STRATEGIC RISK ANALYSIS OF COMPLEX ENGINEERING SYSTEM UPGRADES

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Abstract

Highly complex bespoke engineering products require upgrades during their long service life. These engineering changes can be risky due to the absence of an engineering baseline and/or multiple undocumented operational changes. They present significant challenges to the engineering contractor in terms of budget overruns, schedule impacts/delays, technical failures and ultimately a disappointed customer. Current risk management methods can be subjective and inaccurate. This paper outlines methodology to potentially predict, identify and visualize risks in a strategic structure which can ultimately lead to establishing necessary risk mitigation actions to significantly reduce and manage the risk of complex engineering system upgrade projects.

Keywords: Mid-life upgrade, risk modelling, capability framework, complex engineering project, risk visualisation

Introduction

Highly complex platform systems such as ships, land vehicles and aircraft often require modifications and upgrades to some areas of the system during their long service life [1]. These engineering change projects are inherently ill-informed due to the absence of an engineering baseline and undocumented operational changes. Many of the decisions taken both at the early stages and throughout large scale engineering projects are injudicious due to poor understanding of key risks and their consequences. This leads to budget overruns, schedule impacts/delays, technical failures and ultimately a disappointed customer [2]. In order to develop a sound strategy when undertaking complex projects, engineering organisations need to fully understand what their risk profile is, so they can manage, mitigate or even in some cases decline the task completely.

One of the critical issues in risk management is the perceived subjectivity of the risk assessment by specific personnel, for example, those who are actually working on the project, as compared to those who are related and may have a different set of imperatives to the work. A process that can eliminate as much as possible the subjectivity in both the evaluation stage as well as the data collection would minimize the hazard of inappropriate decisions being made on incorrect information and perception [5].

It is clear that an analysis tool that will allow an organisation to better understand the risks in a new project prior to and at early stages of the project is desirable. This tool should be supported by a risk model that is built on a comprehensive project enterprise model and be able to create a risk profile quantitatively. This paper outlines the methodology for conducting risk analysis into complex engineering projects and developing a potential risk model. The study has been initiated under the Engineering Support Services requirements within the Australian Naval Maritime environment, but it could equally be applied to other countries, industries and disciplines.

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. 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). 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.

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. These risks should be identified in detail and managed continuously even beyond project completion.

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 explained. While they are not completely relevant to this research project, they do offer ways of being manipulated or partially used to achieve my required outcomes. These methods were useful for specific cases but were limited in scope for application to large scale engineering projects. Claypool et al [9] reviewed some basic risk management techniques that had been used for years. However, after conducting surveys with 110 managers they believed there was much room for improvement. They highlighted that little work was conducted in reducing risk in the supply chain which large scale engineering projects would 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. The method was based on categorization of capabilities into six elements as shown in Figure 1. Through a simple modelling process including both cost and availability, the performance of a service system can be estimated. 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.

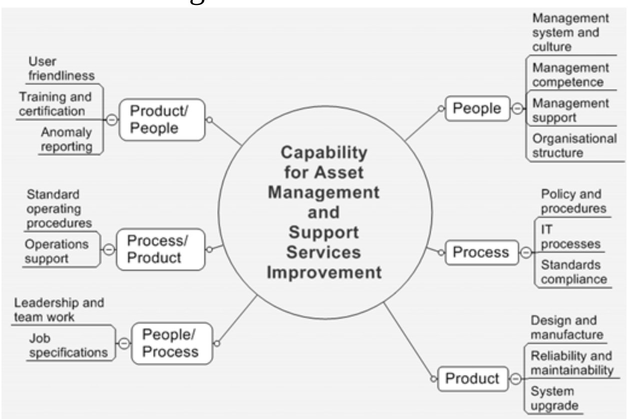

Figure 5 - Capabilities of service systems

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. Cohn [12] offered a commercial software that calculated risk in the form of a risk burndown chart as shown in Figure 2.

Essentially the chart is built from the probability of risk, size of loss in days which gives the number of days' exposure to risk. The chart is created by plotting the sum of the risk exposure values.

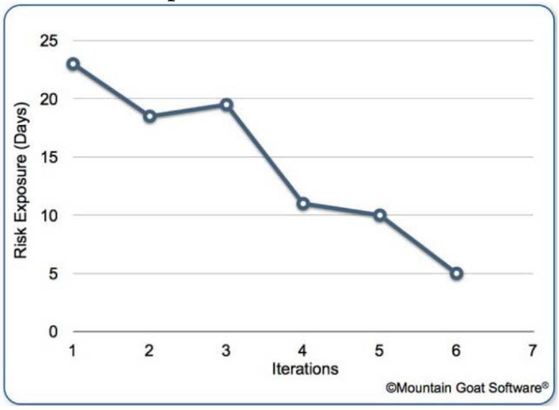

Figure 6 - Risk brundown chart

The risk burndown chart would be an ideal tool for visualizing how different strategies in the allocation of resources, financial investment, cash flow etc could affect risks. However, the risk assessment method is subjective and the outcome can vary greatly among different groups. The value of any risk model will only be perceived as useful if it successfully highlights key risks from quantitative data, offers ways to improve/mitigate the risks identified and is relatively simple and straightforward to apply. While many organisations already attend to highlighting potential risks with an array of tools, software and/or methods, their calibre is often diminished by over-complexity and convoluted processes that are too involved.

Industry Perspective

To understand the value of the proposed risk analysis/model, it is important to develop an understanding of both the organisation being studied and how the business currently manages risk, and the tools and processes that are used.

The activity of UK defence organisation BAE Systems in the Australian marketplace can be traced back to 1961 when the British Aircraft Corporation (Australia) was formed. The business underwent a name change in 1977 when it became British Aerospace Australia. Over the next two decades the business acquired a number of additional companies as it grew and secured its reputation within Australia. In 2008 the company more than doubled its size with the acquisition of Tenix Defence, a privately owned business involved primarily in naval contracts. Since then BAE Systems[1] has gone from strength to strength and is now the largest defence contractor within Australia.

Due to the nature of business, BAE Systems needs to develop risk management tools that provides accurate assessment of the merits and pitfalls in their bids and projects, under the constraints of the organisation's characteristics. Through its lifecycle management strategy, BAE Systems Australia operates a Risk and Opportunity Management Plan (ROMP) for business units, projects and functions. The purpose of the ROMP is to:

- Describe the methodology for clear and continual identification, assessment, development, and monitoring of treatment/promotion plans for R&Os;
- Increase the chance of achieving the Project objectives by facilitating improved decision making based on effective insight into the risks and their associated impacts; and
- Maximise Project performance in terms of the achievement of scope, time, cost and quality objectives by assessing the risks.

The ROMP goes on to state benefits generated by the application of Risk Management include:

- Identification of those risks that require management focus before potential negative impacts are manifested;
- Enables the timely development of treatments to mitigate risks before they occur or reduce negative impacts if they occur;
- Delivery of benefits achieved through the realisation of opportunities. Opportunities are considered potential commercial benefits to BAE Systems; and
- The Risk and Opportunity Management Procedure is compliant with AS/NZS ISO 31000:2009 [13] and is subordinate to the BU Project Management Plan.

The BAE Systems Maritime business unit separates risk into two categories. The first relates to commercial and project risk. The description of this risk is 'an event that may occur causing a negative impact on project objectives, typically expressed in terms of cost, schedule and performance (quality and functionality) or a combination thereof' (BAE Systems Risk handbook). The second is described as technical risk and is defined as 'an event, with a finite probability of occurrence, which could lead to an adverse impact on the technical objectives of a project'. Risks are managed through a process of identification, analysis, evaluation and mitigation which is defined in more detail in Figure 3.

[1] The organisation became known globally to BAE Systems in 1999 with the merger of British Aerospace and Marconi Systems.

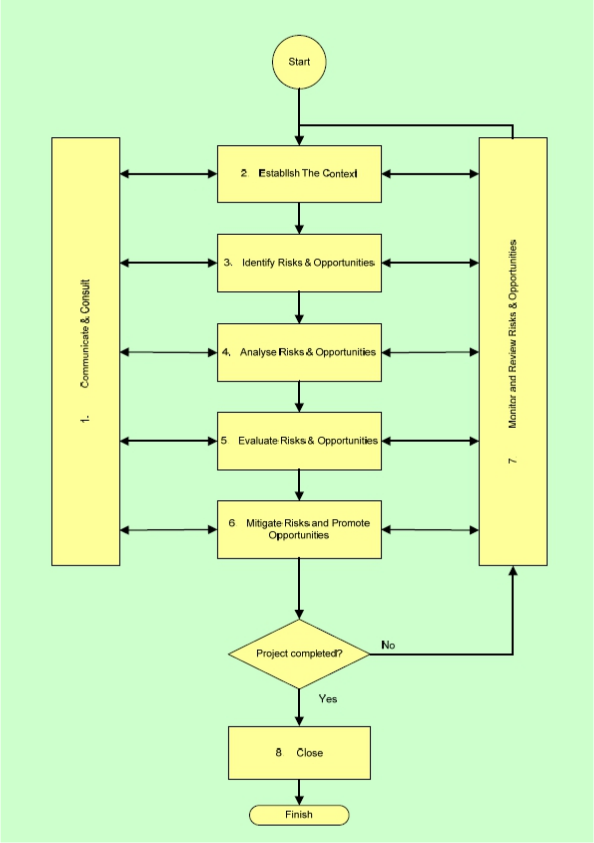

Figure 7 - BAE Systems risk process

The main tool used by BAE System Maritime for risk management 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 which are qualitatively defined typically by brainstorming and project meetings both internally and involving the customer and alliance partners.

When the risk register is populated with risk assessments on the severity/impact of the risk is judged using likelihood and consequence levels from AS/NZS ISO 31000:2009 [13]. These likelihood and consequences values are used to generate potential cost implications of these risks and schedule implications. As part of the alliance these risks are flowed up to the System Programme Office (SPO) and eventually to the Commonwealth of Australia (CoA) where they are combined with risks from other aspects of the proposed change.

BAE Systems also uses some risk management software, but it is important to note that this is not generally used by project managers or engineers. Both the risk register and the risk management software offer sound methods of identifying risks, assessing their significance and financial and schedule implications. However, these tools are not easily maintained or updated as a project progresses and residual risks can in some cases fail to be properly managed resulting in serious financial and schedule impacts. This problem is compounded by the lack of ability to visualise the risk profile and monitor how it evolves through the project life cycle.

Research Approach

This research aims to develop a tool that will allow an organisation to better understand the risks in a new project prior to and at the early stages of the project. To support the tool, a risk model based on generic enterprise architecture framework is being developed to provide a risk profile quantitatively. By segmenting the enterprise into three major sectors, it is possible to identify and visualise specifically what are the key risk drivers and monitor them through the life of the project.

The approach taken for this research is primarily a staged process. This consisted of developing an understanding of the risks of conducting large scale system upgrade projects within the commercial sector, outcome based contractual environment involving key stakeholders in the defence industry and the government and a study to investigate the current thinking of risks and what contemporary methods, models and tools are used in this type of organisation. Research was then conducted into the Australian Naval Maritime environment to develop a theoretical model which could ameliorate the current processes involved in understanding and managing risk throughout the project life cycle.

A survey focusing on three recent major engineering projects was used to assess the perception and experience of a variety of stakeholders involved in these projects while still fresh in their memories. The data generated from the risk survey was analyzed 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 actions that can significantly reduce the risk of conducting complex engineering system projects.

The three projects detailed below have their own unique challenges and risks to overcome in order to achieve success. They have been chosen as sample projects for the risk modelling research conducted within this report, because they are well known within BAE Systems – Maritime, and familiar to the both the Project Management and Engineering Teams. They also offer a good delta in overall financial value and variation in the risk profile.

MH60R Project

The Royal Australian Navy (RAN) ANZAC class of Frigates were originally designed for the operation of the Sikorsky S-70B-2 Seahawk helicopter. However, in June 2011, the Australian Government approved the acquisition of 24 MH-60R Seahawk 'Romeo' naval combat helicopters (Figure 4). The 'Romeo' helicopter was chosen because it represents the best value for money for taxpayers and was the lowest risk option [14].

The acquisition means that Royal Australian Navy will have the capacity to provide at least eight RAN ANZAC class frigates with a combat helicopter at the same time. In order to safely operate the new helicopter from the ANZAC platform, a number of modifications to the ships are required. This has included:

- Installation of new support equipment;
- Changes to the configuration of the hangar and flight deck area; and
- Installation of new landing and taking-off navigation equipment;

This project was successfully completed on the first RAN ANZAC ship in late 2014 with a successful landing of the MH60R helicopter being achieved in early 2015. This project is considered medium size and combined OEM equipment and BAE Systems design and installation.

Figure 8 - MH60R helicopter

A. 1448 4B Phase Array

In late 2005, the RAN ANZAC class frigate 1448 2B Anti-Ship Missile Defence (ASMD) programme commenced. This programme was tasked with delivering an increased defensive capability to the vessels, with the installation of a newly developed phased array radar (PAR) system for target indication/tracking and mid-course guidance and target illumination of the evolved anti-ship missiles in conjunction with other sensor and combat management system upgrades. Major changes to the ship included a new mast and cupola to house the PAR which was developed by CEA Technologies of Australia (Figure 5).

During this programme, some of the highest risks related to the development by CEA Technologies of a cutting-edge phased array radar performance technology, or the product.

Figure 9 - RAN ANZAC frigate with ASMD installation

In addition to the 1448 2B ASMD PAR programme, there is now a pressing need to replace the obsolete long range radar capability on the RAN ANZAC class frigates. Project SEA 1448 Phase 4B – ANZAC Air Search Radar Replacement has been commenced by the Australian Government. The RAN ANZAC frigates use their air search radar to scan at long ranges for potential threats. The radar is an integral part of a modern warship and important for ensuring the safety of the vessel and other friendly ships in dangerous areas. The current RAN ANZAC frigate radar is old and requires replacement with modern technology to maintain the robust front-line capability provided by these ships.

A risk reduction phase of implementing a new technology is currently underway and CEA Technologies are again being considered to design and develop a long range PAR which will most likely be installed on top of the extant ASMD mast. This is considered a major project, with significant risk surrounding the product or new PAR system.

B. New Bilge Keel

Since inception, the RAN ANZAC class frigate has suffered from fatigue cracking of their bilge keels (Figure 6). The origins of the fault can potentially be linked to operating environments which have seen higher loads than originally design for. The primary function of the bilge keel is to stabilise the ship and reduce rolling, this is important for the performance of the vessel especially one that operates a helicopter.

BAE Systems - Maritime has been tasked with the design, manufacture and installation of a new bilge keel set for the RAN ANZAC class of frigates. The project is considered medium with risks surrounding the keel design and installation.

Figure 10 - Example of Bilge Keel on RAN ANZAC Frigate

Modelling Principles

This research aims to remove the subjectivity of risk assessment and define a baseline or 'Ideal' project that is based on a 50% probability of success. 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' is possible. This will subsequently allow an organisation to assess whether this risk profile is acceptable and what strategy/approach can be taken to improve the percentage of success if necessary.

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 as part of the research. The initial objective was to compile a list of risks and then categorize these into product, process and people (3P model).

The compiled risks were then analysed for repeats and commonality within each category. Over 150 risks were identified. To help focus the research in developing quantification methodology, 10 risks from each of the 3P categories was selected based on their generic nature and applicability to the majority of BAE Systems Maritime 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 can 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 question (risk) above was a score out of 1 to 10.

Table 1 - Data analysis for three projects

	MH60R	***1448 4B***	***NBK***
	Product		
Mean	*6.8143*	*7.5286*	*6.2714*
Std Dev.	*2.3676*	*2.4800*	*6.5929*
	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 some useful/meaningful comparisons 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 each of the 3P categories was generated as shown in Figure 7, Figure 8 and Figure 9.

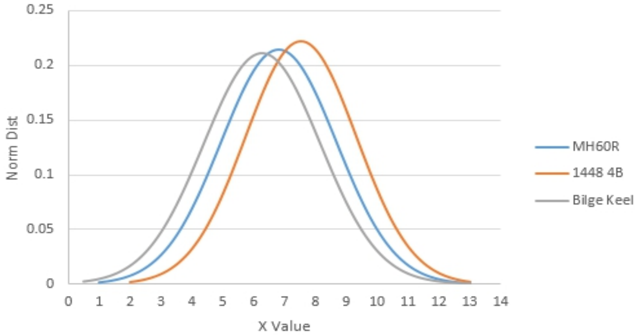

Figure 11 - Product results for three BAE Systems projects

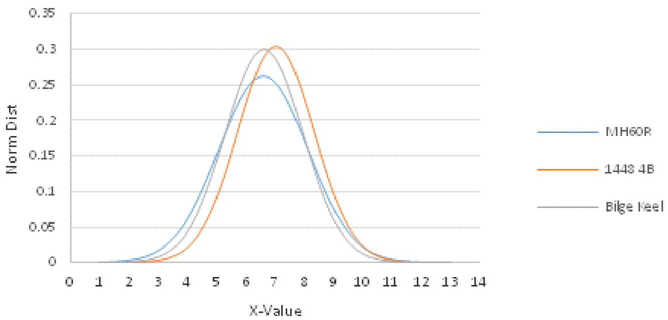

Figure 12 - Process results for three BAE Systems projects

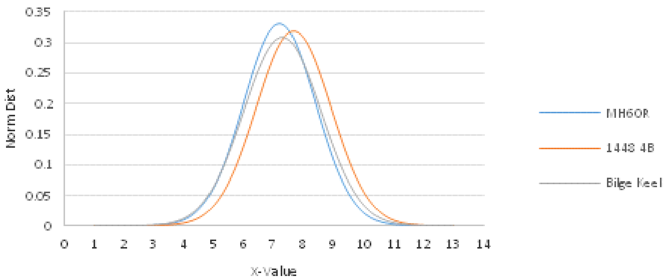

Figure 13 - People results for three BAE Systems projects

A combined graph of the 3P distribution was also generated and is shown in Figure 10.

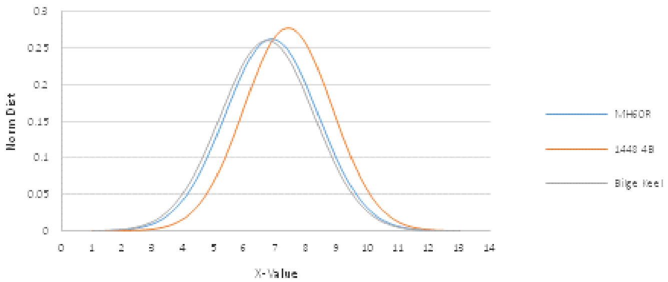

Figure 14 - 3P model results for 3 BAE Systems projects

From the perceived understanding of the nature of the three projects within BAE Systems - Maritime, it is generally agreed that serious challenges relating to the 1448 4B project need to be overcome and it is considered a 'risky' project. MH60R has actually been completed and generally considered a success, while the bilge keel project is clear in scope and is found to sit somewhere between the two.

Benchmark Model

In order to develop the risk model further, the idea 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. Like the flip of a coin, there is a 50% chance it will be heads or tails, a project also has natural chance of 50% for success or failure. So if 50% is as close to the 'perfect' project as it is possible to get, it stands to reason that the greater the delta from 50% a project sits, the less chance of success.

As previously mentioned, the MH60R 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 MH60R data results (or 10%). The outcome of this calculation can be seen in the resulting graph in Figure 11. It should be noted that other methods of setting the benchmark 'Ideal' project can be used, for example, survey a special expert group or find the "best" project in BAE Systems. However, in the context of this research, the outcome does not affect the methodology discussed in this paper.

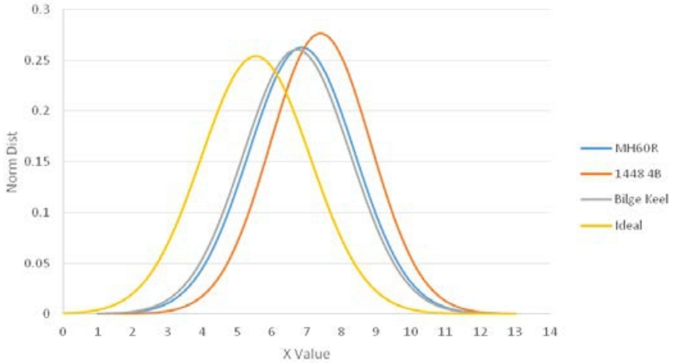

Figure 15 - Three BAE Systems Projects and predicted Ideal Project

As explained before, the 'Ideal' project would have a 50% chance for success. To define this percentage value to the risk model, the area under the graph of the 'Idea' project was established as the 50% success area, or the 'perfect success' area, so the mean of this project was set as the 50% marker. The results of the calculation can be seen from the generated graph in Figure 12.

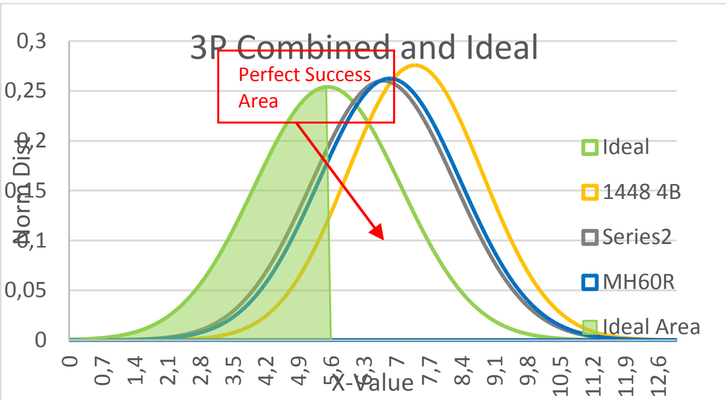

Figure 16 - Theoretical Area of Perfect Success (50%)

As a project moves away (to the right) of the 'Ideal' project, the chance of success begins to diminish because the area under the project curve that is sitting within the 'Perfect Success' area is reducing.

To demonstrate how this risk model can be used to determine potential for success, Figure 13 focuses on the 1448 4B project and compares its percentage for failure against the 'Ideal' project. The graph's X-axis starts at mean value for the 'Ideal' project, with any shift to the right considered an increase in the percentage for failure.

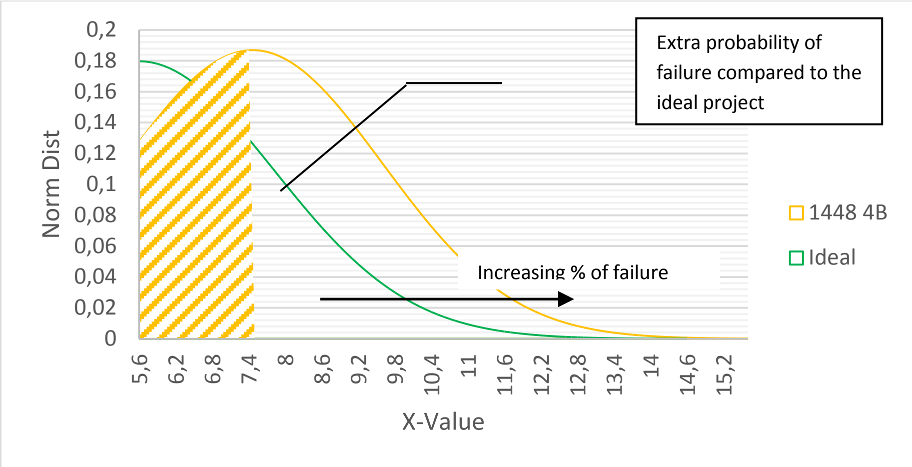

Figure 17 - 1448 4B vs. Ideal - Percentage for success

The failure probability for both 1448 4B and 'Ideal', with normal distributed data was calculated by:

$$\mu_u = \mu_y - \mu_x \qquad (1)$$

$$\sigma_u = \sqrt{\frac{\sigma_y^2 + \sigma_x^2}{2}} \qquad (2)$$

These formulas could be used in MS Excel to develop a differential data set for each project.

From the data analysis and subsequent normal distributions/bell curves, it can be determined that for engineering projects sitting to the right of the 50% success rate mark, the area under the curve is the probability of failure. This area is made up of the potential risk factors identified within the 3P model. Figure 14 indicates the probability of failure (area under the bell curve) for task 1448 4B. The mean value of project 1448 4B is 69%, which is indicated by the calculation: 50 – (69 – 50) = 31. It is within this area that risk factors relating to the development of the new phased array radar, technical expertise, installation concerns, etc. reside.

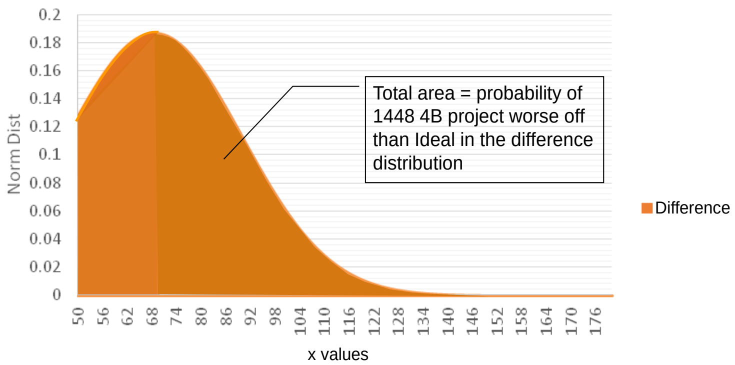

Figure 18 - Probability of failure of 1448 4B

Conclusion

For organisations like BAE Systems, large, complex and challenging projects throw up a myriad of potential risks, and developing an understanding of these risks, their implications and how they can either be managed or mitigated can often be the difference between success and failure. Without a clear understanding of the risk profile the business will be carrying, project managers and engineers critically lack both direction and knowledge to execute tasks. 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 the 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.

The initial data analysis and early development of a risk model, based on the data sets generated from the survey, offers some interesting results. It is essential to acknowledge that the research scope was limited to only three projects, and clearly lacks enough data to be considered comprehensive. Due to the diversity of projects across organisations such as BAE Systems, there will always be some risks that are unique to that specific project. However, there are also many risk factors that are ubiquitous to all projects which vary in their significance and can be used to develop a risk profile baseline.

The risks developed and used in the survey constitute the model's baseline risks which are by no means fully defined or exhaustive. Further development of this work could be a proposed interface for the risk model, such as an internet browser, would allow project managers and/or engineers to apply a risk severity to these baseline risks. It is essential that this interface is quick and friendly to use, to ensure it encourages and meets the expectations of the users. Time consuming complex interfaces put users off and result in poor data entry and meaningless results.

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. Of the three projects chosen, one has been completed and was considered successful (a baseline), one was considered fairly mainstream and the third was considered challenging and risky. The early stages of a risk model was developed to compare the risk profile of these three projects and the initial results look promising. An attempt to identify an ideal project was proposed and a 50% success rate was set. 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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