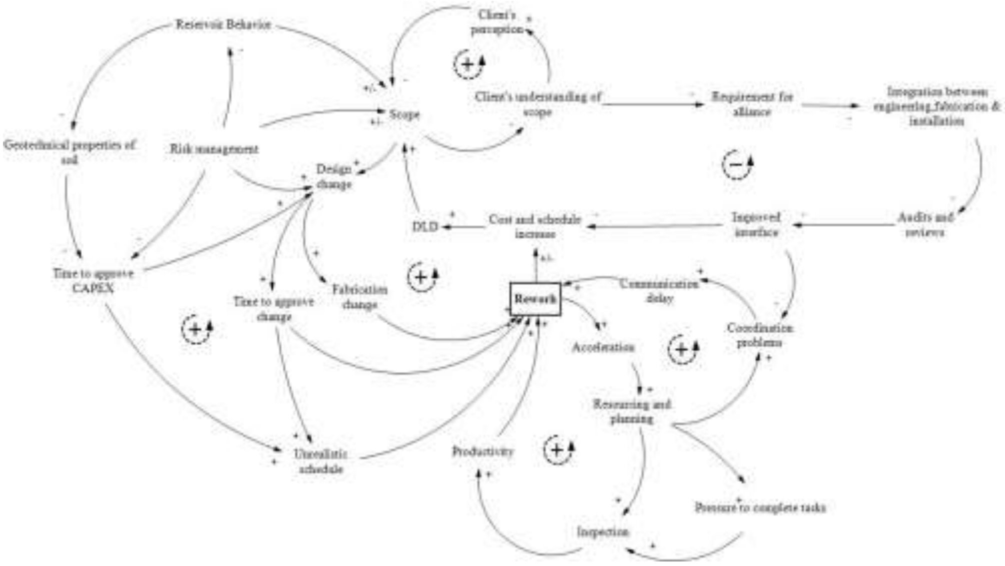


Figure 2: Interrelationship between key variables

An organization's culture influences its ability to learn, particularly in the context of rework reduction (Love *et al*., 2000). A culture conducive to learning is necessary for stimulating innovation, as it enables an organization to anticipate and adapt to the dynamics of a changing environment. An organization where a learning culture exists is characterized as one where all its members value learning and strive for high performance through its application to innovative work (Love *et al*., 2000). A culture adept at learning emphasises open exchange of information and ideas in ways that facilitate exchange and dissemination of knowledge. Culture is based upon the beliefs that are shared within, whereas climate is based upon what an individual's senses about its organizational environment. In the context of a learning climate, it is not the work environment, but the way in which employees are encouraged to respond to it. It would appear 'learning' is not given the priority that is needed by organizations as excessive cost and time overruns are regularly experienced. The same mistakes are being repeatedly made. There is apparently a lack of an awareness of the risks associated with error and rework within the context of project delivery. With this mind, the classification matrix propagated in Figure 1 provides a frame of reference for classifying rework risks. It is common to assess the risk of human error through the use of probabilities such as those contained within techniques such as, Human Error Assessment and Reduction Technique (HEART), Technique for Human Error Rate Prediction (THERP) and Software LIfe Cycle Management (SLIM). As limited knowledge has been made available regarding the measurement and incidence of errors and rework required, the matrix provides a reference point for future decision-making regarding potential risks; though considering the degree of sensitive dependence that prevails as a result of the dynamic nature of project environments, it is unlikely that static probabilities can be considered in line with safety research directions such as Resilience Engineering and High Reliability Organizations.

CONCLUSION

The increasing demand for, and rising costs of, energy has stimulated the need to extract and produce greater volumes of oil and gas. A large number of offshore projects have been built. Many have experienced significant cost and schedule overruns. A significant factor contributing to such cost and schedule overruns is rework. To date there has been limited research that has examined the causal nature of rework in offshore projects. The research presented in this paper has identified the generic causes and presented them in the form of a risk matrix that focuses on people, organization and project. The interdependency that exists between factors is also recognized and as a result a systemic causal model is developed to illustrate the underlying rework dynamics. The systemic approach to rework classification and determination provides the foundations for appropriate risk management strategies in future projects to be determined.

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