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Progressive Risk Reduction Strategy for Complex Engineering Projects

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ABSTRACT: Many large and highly complex engineering projects are undertaken by organisations without clear and well understood technical and commercial risks. Decisions are subsequently made without adequately managing or mitigating potential and residual risks. In cases where these risks are realised, the projects can suffer from budget overruns, schedule impacts/delays, technical failures, reputation loss and ultimately a disappointed customer.

This research has been conducted primarily in the defence environment and explores the use of an enterprise model based on four constituents: product, process, people and environment. These four constituents have been used to develop a ubiquitous set of generic project risks prevalent in defence projects. A comparative risk profile has been generated for current engineering projects which has been developed against previous projects with understood outcomes. One of the critical challenges of this research is the ability of the risk model to account for the perceived qualitative or subjective nature of risk assessments. This paper presents a new method that quantifies and models the relative risk profile of a project throughout the project lifecycle. It allows the continued management and visualisation of risks, and enables a process of continued analysis to both reduce and/or mitigate residual risks progressively to acceptable levels.

This paper illustrates the proposed theory and method by calculating and assessing the risk profile of three engineering projects undertaken within the Australian naval maritime environment. Although defence project data has been used in this analysis, the general theory and method can be easily applied to many non-defence organisations and industries.

Key Words: Mid-life upgrade, risk modelling, capability framework, complex engineering project, risk visualization.

1. INTRODUCTION

Highly complex platform systems such as ships, aircraft and land vehicles often require modifications and enhancements to their systems during their long service life [1]. These engineering change projects can be potentially challenging due to un-configured changes to the baseline. As a consequence, many project management decisions are made without clear understanding of key risks and their consequences. This leads to budget overruns, schedule delays, system failures and disgruntled customers [2]. In order to develop a sound strategy when undertaking complex projects, engineering organisations tend to develop their own bespoke methods for handling risk with varying degrees and levels of success [18]. Risk is defined in ISO 31000 [13] as 'the possibility that something unpleasant or unwelcome will happen'.

Unfortunately, it is all too common in industry to find that risk is treated as an afterthought and even in some cases seen as a box ticking exercise. It is critical that a strategy is developed for handling/ mitigating the identified risks to ensure the success of the project [17]. How well this is achieved can make or break the project and even the organisation.

There are many risk management and analysis tools available in the market place today which offer a variety of attributes [16]. Many of these tools are underpinned by Monte Carlo analysis modelling, which is essentially a mathematical algorithm that was developed in the 1940s for determining unknowns (risks) and providing a series of outcomes or scenarios. These forecast outcomes can go some way to help making informed project decisions but the analysis process can be complicated, time consuming and tedious. In some organisations, the use of such risk management and analysis tools may be conducted by dedicated risk engineers who is trained in such practice. However, in a lot of cases risk analysis is left to either the Project Manager or

Engineers, depending on the type of organisation [5]. While these individuals are no doubt well aware of possible risks relating to their project, the need for a sound understanding of complex and effective risk modelling tools along with schedule pressures can lead to poor demonstration of risk capture and analysis, especially the lack of versatility to manage the risks throughout the project lifecycle.

This research has focused on developing a quantitative risk model that can identify risk, develop a risk profile that can be presented in a visual format, manage and track residual risks throughout a project's life cycle. The potential development of a relationship between the model and a risk burndown chart, such as that in Figure 1, offers a means of associating the identified risks with both their predicted financial and schedule impacts and what affect proposed mitigations will achieve [12].

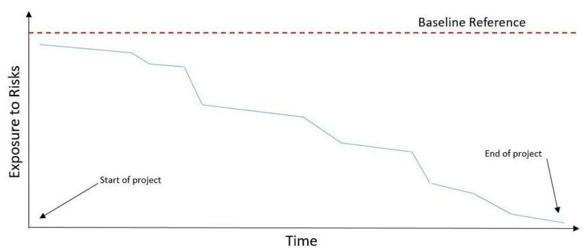

Figure 1 - Example of a Risk burndown Chart

This paper focuses on research that has been initiated under the Engineering Support Services requirements within the Australian Naval Maritime defence environment, but it could equally be applied to other countries, industries and disciplines. It should also be noted that some of the methods of calculation chosen are not mandatory and the proposed model has considered the need for flexibility to allow for alternative interpretations. Some of the methods of how the data has been collected and analysed for development of the risk model developed are explained within this paper.

2. LITERATURE REVIEW

In a large engineering project the chief element of risk arises from the fact that there are many variables that influence and determine the final cost and duration of the project. Essentially, every step of the process is laden with risk. Traditionally, for large scale engineering projects, the focus is on reliability, availability, maintainability and supportability (RAMS), see Figure 2. Barabadi et al [3] claimed that product issues and failures could be reduced and their consequences minimized by the use of tools such as failure mode and effects and critical analysis (FMECA), fault tree analysis (FTA) and event tree analysis (ETA). These are good methods of representing the performance of an engineering system by a quantitative value which can be linked to risks. Markeset and Kumar [4] proposed the idea of the gate model. By passing through checks or gates, and ensuring the tasks were evaluated, the project risks should be better controlled and reduced.

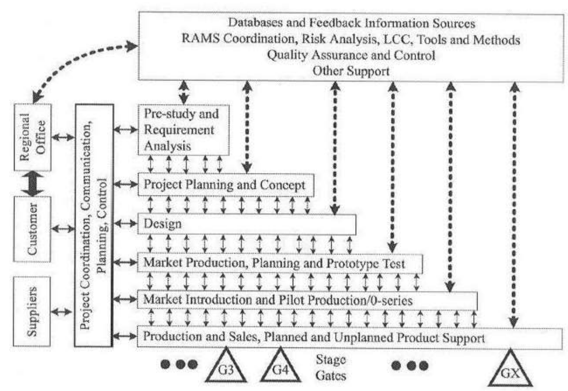

Figure 2 - RAMS Risk Analysis and Systems Engineering Design Cycle

In an alliance, as the different players begin to assess their contractual duties, they try to reallocate risks to the next party. Abi-Karam [6] focused on design-build in construction projects and identified the risks in the proposal, pricing, project schedule, performance measures, contractual liability and safety areas. Modarres [7] went further to identify, rank and predict contributors to risk. Modarres calculated probabilistic risk for different scenarios and some interesting methods of presenting risk in graphical forms. This work illustrated ways of quantifying risks and hence the possibility of ranking accordingly. Ayyub [8] used a number of real life examples and the method used was described in detail. While the examples are not completely relevant to this research project, they do offer ways of being manipulated or partially used to achieve useful outcomes. Claypool et al [9] reviewed some basic risk management techniques that had been used for years. However, after conducting surveys with one hundred and ten managers they believed there was much room for improvement. They particularly highlighted that little work has been conducted into reducing risk in the supply chain which large scale engineering projects depend heavily upon. The authors went on to offer several methods of evaluating a supply chain mainly through surveys and analysis.

Mo [10] studied systems that were designed to support assets in service. Through a simple modelling process including both cost and availability, the performance of a service system can be estimated. The method was based on categorization of capabilities into six elements as shown in Figure 3. This model appeared to be somewhat relevant to the analysis of risk in complex engineering system upgrade projects by calculating indicators of where a company should increase capacity, effort and expenditure to reduce or mitigate risk.

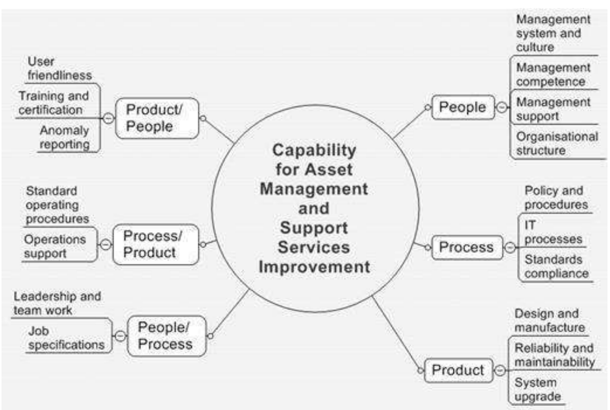

Figure 3 - Capabilities of service systems

With a similar approach, Yim et al [11] developed an interesting methodology for obtaining data and illustrated how they could relate to different complexities of engineering projects. The methodology was to enable project managers to identify risk indicators early in the lifecycle of a project according to complexity of the project and to subsequently initiate effective mitigation.

Operational risk profiling (OPR) is a global risk management process that delivers a known level of residual risk to a capability, in achieving its operational objectives according to Millar [15]. Linking engineering to operations for cost effective management of defence assets based on critical and residual risk. Ultimately, the mitigation for risks identified will determine the total cost of ownership which can be accepted by the operational function based on the available budget. The development of an OPR process can be seen in Figure 4.

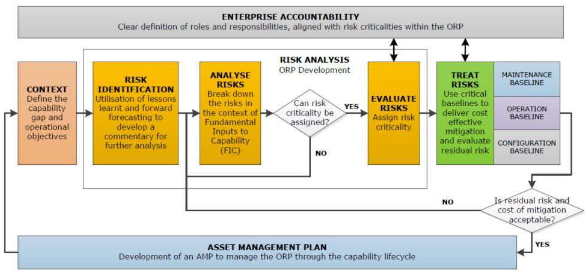

Figure 4 - OPR Development Process

The OPR process is a risk management process based on ISO 13000 standard [13]. However, although the risks are managed by setting up checks and gates, it is not possible to determine the relationship between risks managed in Figure 3 and any particular OPR steps in Figure 4, this approach is basically disjointed.

A typical engineering project in the defence environment will go through some form of Systems Engineering process [14]. Such a plan or process usually includes a number of mandatory stages and theoretical gates which need to be passed before the change can be progressed. See Figure 5 for an example of a Systems Engineering Management Plan (SEMP) used by BAE Systems Australia.

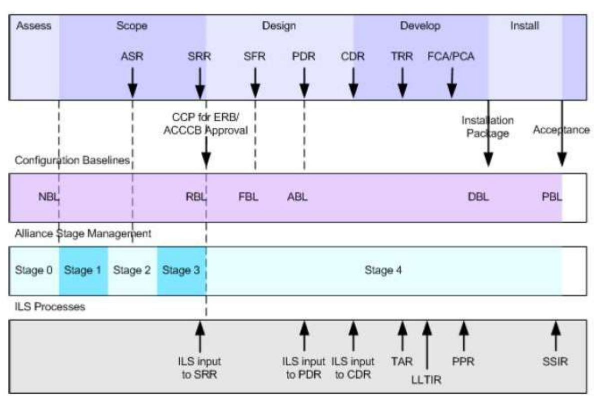

Figure 5 - SEMP process, BAE Systems Australia

Through its lifecycle management strategy [19], an organisation like BAE Systems operates a Risk and Opportunity Management Plan (ROMP) for business units. The main tool for risk management in ROMP used at BAE Systems Australia is a risk register which is usually populated by project managers and engineers alike. The register is based on assessing risks against the likelihood/consequence ratings (Figure 6) which are qualitatively defined typically by brainstorming and project meetings both internally and involving the customer and alliance partners externally.

Risk Rating:

Likelihood	Consequence				
	Insignificant	Minor	Moderate	Major	Catastrophic
Almost Certain	H	H	E	E	E
Likely	M	H	H	E	E
Moderate	L	M	H	E	E
Unlikely	L	L	M	H	E
Rare	L	L	M	H	H

Figure 6 – Example of risk rating

3. RESEARCH APPROACH

This research aims to develop a risk model that is based on generic enterprise architecture framework and is being developed to provide a quantitatively generated risk profile. It is important to state that this model is not intended to compete or replace current risk theory, tools or processes already available, but instead offer a novel and enhanced method for managing and visualising risk throughout the lifecycle of a project. The research focused on the Australian Naval Maritime defence environment to develop a potential numerical indicator which could ameliorate the current processes involved in understanding and managing risk throughout the project life cycle due to manipulation of these factors.

In order to set some form of qualitative baseline which could then be used for both quantitative assessment and analysis, an investigation into risks surrounding complex engineering projects was undertaken based on the 3PE model described by Mo [6], see Figure 7.

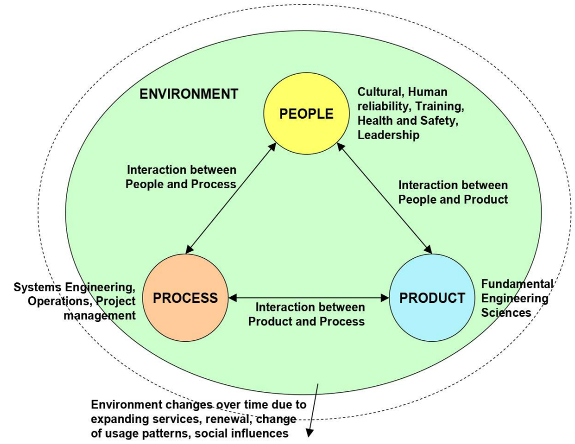

Figure 7 - Product Process People Environment (3PE) model

The main elements in the 3PE model are people, process and product, which are located within an environment. For each of the elements, a list of generic risks, more or less common to all projects was developed, which totalled over three hundred.

A survey was developed based on these risks along with a required importance value. The data generated from the risk survey was analysed and presented by various methods to determine meaningful and useful results. Visualisation tools were also employed to highlight, visualise, manage and control risk as a project progressed through the life cycle. The outcomes of this analysis can then be used as a basis to plan necessary risk mitigation strategies that can significantly reduce the risk of conducting complex engineering system projects.

The risk indicator of a project can be estimated from the 3PE model as a normalized distribution of risk in this project, which is denoted by $N(\mu_j, \sigma_j)$, where j is a particular instance of risk in a project. In order to evolve the risk model further, the theory of generating a percentage of success for a given project was explored. The hypothesis being that an 'Ideal' or 'Perfect' project, would have minimal risk that could be easily mitigated and has a percentage of success which can be established as the benchmark. The Ideal project is defined as a distribution $N(\mu_I, \sigma_I)$.

To calculate the risk of not achieving the Ideal project, the differential distribution will show the risk of the project in relation to the Ideal project. The mean and standard deviation was calculated for each using equations:

$$\mu_R = \mu_j - \mu_I \tag{1}$$

$$\sigma_R = \sqrt{\frac{\sigma_j^2 + \sigma_I^2}{2}} \tag{2}$$

The risk indicator at time of measurement of risks is then defined as:

$$F = \Pr((\mu_j - \mu_I) > 0) \tag{3}$$

The Ideal project is thought to be 100%, i.e. no risk identified. This is basically the probability of any project having a probability of less than 100% from the Ideal project. Due to the SEMP (Figure 5), it is natural to think that each of the stages are designed to mitigate or resolve some of the unknowns in the project lifecycle. Hence, the normalised distribution of the projects should be a function of time as well. This means equation (3) is not a static estimation and should vary with time *t* as well.

$$F(t) = \Pr((\mu_j(t) - \mu_I(t)) > 0) \tag{4}$$

In a properly managed project, the project failure function *F*(*t*) should decrease over time due to efforts to increase $?_j(t)$ at different stages of SEMP. The ultimate goal being to successfully burn risk down in stages, as indicated by the graph in Figure 8.

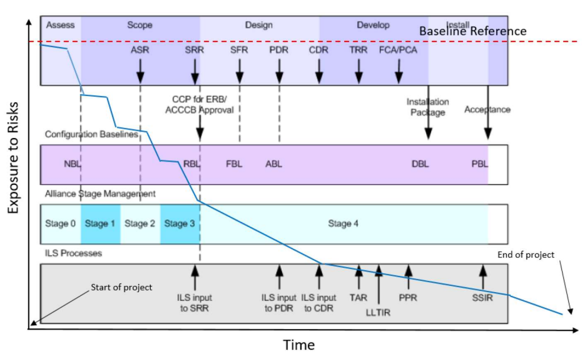

Figure 8 - Burndown risk profile for SEMP stages

4. CASE STUDIES

This research aims to remove the subjectivity of risk assessment and define a baseline or 'Ideal' project. Risk analysis can then be conducted on new projects in a similar manner and the results compared to this 'Ideal' project to assess what 'percentage of success' can be achieved. This will subsequently allow an organisation to assess whether this risk profile is acceptable and what mitigation strategy/approach can be taken to improve the percentage of success if necessary. In order to make sense of the data and begin to develop a risk model, the idea of placing the data into a normal distribution was explored. This would allow data from projects to be compared not only within the 3PE model sections, but more importantly comparisons could be drawn between projects and furthermore the Ideal project. Three projects from BAE Systems Australia – Naval Defence were chosen for this research. While fundamentally different, each project was reasonably well understood and at different stages of the life cycle.

PL1 = This project was completed on budget and schedule with successful commissioning on site and acceptance by the customer. This project is considered medium size and combined OEM equipment and BAE Systems design and installation. The normalized distribution of risk in this project is denoted by $N(\mu_1, \sigma_1)$.

PL2 = This is a current project that is an alliance between BAE Systems, another company (located within Australia) and the Commonwealth of Australia (COA). During this programme, some of the highest risks related to the uncertainty in the development by the new technology of the collaborating company. This is considered a major project, with significant risk surrounding the product. The normalized distribution of risk in this project is denoted by $N(\mu_2, \sigma_2)$.

PL3 = BAE Systems Naval Maritime has been tasked with the design, manufacture and installation of an enhancement for a specific class of ships for the RAN. The project is considered medium size with risks considered manageable as the design, fabrication and installation is to be fully controlled by BAE Systems. The normalized distribution of risk in this project is denoted by $N(\mu_3, \mu_3)$.

The compiled generic risks previously discussed in Section 3 were analysed for commonality and 10 risks from each of the 3P categories was selected based on their generic nature and applicability to the majority of BAE Systems Australia - Naval projects. In order to ensure the survey participants were not either influenced or mislead by the identified risks, each of the 30 risks identified was reworded so they could be appropriately populated into the survey. For each of the questions, it was necessary to establish a quantitative value which could be used for analysis purposes. To ensure that a good spread of data was achieved, a value or metric for each of the questions (risks) above was a scored out of 1 to 10.

Table 1 - Data analysis for three projects

	PL1	*PL2*	*PL3*
		Product	
Mean	*6.8143*	*7.5286*	*6.2714*
Std Dev.	*2.3676*	*2.4800*	*2.5929*
		Process	
Mean	*6.5929*	*7.0214*	*6.6143*
Std Dev.	*2.5101*	*2.1707*	*2.4276*
		People	
Mean	*7.1786*	*7.6500*	*7.2714*
Std Dev.	*2.2321*	*1.9413*	*2.0736*
		3P combined	
Mean	*6.8619*	*7.4000*	*6.7190*
Std Dev.	*2.3727*	*2.2084*	*2.4488*

To overcome the lack of a large data set and develop a model that could provide meaningful comparison between the data, it was assumed that the data is normally distributed. For each of the three projects, the data was separated into the 3P model categories. The mean and standard deviation for each project was calculated and can be seen in Table 1. To visualize the effect of the data, a bell-curve for the combined 3PE values is shown in Figure 9.

Figure 9 - 3P model results for 3 BAE Systems projects

From the perceived understanding of the nature of the three projects within BAE Systems Australia - Naval, it is generally agreed that serious challenges relating to PL2 need to be overcome and it is considered a 'risky' project. PL1 has actually been completed and generally considered a success, while the PL3 project is clear in scope and is found to sit somewhere between the two. This is reflected in Figure 9 where PL2 has a higher risk than the other two projects (clearly shifted more to the right on the graph).

In order to develop the risk model further, the idea of generating a percentage of success for a given project was explored. As previously mentioned, the PL1 project is considered a successful project. It can therefore be judged that its data results must in some way align towards an 'Ideal' project. The approach taken in this research is to assume that an 'Ideal' project would improve, for each question, by one value (1 to 10) better than the PL1 data results (or 10%). The outcome of this calculation can be seen in the resulting graph in Figure 10. It should be noted that other methods of setting the benchmark 'Ideal' project can be used, however, in the context of this research, the outcome does not affect the methodology discussed in this paper.

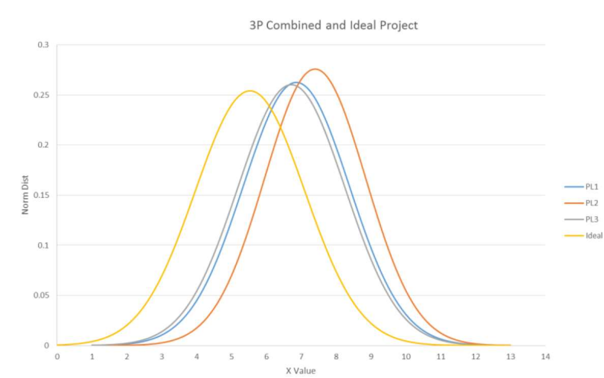

Figure 10 - Three BAE Systems Projects and predicted Ideal Project

As explained earlier, the risk indicator for the projects as compared to the 'Ideal' project can then be expressed as the probability of the differential distribution less than zero. The results of the calculation can be seen from the generated graph in Figure 11.

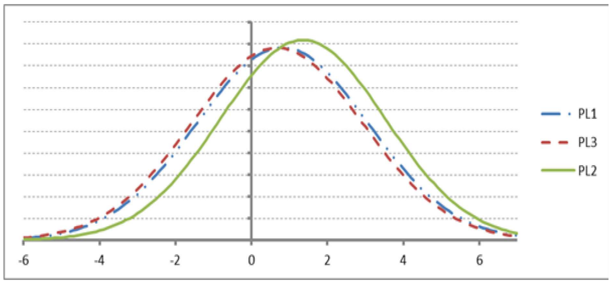

Figure 11 - Theoretical Area of Perfect Success (REDRAW TO SHOW DIFFERENTIAL DIST)

The graph presented in Figure 11 can be interpreted as follows, using PL2 as the example. The differential normal distribution of PL2 against the Ideal project is calculated by equations

(1) and (2) as $N(0.9148, 2.2580)$ using data in Table 1. According to equation (3), the probability of failure is the area under the curve at the right hand side of the Y-axis, i.e. 73.3%. Likewise, the probability of failure for PL1 and PL3 is 64.1% and 61.7% respectively.

5. CONCLUSION

The objective of this research is to develop a risk model that not only identifies the risks but also crucially allows managers and engineers to visualise the risks and manage them throughout the life cycle of the project. The initial risk model developed in this research provides a bell curve which offers a risk profile of a project for comparison with the established benchmark or 'Ideal' project. This risk profile leads to a graphical representation of the risk the task is carrying and the predicted percentage for success. The graphical interface could also offer visualisation of the 3P model categories to potential define/indicate where the main risks primarily reside.

By developing a survey based on some fairly generic risks, and applying it to three well understood projects, the model has offered a method of generating quantifiable data. The early stages of a risk model were developed to compare the risk profile of three projects and the initial results look promising. An attempt to identify an ideal project was proposed as a baseline for success comparison. This was used to compare the other projects against and determined a percentage of success value. While the results appear to follow the perceived nature of the three projects, the risk model is by no means conclusive as a data set of three projects is clearly inadequate and further work is required.

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