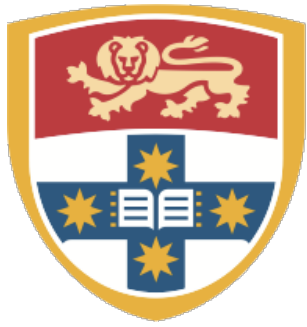




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Project Management Graduate Programme

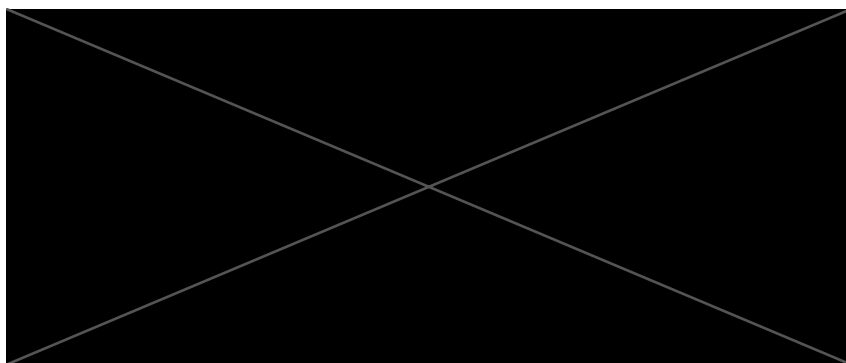
Assignment 1

Challenger Space Shuttle Disaster Case Study

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EXECUTIVE SUMMARY

This report provides a managerial insight into the Space Shuttle Challenger Disaster, aiming to give an effective and optimised methodology that can help NASA with its Space Shuttle Projects. As a consulting group, we first provide the background of the disaster, and then show the business objectives of the project. After identifying the issues, along with the assumptions and constraints, three methodologies are given, including Project Management Office (PMO), Group Decision Support Systems (GDSS), and Probabilistic Risk Assessment (PRA). After comparing the three methodologies vertically and horizontally, the best one is selected to be applied to NASA's space shuttle projects. In particular, as a very important part in project management, the risk management is analysed as an approach to better understanding the real reason underlying the failure of the project. After analysing the triple constraints and SQERT processes, recommendations are given.

Based on a different point of view of project management, this report focuses on the project process, decision-making, and risk management. The major defections and weaknesses in project management are discussed and analysed. It also investigates the fact that how different supporting systems work to assist NASA to better achieve its project goals, as well as how to break through the obstacles, such as limitations, pressures and changeable management, that inhibit the process of the projects.

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1. INTRODUCTION

Challenger disaster could be avoidable. In terms of project process planning and risk management, there has always been a dilemma that must be addressed regarding the methodologies or processes used to manage the decision making and the risks of complex technologies. Having identified the flawed decision-making, and used its characteristics, strategies, and models, it is determined that NASA's decision makers completely underestimated the potentially calamitous consequences of the Challenger launch. NASA's decision makers and project managers disregarded every constraint that militated against a decision to launch Challenger. No alternatives were considered. The launch of Challenger became a surrogate objective displacing the presidential mission objective of linking the Earth to a space station by a fleet of operational spacecraft. Challenger's catastrophe ensued from a flawed process that culminated in a decision with a fatal outcome. A repetition can and must be avoided. This paper examines the poor communication and decision-making process, and lack of professional support from authorized organisations that led to conflict in NASA, with a focus on the Challenger shuttle catastrophe. We will show that, although there were technical causes of the accident, there are deeper root causes. Throughout NASA's history, there have been budgetary and scheduling constraints, pressures from government, and competitions from other countries. In an attempt to meet these externally imposed restrictions, management has unconsciously fallen into the psychological tendencies of groupthink. An invincible attitude amongst NASA officials was a direct cause of the Challenger accident. Management began tolerating increasing amounts of "acceptable flight risks." Management compromised safety, one of the quality components of the project management "triple constraint" of scope, time, and cost. Challenging and questioning have been done in this paper, such as applying Project Management Office (PMO), Group Decision Support System (GDSS), and Probabilistic Risk Assessment (PRA) to the Challenger mission. Risk management and lessons from Challenger tragedy have been also discussed.

STS-51-L is NASA's tenth mission for Challenger, which is scheduled to deploy the second in a series of Tracking and Data Relay Satellites, carry out the first flight of the Shuttle-Pointed Tool for Astronomy (SPARTAN-203)/Halley's Comet Experiment Deployable in order to observe Halley's Comet, and carry out several lessons from space as part of the Teacher in Space Project (TISP) and Shuttle Student Involvement Program (SSIP) (NASA, 2010). Both NASA and the United States government will attach importance to this space shuttle project, which has been placed great expectations.

About Us

Group Two is an Australian based consulting group which is established recently by a group of six people with various backgrounds, such as engineering, mining, and information technology, and we are believed to be the expert in their respected areas of study. The name, Group Two, is taken from our responsibility to deliver two things: solution and satisfaction for each client.

Group Two Consultancy provides solutions for clients to solve their problems and assist them to successfully deliver their project. With excellent customer relationship and in depth project

management skills, Group Two Consultancy will enhance the business relationship with the clients by making sure that each client is satisfied with the solution.

2. BACKGROUND

2.1 About NASA

NASA has been the pioneer in the field of Manned Space Flight Technology and exploration of the outer space. It has a renowned history of space exploration since its inception in 1958. Throughout history, however, there have been several failures along with the many successes (Dimitroff et al., 2005). The Challenger and Columbia accidents, being the most tragic of accidents, having been studied as lessons learned in terms of project management. Figure 2 shows NASA's development in terms of its scope.

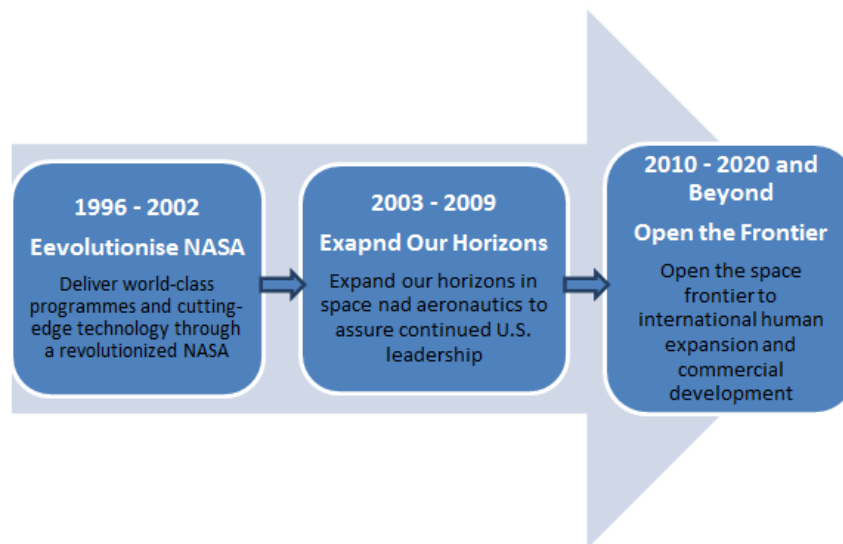


Figure 1 - NASA's development (NASA, 1996)

2.2 The Challenger Disaster

The space shuttle Challenger disaster marked the first American orbital mission to involve in-flight fatalities. It was also the first American human spaceflight mission to launch and fail to reach space (with the first in the world being the Soviet Soyuz 18a mission, though both of the crew members survived) (NASA, 2010).

It was not the unique accident in the history of space exploration - three astronauts were killed in the Apollo disaster in 1967 (Feldman and Leana, 1989). However, comparing to the Challenger disaster which is famous for teacher-in-space plan, the influence of the former is inferior. There are several factors leading to the disaster, such as NASA's organisational culture and decision-making, technology, pressure to launch.

All previous spacecraft before the late of 1960's were designed to fly only a single task, which means that the Challenger cost more in engineering and hardware. In order to deal with

the finance issue, NASA envisioned that the space shuttle could be recycled and be used again. However, the result turned out not to meet NASA's expectations. There were several design flaws, and later study (Spence, 2001) found that one of the flaws led to the loss of the Challenger directly - an inability to assess the link between cool temperature and O-Ring which was damaged on earlier flights. However, technology issue was not the only cause.

There was a special commission which was appointed by United States President Ronald Reagan to investigate the cause of the disaster called The Rogers Commission. It found that NASA's organisational culture and decision-making processes had been a key contributing factor to the accident (Smith and Scobee, 2008). Because high pressure both from international and national called Fly out the Manifest pushed the decision-maker chose to launch the Challenge rather than considering the risk of security of the whole project. As Diane Vaughan (Vaughan, 1996) pointed out that the environmental pressures at NASA, created by scares resources and production pressure forced managers to do amoral calculations that resulted in the launch decision.

In addition, some factors, such as expectations from political, regulatory and public forces blinded the proper estimation of risk. Disasters in high reliability organisations, such as the Challenger disaster, often invoke outrage from stakeholders such as US government, and the public interests (Sullivan and Beach, 2003). Another expert agreed that high expectations are accompanied by severe consequences for failing to meet those expectations (Vaughan, 1996).

2.3 Issues Identified

The preparations for the launch of Challenger were usual, though they were complicated by changes in the launch schedule. The sequence of complex, interrelated steps involved in producing the detailed schedule and supporting logistics necessary for a successful mission always requires intense effort and close coordination. Several issues had been identified before the launch.

Neither Thiokol nor NASA responded adequately to internal warnings about the faulty seal design. Furthermore, Thiokol and NASA did not make a timely attempt to develop and verify a new seal after the initial design was shown to be deficient. Neither organisation developed a solution to the unexpected occurrences of O-ring erosion and blow-by even though this problem was experienced frequently during the Shuttle flight history. Instead, Thiokol and NASA management came to accept erosion and blow-by as unavoidable and an acceptable flight risk.

NASA managers were worried about the Challenger launch for several reasons - economic considerations, political pressures, and scheduling backlog. Unpredicted competition from the European Space Agency also put great pressure on NASA. The shuttle mission just prior to Challenger had been delayed due to bad weather and technical factors, so NASA wanted to launch Challenger without any delays. Besides, political pressure was also a factor. President Reagan had given great expectation on TISP, which is the main topic of the Challenger mission.

3. Assumptions

There are several factors that has been assumed in this report:

1. Coordination between teams
2. Strict/standardized process
3. No delay on material supply
4. Explicit requirements and constraints
5. Valid testing and critical analysis
6. No pressure from other aspects
7. Risk identification (Risk assessment system in NASA) did not have a level for launch cancellation
8. Limitation of solid rockets: cannot be shut down after igniting
9. Hierarchy and complex paperwork limits of the research investigation for the sub-contractors
10. NASA applied a simplistic safety classification system
11. Using solid rocket boosters instead of safer liquid fuelled boosters
12. Limitation of budgets
13. Geographical constraints of teleconferencing system
14. No escape system due to budget and weight limitation
15. No sufficient data available of O-ring for weather conditions lower than 50 F°
16. Limitation of using Asbestos in O-ring part due to regulations

4. BUSINESS OBJECTIVES

Our project team's strategic goals include assisting NASA to better achieve its space exploration projects, scientific discovery and aeronautics research. In this project we aim to provide an optimized methodology or system to help NASA with its space shuttle launch projects. The chosen methodology or system will support these goals by organising prelaunch activities such as predicting the risks, setting up realistic goals, and increasing cooperation and communication between different stakeholders; and by increasing the probability of the successful launch of the space shuttle. We are also ambitious to improve the effectiveness and efficiency of the decision-making procedure prior to and during the launch, focusing on not only technical factors of different components of the space shuttle that might influence the result of the launch mission, but also managerial aspects. With our sound project management knowledge, we will provide NASA with standard management tools, techniques, templates, in order to reduce project cost and increase the project accomplishment probability.

Therefore, in order to meet the requirements and achieve the goals of this project, we will encourage and increase the communication between different stakeholders - the US president, NASA, different contractors, and the American people, etc. The profitability of the success of this project is unprecedented - NASA's reputation and the country's reputation will be boosted, and people's pride in their country's achievements and their president. With the purpose of making sure that our objectives are quantitative, time-frame specific, flexible, understandable, and realistic, this project must meet these criteria and be a success.

5. OPTIONS AND RECOMMENDATION

The advantages of project management have been well documented, but project failure rates still remain high (Dai and Wells, 2004). As stated above, NASA's Space Shuttle Challenger disaster was the product of poor project process and poor project performance. Therefore, it is suggested to explore new process models and organisation structures to support strong project performance. In this paper, three important candidates for improvement are the project management office (PMO), group decision support system (GDSS), and probabilistic risk assessment (PRA). They will be explained in detail respectively, and recommendations will be given in terms of Challenger mission project.

5.1 Project Management Office

5.1.1 Introduction

Project Management Office (PMO) represents the organisational body or entity assigned various responsibilities related to the centralized and coordinated management of those projects under its domain (PMI, 2008). The main function of PMO is to guide the project safely and ensure the achievement of the goal in the way of preventing the mid-air collisions. In the Space Shuttle Challenger case, if NASA had PMO, the key responsibilities of the PMO should be providing project management support functions as follows, and it should have some characteristics to help to achieve the goal of the project (Kendall and Rollins, 2003).

Table 1 - Key Responsibilities and Characteristics

Key Responsibilities
• Being responsible for the direct management • Coaching, mentoring, training, and oversight • Monitoring compliance with organisational policies and standards • Coordinating communication across projects
Characteristics
• It must drive more projects through completion, without correspondingly increasing resources, for example 50% more projects. • Most projects must be completed in drastically shorter time, such a 25% reduction in average cycle time. • The impact of PMO must be clearly felt on both the top and the bottom lines of the organisation. • Executives and managers throughout the organisation must feel that they are getting out of the PMO.

5.1.2 The Position of PMO

In an organisation, the position of the PMO is like the engine of the organisation which is called as Return On Investment (ROI) engine (Kendall and Rollins, 2003), as shown in Figure 3. But there are always some resistances in the organisation preventing PMO to achieve its value. There are some studies indicating that the higher the resistance in the organisation to the PMO, the harder the PMO will perceive its value (see Figure 4).

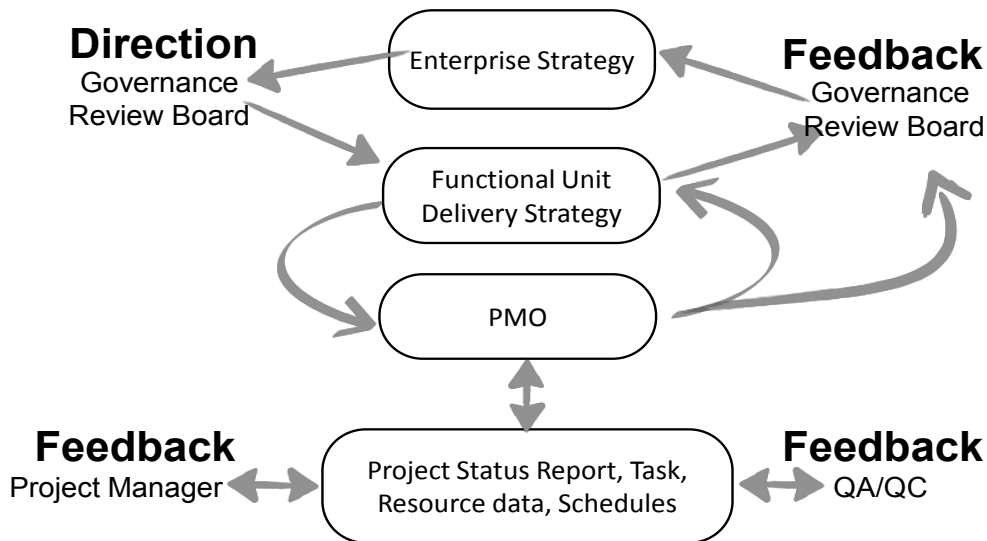


Figure 2 - Position of PMO (Kendall and Rollins, 2003)

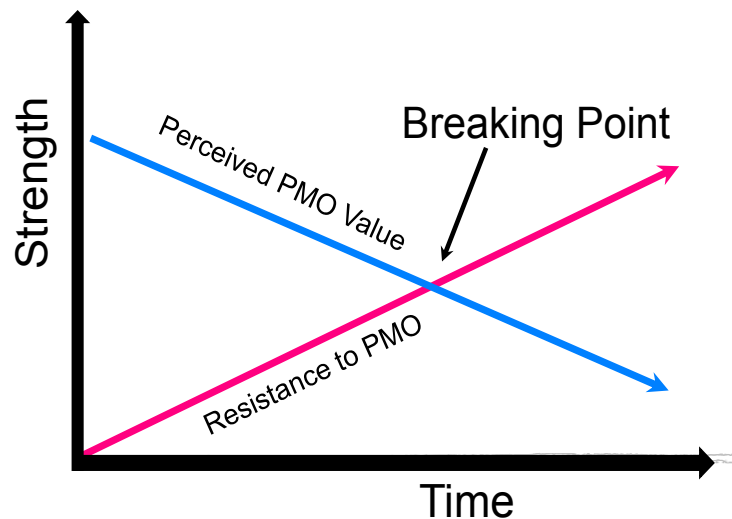


Figure 3 - PMO Value Curve

5.1.3 The Importance of PMO

NASA did not use PMO as a centralized organisational office because PMO was not a mature organisational controlling model at that time. The major challenges for NASA to employ PMO are as follows:

1. Inexperienced project managers
2. Lack of management support
3. Priorities between projects are often muddled or changed continuously
4. Competition for experienced project managers in NASA

However, theoretically, if NASA had PMO at that time, there should be significant benefits from which NASA can gain. For example:

1. Better communication & collaboration

2. Improved reporting systems
3. Improved risk analysis methodologies
4. Clarified customer and sponsor's requirements and expectations
5. High probability of meeting organisational business goals

Better communication and collaboration both inside and outside the organisation can effectively prevent problem when making decisions. PMO also helps to promote risk analysis level of the organisation.

In addition, PMO must have a group of effective stuffs, who can help not only the technological architecture and the information architecture, but also the resource and finance allocations. The ideal structure should be included as follows in Figure 5.

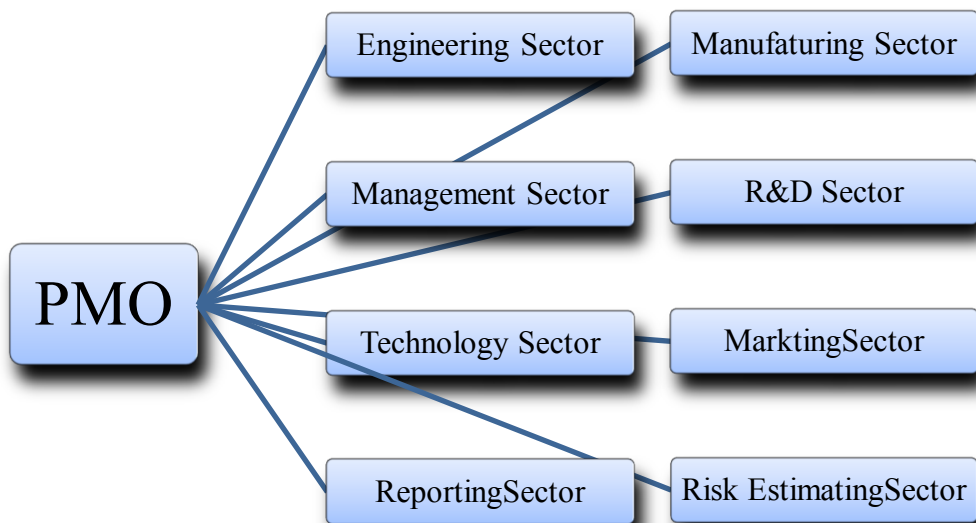


Figure 4 - Ideal Structure of PMO

5.1.4 Recommendations

Although a stand set of PMO presence features has yet to be agreed upon in theory or practice, the literature review led to the identification of the categories enumerated below (Dai and Wells, 2004).

1. Developing and maintaining PM standards and methods
2. Developing and maintaining project historical archives
3. Providing project administrative support
4. Providing human resource/staffing assistance
5. Providing PM consulting and mentoring
6. Providing or arranging PM training

According to Dai and Wells (2004), more and more organisations are moving in the direction of establishing PMOs or have already done so, demonstrating a high level of management confidence in the utility of this innovation. Project performance is highly correlated with PM standards and methods, and project historical archives, which should be considered first. PMOs have been adopted more rapidly in the newer technological areas (e.g. IT).

As more and more organisations are becoming project-oriented, PMOs can provide better practical guidelines and directions for organisations to manage their project. With PMO, NASA should have succeeded in launching the Space Shuttle Challenger and achieve its goals they expected.

5.2 Group Decision Support Systems

5.2.1 Definition

The concept of Decision Support System (DSS) has gained interest by researchers and scientists in 1970s. The evolution of DSS has been further developed into few subfields; one of those categories is Group Decision Support System (GDSS). GDSS has been defined by both Huber and DeSanctis and Gallupe in 1980s, these definitions originally explain what GDSS is:

“A GDSS consists of a set of software, hardware, and language components and procedures that support a group of people engaged in a decision-related meeting.” (Huber, 1982)

“An interactive, computer-based system which facilitates solution of unstructured problems by a set of decision makers working together as a group.” (DeSanctis and Gallupe, 1985)

5.2.2 GDSS Technology

All group decision support systems can be held face to face today by introducing technologies to support the meetings for participants. These technologies enhance efficient and effective meetings of GDSS.

Conventionally, personal computers are provided at each seat positions in a typical decision room, including keyboard, mouse, touch screen, or other devices (Gary, 1987). Group members allow uploading their private work on the public screen which can be seen by others. Additionally, using internet connection (on-line) to hold a meeting provides great flexibility of GDSS in terms of time and geography restrictions.

As defined by Hosseini (Hosseini, 1995), GDSS software, also called groupware, is “tools designed to support communications among members of a collaborative work group”. GDSS software provides functions of personal computers connection within a group, exchanging messages, accessing databases, documenting, and conferencing. Groupware integrates eight distinctive technologies including messaging, conferencing, documenting, work flow, development tools, frameworks, services and vertical market applications (Sauter, 1997). It offers a recording function that allows individuals who cannot attend a meeting to review the concepts, works, and opinions being made. Figure 5 is an example of decision conferencing configuration.

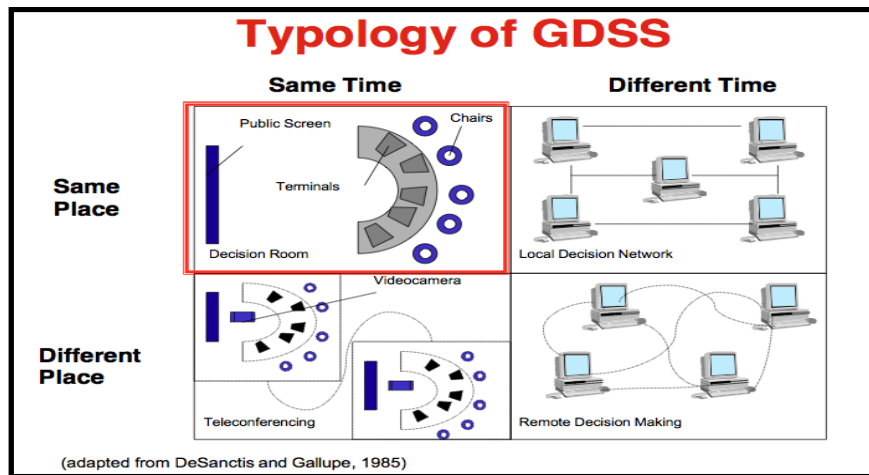


Figure 5 - Four ways of the GDSS meeting (DeSanctis and Gallupe, 1985)

5.2.3 Features of GDSS support

The GDSS must provide support for decision making process that facilitates two-way communication by utilizing technologies within group members. There are two different supports identified from GDSS process: decision making support and process support.

Decision making support includes access to model management tools, databases, mails and other tools. Generally, GDSS are applied to address poor issues; one of particular tools is brainstorming tool using to tackle poor structured problems. It records ideas and comments to develop alternatives in order to solve those issues. Furthermore, the tool requires facilitating concrete ideas by supporting group members to identify concepts, concerns, characteristics and relationships among ideas (Sauter, 1997). Another distinctive feature of GDSS is to communicate parallel, exchanging information simultaneously. With this function, group members do not need to spend time on waiting others to complete their thoughts prior to articulate their own ideas (Sauter, 1997). The ability for participants to work in parallel may contribute to enhancement of productivity of GSS idea-generating group and higher satisfaction of group members (Dennis and Gallupe, 1993). This parallel communication saves time spending on idea generation and information collection. Moreover, the GDSS also present ability of electronic record during meetings. This allows group members who cannot attend meetings to access information that have been compiled and review previous works.

The second process support is anonymity feature. This feature offers ability of posting opinions, providing analysis, and voting without revealing identity to others for participants (Sauter, 1997). Group members enable to post their comments on public screen without embarrassment and social pressure, and more information is shared and generated. The avoidance of groupthink can be reduced to minimum. It is most significant for groups consisting of wide-range different positions in an organisation (Sauter, 1997). Table 2 summaries the advantages and disadvantages of GDSS, some of which have been mentioned above.

Table 2 - Advantages and disadvantages of a GDSS (Aiken et al., 1995)

GDSS	
Benefits	Drawbacks
• Anonymity • Parallel communication • Automated record keeping • More structure and focus on issues • Higher satisfaction • Higher productivity	• Slow communication • Resistance to change- need training • Lack of media richness • Possible increase in conflicts • Misuse of the technology • Cost

5.2.4 Recommendations

In this Challenger Space Shuttle Project, NASA did use the GDSS for decision making process and this system has been successfully implemented in previous missions. However, misuse of the GDSS occurred and associated with management of its information.

Group Support System - critical issues (Forrest, 2005)

- The GDSS system held at same time in different place.
- Only speaker phones with audio were available.
- Insufficient data regarding the O-rings.
- NASA underestimated the issue of O-ring as a low risk situation.
- Any suggestion was rejected by the group if leading to a delay.
- Ideas, suggestions, and objectives were not anonymously.
- Groupthink existed in Thiokol.
- All parties were afraid of political and public response.
- Free and open communication was not encouraged.

NASA did use GDSS to support entire decision making process, but in a wrong way. NASA should have had advanced technology and sufficient budget to upgrade the GDSS system with modern screens and computer system on a meeting. It could have provided better support even the meeting was held in different place. The most serious issue was without anonymity feature. As mentioned in previous section, it provides opportunity for people to post ideas and suggestions without social pressure and embarrassing based on their own professional judgements. Forest (2005) recommended that the GDSS for voting anonymously was the significant factor that would maintain the integrity and quality of the GDSS. However, only senior officials were allowed to vote for their opinions. He believes that if the total GDSS members have right to vote anonymously, the launch cancellation for the final decision would be made. Moreover, the GDSS should establish rules to be followed that requesting for off-line resulting for group thing during the meeting should be permitted. Finally, the organisational culture within NASA should be changed regarding free and open communication. This may result to highly effective information exchange and reduce misunderstanding of communication. If NASA could solve issues mentioned above by revising GDSS process, highly effective GDSS technology would support the entire decision making process and the result of the project would be different.

A specialized GDSS could be employed by NASA when managing space shuttle projects in the future, for example the Aid to Groups of Analysis and evaluation of Projects (AGAP) (Costa et al., 2003). It allows multiple decision makers to cooperate in the evaluation and

selection of investment projects. With its state of the art of economic measures that can be set as criteria for use in several multi-criteria decision aid methods. Both synchronous and asynchronous usage are supported and it can enhance the communications and data sharing during asynchronous group meetings, providing support for decision at individual, interpersonal and collective levels.

5.3 Probabilistic Risk Assessment

5.3.1 Introduction to PRA

Probabilistic Risk Assessment (PRA) has emerged as an increasing popular analysis tool especially during the last decade. PRA is a systematic, comprehensive, and scenario-based methodology to evaluate risks associated with every life-cycle aspect of a complex engineered technological entity (e.g., facility, spacecraft or power plant) from concept definition, through design, construction and operation, and up to removal from service (Stamatelatos, 2000).

Risk is defined as a feasible detrimental outcome of an activity or action (e.g., launch or operation of a spacecraft) subject to hazard(s). In a PRA, risk is characterized by two quantities: (1) the magnitude (or severity) of the adverse consequence(s) that can potentially result from the given activity or action, and (2) by the likelihood of occurrence of the given adverse consequence(s). If the measure of consequence severity is the number of people that can be potentially injured or killed, risk assessment becomes a powerful analytic tool to assess safety performance.

If the severity of the consequence(s) and their likelihood of occurrence are both expressed qualitatively (e.g., through words like high, medium, or low), the risk assessment is called a qualitative risk assessment. In a *quantitative risk assessment* or a *probabilistic risk assessment*, consequences are expressed numerically (e.g., the number of people potentially hurt or killed) and their likelihoods of occurrence are expressed as *probabilities* or *frequencies* (i.e., the number of occurrence or the probability of occurrence per unit time).

There are numbers of tools that can be used in this methodology. Meshkat (Meshkat, 2009) noted that event trees provide a logic thinking of a scenario by providing the list all of possible actions that can be taken in a scenario. Moreover, Todd (Todd, 2009) suggests that fault tree is probably the most commonly used tools in PRA which provides identification of the failures inside the scenario. Figure 6 is an example of event/fault tree of three events which shows the combination of behaviours that may occur. Also, a sample PRA model as shown in Figure 9 in the Appendix, demonstrating a simplified risk model for Loss of Crew and Vehicle (LOCV) due to propulsion accident in the space shuttle ascent phase. In fact, this model is an integrated master logic for the propulsion element of the space shuttle, and it aggregates all accident sequences from a series of sub-event trees which model the “Propulsion” top event in the over-arching mission event tree model (Feng and Musicki, 2005).

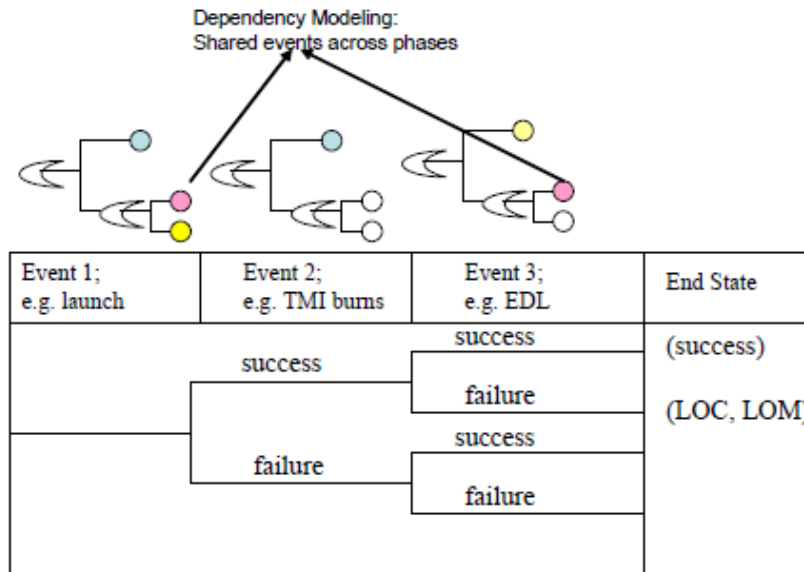


Figure 6 - An Event/Fault Tree (Meshkat, 2009)

To make the analysis of the event tree and fault tree, there are certain types of data that need to be gathered. Maggio (Maggio, 1996) noted that past experience may be the most logical source of data. Moreover, he noted that this single experience data, such as past flights data is not enough to compare the failures over previous shuttle mission, thus data from other mission that used similar equipment and system may also be required in the analysis. Table 3 presents four types of data that are used for the analysis in PRA.

Table 3 - Different data

Data	Example
Actual Data	In-flight anomaly data
Test Data	Thiokol Leak Check Results
Operation Component Data	Rocket motor failure
Generic Data	Other space shuttle

Moreover, from the data and the analysis with the event tree and fault tree, there are numbers of statistical data produced, such as numbers of failures and hazard exposure, which can be captured and can be further analysed. Maggio (Maggio, 1996) noted that one way to analyse those data is to calculate the failure frequency which is an estimation of number of failures in one mission. The following figure shows the calculation to get the number of failure frequency where number of failures is total count of flight failures within the certain items of concern, hazard exposure is number of time or unit-cycles to the certain items of concern, and mission specific operation time is the duration of time which the component is exposed to the hazard during a mission (Maggio, 1996).

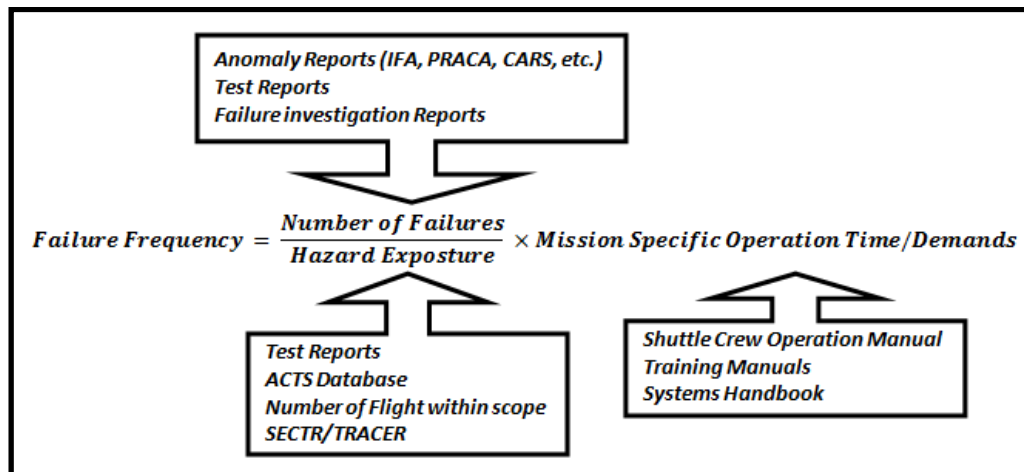


Figure 7 - Formula of Failure Frequency (Maggio, 1996)

After PRA has been done, it usually answers these three basic questions:

1. What can go wrong with the studied technological entity, or what are the *initiators* or *initiating events (undesirable starting events) that lead to adverse consequence(s)*?
2. What and how severe are the potential detriments, or the adverse consequences that the technological entity may be eventually subjected to as a result of the occurrence of the initiator?
3. How likely to occur are these undesirable consequences, or what are their probabilities or frequencies?

The final result of a PRA is given in the form of a *risk curve* and the associated uncertainties. The risk curve is the plot of the frequency of exceeding a consequence value (the ordinate) as a function of the consequence values (the abscissa). If the risk assessment is qualitative, the result can be represented as a two-dimensional matrix showing probability categories versus consequence categories.

5.3.2 Utilization of PRA

When talking about PRA, it is necessary to mention nuclear power plant and aerospace industry. Lots of papers have presented issues and technical insights on the scope, conceptual framework, and essential elements of nuclear power plant PRAs and that of the PRAs in general applications of the aerospace industry (Feng and Musicki, 2005). Also, a lot of researches have shown that PRA have been successfully performed for nuclear power plant design and operation. For example, the Nuclear Regulatory Commission (U.S.NRC, 2010) required that each nuclear power plant in the US perform an Individual Plant Examination (IPE) to identify and quantify plant vulnerabilities to hardware failures and human faults in design and operation.

Recently, PRA studies have been performed on a large number of nuclear power plants in the USA (Park et al., 1998). Due to the potential, severe consequences from nuclear accidents, the safety assessment activities of the nuclear industry have been extensive and multi-disciplinary (Feng and Musicki, 2005). Nuclear power plant can be very scary when nuclear accidents occur. In the last several decades, PRAs have focused on core damage and associated severe

consequences that can occur in nuclear accidents. The PRA technology and applications have acted as a guide when operating the plants.

How does PRA actually work in nuclear power plants to reduce the probability that accidents occur? The use of database accounts for a very important part of the success of the application of PRA. The data can be previous experience data, current testing data, and machine-generated future data, etc. However, surveys (Park et al., 1998) indicate that not all the data is accessible, and the data might be flawed or limited even if it is available. Nowadays, how to make sure the information systems are always accessible to accurate and relevant data is a big challenge for lots of organisations. In addition, people find that for the same case, they may get completely different data from different sources. Therefore, how to solve the differentiation of database is also another big problem facing organisations. Data integration could be a good method.

Due to data being distributed across entities and data repositories, data integration has become perhaps the most important data operation but certainly the most costly accounting for up to 40% of data processing budgets. Data integration requirements are growing dramatically due to astounding growth in semantics (i.e., increasingly sophisticated application and data modelling requirements) and scale (i.e., web-scale data and transaction types, volumes, and distribution) (Brodie, 2010).

5.3.3 Recommendations

For this Challenger project, PRA may be perfect to solve the problem that NASA had. All technical failure that NASA had at that time would have been covered in during the event and fault tree process in PRA. PRA would have seen the failure of the O-Ring, joint of the right solid rocket motor, and testing problem. Moreover, PRA produces numbers that will help management in the decision making process by allocating resources in a cost effective manner. It not only shows where resources should be allocated to be most risk effective and cost effective, but also serves as a basis for determining risk requirements for the Space Shuttle. It is believed that with the numbers will eliminate the risk of having the project become failure, managerial issue, as well as eliminate the pressure from other area.

5.4 Weighted scoring model

Based on the analysis above, the three methodologies will be compared by their performance and capabilities in six different criteria and be scored good, fair, or bad according to the judgment and justification that has been created which is based on the knowledge prior to the recommendation.

The six criteria that are being used in the scoring model are:

- Flexibility – how flexible the method prone to changes
- Risk management – how risk are being managed by the methodology
- Quality of outcome – what is the quality level after the methodology has been one
- Control level – how easy the methodology can be managed
- Familiarity with method – how familiar staff and constructors to the methodology
- Compatibility – how compatible the methodology with NASA structure

PMO is a centralized office which the authority of organisation is highly controlled by specific group, any changes of the construction has gone through PMO thus this methodology

is not flexible to changes but it maintain the control level of the project. Moreover, prior to risk management, risk is only a part of the PMO, it might be neglected during the project thus the risk management is fair. In the quality option which was mainly decided by the project staff and PMO is only a centralized office for the project, thus the effect may be fair. PMO has been used by organisation since 1960's thus the degree of familiarity would be good. Since PMO is an office, NASA may need to restructure their processes in the project.

GDSS may be flexible because meetings can be held in any location and time; it just needs the equipment to support the meeting. GDSS is a support system thus it does not handle risk specifically. Then, the quality of outcome of GDSS may be high quality because it is produced by the group decisions. GDSS may be fairly easy to process the meeting; it needs contributions from the group to produce the decision. Regarding with the familiarity, NASA may have used similar method to hold a meeting and it uses friendly interface of decision making. GDSS may be compatible with NASA as it is mostly a group meeting, it does not need changes in the structure.

PRA may be fair flexible to changes. If there is changes in the project, the methodology just need new data regarding the changes to make new analysis and also may affect other part of the analysis. Since PRA focuses on risk, this methodology may be the best in the risk management section. The quality that this methodology produces may be good because it analyses all possible actions and fault that can happen during the implementation of the project. Then managing PRA may be easy because the methodology is based on the scenario thus the progress is clear. Prior to the project, NASA has done similar risk assessment, but since this methodology is highly competent and consistent method, NASA needs to make sure that the staff and constructors know and understand the methodology. As the matter of compatibility, NASA does not have to restructure the organisation; PRA may be the additional process to the project.

Based on the judgment and justification above, the next table is created to outline the differences between the three methodologies, outstanding PRA as the recommended methodology to approach this project.

Table 4 - Comparison of three methodologies

	Flexibility	Risk Management	Quality of Outcome	Control Level	Familiarity	Compatibility
PMO	Bad	Fair	Fair	Good	Good	Fair
GDSS	Good	Bad	Good	Fair	Fair	Good
PRA	Fair	Good	Good	Good	Fair	Good

5.5 Solutions and Recommendations

Early forms of PRA had their origin in the aerospace industry before and during the Apollo space program. Todd (Todd, 2009) noted that this PRA methodology has been successfully used in other industries such as commercial and government aerospace, chemical, military, nuclear, insurance and financial. Later on, other industries (e.g., nuclear power industry,

chemical industry), US government laboratories and US government agencies expanded PRA methods to higher levels of sophistication in order to assess safety compliance and performance. In recent years, Government regulatory agencies have begun to use risk-based or risk-informed regulation as a basis for enhancing safety without applying undue conservatism. The use of PRA is expected to grow both in the Government and in the private sectors.

Usually, after completing the compulsory PRA efforts, performing organisations usually discovered benefits beyond mere compliance with regulation. These have included new insights into and an in-depth understanding of:

- Design flaws and cost-effective ways to eliminate them in design prior to construction and operation;
- Normal and abnormal operation of complex systems and facilities even for the most experienced design and operating personnel;
- Design flaws and hardware-related, operator-related and institutional reasons impacting safety and optimal performance at operating facilities and cost-effective ways to implement upgrades;
- Approaches to reduce operation and maintenance costs while meeting or exceeding safety requirements;
- Technical bases to request and request and receive exemptions from unnecessarily conservative regulatory requirements.

However, there are numbers of things that need to be taken care in this methodology. Hsu and Musicki (Hsu and Musicki, 2005) noted that PRA is a strict and competent methodology. Failure in the steps of the event tree and fault tree may have impact on the top event fault. Moreover, they also noted that since the parts and component of the space shuttle are being developed by different vendors. Thus, this is the challenge for NASA to put more effort on integrating the models as well as the data that required for the analysis which will improve their decision making.

Performing a PRA has proven to be an extremely valuable tool to improve concepts and designs cost-effectively. Because of its logical, systematic, and comprehensive approach, PRA has repeatedly proven capable of uncovering design and operation weaknesses that had escaped even some of the best deterministic safety and engineering experts. It was very important to examine not only low-probability and high-consequence individual mishap events, but also high-consequence scenarios which can emerge as a result of occurrence of multiple high-probability and nearly benign events.

The Presidential Commission on the Space Shuttle Challenger Accident (a.k.a. the Rogers Commission) made some recommendations both on technical specifications and the shuttle management structure. The project managers for the various elements of the shuttle program felt more accountable to their centre management than to the shuttle program organisation. Other recommendations include formulation of a policy to both impose and remove constraints, revamping of the management structure, and a variety of lesser recommendations (Dimitroff et al., 2005).

6. RISK ANALYSIS

6.1 Risk Management Approaches

The Challenger project failed due to several reasons, with one main reason being that the approach to risk management was inadequate. We have looked at some approaches to risk management that in hindsight could have been applied to Challenger project to avoid the disaster. Australian Standard AS/NSS ISO 3100:2009 is one of the approaches that can be applied into the project.

6.1.1 AS/NZS ISO 31000:2009

ISO 31000:2009 describes the risk management as follows:

'Organisations of any kind face internal and external factors and influences that make it uncertain whether, when and the extent to which they will achieve or exceed their objectives. The effect this uncertainty has on the organisation's objectives is 'risk'.

All activities of an organisation involve risk. Organisations manage risk by anticipating, understanding and deciding whether to modify it. Throughout this process they communicate and consult with stakeholders and monitor and review the risk and the controls that are modifying the risk.' (AS/NZS, 2004)

The standard outlines a structured approach to risk management where it is integral to an organisation and where individual projects are managed for risk management, consistently within the overarching risk management framework of the organisation.

The standard breaks risk management into cascading components of principles at the top, the framework in the middle, and the processes underneath.

By studying the Challenger disaster, it was difficult to see any kind of structured approach to managing risks by both NASA as an organisation and the Challenger project itself (Hubbard, 2009). NASA's approaches as an organisation at the time when Challenger disaster happened were in complete non-conformance with the principles of risk management, as they exist now.

Risk management principles were not clearly articulated, a comprehensive risk management framework was not evident and there were no clearly articulated processes. In particular:

- The unique nature of the program was not effectively acknowledged in terms of risk awareness both internally and externally (Dorfman, 2007).
- There was a poor understanding of risks at the highest level.
- The lack of a systematic and comprehensive risk analysis disempowered technical experts from disputing politicians and senior management (Dorfman, 2007).
- There was an extremely unbalanced power relationship between technicians, politicians and management with the ownership of risk not recognized or understood.
- Political pressure was overbearing, leading to the removal of common sense inhibitions, consequent peer pressure and fear-guided decisions.

- Lack of proper risk management strategies contributed to the vague objectivities around the investment in the O-ring (Lock, 2007).

Lack of a risk strategy was a symptom of overall poor project management practices and poor project health.

6.2 Risk Identification

Potential risks include two parts, internal risks and external risks. Identifying risks is the process of understanding what potential events might hurt or enhance a particular project. It is obvious that there were a lot of potential risks in this case.

First of all, poor definition, there were no unique objectives or clear sponsors at the beginning. Especially, sponsors always take the most weight in a project, even adding unique objectives in the Shuttle Challenger project, may become the biggest risk.

Secondly, funding problems, there were no strong supports as Apollo mission. Congress expected the program to be financially self-supportive. Success always starts from a strong support. If some apartments can offer the fund directly, maybe it goes much easier.

Thirdly, technical problems, flawed database caused the manager made the rash decision at the last. Although the destruction of the Shuttle Challenger was just caused by the hardware failure of a solid rocket booster (SRB) “O” ring, can be found the technology is not perfect, it exists some potential problems.

Fourthly, unscientific group decision support system made the operational decision overcame the safety consideration. Focus is placed on NASA’s use of a group decision support system (GDSS) meeting to make the decision to launch, that the human decision to launch was, in itself, flawed (Hillson, 2007).

Fifthly, ineffective communication is another risk, which brought in big obstacles to managers and frontline departments. The managers, in high position, they do not know the technology about this project, they just make the decision without thinking about the impacts. And the engineers, work in the frontline, just carry out the commands, but do not change ideas with managers. So the ineffective communication splits the whole processing, and causes the failure in the last.

6.3 Risk Prioritization

Risk1: Poor definition

Risk 2: Funding problems

Risk 3: Technical problems

Risk 4: Unscientific GDSS

Risk 5: Ineffective communication

To list risk in prioritization, project stakeholders should list risks they think might threaten the project in the future at first. Then give a score in terms of probability of occurrence and its' impact if it did occurrence. Finally project manager summarize the results in a probability& impact diagram.

Figure 8 the shows the Probability/Impact Scatter. The green area stands for the low risk, the yellow area stands for the medium risk, and the red area stands for the high risk. Then the Probability and Impact can be divided into 10 levels, low to high. Like, the Risk1, because of no unique objectives or clear sponsors, so it takes the (6, 7), becomes the highest level. The Risk 5, Ineffective communication, if the managers and engineers can communicate well or change ideas effectively, that risk can be avoided. So risk 5 is in (4, 5) point, that takes lowest risk. Therefore, it very closes to green area, with a safe overall score.

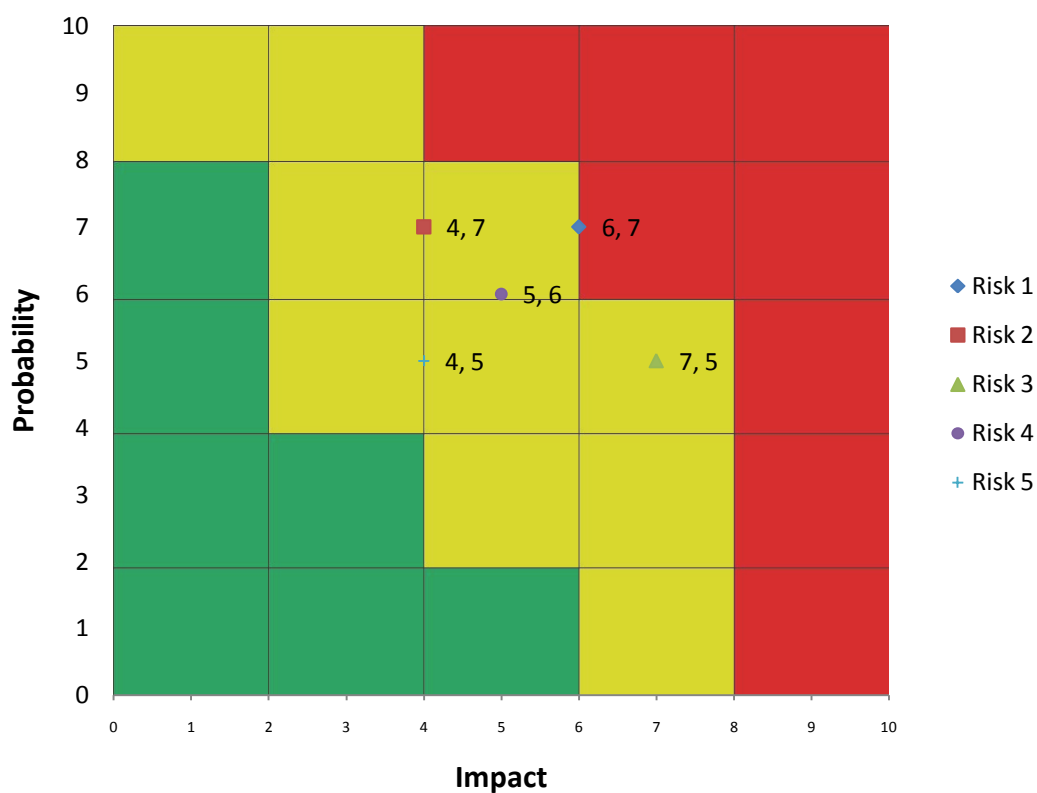


Figure 8 - Probability/Impact Scatter

6.4 Risk Mitigation

Risk 1, it would take time to make different parts of the project clear, unique objective would be defined, specific scope would be brainstormed by different parts of the group, sponsors who would be in charge of funding and supporting would be detailed at the very beginning of the project.

Risk 2, try to find more sponsors to relieve the financial problems on the one hand, compressing the budget on the other.

Risk 3, update the data flow system, multiple information should be collected, data analyses should be careful before the managers make the final decision.

Risk 4, elevate engineers' position in making decision process, exclude entities have nothing to do with the specific problems.

Risk 5, free and equal communication should be brought in, money and time should be paid to improve communication system.

6.5 Contingency Plan

Risk 1, The Project Director should organise a meeting with all key stakeholders and have the Challenger project scope, requirements, specifications, objectives as well as goals clearly re-defined and agreed upon; ensuring that all items are aligned and non-conflicting. Once all items have been verified via a sign-off of documents from relevant stakeholders, the business case and Project Management Plan must then be updated accordingly (Hillson, 2007). All changes required are documented in the change control logbook and articulated to relevant project members. Work performed to-date must then be audited and evaluated against the newly updated business case and Project Management Plan, and any variances are to be noted and submitted to the Change Control Board for verification. An ongoing scope control and verification process must be implemented to ensure the project stays on track as well.

Risk 2, NASA and the Government should take responsibility for this step, to decide who the key sponsor is, and who supports the funding, must be clearly. Making a clear plan for amount of the funding, whatever the total or the parts, just make sure to be supported on time.

Risk 3, Steering Committee should organise a meeting with all key stakeholders and re-gather and evaluate respective stakeholder requirements against project objectives and goals (Hillson, 2007). All conflicting requirements are then to be noted and relevant stakeholders are to be contacted and informed of the issue. Reassessment for all technologic staff, and monitoring each steps of the project should be focused in this meeting.

Risk 4, Current GDSS will be tested and evaluated for deficiencies. A new GDSS will then be designed and created against project objectives and goals ensuring sufficient support. New GDSS will be tested through several trial runs to ensure viability. Once the new, flawless GDSS is implemented, all relevant project members will undergo one month or longer training program to operate new GDSS for this project.

Risk 5, Although it is the lowest risk item, it is an important key for success. A month compulsory people and leadership training course will be delivered to all project managers and leaders. This course will highlight the knowledge and skills required to manage and influence individuals, in turn to promote high performance. Furthermore, on-going teambuilding exercises will be organised for all staff as a means to encourage team momentum, synergy and promote a harmonious environment.

7. SCOPE, TIME AND COST ANALYSIS

Since the scope were clearly defined and documented (writing a scope statement or a project charter, and developing WBS forms) before the launch, if the project succeeded, the scope

would be met. However due to the flawed decision-making process and deficient database, the mission ended up a catastrophe, without any scope goals being achieved. NASA failed to collect valid information about the SRBs, which is a crucial part of managing projects in terms of scope management. Moreover, NASA didn't succeed in verifying scope such as formal acceptance of the project scope by the stakeholders and controlling changes to the project scope. As stated above, the poor scope management directly led to the failure of the project. Also, as the technology of that time was not very advanced, NASA couldn't lean on the effective software to assist in project scope management.

In terms of time management of the Space Shuttle Challenger project, NASA did badly, which was one of the key reasons the project failed. Sequencing activities before the launch could help determine the relationships or dependencies between activities. However, NASA postpones the launch time due to the bad weather and their covetousness of the Vice President's good will. Additionally, because of the poor estimation of the activity durations, different parts had a very unnecessary and badly-organized teleconference in three different locations, resulting that they couldn't reach an agreement on the launch of the space shuttle. Managers overlooked the contingencies that might greatly impact the process of the project and thus the result of the project, and they failed to effectively control the schedule due to people issues. Therefore, it is critical to set realistic project schedules and use discipline to meet schedule goals.

Without a doubt, this project would cost huge amounts of money. Managers must understand several principles of cost management so as to be effective in managing project costs. The average cost to launch a Space Shuttle is about \$450 million per mission (CSTHR, 1986). The costs of the this Mission included: training of the astronauts; building up launch pad; buying Solid Rocket Boosters from contractor Morton-Thiokol; developing experimental equipment to be used in the space for research; etc. However, any little changes of the project schedule would add the cost considerably. In addition to the tragic and unforgettable loss of life, the Challenger accident had, and continues to have, momentous effects on United States and international Space programs. It led directly to an unprecedented restructuring of the Space Station Freedom program resulting in extensive redirection, massive delays and huge cost overruns (CSTHR, 1986). It was just because the budget limit that NASA still chose Morton-Thiokol as its SRB supplier and contractor. Managers in NASA had already realised the incomplete O-ring data and the need for the redesign, but they failed to carry out the actions. Furthermore, the cost was badly tracked, and NASA failed to stay on the budget due to the launch delays and technical issues, although the project manager or stakeholder had the authority to authorise changes to the budget. Due to poor budget determination and costs control, the project's cost had overrun greatly.

8. SQERT MANAGEMENT

In project management, SQERT stands for scope, quality, effort, risk and time (schedule) of a project. They have very close interrelationships between each other. Prior to set up SQERT processes when managing a project, it is essential to take an overview of techniques and activities that are involved in managing these processes. After analysing the SQERT processes of Space Shuttle Challenger case, lessons can be learned as shown in Table 5.

Table 5 - Lessons learned from Space Shuttle Challenger Disaster

Issues	Lessons Learned
Changing Scope	Due to economic considerations, political pressures and scheduling backlog, Space Shuttle Challenger project's scope had been changed to satisfy its clients. For example, when the engineers found the problem from the O-ring, but they ignored the problem without any analysis (Charles, 1989).
Poor Communications	Poor communications can be categorized into two parts: 1. Technological communication The project developed an Electronics Systems Test Laboratory to assist the technological communication including source encoding, channel encoding, spread spectrum, and digital modulation (Tu et al., 2005). However, the system failed to work well as expected. 2. Decision-making communication Most of the decisions were made by engineers, for example Jerald Mason. Some of them had no experience in managing projects. As a result, it was very difficult for the engineers to carry out good communications when they were faced pressures from different aspects.
Poor Risk management	Government research agencies could assist NASA's management with decision-making and project-managing, which can increase the probability of success, but NASA did need good models and tools for risk management.
Insufficient Planning	The disaster was caused not only by the equipment, but the insufficient planning. Without clear objectives and overall plan, the schedule was influenced easily by other factors outside the organisation. Although the weather might cause serious consequences, NASA's covetousness of the Vice President's good will made the project a "project gambling".
Comments	If NASA could prevent unpredictable issues from happening during project management, especially focusing on risk analysis and mitigation, developing a sound decision-making model, and carrying out an effective communication, the Space Shuttle Challenger project could have succeeded.

9. CONCLUSION

This paper has illustrated key issues and managerial insights on the business case, courses of action, risk management, triple constraints requirements, and SQERT processes management of the Space Shuttle Challenger Project and how to select and perform the optimised course of action in order that the Challenger Mission Project could succeed. Explicit explanations of project background, objectives, critical assumptions and constraints have been provided, bringing about the options and recommendations that would greatly support NASA's aerospace projects. After analysing three different methodologies, we recommend the PRA can serve as the best course of action to assist NASA with the Challenger mission. PRA has best solved the problems that existed in the Challenger mission, and provided comprehensive project guidance.

Furthermore, we need to be mindful that project management involves different aspects or factors that are critical for the success of the project. For example, scope, time, and cost management, project planning and processing, risk management, change management, and human resource management, etc. It is essential for project managers to master these skills

and be competent to face any challenges and deal with any contingencies that may occur in the project. Projects are managed by people, thus a professional communication and good interpersonal competences are so indispensable that people are connected with each other to exchange information and carry out the best strategic approaches, aiming to achieve a common goal. Particularly, in NASA - a complicated and highly developed R&D organization, a well-organized support group seems to be vital for both its science research and space programs.

Although sending astronauts into space is great risk itself, by having succeeded in launching many space shuttles, NASA should be experienced in managing such projects effectively and efficiently. Ultimately, we believe that NASA would have no more project failures. Although it is unpredictable, by no means is it a hopeless one. While new biases and issues continue to emerge as NASA develops and evolves, the methodologies from this article are worth further study.

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APPENDIX

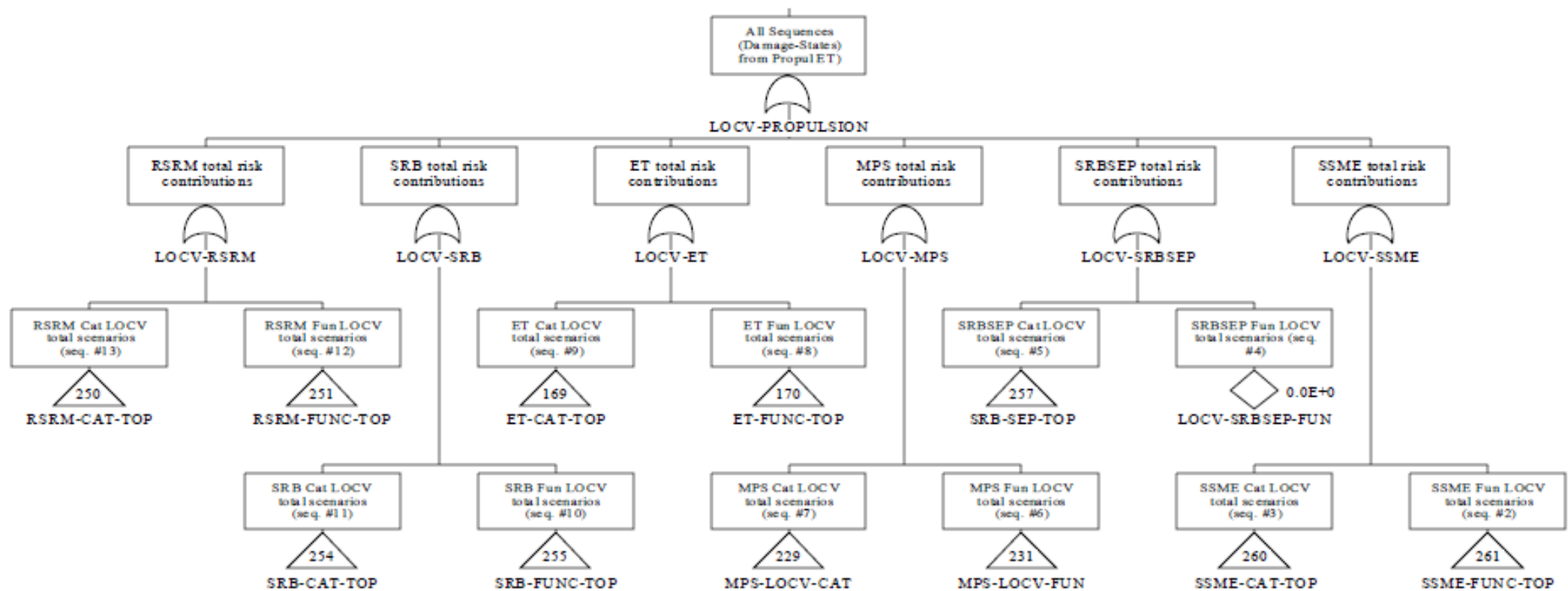


Figure 9 - An example of integrated model element for space shuttle propulsion risk (Feng and Musicki, 2005)