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Contents

Abstract.....	3
Declaration Statement.....	4
Introduction	5
Background	7
Elements of failure.....	8
Scope creep	8
Unclear goals and objectives	9
Inadequate risk management.....	9
Inadequate quality assurance.....	9
Poor project planning	9
Poor leadership.....	10
Lack of suitable resource	10
Inadequate communication	10
Supply chain difficulties	10
Literature review	12
Risk.....	12
Project leadership, governance and performance	14
Risk mitigation	16
Theories and Principles.....	17
Dempster-Shafer Theory	17
Daniel Bernoulli	18
Daniel Katz and Robert Khan	20
Fuzzy logic.....	21
How to manage risk	22
FMEA	22
4T hazard response	25
Risk Register	27
Decision trees	28
Contingency Planning.....	29
Project specific risks within the electrical engineering sector.....	31
Material supply.....	31
Resource	33
Technical difficulties, lack of clarity and design change	35
Scope growth and changes.....	37
Insufficient Front End Engineering Design (FEED)	39

Quality standards	41
Safety standards	43
Theft	45
Case Study – Hydrogen plant Germany	47
Contract	47
Import/ export of material and equipment.....	47
Installation standards	48
Project complexity	48
Supporting services	48
Procuring additional material in the EU	48
Accommodation costs/ Fluctuating travel costs	49
Visa/ working time difficulties	49
Other working parties.....	49
Permits/ setting to work.....	49
Liquidated damages	50
Seasons effect on labour	50
Conclusion of case study	50
Analysis	52
Case study risk matrix.....	53
Case study vulnerability matrix	56
Conclusion	59
Recommendation and further work.....	61
References	62
Figure 1 - Elements that have a negative effect on a project.....	8
Figure 2 - Risk management process	13
Figure 3 - Project governance model.....	15
Figure 4 - Risk neutral, prone and averse	19
Figure 5 - Severity rating table.....	23
Figure 6 - Occurrence rating table	24
Figure 7 - Detection rating scale	24
Figure 8 - 4T risk matrix	25
Figure 9 - 4T hazard risk zones.....	26
Figure 10 - Risk Register.....	27
Figure 11 - Decision Tree	28
Figure 12 - Contingency Plan Table.....	30
Figure 13 - Risk matrix	52
Figure 14 - Probability matrix	52
Figure 15 - Case study risk matrix.....	55
Figure 16 - Vulnerability control	56
Figure 17 - Project Vulnerability Matrix.....	58

Abstract

This dissertation focuses on risk mitigation during the delivery of engineering projects. Initially there is an introduction and background of the reasoning for undertaking research into this topic. Elements of failure are then reviewed to give an insight into common difficult areas of delivering engineering projects. A literature review is undertaken to explore risk and mitigation measures that have been developed. Theories and principles are then documented to gain an understanding of previous research areas and how they have shaped the environment today. Project specific risks in the field of electrical engineering projects are then detailed to give an overview of specific risk within the electrical sector. A case study is detailed and scrutinised to develop an understanding of the particular points of failure on that project. Finally, the document concludes with an overview of the knowledge gained during the research process. Further opportunities and recommendations are then documented.

The purpose of this dissertation is to gain an understanding of the reasons many engineering projects fail, the drivers for this and to develop mitigation strategies to counteract the risks.

The method used to gain these insights has been through extensive literature reviews and review of case studies. Theories and principles were also reviewed to determine how applicable they are in modern engineering projects.

The results show that the risks and causes are common across many projects in multiple different sectors and industries.

To conclude, the strategies that have been developed will assist in mitigating risks and improving the outcome of projects if they are implemented and followed during project delivery.

Declaration Statement

Author's Declaration

I declare that the work in this dissertation was carried out in accordance with the regulations of UWTSD. The work is original except where indicated by special references in the text and no part of the dissertation has been submitted for any other degree.

Any views expressed in the dissertation are those of the author and in no way represent those of the UWTSD.

The dissertation has not been presented to any other University for examination either in the United Kingdom or overseas.

I hereby give permission for my work, if accepted, to be available for photocopying and inter-library loan, and for the title and summary to be made available to outside organisations.

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Introduction

This dissertation investigates the risks faced when delivering engineering projects. Theories and principles relating to risk mitigation are researched. The elements relating to project failure are documented as well as risks specific to the electrical engineering sector. A case study is reviewed and analysis undertaken on this to determine what control measures can be introduced to mitigate the risks faced.

In today's rapidly evolving global business landscape, organisations face a myriad of uncertainty that can significantly impact operations, financial stability, and reputation. These uncertainties, commonly referred to as risks, can arise from a variety of sources such as technological advancements, economic fluctuations, regulatory changes, natural disasters, and unexpected events like a global health crisis. The effectiveness and ability of a business to identify, assess, mitigate, and manage these risks is paramount to their long-term success and sustainability.

Hornbill Engineering is a multi-discipline contractor primarily offering electrical engineering services. They have been operating since 1989 across primarily power generation, petrochemical, utilities, renewables, cryogenics, pharmaceutical, oil, water and metal industries. They offer services for:

- Systems Design & Control Automation,
- Panel Manufacture,
- Low voltage & instrumentation,
- High voltage,
- Hazardous area,
- Outsourcing & calibration services,
- Personnel hire.

The company operates globally and as such, face's frequent complexities during some projects in relation to its supply chain and general project delivery management. This dissertation aims to address some of these issues and will offer a research review to better understand these difficulties and develop a strategy and method to help mitigate these project risks.

The concept of risk management is not new, but, overtime, the complexity and diversity of tasks involved in engineering projects has grown. The stakes are as high as ever, and in an environment where everything is interconnected, the disruption of one part of the supply chain can reverberate throughout the organisation. The rapid pace of technological advance has brought both incredible opportunity and unprecedented vulnerability. This dissertation will aim to provide a comprehensive exploration of risk management strategies in Hornbill Engineering's business models as well as investigate opportunity to improve and complement existing risk mitigation models. The reasons for carrying out this research is

because, although there are many risk management processes implemented in engineering today, the issues remain, this research aims to improve that situation. The outcome of this dissertation will allow for strategic planning ensuring more effective operations, reducing time pressures, and identifying issues become they cause problem and disruption.

Background

A project is a temporary endeavour detailing a set of tasks that must be completed to arrive at a desired outcome or achieve a desired goal. The tasks may be simple or complex but ultimately can be broken down into objectives and the steps needed to achieve them (Yarborough, 2021). Although many engineering projects are meticulously planned, it is reported that only 35% of projects undertaken worldwide are delivered successfully. This indicates that a staggering 65% of projects are unsuccessful in terms of delivery within budget, completion in agreed time scales or fulfilling stakeholders' expectations. (Nieto-Rodriguez, 2021).

According to a survey by Axelos, this 65% project failure rate costs the UK economy a colossal £250BN through additional spend and lost opportunities.

Given the current project failure levels within the engineering industry, I feel that a study to try and understand the key points of failure and how these can be mitigated could be a beneficial undertaking. Project management and project planning is not being implemented effectively as surveys show a high failure rate in project delivery.

Although there are many research papers on the management of project failure, there is a lack of focus on mitigating the chance of these failures occurring prior to the project being undertaken. The major issues that need to be addressed are, that the large risk areas are known based on the execution of other major projects, but the same errors continue to be a critical failure point in present projects. Understanding these failures and developing methods to mitigate these issues from occurring could aid in providing a successful project delivery and as a result a decrease in costs to stakeholders.

Risk mitigation refers to the process of identifying potential risks that could have a negative impact on a project, developing strategies to reduce the likelihood or eliminate those risks from occurring completely can be achieved through implementation of risk identification measures, risk assessment, risk response planning, risk monitoring and control and contingency planning (Ahmed, 2017).

As technology continues to evolve, the importance of delivering successful engineering projects is as prevalent as ever.

At Hornbill Engineering, multiple projects are undertaken. Many of the issues investigated within this document are faced on many projects. The intent of this dissertation is to investigate the reasons why this happens, the effects it has on the project, and the most ethical, effective, and efficient way the resolve these issues and mitigate against recurrence.

Elements of failure

The search for factors that positively and negatively influences the success and failure of engineering projects has long been of great interest to both researchers and project delivery teams (PINTO & SAMUEL J. MANTEL, 1990). Several research streams have highlighted factors that consistently contribute to project failure. The most prevalent of these are detailed below.



Figure 1 - Elements that have a negative effect on a project

Scope creep

A project scope is the boundaries of a project, including goals, budgets, deadlines, and deliverables. Scope creep is anything outside of the boundaries and is a major issue in the delivery of projects caused by an incomplete definition of the scope. This in turn leads to changes in the scope that causes negative effects on time, costs, quality, and risks to project completion (Ajmal, et al., 2020) Scope creep is not a problem in specific sectors, it is a common issue among a range of industries and sectors. If the initial scope set out at the beginning of a project is poorly defined it is usually the cause of scope creepage (Mirza, et al., 2013). There are other elements that can contribute to scope creepage, project managers can tend to alter elements of a project to increase functionality or add features without appreciating the effects on boundaries and time (Gibson, et al., 2006), inadequate communication and changes in business environment.

Unclear goals and objectives

Unclear goals and objectives can create confusion and leave unknowns open to interpretation. This can lead to a lack of direction and lower work output. When goals are unclear, this lends itself to wasted resource time and can cause the project team to become frustrated. Objectives should have a clear end requirement, and the steps detailed to meet that requirement. The objectives should have a set timeline and should be measured and monitored throughout the task timeline. Objectives should have an owner, someone who is responsible for ensuring completion, they need to communicate and feedback any problems to ensure the task is delivered on time, to standard and budget. Clear goals and objectives are critical for delivery of a successful project. Goal setting is valuable to project teams and the individuals involved that want to control the outcome, understanding the current state and the target objective can motivate workers to achieve the goals set out (Lopez, 2016).

Inadequate risk management

Substandard risk management can lead to not identifying, assessing, or mitigating risks or threats that could be detrimental to the successful delivery of a project. These risks could also damage reputations, lead to financial losses, and cause opportunities to be missed. There are many reasons why risk management may be inadequate, these may be lack of experience in risk management within the project team, failure to prioritise risk management, insufficient resources or insufficient risk analysis, management, or culture. The project team should choose effective tools to create a realistic project in the preparation phase and implement a precise process of the risk management process (Buganová & Šimíčková, 2019).

Inadequate quality assurance

Quality assurance in a project ensures that the product or services being provided are up to the required standard and meet the specified requirements. Inadequate quality assurance during the design and preparation stage, during or on the completion may result in that product or project being substandard and not meeting the required levels of quality. Issues with quality being substandard is usually down to time restraints during the project. Projects should have a quality control plan which stipulates standards to be met, procedures, processes, training requirements, review documents, industry standards and expectations and measures specific to the project (Salvi & Kerkar, 2020)

Poor project planning

A project plan incorporates all elements of the project. It takes into consideration the scope of the project, the time schedule with milestones and deadlines, a breakdown of the labour resource required

to carry out the tasks associated with the project, the risk management plan and budget information in relation to all elements of the project (Project Management Institute, 2008). Poor project planning can influence all aspects relating to the project.

Poor leadership

A poor project leader can create a lack of clarity in the project and distort the goals and expectations. This can then cause the project to overrun, increase costs and cause frustration to team members, customers, and other stakeholders. A project leader should be interpersonal, person orientated and a social influence to ensure the project team are led in direction, course, action, and opinion (Müller, et al., 2022).

Lack of suitable resource

Resource refers to labour, plant and equipment, material, and facilities. Difficulty in acquiring any of the elements of resource could negatively affect the outcome of a project. Having a limited quantity of resource of any description will put additional strains on the project delivery. This can be off set using resource levelling methods which involves increasing time frames, delaying noncritical items, or using other resources that may not be utilised fully (Kidston & Haward, 2015).

Inadequate communication

Good communication is one of the most critical elements of project management. An effective communications route ensures that all stakeholders are well informed, kept up to date and are aware of project progress and any issues. Clear and concise communication assists with efficiency and creates a transparent, trusting, and credible environment for all parties involved. Communication has been referred to as the lifeblood of a project. A communication plan should be created, and all members of the project must understand the requirements of the system and how that system should be used (Zulch, 2014).

Supply chain difficulties

In recent times, supply chains have been affected by global events such as COVID-19, Brexit trade barriers and labour shortages. COVID-19 and Brexit influenced the labour shortages faced and exacerbated these shortages. Many EU nationals working in the UK during, and at the end of the Brexit transition located back to their country of origin shortly after the pandemic began, and many have not returned due to eligibility. It is reported that between 1.4-1.5 million EU nationals left the UK due to Covid (Committee, 2021). During the pandemic many vocational qualifications training was disrupted, this in turn reduced the inflow of newly qualified staff entering the resource pool, an example of this is the DVLA reducing the

number of HGV driving tests by 30,000 during the pandemic, given the average training time for a driver is 18 months, this has had a knock-on effect. The self-isolation rule also contributed to the difficulties of available labour, in July 2021, just under 700,000 people in England and Wales had been instructed to self-isolate (Anon., 2022). Whilst Covid and Brexit contributed to the supply chain issues, this has also highlighted long standing issues within the haulage industry. Reports from the Road Haulage Association show that prior to pandemic there was already a 60,000 HGV driver shortage, this coupled with the average driver being 55 years of age and many others approaching retirement, and with the delay in new resource entering the industry has worsened the situation within the haulage industry (GOVERNMENT, 2021).

Literature review

Risk

Risk refers to the potential for an event or situation to result in an adverse or unexpected outcome. It is an inherent part of many aspects of life and business and involves the uncertainty of future events and their potential consequences. Risk can be quantified and assessed in various ways, it also plays a crucial role in decision making and planning.

When calculating risk, there are some elements to consider.

- Risk identification: The first step is to identify the specific risk or risks to be assessed. They must be clearly defined to identify what the outcome may be.
- Data gathering: Obtain any data that could provide insight to the risk.
- Probability assessment: Estimate the likelihood of the risk occurring. This can be achieved using multiple methods including historical data, expert opinions, statistical analysis and mathematical models.
- Impact assessment: Evaluate the severity of potential consequences and impact of the risk if it was to occur. This assessment may include financial implications, operational disruptions, and any other relevant disruptions.
- Risk metrics: Use quantitative measures to express the risk. This includes:
 - Risk probability: Numerical representation of the likelihood of occurrence.
 - Risk impact: A quantitative assessment of the severity of impact.
 - Risk exposure: The product of risk probability and risk impact to understand the overall measure of the risk magnitude.
- Risk scenarios: Consideration of the potential different outcomes if the identified risk was to occur. This is particularly important if there are multiple factors or variables which can produce a range of potential outcomes.
- Sensitivity analysis: Assess how changes in variables can affect the calculated risks. Sensitivity analysis helps identify which factors have the most significant impact of the risk assessment.
- Risk mitigation strategies: Develop and evaluate strategies to mitigate or manage the identified risks. This may involve risk avoidance, risk reduction, risk transfer, or risk acceptance, depending on the nature of the risk.
- Risk communication: Clearly communicate the outcome of the risk assessment with relevant stakeholders so informed decisions can be made.
- Regular review: Risk is not static; it can change and evolve due to many factors. Risk assessments should be regularly reviewed to remain accurate and relevant.

- Risk management tools: Use of various software tools, risk assessment matrices, decision trees and many other methods can aid in risk calculation and analysis, particularly with complex situations.

The below risk management process highlights the steps required to establish, identify, analyse, evaluate and treat risks. The diagram clearly details the steps and where clear communication and the monitor and review functions should be implemented.

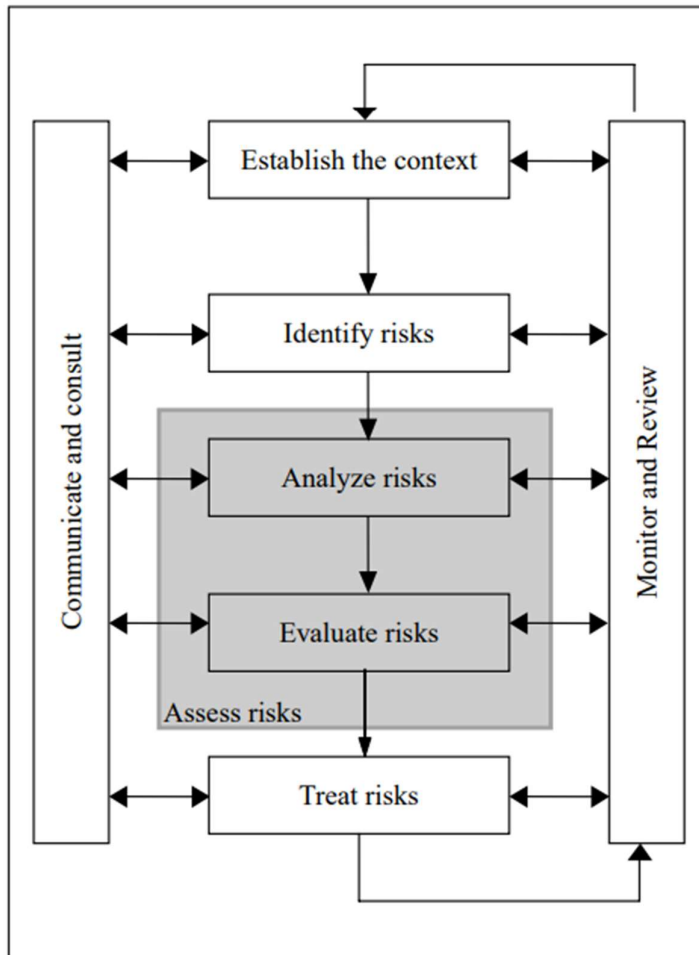


Figure 2 - Risk management process

(Ahmed, et al., 2007)

Project leadership, governance and performance

Project governance is a term used by many different researchers to have different meanings and different implications. Though, the terms' single objective is to advance project performance. Project governance can be represented as a set of moralities of authority, accountability, leadership, control and direction of a project. Governance should be used to initiate, terminate and maintain relationships with stakeholders involved in the project, internally and externally. Organising these relationships with internal stakeholders, including project teams and company management as well as external stakeholders, such as suppliers, the client, end user and any governing bodies, tend to create a substantially better project success rate.

Governance places priority on the process of controlling the project, though not with project authority in regards to compliance but in regard to creating robust relationships and driving favourable decisions for the project. Governance also places concern on the project management processes from planning through to completion. This concept of governance of a project also develops a relationship with the project team members to deliver the project in uncertain environments. Project governance is key to providing control over the project process and manage relationships between the project team and the client (Haq, et al., 2018)

An effective project governance plan creates relationships with stakeholders. Effective risk management strategies rely on a collaborative approach. Collaboration when determining and reviewing risks and producing a risk register ensures a broader spectrum of input and increases the probability of capturing more risk elements, thus assisting in mitigating increased elements of risk. Having created positive relationships with multiple stakeholders and involving them in the risk management development and review process, it will create a teamworking approach and harbour an understanding if an issue was encountered.

The below model diagram depicts where project governance feeds into project risk management and subsequent project output.

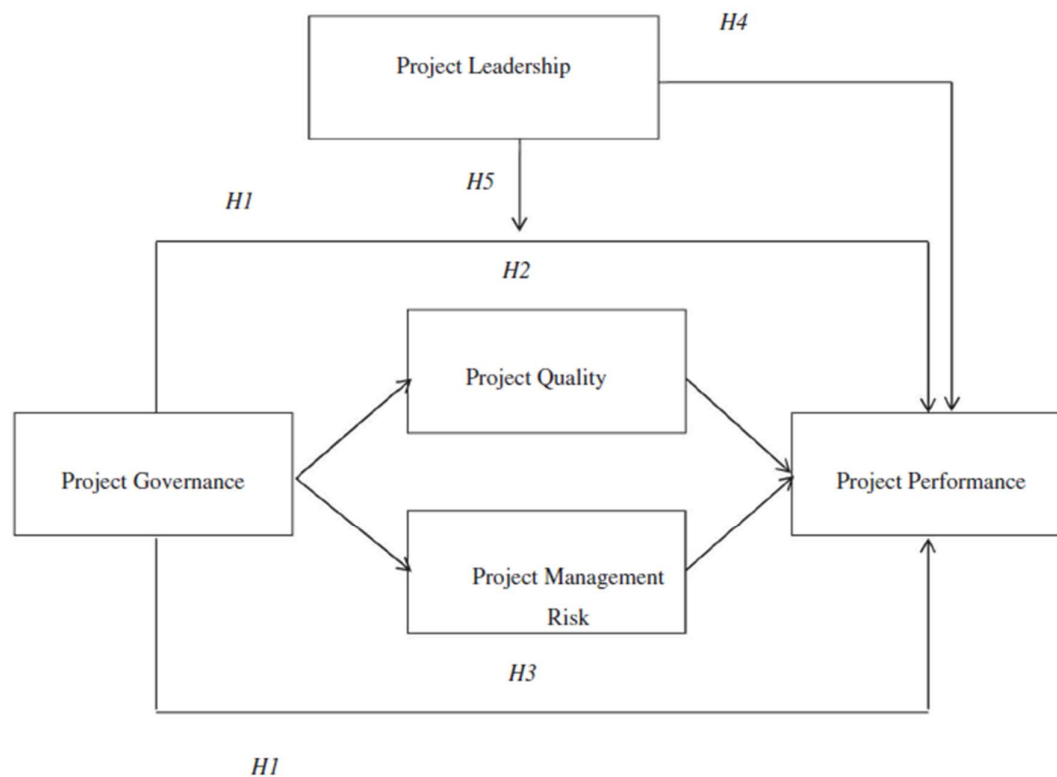


Figure 3 - Project governance model

(Haq, et al., 2018)

Risk mitigation

Risk mitigation is the process an organisation undertakes to reduce its exposure to the various risks it may face. Businesses face many risks, some of which can cause severe disruption and can result in financial loss or the ability to deliver a product or project. Mitigation is a prudent step every company should undertake to avoid such unwanted events (Risk Optics, 2023).

The Project Management Book of Knowledge (PMBOK) by the Project Management Institute (PMI) highlights Project Risk Management (PRM) as one of the eight main areas of Project Management, PRM is viewed as a process that accompanies the project during all phases, planning, execution, control, completion and closure.

PRM can be broken down to two main phases, risk assessment, consisting of risk identification, analysis and prioritisation, and risk control which contains risk management planning, risk resolution, risk monitoring, tracking and correcting.

There are many options to handle risk mitigation, these include:

- Accepting – this is when the risk is acknowledged and deliberately accepted without engaging any special efforts or strategies to control it. This approach would need approval by the designated program/project leader.
- Avoiding – this approach would require constraints to eliminate or reduce the risk by adjustment in the project risk area in relation to funding, schedule or technical element in relation to the known risk.
- Control – controlling the risk would require actions that minimise the likelihood of the risk occurring or the severity of impact if the risk was to materialise.
- Transfer – reassigning the accountability to other stakeholders will eliminate the immediate effect.
- Monitor – monitoring the risk and evaluating any changes to ensure the impact of the risk does not become severe.

The above handling options require assessment of the combination of the probability of occurrence and the severity of the potential outcomes. The assessment should be carried out by all stakeholders to ensure all aspects have been considered and the best course of action is undertaken (Mitre, 2013).

Theories and Principles

Dempster-Shafer Theory

The Dempster-Shafer theory was created by Arthur P. Dempster and Glenn Shafer. It is a theory of belief functions also referred to as evidence theory or Dempster-Shafer theory (DST). This theory is a generalisation of Thomas Bayes' theorem that describes the probability of an event based on information of prior knowledge of the elements of the event (Shafer, 1976). This is calculated using the conditional probabilities formula:

$$P(A/B) = \frac{P(B|A).P(A)}{P(B)}$$

Where A,B = events,

$P(A|B)$ = the probability of A given B is true,

$P(B|A)$ = the probability of B given A is true,

$P(A)$, $P(B)$ = the individual probabilities of A and B).

The Bayesian theory requires probabilities for each question, the DST belief function allows for the degrees of belief for these questions that may not have the mathematical probabilities. The difference of the probability from belief will determine how closely related the questions are. The DST is based on the ideas of the degrees of belief of the question and the probabilities of the of the related question.

Belief functions are adapted based on the representation of evidence as they admit a genuine rule of a combination of evidence. This combined evidence gives a measure of belief. The concept of the combination rule is a precise formula using assumptions that determine a unique rule, this approach removes the independence and irrelevant assumptions. Based on the assumptions being relevant this justifies the rule (Wilson, 2013).

Daniel Bernoulli

Daniel Bernoulli, an 18th-century Swiss mathematician, made significant contributions to various fields of mathematics, including probability theory and statistics. While he is perhaps best known for his work in fluid dynamics and the development of Bernoulli's principle, he also made important contributions to the understanding of risk management.

Bernoulli's work on risk management is primarily associated with his seminal work "Exposition of a New Theory on the Measurement of Risk," published in 1738. In this work, he introduced the concept of utility theory, which revolutionized the understanding of decision-making under uncertainty and laid the foundation for modern risk management theory.

One of the key insights of Bernoulli's utility theory is that individuals do not make decisions based solely on the expected monetary value of different outcomes but also take into account their personal preferences or attitudes towards risk. He argued that people are risk-averse when it comes to gains but risk-seeking when it comes to losses, a concept known as the "Bernoulli principle."

Bernoulli's work highlights the importance of understanding individuals' risk attitudes and preferences in making decisions involving uncertainty. This insight is fundamental to risk management, as it underscores the need to consider not only the probability and magnitude of potential losses but also the subjective perception of risk by stakeholders.

In modern risk management, Bernoulli's ideas continue to inform decision-making processes, particularly in fields such as finance, insurance, and investment management. By incorporating insights from utility theory, risk managers can better assess and mitigate risks, taking into account the preferences and attitudes of stakeholders to achieve more effective risk management strategies (Stearns, 2000).

The graphs below detail the difference in risk neutral, risk prone and risk averse attitudes. The risk neutral attitude is linear and this is due to evaluating risk, focus is solely on the potential benefit irrespective of risk. The risk prone mindset takes risks, sometimes calculated, which can result in a negative outcome, however, depending on the scenario, the outcome may be positive and worthwhile. The risk averse graph shows that risk is avoided wherever possible, and is a safer option, this mindset however will not experience the opportunity to capitalise on a potential positive outcome. In projects, it is crucial that these attitudes are implemented in the right scenario, with a health and safety issue, you would not encourage a risk prone attitude, whereas, an idea to reduce cost or accelerate program may benefit from this mindset.

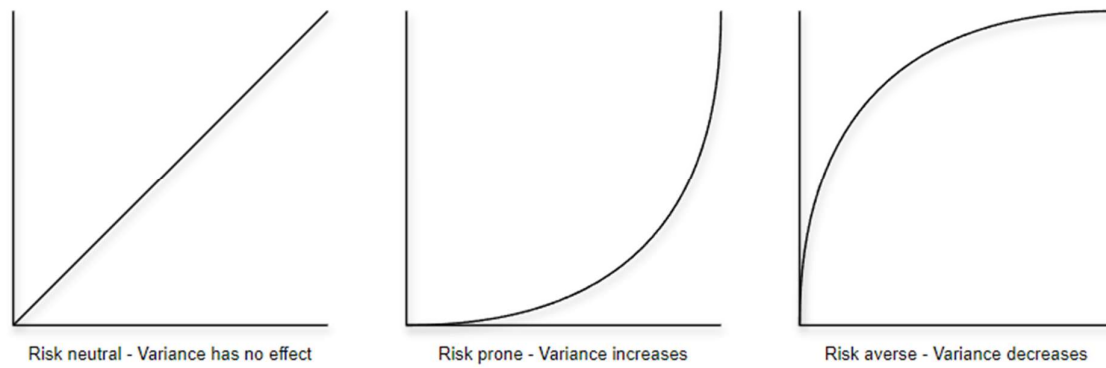


Figure 4 - Risk neutral, prone and averse

(Stearns, 2000)

Daniel Katz and Robert Khan

Katz and Khan developed one of the modern management theories frameworks for an open systems theory that encompasses four elements

1. Energetic inputs in the organisation,
2. The transformation of these inputs into the system,
3. Energetic outputs,
4. Recycling.

The energetic input element refers to external influences, including employees, material and capital, as well as recognition, status, satisfaction and personal reward. The transformation of these particulars includes the energy and effort to provide services or products created as a result of the inputs. The outputs are simply the elements created. The recycle aspect is the fact that the outputs are fed directly back into the organisation.

As well as developing this four-phrase open system, Katz and Khan detailed several other aspects required to create a successful organisation. The universal law of entropy allows a company to thrive if the energy imported from the environment exceed the amount it expends, achieving negative entropy. The characteristic of dynamic homeostasis also contributes to a successful organisation as the subsections of the business, i.e. design, manufacturing and sales are in equilibrium so that the supply and demand is in balance. They also characterise the open system by equifinality, meaning that the company arrives at the same final point through a number of paths, these paths are not fixed and both develop organically as they are influenced by internal and external influences.

Open systems theory makes the assumption that organisation is made up of multiple sub systems. Each of these systems receives inputs from other systems, and produces an output which feeds into another system. These are not necessarily departments of the business; they may be activities within a task. An important aspect of the open system theory is that not all sub systems are necessarily equally essential, meaning a failure in one sub section will not automatically disrupt the entire system. Whereas in a traditional organisational theory, a failure in any part of the system will have an equal effect on the process (Anon., 2024)

Fuzzy logic

Fuzzy logic was developed by Lotfi Zadeh in 1965, it attempts to reflect data used in information processing and derives logical rules for this kind of sets of data. The term fuzzy logic is an approach that uses multiple variables of truth values that are processed through the same variable. The process attempts to solve problems using an open, imprecise array of data and heuristics to create an accurate spectrum of conclusive results. This approach gives an opportunity to mimic real life scenarios where absolute truth and false statements are rare. Fuzzy logic stems from the mathematical field of multivalued logic, where it deals with vague data rather absolute truth or false information. Today fuzzy logic is used in a variety of applications including engineering, business decision making and industrial applications as it mimics the way humans analyse problems. In traditional standard logic where statements are either true or false, fuzzy logics uses a scaled approach from 0 to 1, where 0 is false and true is 1, the degrees in between are factors of truth between 0 and 1. The pros of fuzzy logic are that it is more likely to reflect real world problems rather than classic logic, it requires lower hardware requirements than classic logic and it can produce more accurate results with inaccurate data. The cons are that it requires a broad validation and verification and are dependent on human expertise and knowledge (Scott, 2023)

How to manage risk

There are many theories and practices currently utilised in the engineering and construction field that are used to manage and reduce risk in engineering and construction projects. One of the most notable is FMEA.

FMEA

FMEA is Failure Mode and Effects analysis, it is a structured and systematic method of identifying and preventing potential issues or failures within a system or process before they occur. FMEA was introduced in the late 1940s by the US military, in the 1960s, FMEA was used by the aerospace industry as a design methodology for reliability and safety requirements. In the 1970s, Ford Motor company introduced FMEA to the automotive sector for safety and regulatory consideration (Sharma & Srivastava, 2018). FMEA is now widely used across multiple sectors including manufacturing, healthcare, and engineering to proactively identify and address potential failures with processes and products.

FMEA consists of the following steps:

1. Identifying the system or process to be analysed.
2. Breaking down the system or process into its individual components or steps.
3. Identify potential failure modes for each component or step.
4. Assessing the severity, frequency occurrence, and detection probability of each failure mode.
5. Assigning a risk priority number (RPN) to each failure mode based on the severity, frequency/occurrence, and detection scores.
6. Identify actions that can be taken to reduce the RPN for each failure mode.
7. Implement the recommended actions and re-evaluate the RPN for each failure mode.

An FMEA uses three criteria to assess a problem, 1, the severity of the effect on the customer, 2, the frequency in which the problem is likely to occur, and 3, how easily the problem can be detected. Each criterion is scored between 1 and 10, 1 being low and 10 being high. When all three elements have been scored, the risk priority number (RPN) can be calculated. The formula for calculating the RPN is, $RPN = \text{severity} \times \text{occurrence} \times \text{detection}$ (Dendera-Gruszka & Kulińska, 2020)

There is no definitive threshold for determining which RPN output requires most attention, this requires further input from other elements, such as whether the problem is safety, legal or regulatory related. A starting point for prioritising corrective actions could be to review the Pareto principle. The Pareto principle states that 80% of issues are caused by 20% of the problems, which are the vital few (Forrest, 2010).

The actions to be implemented to reduce the RPN will be specific to each process, but typically to reduce the severity, a more robust product or process could be implemented to be able to tolerate

and withstand a failure without effecting the end user. To reduce the chance of occurrence, steps can be taken to understand the root cause of the issue and eliminating it, this could be achieved through root cause analysis and implementing control through training or reliable equipment and processes. Detecting the failure before it causes a problem to the end user may be achieved by introducing more quality control procedures, implementing more frequent inspections, and improving communications between the different teams proving the product or service (Hartwell, 2022)

The three elements, severity, occurrence, and detection used to determine the risk priority number are shown in the tables below. The numerical values assigned to each element are dependent on the severity of failure, probability of occurrence and likelihood of detection respectively are detailed (Díaz & Soares, 2020).

Severity scale		
Rating	Failure effect	Description
10	Apocalyptic safety or regulatory issue, apocalyptic impact on customer satisfaction	The failure mode has an apocalyptic impact on the product or service. It may cause an apocalyptic level of performance issues or inconvenience to the customer. There may be apocalyptic safety or regulatory non-compliance issues associated with it.
9	Extreme safety or regulatory issue, extreme impact on customer satisfaction	The failure mode has an extreme impact on the product or service. It may cause extreme performance issues or inconvenience to the customer. There may be extreme safety or regulatory non-compliance issues associated with it.
8	Catastrophic safety or regulatory issue, catastrophic impact on customer satisfaction	The failure mode has a catastrophic impact on the product or service. It may cause catastrophic performance issues or inconvenience to the customer. There may be catastrophic safety or regulatory non-compliance issues associated with it.
7	Critical safety or regulatory issue, critical impact on customer satisfaction	The failure mode has a critical impact on the product or service. It may cause critical performance issues or inconvenience to the customer. There may be critical safety or regulatory non-compliance issues associated with it.
6	Severe safety or regulatory issue, severe impact on customer satisfaction	The failure mode has a severe impact on the product or service. It may cause severe performance issues or inconvenience to the customer. There may be severe safety or regulatory non-compliance issues associated with it.
5	High safety or regulatory issue, major impact on customer satisfaction	The failure mode has a major impact on the product or service. It may cause major performance issues or inconvenience to the customer. There may be high safety or regulatory non-compliance issues associated with it.
4	Moderate safety or regulatory issue, significant impact on customer satisfaction	The failure mode has a significant impact on the product or service. It may cause significant performance issues or inconvenience to the customer. There may be moderate safety or regulatory non-compliance issues associated with it.
3	Low safety or regulatory issue, moderate impact on customer satisfaction	The failure mode has a moderate impact on the product or service. It may cause moderate performance issues or inconvenience to the customer. There may be some safety or regulatory non-compliance issues associated with it, but they are low.
2	Slight safety or regulatory issue, minor impact on customer satisfaction	The failure mode has a slight impact on the product or service. It may cause minor performance issues or inconvenience to the customer. There may be some safety or regulatory non-compliance issues associated with it, but they are minor.
1	No safety or regulatory issue, minor impact on customer satisfaction	The failure mode has little or no impact on the product or service. It may only be a minor inconvenience to the customer, and there are no safety or regulatory non-compliance issues associated with it.

Figure 5 - Severity rating table

Occurrence scale		
Rating	Probability	Criteria
10	Extremely high	1 in 10
9	Very high	1 in 20
8	Repeated failures	1 in 50
7	High	1 in 100
6	Moderately high	1 in 500
5	Moderate	1 in 2000
4	Relatively low	1 in 10,000
3	Low	1 in 100,000
2	Remote	1 in 1,000,000
1	Nearly impossible	Failure is eliminated through preventative control measures

Figure 6 - Occurrence rating table

Detection scale		
Rating	Detection	Criteria
10	Almost impossible	No known controls to detect failure mode.
9	Very remote	Very remote likelihood current controls will detect failure mode.
8	Remote	Remote likelihood current controls will detect failure mode.
7	Very low	Very low likelihood current controls will detect failure mode.
6	Low	Low likelihood current controls will detect failure mode.
5	Moderate	Moderate likelihood current controls will detect failure mode.
4	Moderately high	Moderately high likelihood current controls will detect failure mode.
3	High	High likelihood current controls will detect failure mode.
2	Very High	Very high likelihood current controls will detect failure mode.
1	Almost certain	Current controls will almost certainly detect failure. Reliable detection controls are proven on similar processes.

Figure 7 - Detection rating scale

4T hazard response

A method of responding or addressing risk can be found in the 4T approach. The 4T approach uses the responses, 'Tolerate, Treat, Transfer or Terminate'. The tolerate response accepts the risk and indicates that the exposure of the risk may be tolerable without any further action being taken to address the risk. Although, the risk may not be tolerable the ability to resolve the risk may be limited or the cost of addressing the risk may not be proportional to the benefit gained from taking any action to resolve the risk. The treat response to hazards or risks is to address, control and reduce the risks. Although the process that is giving rise to the risk continues, control measures are implemented to constrain or reduce the risk to an acceptable level. To transfer the risk often involves a third party, this can be achieved through conventional insurance methods or employing the services of another party to take on the risk in another way or engaging them to undertake the task that pose the risk. The terminate response to controlling a risk is to completely stop the activity posing that risk to avoid and eliminate the hazard. This may be the only option to contain the risk and reduce to an acceptable level, this method can be difficult to implement depending on the industry.

The risk matrix below indicates the response of each of the 4Ts in relation to the likelihood and impact of risk. Low risk, low likelihood indicates a tolerate response, high likelihood with a low impact indicates a treat response, low likelihood with a high impact suggests a transfer response while a high likelihood and high impact indicates a terminate response (Hopkin, 2017)

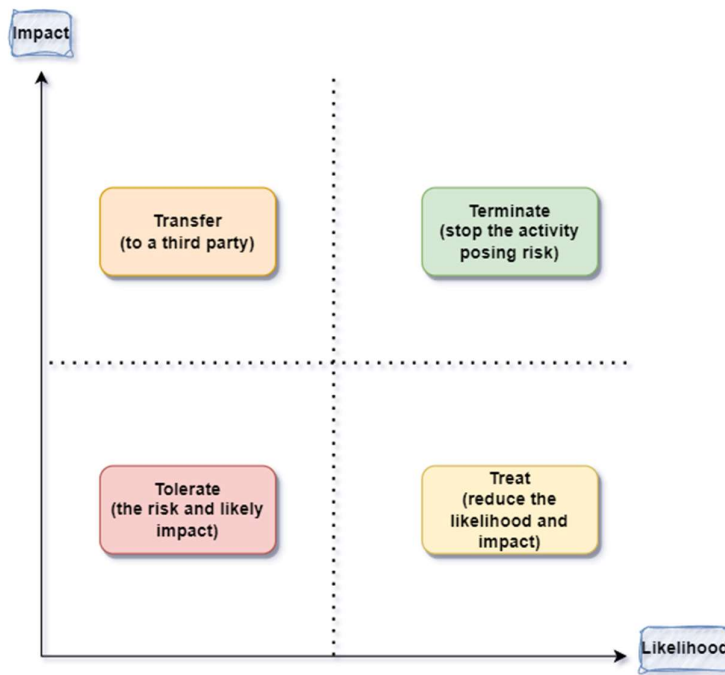


Figure 8 - 4T risk matrix

The control methods associated with each of the 4T responses include preventative measures to terminate a risk. This response limits the possibility of an undesirable outcome being faced. The more important it is to stop an undesired outcome the more preventative controls will be put in place to irradiate the risk being faced at all. Corrective actions are used to treat the risk, these actions limit the amount of loss faced when they have been realised but also contribute to recovering the damage incurred. Directive control is used to transfer the risk to another party, this is instruction based but dependent on the people engaged to follow safe systems of work. Detective controls are introduced when tolerable undesirable outcomes have been realised, this control is based after the event and are only suitable when loss or damage can be accepted.

The hazard risk zones below show at which points between likelihood and impact each stage of risk control should be implemented. The graph shows that the comfort zone is where there is low impact and low likelihood, the cautions and concerned zones merge into a central zone but is dependent on the impact levels of the risk (Hopkin, 2017).

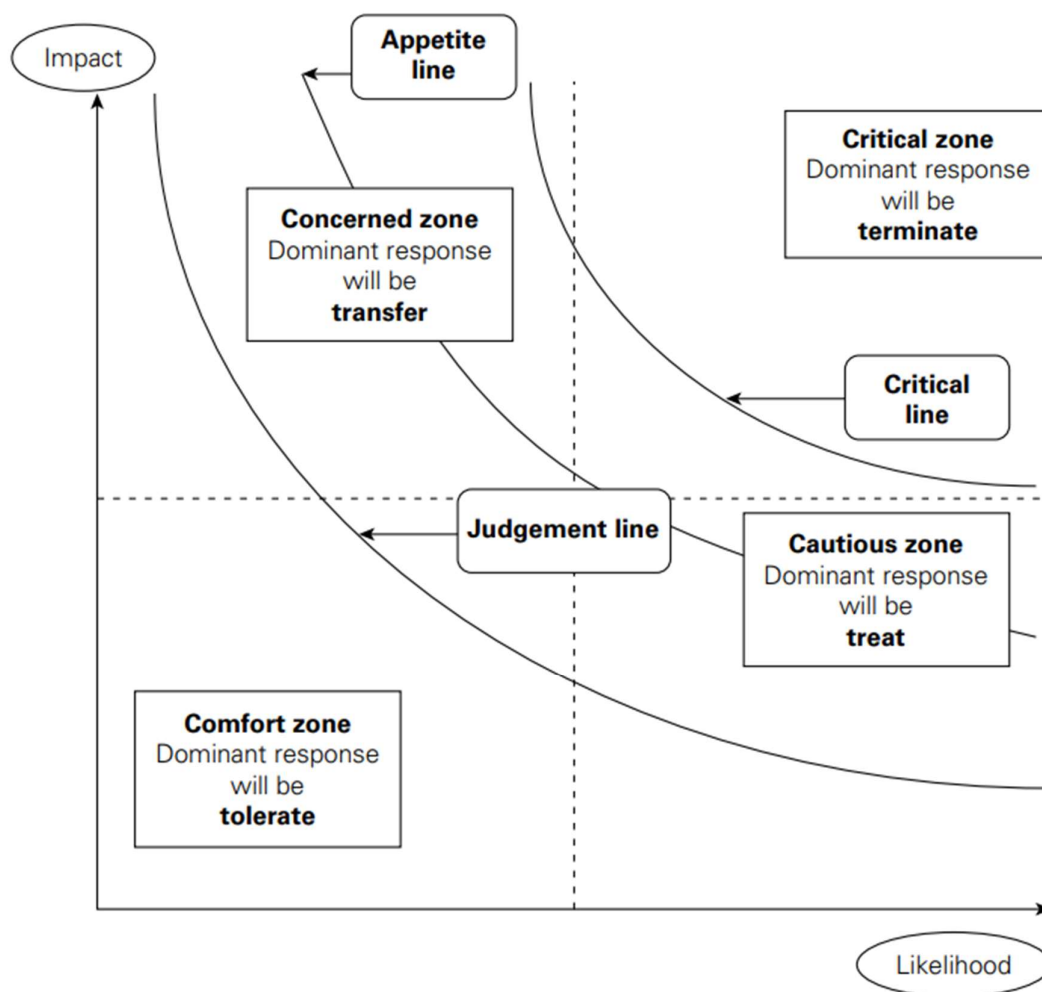


Figure 9 - 4T hazard risk zones

Risk Register

A risk register is a document and tool used within project management to identify, assess, and prioritise risks that could have a detrimental impact on the success of a project. A risk register is a fundamental part of a project as it allows key stakeholders to identify and take steps to mitigate, reduce or manage the potential risks within the project. The document allows for the project to be audited and can aid in providing historical data of the project to enable learning, improve communication and increase the probability of success (Patterson & Neailey, 2002)

The key elements to be included in a risk register are detailed in the figure below. They include a risk ID number, a description of the risk, the person responsible for the risk, the event that triggers the risk to be highlighted, the area of the project to be effected, the probability of occurrence, the impact or severity level on the project, a totalised risk score (probability x impact), the expected result, the type of risk response, the trigger that will initiate a response to be undertaken, the person who will implement the response, a description of the response to be implemented and the expected outcome when the response has been completed.

Project 01 Risk Register														
Positive Risk Response Options		Exploit	Share	Enhance	Accept	Risk Something which has not happened, but might								
Negative Risk Response Options		Avoid	Transfer	Mitigate	Accept	Issue Something which has already happened								
Alternate Response Options		Contingency				No longer active								
Risk ID	Description	Risk Owner	Risk Trigger	Risk Category	Probability (1-3)	Impact (1-3)	PI Score	Expected Result, No Action	Risk Response Type	Response Trigger	Response Owner	Response Description	Expected Impact of Response	
	Description of the risk	Name of person who monitors the risk	How you know the risk is becoming an issue or has reached a point that requires action.	Group defines the types of risks (technology, financial, staffing, etc.)	Group sourced rough estimate of how likely this is to occur	Group sourced rough estimate of how significant the impact of this risk will be if/when it becomes an issue	Probability multiplied by Impact	What will happen if the risk becomes an issue and no action is taken	Decision made by group on how to respond to this risk (see above in blue)	How do you know it is time to put the response into play	Who is responsible for initiating the response	What is the response	What do you expect will result from the response	
SF01	Key materials for the project to progress have been delayed.	John Smith.	Delivery date update from product supplier has slipped due to shortage of raw material required to produce component parts.	Financial/ Project delivery	2	3	6	We will not be able to deliver the project within the agreed timeline and incur liquidated damage costs.	Contingency	Further slippage of equipment delivery date will delay project.	Shaun Farthing.	Order equipment from another supplier before delay causing date cut off.	The response will incur costs from ordering of additional equipment, but will be less than incurred if project is not delivered on time. Claim to be made against original equipment supplier.	

Figure 10 - Risk Register

Decision trees

When approaching a project, there are often several routes that could be taken to the end goal, projects are a multi-phase decision process. The decision tree technique is a model that is widely used for this application. The method assumes that for each decision, there are a finite number of options to review (Nowak, 2017). The image below depicts the layout of a typical decision tree.

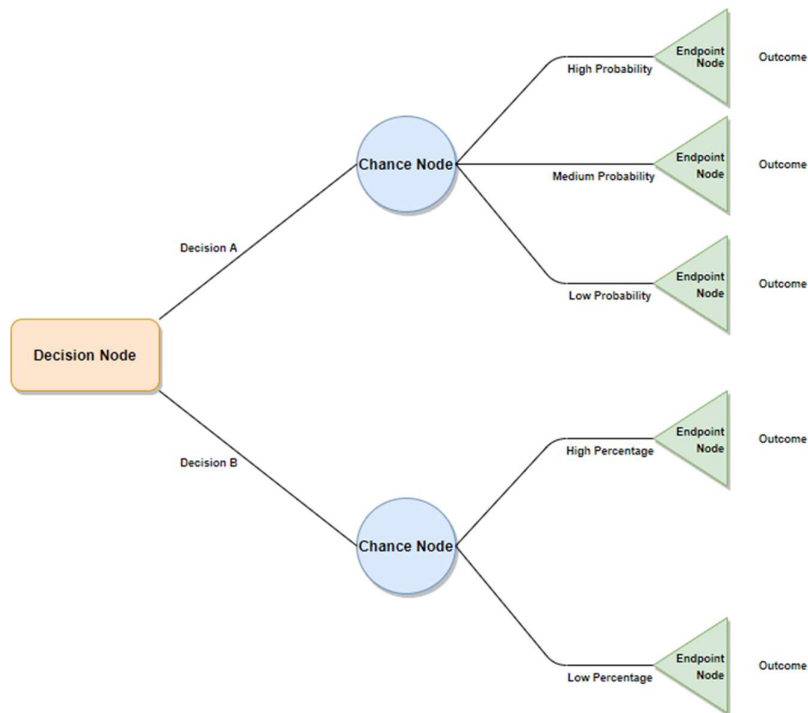


Figure 11 - Decision Tree

The decision tree has 4 elements, decision nodes, chance nodes, end nodes and branches. The decision node indicates where there is a choice to be made, the chance nodes show uncertain outcomes, end nodes show the end point/ outcome, and, finally, there are branches, these join the nodes together (Thomas, 2022). The decision tree gives clarity through simple layouts, they are efficient because information can be input easily, and they can be adapted for multiple uses.

Contingency Planning

Contingency planning is an actionable plan that can be used for when a risk materialises causing delays to the progress of a project. Contingency planning does not necessarily mean that there is no confidence in the original project plan, it shows a dedication to the level of detail required to ensure that the project runs as planned, and ensures maximum preparation to deal with the issues if they arise (Wilson, 2022)

Although contingency planning forms part of the risk management process, risk management focuses on identifying and mitigating the risks, whereas contingency planning is the strategy that should be used to overcome the risk that has arisen (Wilson, 2022)

There are two approaches that can be used for estimating the cost of contingency, these are deterministic and probabilistic methods. The deterministic approach is more traditional, this method expresses risk contingency as a percentage of the project, generally, the initial stages will be larger as there will be more areas producing a higher number of risks, the percentage will decrease as the project develops, as the work scope is being completed, therefore, there are less elements contributing to the potential of risk. The probabilistic method breaks down the elements of costs contributing to the project and assigns them a probability distribution function (PDF). The PDF relates to the actual value of the task being undertaken, if the task was to be carried out more than once, this will then give a cumulative value to that task. This can be used to indicate potential increase or decrease to project cost based on changes to the cost components. There are different approaches to this method, one of them is expected value, where it is assumed that all risks to the project are adequately identified, this method calculates the impact value and probability of occurrence. These are then classified into variable or fixed risks, all the risks are evaluated on the maximum and average risk values, the average value is entered as the risk contingency value for the project. Method of moment is another method that goes a little further and calculates the standard deviation for each of the risks and the average and maximum risk values. The final value is expressed as a continuous probability distribution. Monte Carlo simulation simulates and trials the project, assigns a chosen value to each cost component depending on the parameters of the probability distribution. The values are summed to produce the project cost. This method is simple, understandable, and easy to use (Akinradewo, et al., 2019)

The figure below details a typical contingency table details the risk, probability, preparation task and response action.

<i>Risk</i>	<i>Probability</i>	<i>Preparation</i>	<i>Response</i>
Many employees call in sick.	High	Collect employee phone numbers or emails so you can contact them for an unscheduled shift.	Immediately contact employees requesting them to come in for an unscheduled shift.

Figure 12 - Contingency Plan Table

Project specific risks within the electrical engineering sector

Although there are many elements that are common risks within project delivery generally. The items below are more specific with the electrical engineering contracting industry.

Material supply

Naturally, to complete electrical engineering projects, various materials are going to be required. These range from metal work required for cable containment, electrical enclosures and supporting structures, to copper and PVC for cables and more specific, specialist material used in PCBs, control components and switch gear. The highest risk factors in relation to material supply are:

1. **Component shortages:** Electrical engineering relies on a wide range of components, from semiconductors and cables to transformers and circuit breakers. Shortages of these components, driven by factors such as increased demand, supply chain disruptions, or geopolitical issues, can delay projects and increase costs.
2. **Lead times:** Long lead times for critical electrical components can hinder project schedules. Manufacturers may have extended delivery times, especially for specialized or custom components.
3. **Price fluctuations:** The cost of electrical components can vary due to market conditions, changes in materials costs, and fluctuations in currency exchange rates. These price fluctuations can impact project budgets and profitability.
4. **Quality control and counterfeit products:** Ensuring the authenticity and quality of electrical components is crucial to the safety and reliability of electrical systems. Counterfeit or substandard components can lead to system failures and safety hazards.
5. **Environmental regulations:** Environmental regulations, such as RoHS (Restriction of Hazardous Substances), can restrict the use of certain materials in electrical components. Complying with these regulations may require sourcing alternative materials, which can be challenging and time consuming.
6. **Supply chain disruptions:** Natural disasters, geopolitical conflicts, labour strikes, and other disruptions in the global supply chain can impact the availability of electrical components and materials. Electrical engineering projects that rely on just-in-time inventory systems may be particularly vulnerable to these disruptions.
7. **Transportation and logistics:** Efficient transportation and logistics are essential for the timely delivery of electrical materials and components. Delays in shipping, customs clearance, or transportation issues can affect project timelines.

8. Qualification and certification: Ensuring that materials meet relevant standards, certifications, and safety requirements is a critical part of electrical engineering. Delays in obtaining the necessary qualifications or certifications can slow down projects.
9. Research and development challenges: In some cases, new technologies or materials may not be readily available or thoroughly tested for electrical engineering applications, making it difficult to adopt innovative solutions.
10. Economic factors: Economic conditions, such as inflation and economic instability, can impact the cost and availability of materials for electrical engineering projects.

To address these supply difficulties, electrical engineers and project managers need to carefully plan, source materials from reliable suppliers, consider alternative components, maintain buffer stocks, and stay informed about market trends and regulatory changes. Additionally, developing resilient supply chain strategies and diversifying sources of supply can help mitigate some of these challenges.

Resource

Labour resource difficulties in electrical engineering projects can arise from various factors, and addressing these challenges is crucial for successful project execution. Some common difficulties in managing labour resources in electrical engineering projects include:

1. **Skilled Labour Shortages:** Finding and retaining skilled electrical engineers, technicians, and labourers with the necessary expertise can be challenging. Skilled labour shortages can lead to delays and increased labour costs.
2. **Project Complexity:** Electrical engineering projects can be highly complex, especially in areas like power distribution, renewable energy, or industrial automation. Complex projects require skilled labour with specific knowledge and experience.
3. **Changing Regulations:** Electrical engineering projects are subject to strict safety and regulatory standards. Adapting to changing regulations and ensuring compliance can be time-consuming and costly. Projects undertaken that do not conform to the correct standards can incur additional costs through delays and remediation work, this in turn will affect programme and profitability.
4. **Workforce Productivity:** Ensuring that the workforce remains productive and motivated throughout the project is essential. Productivity issues can arise due to various factors such as poor working conditions, lack of training, or communication problems. Lack of productivity will increase the programme duration and in turn cause additional cost through labour charges and liquidated damages if milestones are not met.
5. **Workforce Scheduling:** Efficiently scheduling and managing the labour force to meet project deadlines can be challenging, especially in projects with numerous tasks and dependencies. A balance of the correct resource and quantity must be managed to ensure required progress whilst not using unnecessary allocated resource hours.
6. **Remote Work and Collaboration:** In some cases, electrical engineering projects may require collaboration among team members spread across different geographic locations. Coordinating remote work can be challenging and may require the use of technology and effective communication tools.
7. **Subcontractor Coordination:** Large electrical engineering projects often involve subcontractors for specialized tasks, such as civil and mechanical engineers or system integrators. Coordinating subcontractors and ensuring they meet project timelines and quality standards can be challenging.
8. **Safety Concerns:** Electrical engineering projects can be hazardous, so maintaining a strong focus on safety is essential. Ensuring that all labour resources adhere to safety protocols and have the necessary training is vital.

9. Budget Constraints: Managing labour resources within budget constraints is a common challenge. Labour costs can escalate due to factors like overtime, delays, or unforeseen project changes.
10. Technology Advancements: The rapid evolution of technology in the electrical engineering field may require ongoing training and skill development for the workforce to keep up with the latest tools and methodologies.

To address these labour resource difficulties, project managers and engineering teams should prioritize proper planning, training, communication, and safety measures. Leveraging project management software, regularly updating workforce skills, and maintaining open lines of communication can help mitigate these challenges and lead to the successful completion of electrical engineering projects.

Technical difficulties, lack of clarity and design change

In electrical engineering projects, as in many other technical fields, there are specific risks associated with technical requirements, lack of clarity, and changes in design. These risks can impact project timelines, budgets, and overall success. Below lists some of the key risks associated with each of these factors:

1. Technical Requirements:
 - a. Incomplete or inaccurate requirements: If the initial project requirements are not well-defined, incomplete, or contain errors, it can lead to misunderstandings and misalignments between the project team and stakeholders, resulting in suboptimal solutions.
 - b. Scope creep: Changes and additions to technical requirements during the project can lead to scope creep, which can increase project costs, extend timelines, and introduce complexity.
2. Lack of Clarity:
 - a. Misinterpretation: When project requirements are not clearly defined, there is a risk of misinterpretation, which can result in design and implementation errors.
 - b. Ambiguity: Ambiguous requirements can lead to different team members interpreting the same specifications in different ways, potentially causing confusion and rework.
 - c. Delays in decision-making: Lack of clarity in technical requirements can lead to delays in decision-making as stakeholders attempt to resolve ambiguities or conflicting interpretations.
3. Changes in Design:
 - a. Increased costs: Frequent design changes can result in increased engineering and construction costs due to the need for additional materials, labour, and equipment.
 - b. Project delays: Frequent design changes can cause project delays as the team must rework existing designs or start over, pushing back the project schedule.
 - c. Reduced system reliability: Frequent changes in design can introduce complexities that reduce the reliability and robustness of the electrical system.

To help mitigate these risks in electrical engineering projects, it's important to:

- Begin with a well-defined and comprehensive set of technical requirements, and involve all relevant stakeholders in their development.
- Maintain clear and open communication channels between the project team and stakeholders to address any ambiguities or issues promptly.

- Implement a change control process to manage design changes effectively, ensuring that they are well-documented, evaluated for impact, and approved by the appropriate authorities.
- Utilise project management tools and methodologies to monitor and control scope, schedule, and budget.

Additionally, conducting risk assessments and regularly reviewing project progress against the initial requirements can help identify and address potential issues before they significantly impact the project.

Scope growth and changes

Scope growth in electrical engineering projects can introduce various risks that may impact the project's success. Specific risks in electrical engineering are:

1. **Schedule Delays:** Additional work due to scope growth can extend the project timeline. Delays may occur if the project team is not adequately prepared or if the new requirements significantly impact the original schedule.
2. **Budget Overruns:** Scope growth often leads to increased costs for materials, labour, and other resources. If the budget was not initially designed to accommodate the expanded scope, it may result in financial challenges for the project.
3. **Resource Constraints:** The sudden expansion of project scope can strain the availability of skilled personnel, equipment, or materials. This can lead to difficulties in managing and executing the additional work efficiently.
4. **Quality Issues:** Rapid changes in project scope may compromise the quality of work if the team is not given sufficient time to assess and implement the required changes. This can result in subpar performance or even safety concerns in electrical engineering projects.
5. **Communication Breakdowns:** In projects with scope growth, effective communication becomes even more critical. If there are misunderstandings or insufficient communication about the changes, it can lead to errors, rework, and potential conflicts within the project team.
6. **Integration Challenges:** Additional scope may require integration with existing systems or components. This can be complex and may lead to compatibility issues, requiring additional time and resources to ensure seamless integration.
7. **Contractual Issues:** Scope changes may have contractual implications, leading to disputes between project stakeholders. This can include disagreements over payment, timelines, and the responsibilities of each party involved.
8. **Regulatory Compliance:** Changes in scope may introduce new regulatory requirements or necessitate modifications to existing compliance measures. Failure to address these changes properly can lead to legal and regulatory issues.
9. **Technology Risks:** If the scope growth involves the adoption of new technologies, there may be risks associated with their implementation, including technical challenges, compatibility issues, and a learning curve for the project team.
10. **Stakeholder Dissatisfaction:** Project stakeholders, including clients and end-users, may become dissatisfied if the scope changes affect their expectations. Managing stakeholder expectations and obtaining their approval for scope changes is crucial to maintaining project support.

To mitigate these risks, it's essential to have a robust change management process in place, conduct thorough impact assessments before approving scope changes, and communicate effectively with all project stakeholders throughout the project lifecycle.

Insufficient Front End Engineering Design (FEED)

Front-End Engineering Design (FEED) is a crucial phase in the project life cycle, especially in the electrical engineering sector. A lack of FEED can introduce various risks and challenges that may impact the project's success.

1. **Incomplete Project Scope:** Without a comprehensive FEED, the project scope may be inadequately defined. Lack of clarity on project requirements can lead to misunderstandings, changes, and scope creep during later stages.
2. **Budget Overruns:** Incomplete understanding of project requirements can result in inaccurate cost estimates. Without a thorough FEED, it is challenging to identify and account for all necessary electrical components, materials, and labour costs.
3. **Schedule Delays:** Inadequate planning and foresight during FEED can lead to delays in the project timeline. Unforeseen challenges may arise during detailed design and construction, causing schedule disruptions.
4. **Design Changes:** A lack of detailed engineering specifications can lead to frequent design changes during later stages. Changes in design can result in rework, delays, and increased costs.
5. **Safety and Compliance Issues:** Incomplete FEED may result in overlooking safety and regulatory compliance requirements. Failure to address these issues early in the project can lead to redesigns, reworks, and legal complications.
6. **Quality Assurance Challenges:** Without a well-defined FEED, it may be challenging to establish quality assurance processes and standards. Inadequate quality controls can result in suboptimal electrical systems and potential operational issues.
7. **Vendor/Supplier Issues:** Lack of detailed specifications in the FEED can lead to difficulties in selecting appropriate vendors and suppliers. Incompatibility issues or the need for last-minute changes can arise when working with suppliers.
8. **Resource Allocation Problems:** Incomplete FEED may make it difficult to accurately estimate resource requirements, including manpower and equipment. Poor resource planning can lead to shortages, bottlenecks, and inefficiencies.
9. **Communication Breakdowns:** Insufficient documentation and communication during the FEED phase can lead to misunderstandings among project stakeholders. Clear communication is essential for successful project execution.
10. **Operational and Maintenance Challenges:** Inadequate consideration of long-term operational and maintenance requirements during FEED may result in suboptimal system performance. Lack of attention to these aspects can increase the total cost of ownership over the project's life cycle.

To mitigate these risks, it is crucial to invest time and effort in the FEED phase to thoroughly define project requirements, assess potential challenges, and establish a solid foundation for the subsequent stages of the project.

Quality standards

Poor quality standards in the electrical engineering sector can pose various project risks that can impact safety, reliability, and overall project success. This issue can arise from the material supply and the UKCA standards not being met but also from substandard workmanship. Some specific project risks inherent with this are:

1. Safety Hazards:
 - a. Electrical Shock and Fire Hazards: Substandard materials and poor workmanship can lead to electrical faults, increasing the risk of shocks and fires.
 - b. Malfunctioning Equipment: Poorly designed or manufactured electrical components may malfunction, leading to hazardous conditions.
2. Reliability Issues:
 - a. System Failures: Inadequate quality control may result in the production of unreliable electrical systems that are prone to failure, causing disruptions and downtime.
 - b. Equipment Breakdowns: Poor-quality components can lead to premature equipment failures, requiring frequent maintenance and replacements.
3. Compliance and Legal Issues:
 - a. Regulations Violations: Failure to meet industry standards and electrical regulations may result in legal consequences, fines, and project delays.
 - b. Regulatory Non-Compliance: Poor quality may lead to non-compliance with safety and environmental regulations, causing legal challenges and project setbacks.
4. Cost Overruns:
 - a. Rework and Repairs: Poor quality may necessitate rework and repairs, increasing project costs significantly.
 - b. Warranty Claims: Defective components may lead to warranty claims, resulting in additional expenses for the project.
5. Project Delays:
 - a. Redesign and Retrofitting: Discovering quality issues late in the project may require redesign and retrofitting, causing delays in project timelines.
 - b. Inspection and Approval Delays: Frequent inspections and rework may delay project approvals, pushing back completion dates.
6. Reputation Damage:
 - a. Client Dissatisfaction: Poor-quality electrical systems can lead to client dissatisfaction, damaging the reputation of the engineering firm.
 - b. Loss of Future Opportunities: Negative publicity and poor project outcomes may lead to a loss of future business opportunities.
7. Supply Chain Risks:
 - a. Vendor Reliability: Poor quality standards in the supply chain can lead to unreliable vendors, causing disruptions in the procurement of materials.

- b. Counterfeit Components: The use of substandard or counterfeit components can compromise the integrity and performance of the electrical systems.
- 8. Environmental Impact:
 - a. Waste and Pollution: Poor manufacturing processes and materials may contribute to environmental pollution and waste, leading to environmental compliance issues.

To mitigate these risks, it's crucial for electrical engineering projects to adhere to high-quality standards, conduct thorough testing and inspections, and ensure compliance with industry regulations and codes. Establishing a robust quality management system and fostering a culture of quality within the organization are essential components of successful risk mitigation in the electrical engineering sector.

Safety standards

Poor safety standards in the electrical engineering sector can pose significant risks to both the workers and the overall project.

1. Worker Safety:
 - a. Electrocution: Inadequate safety measures may lead to electric shocks, which can result in severe injuries or fatalities.
 - b. Burns and Fires: Poor safety practices increase the risk of electrical fires and burns, jeopardizing the well-being of workers.
2. Legal and Regulatory Compliance:
 - a. Penalties and Fines: Non-compliance with safety regulations may lead to legal consequences, including fines and penalties, which can impact project costs and timelines.
3. Project Delays:
 - a. Accidents and Investigations: Worksite accidents may trigger investigations and shutdowns, causing delays in project timelines.
 - b. Reputation Damage: Delays and accidents can damage the reputation of the project and the companies involved.
4. Increased Costs:
 - a. Medical Expenses: Injuries result in medical expenses for affected workers, potentially leading to increased project costs.
 - b. Insurance Premiums: Poor safety records can result in higher insurance premiums, affecting the overall project budget.
5. Worker Productivity:
 - a. Stress and Morale: A lack of safety measures can lead to increased stress among workers, affecting morale and productivity.
 - b. Absenteeism: Injuries may lead to absenteeism, impacting the workforce and potentially causing delays.
6. Equipment Damage:
 - a. Electrical System Failures: Unsafe practices can lead to equipment failures and damage, requiring repairs and replacements, which can be costly.
7. Litigation:
 - a. Lawsuits: Injuries or fatalities may result in legal action against the project or the companies involved, leading to additional financial and reputational risks.
8. Quality of Work:
 - a. Distraction and Frustration: Unsafe working conditions can distract workers and lead to frustration, potentially impacting the quality of their work.
9. Environmental Impact:
 - a. Accidental Releases: Electrical incidents may lead to environmental hazards, affecting the surrounding ecosystem and potentially resulting in additional cleanup costs.

10. Project Abandonment:

- a. Regulatory Shutdowns: Serious safety violations may lead to regulatory shutdowns, forcing the project to be abandoned or suspended.

To mitigate these risks, it's crucial for electrical engineering projects to adhere to strict safety standards, provide comprehensive training for workers, conduct regular safety inspections, and prioritize a culture of safety throughout the organization.

Theft

Theft in the electrical engineering sector can pose significant risks to projects, affecting both the progress and the overall success of the endeavours.

Material Loss:

1. **Copper Theft:** Copper is a valuable material used in electrical components. Theft of copper cables, wiring, or other components can lead to material loss, requiring replacement and causing delays in project timelines.

Financial Impact:

2. **Cost Overruns:** The replacement of stolen materials, repairs, and additional security measures can lead to unexpected costs, causing budget overruns that may impact the financial health of the project.

Project Delays:

3. **Replacement Time:** The time required to replace stolen materials can result in project delays. Delays may affect deadlines, client expectations, and overall project schedules.

Security Costs:

4. **Increased Security Measures:** To mitigate theft risks, projects may need to invest in enhanced security measures such as surveillance systems, security personnel, and access control. These additional costs can impact the project budget.

Safety Concerns:

5. **Unsafe Conditions:** Theft may result in compromised electrical systems, leading to unsafe working conditions for both workers and the general public. Addressing safety concerns may require additional time and resources.

Reputation Damage:

6. **Client Perception:** Theft incidents can harm the reputation of the electrical engineering firm, affecting client trust and confidence. Clients may question the ability of the firm to manage projects securely.

Insurance Premiums:

7. **Increased Insurance Costs:** Frequent theft incidents may lead to higher insurance premiums for the project, impacting the overall cost of project management.

Legal Consequences:

8. **Liability Issues:** Theft may result in legal issues, especially if the stolen materials cause harm or damage. The project may face liability claims and legal proceedings.

Data Security Risks:

9. **Intellectual Property Theft:** Theft of sensitive project information, designs, or intellectual property can occur, posing risks to the company's competitiveness and potentially leading to legal disputes.

Supply Chain Disruption:

10. Supplier Relationships: Theft of materials from suppliers or during transportation can disrupt the supply chain, leading to delays in obtaining necessary components for the project.

Environmental Impact:

11. Improper Disposal: Stolen electrical components may be improperly disposed of, leading to environmental hazards and potential legal consequences.

To mitigate these risks, electrical engineering projects should implement comprehensive security measures, including surveillance, access control, and collaboration with law enforcement. Additionally, insurance coverage and contractual agreements can be structured to address potential theft-related issues.

Case Study – Hydrogen plant Germany

The project detailed in this case study was carried out in the Mannheim area of Germany. The overall scope of the project was to provide electrical and instrument services for a new build process plant that produced industrial grade and ultra-high purity hydrogen using three purifiers. The hydrogen was a by-product from a nearby chemical company that provides 4000 cubic m/h of hydrogen to the site where it is then purified. The process then sees it being compressed up to 600 bar and distributed over ten loading bays into road tanker trailers.

The electrical, control and instrument remit of this project was:

- Supply of installation equipment (cable containment, cables, control panels, junction boxes and specialist installation equipment)
- Electrical installation
- Testing
- Hazardous area inspections
- Loop checking
- Commissioning

The difficulties faced during this project are discussed and evaluated below.

Contract

The contract entered in this project was using the client's standards terms and conditions and was not investigated or scrutinised thoroughly enough. This posed difficulties during this project as there were many dependencies on third party interaction around work faces and payment structure. The contract did not allow flexibility for deviation, changes and payment application. The terms in the contract were also ambiguous and vague causing misunderstanding and disputes during the project. The risk allocation of the project in terms of liquidated damages were not thoroughly reviewed and the bearing that other contractors and the client had on the milestones being reached were unrealistic and not negotiated. The communication channels with the European client often proved inefficient with a clarity and misunderstanding particularly in relation to the legal aspects of the contract with the complex terminology for non-legal professionals around understanding of terms and conditions and misinterpretations.

Import/ export of material and equipment

The project required specific and specialist items of material and equipment to be sent from the UK into Germany. Since Brexit, the UK is no longer part of the EU customs union, this imposed difficulties around declarations, tariffs and other customs procedures to enable the moving of goods and equipment between the UK and Germany. Tariffs and duties needed to be paid for material, this was not accounted for in the project quotation. Declarations of product details for all equipment to be transported were to be produced, this required specific commodity codes (HS numbers) which we had to contact various manufacturers and suppliers for to ensure they matched the items being transported, this incurred a vast amount of labour hours that hadn't been allowed for. Customs also required a 'buyer' for the material being transported, this was another element that was unknown, this was not realised until the transport vehicle was at the customs gate, this further delayed the transport of material as we had to arrange and complete the relevant documentation with the client. Disruption in transport crossings due to operational issues as a result of poor weather also contributed to delays in travel and transport of material and equipment.

Installation standards

The standard of the electrical installation was based on British Standards, although these are based on international electrical standards, the client had expectations of their standard practices that were not in keeping with the levels of workmanship expected. Part of the work scope required inspection of a third-party contractors work that was appointed by the client. On inspection, some of the work did not meet the standards that were expected. This created difficulties in the inability to sign off this element as fit for purpose. This was encountered as there was discrepancies with technical specification, product certification, installation standards and competency of the staff installing this equipment, documentation and audit process as well as language and cultural barriers.

Project complexity

Due to the nature of the project, and specifically in relation to the operation of the plant. The complexities around the integration of equipment being supplied by multiple parties caused difficulties and misunderstanding. As different elements in relation to equipment was being supplied by various parties, the way in which it interacted was misunderstood. Adaptions had to be made to allow the equipment to operate as required. This was caused by different parties' interpretation of the system and how it operated. This caused additional works in that extra cables were required which incurred additional time and material. The lack of prior engagement and technical review between all stakeholders contributed to the misunderstanding of operation of this complex project.

Supporting services

The project required some high-level working and as a result required access equipment in the form of scaffold and mobile elevated working platforms. Due to the geographical difficulties and holding accounts with local contractors, the client provided these supporting services. This posed some difficulties that were not envisaged prior to starting the project. The scaffolding service provider was directly contracted by the client, and, as a result needed to be instructed by the client to modify and install scaffolding structures. We could not instruct the supplier ourselves as their contract was with our client, this caused delays in installation and modification of scaffold as well as misinterpretation of requirements. The scaffold installation did not always meet the safety requirements that are adapted in the UK, again causing delay through modification, discussion and consultations. The provision of mobile elevated working platforms was also supplied by the client. One machine was provided for the contract, this was not suitable for all areas that required access, it was an insufficient quantity for the amount of personnel requiring to use it and was often unusable due to faults. Debates with the client on providing additional machines and timely repair of the machine onsite caused significant delays in accessing and installing equipment in areas requiring this equipment.

Procuring additional material in the EU

Prior to starting the project, consideration was given to using an electrical wholesaler who the company had a UK account with, but they have branches throughout Europe. Although, the majority of the materials required to deliver the project were procured in the UK and shipped in a shipping container to the site prior to the project beginning, due to the additional works and some materials required not being considered at the time of order, additional material was required during the delivery of the project. This was assumed to be a simple process as the company had an account with the supplier in the UK, who had a branch local to the worksite, however when placing the order for the first additional materials,

difficulties were faced. As the account was held with the UK branch, orders had to be booked through the UK, this caused delays in the order of material as there was additional persons involved. Then, it was learned that the branch locally doesn't stock the material that we were largely using, this meant they had to source it from another branch, which caused further delay. Once the material was sourced, it was then learned that the branch does not have daily deliveries to the project area, this then implemented even further delays with delivery timings. Although, there were other suppliers locally, they would not deal with UK companies that did not hold a German bank account.

Accommodation costs/ Fluctuating travel costs

During the bid and quotation stage of the project, costs were allocated on a fix sum basis per night for accommodation and per journey for travel to and from the UK. This cost was based on average. During the process, a booking agent was used to manage this element, the agents' costs were not considered and the levels of fluctuation were underestimated causing increased costs that had not be accounted for.

Visa/ working time difficulties

The project was being carried out in the Schengen area of the European commission; this area comprises of 27 countries. UK citizens are only able to stay in the area for 90 days within a 180-day period. This was not considered at the proposal stage. This caused difficulties in rotating the project team to ensure nobody exceeded their allowed time in the area. This contributed to additional travel costs due to staff rotation and also caused issues in relation to knowledge gaps on the project requirements, progress and decision making. All employees also required additional insurance for working in the area. The area also only allowed 10-hour daily working, 6 days per week. It was understood prior to the project beginning that 7-day working was allowed, local council policy prohibited this and as a result, no work was undertaken on Sundays, this caused reduced progress for the team during their 90-day working period.

Other working parties

As with the majority of projects, there were multiple working parties completing different elements of the project. This project had a civils team, mechanical team, specialist fire protection company, process operators, commission teams as well as the electrical and instrumentation team. These different elements were managed by different managers. Each individual team had an agenda to complete their work scope, communications between working parties and their leaders was not sufficient. Frequently, there was a clash in the working areas where multiple teams were trying to work in the same area, this caused delays in starting and restarting in different work areas. Time was lost through this process, setting up equipment, gathering the material to undertake the task and arranging the labour required to do those tasks. Collaborative planning and designating work areas was not thorough and effective.

Permits/ setting to work

The permit system on this project was generic, with general site risks addressed and a general permit to work issued. This system didn't account for the multiple working parties and their interaction with each other, with work areas often becoming congested with multiple working parties. During the commissioning phase of the project, the permit system became cumbersome due to the interaction of multiple work parties, working on the same systems when trying to introduce energy sources, the process was slow and inefficient. The exercise missed the combined, collaborative approach.

Liquidated damages

The contract for this project contained a liquidated damage clause. The steps to invoke this clause were not thoroughly investigated or disputed prior to entering the contract. The LD did not have links to programme delays, additional works or delays incurred as a result of third-party involvement. This made the clause difficult to dispute when the project was underway. As a result, additional labour was sourced to meet the delivery dates detailed on the LD clause, this in turn resulted in additional labour costs and travel and accommodation costs.

Seasons effect on labour

This project started in September and continued through into the new year and into the following summer. This duration, specifically at times where we were working during holiday seasons caused restraints on labour resource. Personnel had holidays pre-planned, this caused issues with maintaining the required labour levels to meet the project program, particularly with employees that had particular skill sets and those doing a supervisory role. The company also had a policy with the carrying over of holidays into the new year, so those with excess holidays over the carry over allowance also had to use holidays before the year end, this also added to the labour restraint. Labour resource was also affected by personnel that had holidays booked within the Schengen area, as time within this region is limited to 90 days within a 180-day period, those who also had holidays booked in this area had to reduce their working time on the project to ensure they had sufficient time remaining in the area for their holiday.

Conclusion of case study

To conclude the observations found in the case study on the hydrogen plant project, there are many failings that I feel could have been addressed to improve the outcome of the project. I feel that the communication between all stakeholders was not efficient enough. A combined project review with all parties, client and all sub-contractors should have been completed. A thorough review of the contract document with a suitably trained specialist could have allowed for better terms being negotiated, the clauses could have been agreed in a fairer manner for all contract members, liquidated damage terms could have been altered so that effects from other contractors did not affect the timeline agreed for the electrical scope of works. Payment milestones based on specific measures of work could have been agreed to improve the cash flow on the business. A specific risk reduction meeting and review should have been undertaken to consider and reduce all factors effecting the legal and financial liabilities associated with the project. With regard to the importation of material, earlier engagement and collaboration with the supply chain could have prevented the difficulties faced when shipping material. Specific codes for all material and the associated documentation could have been arranged in advance to prevent the delays faced. A specific procurement service with specialists in the field of international shipping would have prevented the issue faced. Prior agreement with the client to accept the products as a buyer should have also been arranged. The difficulties faced in relation to the standard of installation required by third party interaction with our equipment should have been discussed beforehand. The standards that we required to be able to certify the installation should have been made clear, and documented as part of a pre start meeting. This would have removed any ambiguity and made the requirements clear and particular. There was a lack of clarity and a misunderstanding regarding cultural barriers and expectations, a detailed, collaborative discussion should have been undertaken prior to project start. The project complexity issues stemmed from insufficient design review on issue of engineering construction and system operating documents. An engineering review with engineers present from the multiple disciplines required on this project should have been undertaken and the

documents scrutinised to ensure that the required operational outcomes could have been achieved with the design submitted. If, as found, this was not the case, a further meeting with the client and design authority should have been undertaken. Most of the problems encountered could have been rectified prior to starting on a site level. This would have provided a smoother execution of the project whilst minimising delays and the need for additional material and labour resource. On reflection of the supporting services, a clear, defined plan of requirements should have been agreed during a pre start site visit. This would have potentially reduced the waiting time for scaffold etc. Or, we should have taken control of these services and provided them within the electrical contract. This would have given us control to engage with the services provider ourselves and escalate issues more promptly reducing non-productive time. Procuring material within the EU proved difficult as the company did not hold a German bank account. Engagement directly with wholesalers in the area should have been investigated prior to beginning the project. This would have enabled accounts to be set up in advance, reducing the lead time on materials from the UK, therefore, reducing the downtime and associated productivity. Fluctuating costs in relation to travel and accommodation could have been examined and tracked for a longer period of time to gain a better understanding of these markets to allow a more accurate forecast of costs. Alternatively, a pre agreed rate with a travel company could have been agreed for a set duration, this would have allowed for accurate costing. Another option could have been to engage with the client and agree that travel and accommodation costs are captured at cost and reimbursed, this would eliminate over quoting and may have worked out better for both parties. Resource restrictions in relation to the maximum 90-day stay could have been avoided through prior planning and investigation into the area and restriction. This was faced as a result of naivety of international projects and lack of planning. An accurate resource structure plan should have been implemented. This could have been complimented by engaging labour who originate or are citizens within the Schengen area. This would have provided some resilience within the resource pool. Clashes with other working parties working in the same areas of site contributed to severe additional time being incurred, this issue could have been resolved by pre planning the working area activities. This aspect was driven by the client, but engagement with all working parties could have resolved this issue. A planning meeting at the end of the working day to plan the work areas for all contractors the next day would have reduced delays and the remobilisation to other work areas, saving time and delay costs for all contractors. Permit delays were faced due to not having a specified permit issuing authority in place. Having a dedicated resource managing this element would have allowed for a more streamlined issue and sign off process, this would also have reduced non-productive time. The liquidated damages, as with a lot of elements during this project were not given enough of a review by the relevant department. A lack of review for managing the risks that were presented in them implemented, or the elements that were able to be controlled or not controlled contributing to them being implemented. A risk reduction meeting could have highlighted these factors and they could have been addressed prior to accepting the contract. The seasonal effect on the availability of resource was difficult, particularly due to the working time restrictions in the area. This element could have been improved by producing a detailed project plan with individual labour listed against tasks and duration. Prior engagement with employees to determine individuals' availability and restrictions could have prevented this difficulty. Also, having a larger labour pool where personnel could be swapped more regularly could have been beneficial. To summarise, a lack of engagement with specialists in particular areas was missing, sufficient risk management was not carried out and a general lack of planning and appreciation of the difficulties and complexities of the project was not present. Relatively simple steps could have vastly improved the outcome of the project.

Analysis

To analyse the risks faced during the project, a quantitative risk identification matrix has been produced.

The following risk matrix detailing the risks associated with the project have been categorised using the below risk and probability matrixes.

The methods allow for a numerical value to be obtain based on the likelihood and the severity of the outcome.

Likelihood	Impact					Key	
	Negligible or no impact (1)	Minor impact (2)	Moderate impact (3)	Major impact (4)	Catastrophic impact (5)		
Very rare (1)	1	2	3	4	5	1-4	Low
Not likely (2)	2	4	6	8	10	5-10	Medium
Possible (3)	3	6	9	12	15	11-16	Significant
Very likely (4)	4	8	12	16	20	17-25	High
Almost definite (5)	5	10	15	20	25		

Figure 13 - Risk matrix

Likelihood	Consequence				
	Insignificant <i>Risk is easily mitigated by normal process</i>	Minor <i>Delays of up to 10% of schedule and additional cost of up to 10% of budget</i>	Moderate <i>Delays of up to 30% of schedule and additional cost of up to 30% of budget</i>	Moderate <i>Delays of up to 50% of schedule and additional cost of up to 50% of budget</i>	Catastrophic <i>Project abandoned</i>
Certain <i>>90% chance</i>	High	High	Extreme	Extreme	Extreme
Likely <i>50% - 90% chance</i>	Moderate	High	High	Extreme	Extreme
Moderate <i>10% - 50% chance</i>	Low	Moderate	High	Extreme	Extreme
Unlikely <i>3% - 10% chance</i>	Low	Low	Moderate	High	Extreme
Rare <i><3% chance</i>	Low	Low	Moderate	High	High

Figure 14 - Probability matrix

A specific risk matrix has been created detailing the specific risks and hazards associated with the project in Germany. This is detailed below.

Case study risk matrix

Item No.	Hazard	Potential risks	Inherent risk rating (no control measures)	Control measures to reduce risk	Residual risk (with controls)
1	Contract misunderstanding	• Misunderstanding of requirements of obligations. • Relying on other contractors to complete work to allow Hornbill installation. • Payment milestones not agreed, unclear terms. • Ambiguous terminology of requirements, leading to misinterpretation. • Poor communication during contract review. • Liability not fully understood. • Financial loss through LDA not reviewed and agreed. • Performance issues for third parties not scrutinised for effects on Hornbill progress. • Opportunities to gain through early delivery, good safety record not included in terms. • Regulatory compliance not fully understood for deliverables. • Difficulty in dispute resolution.	High	• Thoroughly review the contract, seeking clarification on any terms or concepts that are unclear. • Consult with legal or financial professionals to ensure full understanding before signing. • Negotiate terms that are fair and favorable to all parties involved. • Keep records of all communications and agreements related to the contract. • Regularly review contracts and update them as necessary to reflect changes in circumstances or requirements.	Low
2	Material supply	• Delay of progress. • Incorrect material delivered. • Incorrect quantity of material delivered. • Geopolitical and economic factors. • Natural and environmental factors. • Transport and logistics risks. • Dependencies. • Demand. • Financial risks.	High	• Identify critical material and long lead time items and order in advance. • Collaborate with supply chain. • Evaluate suppliers for being the most suitable, closest warehouse to project in Germany. • Evaluate the vulnerability of the suppliers, previous history of supply and experience. • Research geopolitical and economic factors of the project area to ensure there are no policies or tensions preventing import. • Review transport and logistics (congestion, customs delays, infrastructure, documentation, frequency of deliveries) • Dependency and diversification - identify multiple suppliers and specify material supply which each. • Review material demand and fluctuations of availability. • Specify standard and compliance requirement prior to order and check on delivery. • Check suppliers financial standing and reliability history.	Low
3	Installation standards	• Substandard installation. • Misunderstanding of standards requirements. • Misalignment between client and Hornbill expectations. • Poor workmanship. • Rework as a result of incorrect work. • Faults on installation. • Damage to equipment during installation. • Damage to equipment by third parties.	Medium	• Carry out regular inspections during the installation phase. • Engage independent quality assurance personnel. • Arrange replace equipment in case of damage in advance. • Ensure all personnel are suitably trained and competent. • Identify vulnerable areas. • Ensure continuous monitoring and review. • Collaborate with client to ensure understanding and expectation.	Low

4	Project complexity	• Misunderstanding of requirements. • Unknown information on the equipment being installed. • Suitability of personnel undertaking work. • Dependencies on other contractors. • Changes in regulatory and compliance.	Medium	• Develop a solid project programme, and include specialist visits for complex items. • Gather information of all equipment being installed prior to project being undertaken. • Ensure personnel are suitably trained and competent for the tasks being undertaken. • Ensure third party approval visits are booked in advance and early engagement is undertaken. • Provide training on specialist equipment. • Develop a risk management plan to capture risks and develop mitigation strategies. • Engage local assistance to reduce communication issues through cultural differences and language barriers.	Low
5	Support services (scaffold, hired equipment)	• Delays through awaiting support services. • Support services below standard installation/ quality of work. • Poor dependability/ reliability. • Non-compliant installation and services. • Poor communication and coordination. • Lack of flexibility.	Medium	• Ensure support services have sufficient resource through resource planning. • Agree standards of services provided before engagement. • Check previous work history for reliability. • Engage early to ensure requirements are understood and agreed. • Use multiple service providers for the same scope (break out areas). • Ensure terms of provision are agreed in advance.	Low
6	Fluctuating costs	• Additional costs incurred through fluctuations. • Overspend on project. • Budget exceeded. • Liquidated damages for late delivery.	High	• Identify potential cost fluctuations during bid process. • Review historical data for typical travel, hotel, transport and shipping costs. • Quantify the potential value of fluctuation. • Carry out a probability assessment. • Ensure strategy is in place in case of fluctuations (charge back to client or factor into contract) • Monitor, review and control regularly.	Medium
7	Working times	• Labour shortage. • Additional costs due to labour circulation. • Additional costs due to additional flights, taxis and visas. • Fatigued workers due to working for longer periods. • Health and safety risks due to fatigue. • Legal compliance. • Decreased concentration.	High	• Engage local labour to bridge shortfall. • Ensure a robust resource plan is produced and implemented. • Optimise shift schedules. • Manage workload for all employees to ensure prioritisation and workload. • Ensure suitable labour for tasks as required. • Ensure legal compliance requirements are strictly followed. • Rotate staff sufficiently to ensure adequate rest periods are received. • Monitor and review regularly. • Communicate and consult all personnel. • Maintain accurate records of working patterns. • Develop contingency plan to maintain required labour levels.	Medium
8	Other contractors	• Delays due to access hindered by other contractors. • Rework due to requirements of other contractors. • Replacement of equipment due to damage by third parties. • Loss of material due to theft. • Health and safety issues due to working areas.	Medium	• Identify health and safety concerns through collaborative meetings and document in a risk assessment. • Ensure clear lines of communication detailing requirements and concerns. • Coordinate through a programme to limit work area clashes. • Ensure material and equipment is securely stored and locked. • Undertake regular reviews to ensure equipment does not get damaged. • Install barriers to ensure equipment is not damaged. • Limit access to work areas to required personnel only. • Install access control system to work areas to limit and track access to areas. • Promote an inclusive culture to avoid cultural and communication barriers.	Low

9	Permits	•Delays to starting each morning due to waiting for permits. •Stop/ starting different work areas due to multiple contractors in the same area.	Medium	•Create a designated permit office and issuer. •Agree set times for permits to be issued. •Work areas and access limitations to be agreed in advance. •Planning meetings with all contractors to agree work areas in advance. •Clear communications with work activities through lookahead meetings.	Low
10	Liquidated damages	•Not factored in during quotation submission. •Financial loss. •Reputational loss. •Insurance claims.	High	•Review contract in detail with required professionals before entering contract. •Agree terms and question ambiguous statements. •Ensure insurance/ bonds are in place for LD requirements. •Create contingency plans to avoid LDs. •Produce robust programme and monitor.	Medium
11	Seasonal effects	•Outside working difficult during winter season (snow, ice, rain). •Holidays for key personnel.	Medium	•Provide temporary shelters for work areas with sensitive equipment. •Ensure work areas have provisions for the weather expected (grit etc). •Review weather forecast and plan work around this. •Create resource planner to ensure holidays taken have suitable replacement resource.	Low
12	Health and safety	•Cultural differences. •Misinterpretation of requirements.	High	•Ensure risk assessments and method statements are robust and agreed in advance. •Collaborate with all stakeholders and set out expectations. •Ensure risks are clear identified. •Clearly detail control measures. •Ensure all personnel understand requirements and restrictions. •Regularly review and update where required. •Ensure consultation and communication is open and engaging. •Document clearly so all can understand.	Medium

Figure 15 - Case study risk matrix

Case study vulnerability matrix

Following risk analysis through the matrix production, the hazards highlighted were then measured to understand the vulnerability these hazards would have on the delivery and ultimate success of the project.

The four main elements to determining and mitigating these vulnerabilities are depicted below.

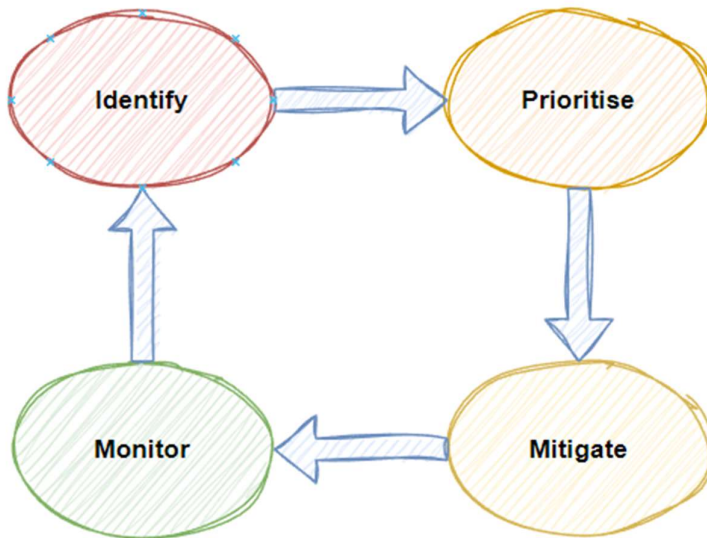


Figure 16 - Vulnerability control

The process is to identify the vulnerabilities of the project. Prioritise them based on the most critical to be fixed. Mitigate the critical vulnerabilities at scale and in real time and then implement continuous monitoring to ensure the items identified remain in mitigation and new vulnerabilities faced are captured early.

The matrix below details the hazards detected in the case study project and details the impact of vulnerability they had.

Item No.	Hazard	Impact on Project	Vulnerability Rating (no measures in place)	Measures for Resilience	Vulnerability Rating (with measures in place)
1	Contract misunderstanding	•Financial loss. •Incompletion of project. •Scope creep. •Delays. •Timeline issues. •Quality issues. •Disputes and legal issues. •Reputational damage. •Resource mismanagement. •Negative impact on stakeholder relationships.	High	•Clarify terms. •Regular communication. •Detailed documentation. •Legal reviews. •Training.	Low
2	Material supply difficulties	•Schedule delays. •Cost overruns. •Quality issues. •Resource lost time. •Reputational damage. •Resource mismanagement. •Negative impact on stakeholder relationships.	High	•Diversify suppliers •Inventory management (buffer stock). •Forecast and planning. •Improve supplier relations. •Utilise technology (supply chain management software).	Low
3	Poor Installation standards	•Delays through rework. •Cost overruns through additional material and labour time. •Reduced lifespan •Maintenance issues. •Reputational damage. •Increased risk of accidents. •Negative impact on stakeholder relationships. •Regulatory non-compliance. •Environmental hazards. •Loss of credibility. •Negative publicity. •Client dissatisfaction.	Medium	•Training and certification of installers. •Implement rigorous quality control and inspections regimes. •Establish clear guidelines and standards requirements. •Regular audits to identify risks early.	Low
4	Increased Project complexity	•Increased risk through variables and dependencies. •Higher costs (specialist labour). •Extended timelines. •Coordination challenges causing delays. •Decision making difficulties causing delays. •Scope creep.	Medium	•Thorough planning. •Agile methodologies. •Effective communication. •Risk management strategies. •Skill development. •Utilise project management tools.	Low
5	Difficult Support services (scaffold, hired equipment)	•Delays through lack of resource. •Quality issues. •Communication breakdown. •Dependencies issues. •Lack of control. •Performance variability.	Medium	•Vetting and due diligence checks. •Clear contracts and service level agreements. •Regular monitoring and audits. •Effective communication methods. •Risk management plans. •Training and onboarding. •Cultural integration.	Low

6	Fluctuating costs	•Budget overrun. •Currency fluctuations. •Cash flow issues. •Profitability issues. •Client relationship.	High	•Contingency planning. •Regular monitoring and reporting. •Value engineering. •Fixed price agreements. •Strong supplier relations.	Low
7	Working times	•Productivity and efficiency. •Focus and attention. •Team dynamics and morale. •Increased errors. •Health and safety issues. •Quality assurance.	Medium	•Implement flexible schedules. •Encourage regular breaks. •Monitor workload. •Foster and healthy work environment. •Utilise time management techniques.	Low
8	Other contractors	•Misscommunication causing delays. •Lack of coordination causing delays. •Scheduling conflicts. •Resource conflicts. •Material shortage. •Unsafe work environment. •Non compliance with protocols. •Blame.	Medium	•Thorough planning. •Clear communications. •Coordination meetings. •Strong emphasis on a safe environment. •Effective project management plan.	Low
9	Permit delays	•Increased cost through delay. •Schedule disruption. •Contractual issues. •Resource reallocation. •Idle resources. •Social tension.	Medium	•Thorough planning. •Mitigation strategies. •Proactive communication. •Clear programme. •Stakeholder engagement.	Low
10	Liquidated damages	•Increased financial risk. •Disputes. •Relationship impacts.	High	•Clear contractual terms. •Effective project management plan. •Collaboration with all parties. •Clear dispute process.	Medium
11	Seasonal effects	•Delays to working through weather conditions. •Project schedules affected. •Stakeholder availability. •Resource availability.	Medium	•Planning of work considering weather forecast. •Resource tracker utilisation.	Low
12	Poor Health and safety	•Increased chance of accidents and near misses. •Decreased productivity. •Damage to reputation. •Increased costs. •Decreased morale. •Decreased employee retention.	High	•Develop solid health and safety plan and expectations. •Continuous monitoring and improvement. •Clear requirement. •Encourage a positive environment. •Prioritise health and safety above everything. •Provide training. •Provide suitable equipment. •Harvest a collaborative environment.	Low

Figure 17 - Project Vulnerability Matrix

Conclusion

In conclusion, the implementation of effective risk management practices within engineering project management is vital for ensuring project success and mitigating potential challenges. This dissertation has explored various aspects of risk management, including its significance, methodologies, tools, theories, principles and strategies, within the context of engineering projects. Through a comprehensive analysis of relevant literature, case studies, and expert theoretical insights, several key conclusions can be drawn.

Firstly, it is evident that risk management plays a crucial role in identifying, assessing, and addressing potential threats and opportunities throughout the project lifecycle. By systematically analysing risks, engineering project management teams can anticipate obstacles and challenges, develop proactive mitigation plans, and allocate resources more efficiently. This proactive approach not only reduces the likelihood of project failures but also enhances the overall resilience of the project against unforeseen events.

Secondly, the adoption of structured risk management frameworks and methodologies, such as the Project Management Institute's (PMI) Risk Management Framework or the International Organization for Standardization's (ISO) risk management standards, provides a systematic and standardized approach to managing risks. These frameworks offer guidelines and best practices for identifying, analysing, and responding to risks, thereby facilitating effective decision-making and promoting consistency across projects. The theories and principles of Arthur P. Dempster and Glenn Shafer, Daniel Bernoulli, Katz and Khan and Lofti Zadeh researched within this dissertation are also still very effective and the principles they have created are still very applicable today.

Furthermore, the use of risk management tools and techniques, such as risk registers, probability-impact matrices, decision trees and contingency planning, enhances the accuracy and effectiveness of risk assessment and mitigation efforts. These tools enable project managers to prioritize risks based on their likelihood and impact, allocate resources accordingly, and develop robust contingency plans to address potential threats.

Moreover, effective communication and collaboration among project stakeholders are essential for successful risk management. Engaging stakeholders throughout the risk management process fosters transparency, builds trust, and ensures that all relevant perspectives are considered when identifying and addressing risks. Additionally, regular risk reviews and updates enable project teams to adapt to changing circumstances and incorporate new insights into their risk management strategies. The update of these processes throughout the lifecycle of the project is key to ensuring that developing risks are captured, these documents are to be live documents that develop with the project through its various stages as different risk elements will emerge.

It is important to acknowledge that while risk management can significantly reduce the likelihood of negative outcomes, it cannot eliminate all uncertainties entirely. Engineering projects inherently involve complex systems, dynamic environments, and various stakeholders, making them susceptible to unforeseen risks and challenges. Therefore, it is essential for project managers to adopt a proactive mindset, remain vigilant, and continuously monitor and reassess risks throughout the project lifecycle.

In conclusion, effective risk management in engineering project management is a multifaceted process that requires careful planning, diligent execution, and ongoing evaluation. By integrating risk management practices into project planning and execution, engineering teams can enhance decision-making, optimize resource allocation, and ultimately improve project outcomes. However, successful risk management requires commitment, collaboration, and a proactive approach from all project stakeholders. By prioritizing risk management as a core aspect of project management, engineering projects can navigate uncertainties more effectively, minimize disruptions, and achieve their objectives with greater confidence.

Recommendation and further work

Further work in the field of risk mitigation within the delivery of engineering projects I feel should focus on a few areas. Firstly, I feel that training plays a substantial part in this process. Ensuring that personnel involved in the delivery of engineering projects have suitable and sufficient knowledge and experience. Due to current resource restrictions that many companies are facing encourages leaders to 'lean' on a limited pool of resource. Although this labour pool may have sufficient knowledge in the areas that they have trained, more pressure is being dealt to become multi disciplined and more rounded. Whilst I feel that this is generally a positive thing, sufficient training must be in place to allow those individuals the chance to learn and become the rounded individual that is required. However, this takes time, dedicated structured training and the time from experienced members of the team to mentor and develop other team members.

The sharing of lessons learned across the industry could be beneficial. The likelihood that we will be the first person to encounter a specific problem is unlikely. I feel that the sharing of both positive and negative experiences and outcomes could provide valuable information to ongoing and future projects. Although this process is in place internally across many companies, I feel that sharing these experiences externally would be beneficial to industry. It is common that safety lessons across industry are shared, the same approach could be adopted for engineering project delivery risks.

There are many individuals who have decades of experience in delivering engineering projects, there are also many experts who specialise in specific areas of engineering project management and risk management. I feel that a platform to showcase this specific expertise would be extremely positive. I feel that a forum or application where users can access knowledge, information and documentation to help provide guidance and knowledge for any queries or problems being faced would be helpful. I think this could be achieved through the development of an application.

I also feel that to gain a better understanding from people in the position of delivering engineering projects as to why they feel engineering projects often fail, interviews and surveys need to be undertaken. This would give a first-hand account of the issues often faced, this information would be key to developing an application or forum. An industry wide event would also allow networking and interaction for learning and developing the skills required to operate within the engineering project management sector. This would also be a good platform to understand the issues being faced and develop a software to help alleviate these issues.

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