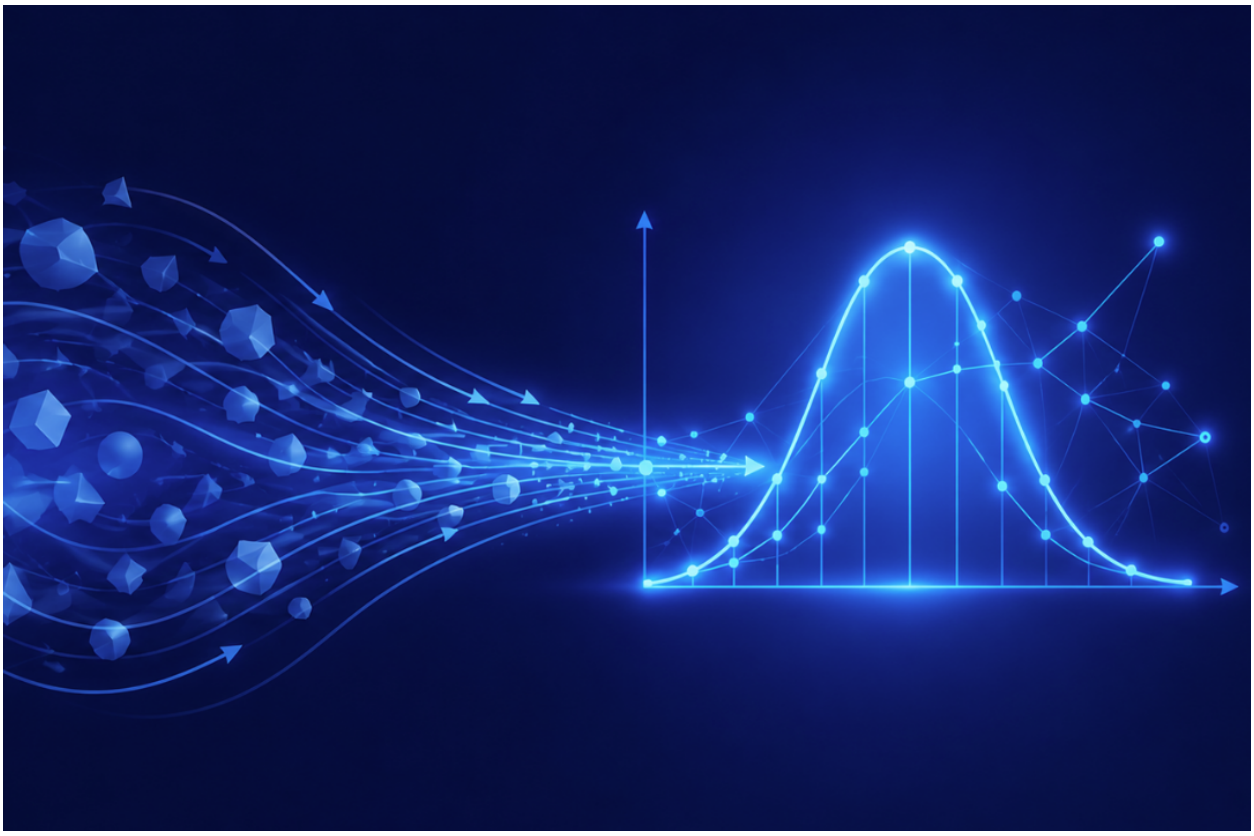

Project Risk Aggregation for Portfolio Analysis

Framework Development for Vattenfall Services Nordic AB

Master's thesis in Design and Construction Project Management

ELIN ELIASSON

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DEPARTMENT OF ARCHITECTURE AND CIVIL ENGINEERING

CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2026

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MASTER'S THESIS 2026

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Cover: AI-generated illustration showing how input data is used to quantify uncertainty and visualise the results through a probability distribution.

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ABSTRACT

Organisations that manage multiple projects at the same time need to understand both the risks in each individual project and the overall risk exposure in the entire project portfolio. This thesis investigates how project risk information can be aggregated to support portfolio-level risk analysis. The research was conducted as a case study at Vattenfall Services Nordic AB (VSN) with the aim of developing a risk management framework.

The study adopts an abductive research approach and combines a literature review, document analysis and 13 semi-structured interviews with tender engineers and project managers. In addition, a conceptual uncertainty analysis based on Monte Carlo simulation is developed to demonstrate how project risks can be analysed quantitatively and aggregated at portfolio level.

The findings indicate that current risk identification and assessment practices are based on individual intuition and informal processes. Estimators use “embedded margins” directly within base cost estimates, which reduces transparency and obscures the actual risk exposure. Furthermore, inconsistent assessment methods make it impossible to aggregate risk data across the portfolio.

To address these limitations, the thesis proposes a framework that introduces common principles for classification and assessment. Uncertainties are classified as uncertain known factors (Type A) or known uncertain factors (Type B), and deterministic single-value estimates are replaced by probabilistic analyses based on Monte Carlo simulations. The framework also supports continuous risk monitoring and feedback processes to strengthen organisational learning and knowledge transfer.

The standardisation of project data enables the aggregation of individual project distributions into a combined portfolio-level distribution. This equips management with an overview of the total financial risk exposure. In the long term, the framework may support more informed decision-making and improved allocation of resources.

Key words: Project Risk Management, Portfolio Risk Management, Risk Aggregation, Contingency Reserve, Management Reserve, Uncertainty Analysis

Aggregering av Projektrisker för Portföljanalys
Utveckling av Ramverk för Vattenfall Services Nordic AB

Examensarbete inom masterprogrammet organisering och ledning i bygg- och fastighetssektorn

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SAMMANFATTNING

Organisationer som hanterar flera projekt samtidigt behöver förstå riskerna inom enskilda projekt, men även den totala riskexponeringen över hela portföljen. Denna studie undersöker hur projektriskinformation kan aggregeras för att stödja riskanalys på portföljnivå. Studien genomfördes som en fallstudie på Vattenfall Services Nordic AB (VSN) med syftet att utveckla ett ramverk.

Studien tillämpar en abduktiv forskningsansats och kombinerar en litteraturstudie, dokumentanalys och 13 semistrukturerade intervjuer med anbudsingenjörer och projektledare. Därutöver utvecklas en konceptuell osäkerhetsanalys baserad på Monte Carlo-simulering för att demonstrera hur projektrisker kan analyseras kvantitativt och aggregeras på portföljnivå.

Resultaten visar att nuvarande metoder för identifiering och bedömning bygger på individuell intuition och informella processer. Det används ”inbyggda marginaler” direkt i grundkalkyler vilket minskar transparensen och döljer den faktiska riskexponeringen. Dessutom gör inkonsekventa bedömningsmetoder det omöjligt att aggregera riskdata över portföljen.

För att hantera dessa begränsningar föreslår studien ett ramverk som introducerar gemensamma principer för klassificering och bedömning. Osäkerheter klassificeras som osäkra kända faktorer (Typ A) eller kända osäkra faktorer (Typ B), och deterministiska punktestimat ersätts av probabilistiska analyser baserade på Monte Carlo-simuleringar. Ramverket stödjer även kontinuerlig riskuppföljning och återkopplingsprocesser för att stärka organisatoriskt lärande och kunskapsöverföring.

Genom standardisering av projektdatan kan individuella sannolikhetsfördelningar kombineras till en aggregerad portföljfördelning. Detta ger ledningen en probabilistisk översikt över den totala finansiella riskexponeringen. På lång sikt kan ramverket bidra till mer välgrundade beslut och förbättrad resursallokering.

Nyckelord: Projektriskhantering, Portföljriskhantering, Riskaggregering, Riskreserv, Osäkerhetsanalys

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Acknowledgements

This thesis marks the end of our education in Civil Engineering at Chalmers University of Technology. Over the past five years, we have learned to approach complex problems, make decisions under uncertainty and accept that not everything can be fully predicted. In many ways, this thesis reflects those lessons. Working with risk and uncertainty has not only been the subject of this study, but also a part of the process itself.

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Elin Eliasson and Emma Ralgård Jansson

List of Acronyms

List of acronyms that will be used in the thesis listed in alphabetical order:

AI	Artificial Intelligence
APV	Tender Process Tool
EMV	Expected Monetary Value
EMVC	Expected Monetary Value Combined
ERM	Enterprise Risk Management
HSSEQ	Health, Safety, Security, Environment and Quality
ISO	International Organization for Standardization
KPI	Key Performance Indicator
KRI	Key Risk Indicator
MCS	Monte Carlo Simulation
PIM	Probability and Impact Matrix
PMI	Project Management Institute
PPRM	Project Portfolio Risk Management
PPV	Project Process Tool
SIS	Swedish Institute for Standards
VaR	Value at Risk
VSN	Vattenfall Services Nordic AB

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1 Introduction

Projects are expected to deliver intended objectives under conditions characterised by uncertainty, time pressure and constrained resources (Project Management Institute, 2021). Despite careful planning, many projects experience cost overruns, schedule delays or fail to meet intended objectives (Canesi et al., 2025; Gupta & Thakkar, 2018). A common explanation for these outcomes is the insufficient understanding of uncertainty (Aven, 2016). Risk management has therefore become a central part of project management since it provides structured approaches for identifying and addressing uncertainties that may affect project performance (Project Management Institute, 2021).

Traditional risk management is typically applied at the level of individual projects and focuses on identifying, analysing and responding to project-specific risks (Project Management Institute, 2021; SIS, 2018). While this approach can support decision-making within single projects, several studies indicate that it is insufficient in organisational contexts where multiple projects are executed simultaneously (Micán et al., 2021; Teller et al., 2014).

Evaluating risks in isolation provides only a limited understanding of the organisation's total risk exposure, which refers to the combined effect of risks across all projects in a portfolio. Even if individual projects have manageable risks, their combined impact may create uncertainty for the organisation. Traditional risk management focuses on individual deliverables, but a portfolio perspective is necessary to analyse the aggregated financial uncertainty and risk exposure of the organisation. Bai et al. (2025) emphasise that managing multiple projects simultaneously requires a shift from project-centric assessment to a broader view of the portfolio's combined risk profile.

These limitations of project-level risk management have motivated the development of portfolio risk management as a complementary and more strategic approach (Micán et al., 2021). It extends the scope of traditional risk management by addressing portfolio-level risks, such as strategic misalignment and resource allocation challenges, as well as risks arising from interdependencies between projects (Bai et al., 2025; Teller et al., 2014). Empirical studies show that organisations achieve higher portfolio performance when formalised project-level risk management is combined with systematic integration of risk information at portfolio level (Teller et al., 2014; Zanfelicce & Rabechini Jr, 2021).

Despite this potential, the practical application of portfolio-level risk analysis remains limited, particularly in organisations where project-level risk management practices are not sufficiently structured or consistently applied (Micán et al., 2021;

Zanfelicce & Rabechini Jr, 2021). A challenge in practical risk management is that the estimation process often becomes highly subjective and relies on informal assessments and intuition instead of standardised data (Karlsen & Lereim, 2005). This subjectivity may lead to the adoption of ”embedded margins”, where uncertainties are hidden directly within base cost estimates instead of being documented as explicitly identified risks (Chapman & Ward, 2003). This lack of transparency obscures the true risk exposure.

To address these limitations, quantitative risk analysis methods have been proposed to provide structured and probabilistic representations of uncertainty. According to Aven (2016), such methods enable a more explicit treatment of uncertainty. Among quantitative techniques, Monte Carlo simulation is widely recognised for its ability to model uncertainty (Kwak & Ingall, 2009). Monte Carlo simulation accounts for uncertainty in input data and quantifies the resulting uncertainty in model outputs. This enables improved analysis and visualisation of risk exposure, thereby supporting informed decision-making under uncertainty (Aven, 2016; Bai et al., 2025).

This highlights the need for further research on how project risk management processes can be developed to support portfolio-level analysis and how quantitative methods can be integrated as decision-support tools. Against this background, this thesis investigates how risk management practices at project level can be developed to enable analysis of risks at portfolio level.

1.1 Context and Problem Statement

This thesis is conducted as a case study at Vattenfall Services Nordic AB (VSN), which is part of Vattenfall AB and owned by the Swedish state. State ownership involves obligations related to transparency, long-term value creation and responsible management of public resources (Regeringskansliet, 2025). VSN operates within the Swedish energy sector and delivers maintenance, contracting and consultancy services related to energy and electrical infrastructure. The company conducts project-based operations and is involved in the planning, execution and maintenance of infrastructure assets throughout their lifecycle. According to VSN, a project has specific requirements in terms of time, cost and goal achievement.

VSN manages approximately one thousand projects each year, which vary in size, complexity and risk exposure. This thesis focuses on project risks that at VSN are expressed in financial terms. Those risks include events leading to cost overruns, schedule deviations or failure to meet project objectives. Risks related to health, safety, security, environmental impact and compliance with quality standards (HSSEQ risks) are managed through separate processes at VSN and are therefore excluded from this thesis.

Risk analyses for project risks are currently carried out during the tender phase by the tender team and throughout the project execution by the project manager. During tendering, project risks are assessed to support bid preparation, while during project execution, risk management is intended to support planning, monitoring and control of project outcomes. However, the available documentation indicates that the risk management process is not applied in a fully consistent or standardised manner across different projects. Approaches to identifying, assessing and managing risks appear to vary, and the transfer of risk information following contract award is not clearly defined. It is therefore difficult to ensure a coherent handling of risks throughout the project lifecycle.

Risk information is currently used at the individual project level and provides limited support for comparison between projects. This limits VSN's ability to understand overall risk exposure across its project portfolio and to analyse how risks from different projects interact. There is currently no approach for assessing how the inclusion of new projects affects the overall risk profile of the portfolio.

VSN has identified a need for a more structured overview of risk exposure at portfolio level. Such an overview is intended to make it possible to relate risks identified in new tenders to the risks already present in the existing portfolio. This would support the tender process by providing a better basis for evaluating bids, comparing alternative projects and understanding how individual projects affect the organisation's overall risk exposure. At the management level, a portfolio overview of risk exposure would support more informed decision-making by providing improved transparency. During project execution, improved visibility and analysis of risk exposure are expected to support project managers by giving them a clearer picture of the risks they need to manage and by enabling more proactive work with risk mitigation and follow-up.

To enable this development, risk management practices at project level need to be reviewed and further structured to ensure that risk information is consistent across projects. This consistency is a necessary condition for aggregating and analysing risks at portfolio level (Teller et al., 2014). VSN is interested in analytical methods that support portfolio-level risk analysis and provide a clearer understanding of uncertainty and total risk exposure. In this context, Monte Carlo simulation is considered a relevant technique for incorporating uncertainty in project-level inputs and quantifying how this uncertainty affects the overall risk exposure.

1.2 Aim

The overall aim of this thesis is to support Vattenfall Services Nordic AB in aggregating project risks to enable analysis of risk exposure at portfolio level, in order to support decision-making. The thesis addresses a need to move from isolated project-level risk assessments towards a portfolio-level perspective that provides an overview of how individual project risks contribute to total risk exposure. Such an overview is intended to enable comparison between projects and to support informed decisions related to both ongoing and future projects.

To achieve this, the thesis seeks to describe and analyse how project risks are currently identified, assessed and managed within individual projects. This includes examining how risk information is documented, how assumptions and risk reserves are established and how risks are followed up throughout the project lifecycle. The study further aims to identify limitations and improvement areas in current project-level risk management practices that affect the consistency and comparability of risk information. Based on this, the thesis seeks to clarify what requirements project-level risk information must fulfil in order to be suitable for aggregation and analysis at portfolio level.

Based on the findings of the study, the aim is to develop a conceptual framework that demonstrates how project risk information can be structured and managed to enable portfolio-level analysis of risk exposure. The framework is intended to incorporate Monte Carlo simulation as a means of analysing uncertainty and aggregating project-level uncertainties into a probabilistic representation of total portfolio risk exposure. Furthermore, the framework aims to demonstrate how such information can support informed decision-making and organisational learning within VSN.

VSN has also expressed a need for a clear and accessible overview of risk exposure. Therefore, the study aims to identify and propose relevant Key Performance Indicators (KPIs) that can support the visualisation and communication of uncertainty at both the project and portfolio levels.

To demonstrate the practical functionality and modelling logic of the framework, the study includes an illustrative project and portfolio analysis. Furthermore, the framework aims to support estimators and project managers by establishing a structured feedback loop where historical data is utilised to improve future risk identification and cost assessments.

1.2.1 Research Questions

Based on the aim of the thesis, the following research questions are formulated to guide the study:

1. How are project risks currently identified, assessed and managed within individual projects?
2. What requirements must project-level risk information fulfil in order to enable aggregation and analysis of risk exposure at portfolio level?
3. How can uncertainties in project outcomes be analysed and aggregated to describe portfolio-level risk exposure?
4. How can risk information be used to support decision-making and organisational learning?

1.3 Research Contribution

This thesis contributes to the development of portfolio-level risk management at VSN by proposing a structured framework that provides guidelines for analysing and managing project risks across a portfolio. The framework offers a systematic basis for understanding uncertainty and thereby supporting informed decision-making within the organisation. Beyond its direct contribution to VSN's internal processes, the proposed framework may also be relevant in other project-based and construction contexts.

From a broader perspective, the study contributes to the growing body of research that emphasises the importance of moving beyond isolated project-level risk assessments towards a more integrated portfolio perspective. The thesis demonstrates how qualitative risk management practices can be combined with probabilistic quantitative analysis to improve transparency and understanding of aggregated uncertainty across multiple projects.

2

Theoretical Background

Projects are carried out in environments where uncertainty is always present. Conditions may change over time and unexpected events can influence how a project develops. These uncertainties can affect whether project objectives related to cost, time and quality are achieved. Because of this, risk management has become an important part of project management. Risk management provides a structured way to describe and analyse uncertainty and to understand how different events may influence project outcomes (Project Management Institute, 2021). This chapter introduces central concepts related to risk and uncertainty and describes how risk management is commonly understood in project-based organisations. It further presents approaches for analysing risks and discusses how risk information can support decision-making.

2.1 Definition of Risk and Uncertainty

Projects operate in environments characterised by uncertainty because they involve temporary and unique undertakings that require decisions about future conditions whose outcomes cannot be predicted with certainty (Sanchez et al., 2009). Project-based organisations must therefore plan and allocate resources based on assumptions regarding cost, time, performance and external factors, even though complete information is rarely available (Aven, 2016). This condition of incomplete knowledge forms the basis of uncertainty in projects and influences planning and decision-making. Uncertainty can thus be understood as the lack of complete knowledge about future events and possible consequences (Aven, 2016).

Risk arises from this uncertainty and according to SIS (2018), risk is defined as the "effect of uncertainty on objectives". In project management literature, risk is commonly described as an uncertain event or condition that, if it occurs, has a positive or negative effect on at least one project objective, such as time, cost or quality (Project Management Institute, 2021). This definition highlights that risk is directly linked to defined objectives and that it includes both negative consequences and positive opportunities.

In order to make uncertainty manageable, organisations translate it into assessable risks (Sanchez et al., 2009). This involves estimating the likelihood of occurrence and the magnitude of potential consequences, thereby providing a basis for comparing and prioritising different sources of exposure (SIS, 2018). However, such estimates are themselves influenced by the quality of available information and by the assumptions underlying the assessment process, which means that risk evaluations remain inseparable from the uncertainty on which they are based (Aven, 2016).

To manage incomplete information, Project Management Institute (2024) presents a framework that classifies risks. The framework can be seen in Figure 2.1 and it is intended to structure risk information and divide project knowledge and uncertainty into different categories:

Figure 2.1: Risk classification adapted from Project Management Institute (2024).

- **Unknown-knowns:** Knowledge that exists within individuals or the organisation but is not clearly expressed or shared. It may be based on experience, routines or assumptions. Because it is not openly discussed or documented, it can be overlooked in decision-making and create blind spots in the project.
- **Unknown-unknowns:** Uncertainties that remain unrecognised before their occurrence. Since they lie beyond existing assumptions and experience, they can not be anticipated through conventional risk identification processes, which makes them difficult to foresee and proactively manage.
- **Known-knowns:** Facts and information that are identified and documented, such as approved plans, defined requirements and established project conditions. This knowledge forms the basis for planning, monitoring and controlling the project and is not a risk.
- **Known-unknowns:** Identified risks. The project team is aware of existing knowledge gaps and can therefore assess and potentially mitigate these uncertainties through structured risk management practices.

Project risk management should not focus solely on measurable risk events, but should also acknowledge the broader condition of uncertainty from which they emerge (Chapman & Ward, 2003). This view is reinforced by Edwards et al. (2025), who emphasise that risk cannot exist without uncertainty, as risk represents the manifestation of uncertainty in relation to defined objectives. Similarly, Burtonshaw-Gunn (2009) describes risk management as a structured means of managing uncertainty rather than eliminating it.

2.2 The Risk Management Process

In the field of risk management, ISO 31000:2018 provides an international standard that outlines general principles and a structured process for managing risks. The standard has been adopted as SS-ISO 31000:2018 by the Swedish Institute for Standards (SIS, 2018). According to the standard, risk management should be integrated into all organisational activities and tailored to the organisation's internal and external context. Figure 2.2 illustrates the overall structure of the risk management process and shows how its main components are connected.

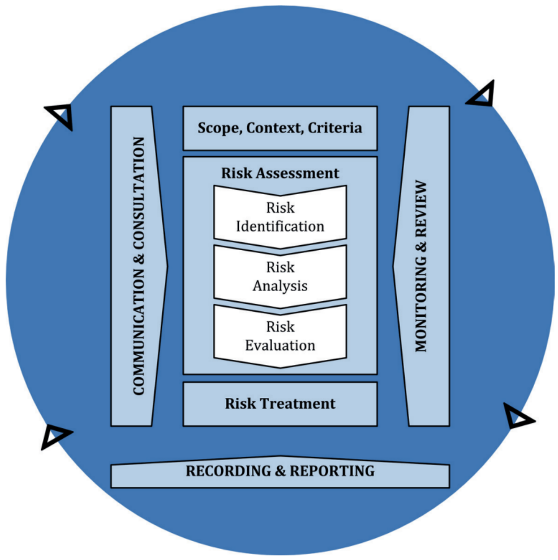


Figure 2.2: The Risk Management Process retrieved from ISO 31000 (SIS, 2018)

2.2.1 Risk Identification

Risk identification constitutes the starting point of the risk assessment process and aims to determine which uncertainties may influence the achievement of objectives (SIS, 2018). According to ISO 31000, this step involves identifying sources of risk, potential events, their causes and possible consequences. The purpose is to create an overview of uncertainties before further analysis and evaluation.

The identification process should also include opportunities, defined as uncertain events with positive effects on project objectives (Sanchez et al., 2009). This perspective is consistent with ISO 31000, which states that risks should be identified regardless of whether their consequences are negative or positive and regardless of whether their sources are under the organisation's direct control (SIS, 2018).

Risk identification is often conducted through workshops, brainstorming sessions, expert interviews, historical data analysis and the use of risk checklists (Project Management Institute, 2021). Historical data from similar projects can provide insight into recurring uncertainties and performance deviations (Gupta & Thakkar, 2018). However, Aven (2016) emphasises that past experience must be assessed in relation to the strength of the underlying knowledge and the contextual differences between projects. This highlights that identification depends on judgement and interpretation.

Despite the recommendations in ISO 31000, research indicates that risk identification practices in project-based organisations are often inconsistent. Sanchez et al. (2009) describe how risk management approaches may vary between projects and depend on individual project managers. Such variation can limit comparability and reduce the reliability of risk information (Micán et al., 2021).

To strengthen the identification process, the literature advocates using structured categorisation of risk sources. The use of predefined categories may reduce the likelihood that relevant sources of uncertainty are overlooked and may support more consistent identification practices (Edwards et al., 2025; Zavadskas et al., 2010). In addition, Edwards et al. (2025) argue that risk identification should not rely solely on unstructured brainstorming since this can lead to incomplete and biased outcomes. Instead, the use of predefined categories or frameworks provides cognitive support and helps practitioners identify risks more consistently (Edwards et al., 2025).

2.2.2 Risk Analysis

The purpose of risk analysis is to develop an understanding of the nature of risk and to determine its level by examining the potential consequences and likelihood of identified events (SIS, 2018). The ISO 31000 standard emphasises that this process should account for uncertainty, including the reliability of available data, assumptions made during assessment, and potential variability in outcomes. Aven (2016) similarly argues that risk analysis should not be reduced to numerical estimation alone, but should include reflection on the strength of knowledge and the limitations underlying probability assessments.

ISO 31000 further describes that a single event may have multiple causes and consequences, and that these consequences may affect several objectives simultaneously. The level of detail applied in the analysis may vary from qualitative to quantitative depending on the availability of data, the complexity of the situation and the resources available for the analysis (SIS, 2018). However, it can be noted that insufficient or overly simplified analysis of risks may contribute to inaccurate forecasts and financial deviations in projects (Canesi et al., 2025; Gupta & Thakkar, 2018).

Although ISO 31000 suggests that both likelihood and consequences can be considered in risk analysis, the standard does not prescribe how these should be calculated or quantified in mathematical terms. Research has therefore complemented the standard by highlighting limitations in traditional deterministic approaches and by proposing more advanced methods for representing uncertainty. Traditionally, likelihood and consequences have often been assessed as single-point estimates, such as a specific cost impact or schedule delay. Kwak and Ingall (2009) suggest that deterministic approaches based on point estimates may lead to an underestimation of risk, as they do not account for the statistical variability of uncertain outcomes. Instead, they advocate the use of probabilistic methods that represent uncertainty. Similar arguments are made by Senova et al. (2023), who emphasise that uncertainty should be modelled using probability distributions.

From this perspective, probabilistic approaches enable likelihood and consequences to be expressed as distributions rather than point estimates, allowing the combined effect of uncertainty to be analysed. Such an approach provides decision-makers with probabilistic information, for example, the probability of meeting a given budget or schedule target. This is consistent with the principles of ISO 31000, which emphasise the need to recognise and analyse the nature and degree of uncertainty when assessing risks (SIS, 2018).

In situations where reliable quantitative data are limited or unavailable, which is common in construction and infrastructure projects, alternative approaches for handling uncertainty have been proposed. Zavadskas et al. (2010) suggest the use of Grey Systems Theory as a means of analysing risks under conditions of incomplete information. Rather than assigning a precise value to likelihood or consequence, parameters are expressed as intervals, for example, within a defined range. This allows uncertainty to be represented explicitly without forcing unrealistic precision. By working with intervals, the analysis becomes more robust in situations characterised by limited data. Such an approach aligns with ISO 31000, which states that risk analysis should be based on the best available information, while acknowledging uncertainty, limitations and assumptions in the data used (SIS, 2018).

2.2.3 Risk Evaluation

Risk evaluation constitutes the final step within the risk assessment process and the purpose is to compare the results of the risk analysis with predefined risk criteria in order to support decisions on risk treatment and prioritisation (SIS, 2018). Risk evaluation therefore represents the step where analysed risks are assessed in relation to organisational objectives, risk tolerance and acceptance levels. ISO 31000 emphasises that the criteria used for evaluation should be defined in advance and aligned with the internal and external context of the organisation, ensuring that decisions are consistent and transparent (SIS, 2018).

In practice, risk evaluation often involves comparing and ranking risks to determine which require further action and which may be accepted. ISO 31000 notes that such prioritisation should take uncertainty and assumptions into account and should not rely solely on rigid thresholds or simplified classifications (SIS, 2018). If the uncertainty underlying the analysis is ignored during evaluation, there is a risk that decisions are based on an overly narrow or misleading representation of risk exposure (Aven, 2016).

Empirical research indicates that insufficient alignment between risk criteria and organisational objectives may lead to inconsistent decision-making across projects (Micán et al., 2021). Teller et al. (2014) further emphasise that inconsistent evaluation practices may limit transparency and reduce the effectiveness of risk management at higher organisational levels. This suggests that clearly defined and consistently applied evaluation criteria are essential for ensuring comparability and supporting informed decisions.

2.3 Risk Management Across the Project Lifecycle

Risk management should be integrated throughout the entire project lifecycle, covering both planning and execution phases (Project Management Institute, 2021). However, research consistently emphasises that the early stages of a project are particularly critical. Burtonshaw-Gunn (2009) argue that risks should be addressed as early as possible, as proactive measures reduce the likelihood that uncertainties escalate into costly deviations. This perspective aligns with the lifecycle model presented by Project Management Institute (2021), which highlights that stakeholder influence over project outcomes is greatest in the initial phases, while the cost of implementing changes increases significantly as the project progresses.

Empirical studies in infrastructure and construction projects further demonstrate the consequences of insufficient early risk management. Inadequate identification and assessment of risks during planning are frequently associated with later cost overruns and schedule delays (Canesi et al., 2025; Gupta & Thakkar, 2018). Risk identification should therefore be conducted during the planning or tender phase, when scope, cost estimates and schedule assumptions are still being established (Project Management Institute, 2021).

Karlsen and Lereim (2005) highlight a dilemma at the planning stage, which is illustrated in Figure 2.3 as the influence/information gap. At the beginning of a project, the ability to influence design and control outcomes is at its highest level, but detailed information regarding schedule and cost drivers is limited. Limited availability of information increases uncertainty and associated risk, thereby creating a strong connection between risk assessment and project budgeting. According to ISO 31000, risks that are not identified cannot be analysed or treated, making identification the foundation of the entire risk management process (SIS, 2018).

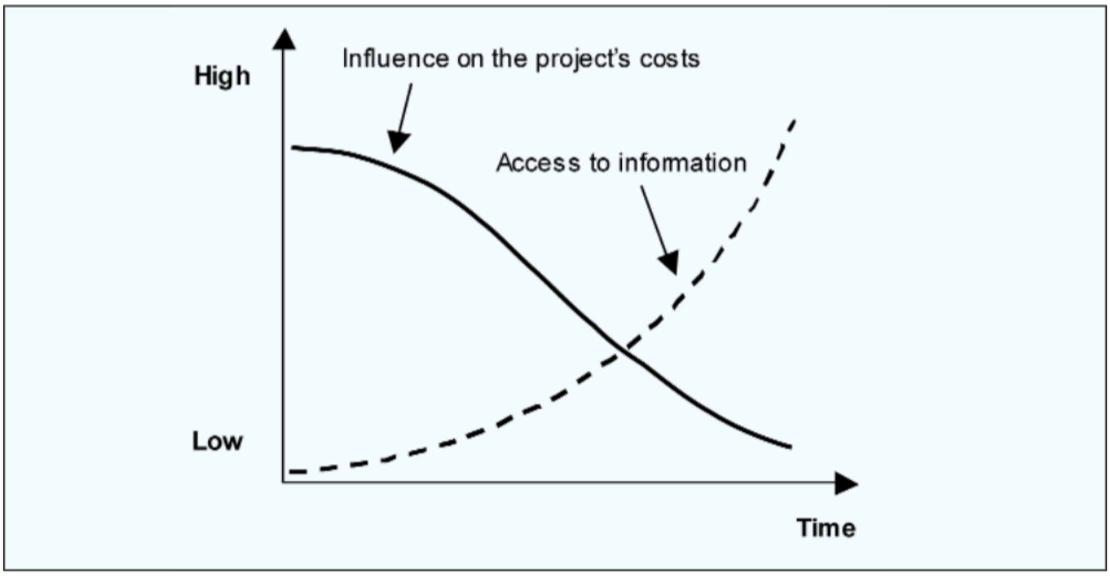


Figure 2.3: Influence/information gap retrieved from Karlsen and Lereim (2005)

At the same time, risk management cannot be limited to early planning activities. ISO 31000 defines risk management as an iterative and dynamic process that requires continuous monitoring and review as conditions evolve (SIS, 2018). Project Management Institute (2021) similarly suggest that risk management processes should be performed throughout the project and updated whenever significant changes occur. As execution progresses, assumptions are tested, uncertainties materialise, and new risks may emerge due to technical challenges, stakeholder decisions or external developments (Micán et al., 2021).

Sanchez et al. (2009) argue that infrequent reviews undermine the effectiveness of risk management, since they fail to capture evolving project realities. This perspective is supported by Edwards et al. (2025), who emphasise that uncertainty changes over time as project elements are completed and new information becomes available. Continuous reassessment is therefore necessary to ensure that risk exposure reflects the current state of the project and not outdated assumptions.

The tendering phase represents a particularly critical point in the lifecycle. During this stage, organisations must evaluate uncertainties related to scope, cost and schedule before contractual commitments are made. Project Management Institute (2021) highlights the importance of identifying and analysing risks early to support realistic budgeting and contingency planning. However, limited information during tendering increases estimation uncertainty, which may lead to underestimation of potential deviations. In such contexts, analytical approaches that address incomplete or imprecise data become valuable (Zavadskas et al., 2010).

2.4 Organisational Levels of Risk Management

Risk management can be seen as a hierarchical and integrated framework that spans over multiple organisational levels. According to Project Management Institute (2024), risk management is applied across four main organisational levels: project, programme, portfolio and enterprise. The levels are illustrated in Figure 2.4. Each level has its own purpose and scope, but they are closely interconnected and influence each other. As management moves up in level, the scope will get larger (Piterska & Kramskiy, 2017).

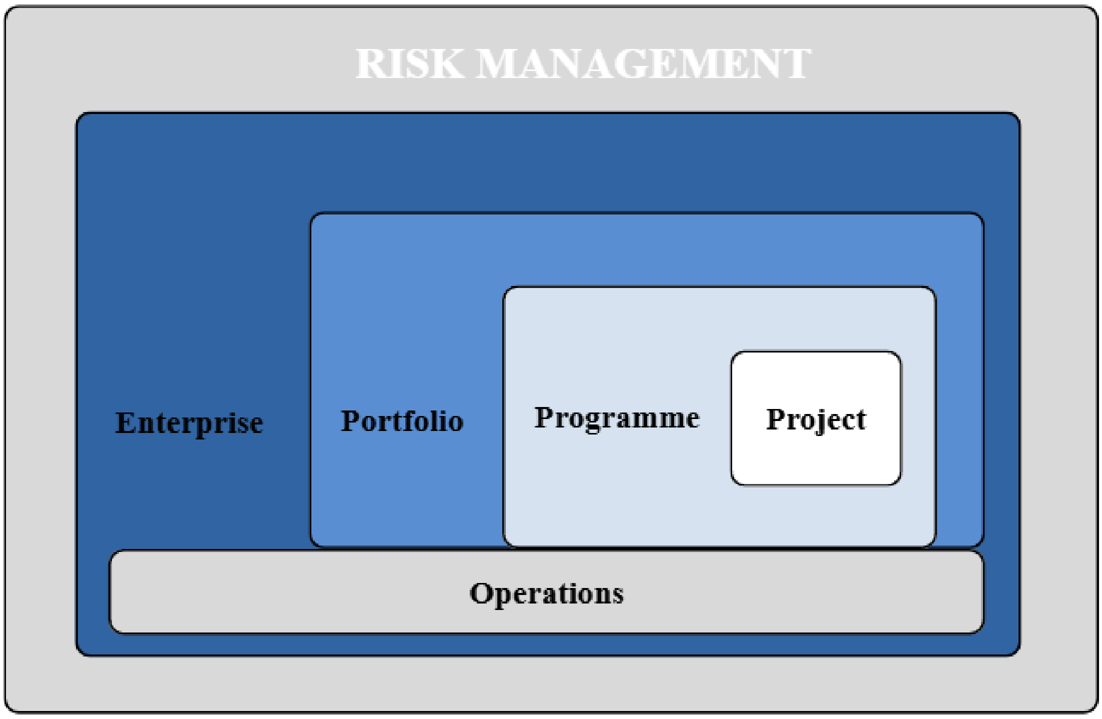


Figure 2.4: Risk management across enterprise, portfolio, programme and projects, adapted from Project Management Institute (2024)

2.4.1 Project Level

The lowest level in the framework is the project level. A project is defined as ”a temporary endeavour undertaken to achieve one or more objectives” (SIS, 2023). It is fundamental to establish clear project objectives, as it clarifies the project’s purpose and provides the basis for evaluating success later on (Edwards et al., 2025). Risks at this level are generally specific, internal and local to the project environment. A limitation identified by Olsson (2008) is that risk management at this level is often isolated. Experiences and lessons learned remain within the project team, failing to foster organisational learning (Olsson, 2008; Piterska & Kramskiy, 2017).

2.4.2 Programme Level

A programme is described as ”a group of programme components managed in a coordinated way to realise benefits” (SIS, 2023). A programme consists of multiple projects that are related or similar and therefore managed in a coordinated way to achieve benefits and control in a way that would not be possible if the projects were managed individually. The focus shifts to risks arising from the interfaces and interdependencies between projects within the programme. The programme manager must scan the contextual environment for risks that affect the whole programme, such as shared resource bottlenecks. Risk management at this level extends beyond individual deliverables to focus on benefits (Piterska & Kramskiy, 2017).

2.4.3 Portfolio Level

Portfolio management focuses on balancing the mix of projects to meet strategic goals and links projects to the corporate strategic vision (Project Management Institute, 2024). A portfolio is ”a collection of portfolio components grouped together to facilitate their management to meet strategic objectives” (SIS, 2023). At this level, risk management goes beyond the sum of individual components but also considers interdependencies between them (Project Management Institute, 2024). According to Piterska and Kramskiy (2017), the goal of risk management at this level is not just to minimise threats, but to ”manage reserves for major unexpected risk events”. It involves balancing the portfolio between high-risk/high-reward initiatives and low-risk/stable projects to maximise overall organisational value. According to SIS (2023), the structure of the portfolio represents a “snapshot” of the components included in the portfolio. This snapshot reflects the strategic objectives of the organisation that the portfolio is designed to achieve.

Furthermore, Val and Chumber (2011) describe portfolio risk management as a bridge needed to close the gap between different organisational levels. They identify a gap where project managers focus on delivery targets, while managers at the enterprise level focus on strategic alignment and shareholder value. Without a functioning portfolio-level to bridge this gap, projects may continue to execute according to plan even if they no longer serve the changing business objectives. Portfolio risk management therefore facilitates a communication channel that ensures that strategic changes are communicated down to projects, and that critical risks at project level are communicated up for management awareness.

2.4.4 Enterprise Level

The enterprise is the overarching entity (company or business) (Project Management Institute, 2021). Enterprise Risk Management (ERM) addresses systemic risks that impact the entire organisation, such as macroeconomic fluctuations, regulatory changes or market conditions. At this level, risk management is not just about aggregating project data but establishing a "global information" baseline to evaluate the effectiveness of response activities across the whole business (Cai et al., 2022). Val and Chumber (2011) describe ERM as the application of risk management across all areas of a business, extending beyond projects and programmes to include contracts, facilities, assets, and corporate functions. ERM provides a consolidated view that allows the organisation to identify central responsibilities and common response actions by integrating risk information from various business units.

2.5 From Project-Level to Portfolio-Level

Risk management is traditionally applied at the level of individual projects, where uncertainties are assessed in relation to specific objectives such as cost, time and quality (Project Management Institute, 2021). This approach supports operational control and enables project managers to monitor deviations within defined project boundaries. Its primary purpose is to ensure that each project delivers according to its predefined scope and performance criteria.

However, organisations that manage multiple projects simultaneously are exposed to uncertainties that extend beyond individual contracts. Sanchez et al. (2009) emphasise that risk management should not be limited to single projects but also consider how projects collectively influence organisational objectives. This broader perspective aligns with ISO 31000, which emphasises that risk management should be integrated across organisational levels and embedded in strategic decision-making processes (SIS, 2018). Together, these perspectives indicate that risk information must be structured in a way that supports oversight at higher organisational levels.

When risks are evaluated only at project level, management may lack visibility of the combined risk exposure and interactions between projects. Teller et al. (2014) show that portfolio performance improves when risk information from individual projects is systematically aggregated and analysed at higher organisational levels. Aggregation enables management to assess overall exposure, prioritise initiatives and evaluate whether the combined risk profile aligns with organisational risk tolerance. This logic corresponds with the distinction made by Reyck et al. (2005) between "doing projects right" and "doing the right projects". While project management focuses on effective execution, portfolio management concerns the selection and balancing of projects in a way that maximises overall organisational performance. Such balancing requires insight into aggregated risk and return profiles rather than separate project-level evaluations.

The concept of Project Portfolio Risk Management (PPRM) builds on this distinction by framing risk management as a mechanism for balancing risk and return across the entire portfolio (Reyck et al., 2005; Teller et al., 2014). From this perspective, risk management is not limited to mitigating uncertainties within projects but functions as decision support for shaping portfolio composition. As noted by Teller et al. (2014), the project manager's focus is primarily on meeting contractual objectives and managing risks that threaten project deliverables, whereas portfolio management adopts a broader view in which value is defined in terms of strategic alignment and overall investment performance. This shift implies that risk models must inform higher-level decisions regarding resource allocation, prioritisation and evaluation of new projects.

2.5.1 Aggregation of Project Risks at Portfolio Level

For an organisation to aggregate risks from individual projects into a portfolio-level overview, the quality of the underlying project data must be high (Kock et al., 2020; Teller et al., 2014). The literature warns against the principle of "garbage in, garbage out", meaning that if risk information reported from projects is inconsistent, outdated, or highly subjective, portfolio-level analyses will lead to misleading results and potentially flawed strategic decisions (Kock et al., 2020). Meaningful aggregation therefore requires that risk information at project level meets specific requirements related to formalisation, standardisation and quantification.

A fundamental prerequisite for aggregation is that all projects within the portfolio use a common and consistent structure for risk reporting (Teller et al., 2014). This implies that organisations must establish a shared taxonomy and consistent assessment scales for risks. If one project assesses risks qualitatively, for example, using verbal categories such as "high" or "low", while another project uses quantitative measures such as monetary values, mathematical aggregation of total risk exposure becomes infeasible (Kock et al., 2020). Risk information must therefore follow standardised templates in which likelihood and consequences are defined in a way that enables comparison across different types of projects (Teller et al., 2014).

To support advanced portfolio-level analyses, such as simulations of total portfolio cost or schedule outcomes, deterministic point estimates are insufficient. Several authors argue that uncertainty should instead be represented using probability distributions rather than single values. Kwak and Ingall (2009) and Senova et al. (2023) emphasise that projects should report uncertainty in terms of ranges or distributions, for example by specifying minimum, most likely and maximum values. Without this type of data, portfolio management is unable to calculate confidence intervals for overall portfolio outcomes, which often results in underestimated cost and schedule reserves. Aggregating deterministic values fails to capture the statistical variance that arises when multiple uncertain projects are executed simultaneously (Kwak & Ingall, 2009).

In addition to quantification, portfolio-level aggregation requires information about the context in which risks occur. Traditional risk reporting often treats risks as isolated events within individual projects. However, research shows that risks frequently act as triggers for other risks through shared resources, technical interfaces or organisational linkages (Qazi & Dikmen, 2021). For aggregation to be meaningful, project-level risk reports must therefore include information about interdependencies and potential cross-project effects. Without such information, portfolio management cannot identify systematic risks or risk paths, where disturbances propagate through the portfolio and amplify overall risk exposure (Bai et al., 2025; Qazi & Dikmen, 2021).

Risk information should be continuously updated to support effective portfolio-level decision-making. Sanchez et al. (2009) criticise approaches where risk management is treated as a one-time activity, such as being conducted only at project initiation. Since both project environments and portfolio conditions evolve over time, risk information can quickly become outdated if projects lack routines for continuous monitoring and regular updates of risk registers. For portfolio management to act proactively, changes in the risk profile must be reported close to the time at which they are identified instead of being deferred to fixed reporting intervals (Sanchez et al., 2009).

2.6 Methods for Analysing Risks

Risk analysis is generally divided into qualitative and quantitative methods, which can be used separately or together depending on the project's complexity and the availability of data (Burtonshaw-Gunn, 2009). The purpose of these methods is to improve the understanding of uncertainty and its potential impact on project objectives. By analysing identified risks, organisations can prioritise risk responses, support decision-making and establish an appropriate basis for contingency planning.

2.6.1 Qualitative Risk Analysis

Qualitative risk analysis is the process of prioritising individual project risks for further analysis or action by assessing their probability of occurrence and their impact. It is often the first step in the analysis process and serves to focus efforts on high-priority risks (Project Management Institute, 2017).

A widely used tool for visualising these assessments is the Probability and Impact Matrix (PIM), also referred to as a Heat Map or risk matrix (Cai et al., 2022; Kutej et al., 2025; Project Management Institute, 2021). This matrix maps the probability of a risk occurring against its potential severity regarding project objectives such as cost, time or quality. The matrix typically uses ordinal scales (e.g., Low, Medium, High) or cardinal scales (numeric values) to assign a risk according to two primary input dimensions: likelihood (or probability) and consequence (or impact) (Burtonshaw-Gunn, 2009; Cai et al., 2022).

The risk matrix visualises these scores, often using a "traffic light" colour scheme (red, yellow, green) to categorise risks into urgency zones. This visualisation helps project managers identify high-priority risks that require management or quantitative analysis, versus low-priority risks that may only require monitoring (Burtonshaw-Gunn, 2009). An example of such a matrix is illustrated in Figure 2.5. Risks positioned in the red zone are typically associated with both a high probability of occurrence and a high potential impact, indicating a level of exposure that may require treatment.

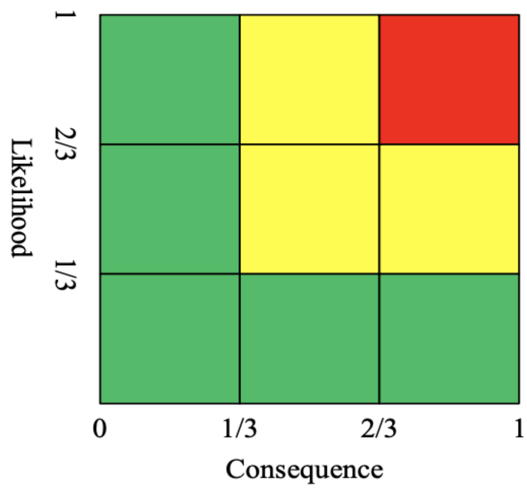


Figure 2.5: Example of a risk matrix retrieved from Cai et al. (2022)

While this method is simple and easy to use, it has also been criticised. Chapman and Ward (2003) argue that defining risk only as ”Probability × Impact” is problematic because it treats risk as an expected value and thereby ignores factors such as variance and overall risk efficiency. Risk efficiency refers to the balance between risk and reward (Project Management Institute, 2024). Chapman and Ward (2003) further warn that relying only on this sort of matrix can lead to a simplistic, ”paint-by-numbers” approach to risk management. By placing risks into broad categories and adding up risk scores, this matrix may hide important information and therefore provide limited insight compared to more advanced quantitative methods. However, completely abandoning the risk matrix is often unrealistic, since it is still a useful tool in uncertain situations where detailed quantitative data is lacking (Cai et al., 2022).

2.6.2 Quantitative Risk Analysis

Quantitative risk analysis numerically analyses the combined effect of identified risks and other sources of uncertainty on overall project objectives (Project Management Institute, 2017). A widely used method for this purpose is Monte Carlo simulation (MCS) (Lehman & Groenendaal, 2020). It is a statistical technique that analyses uncertainty by performing repeated simulations of a project model. Instead of relying on deterministic (single-point) estimates, which fail to account for the range of possible outcomes, the method uses probability distributions to represent uncertain input variables (Lehman & Groenendaal, 2020). MCS is a mathematical technique that can combine expert judgement with numerical simulation to analyse complex, uncertain scenarios from a probabilistic perspective (Allahi et al., 2017). During a simulation, values are randomly sampled from distributions to calculate a project outcome. After thousands of iterations, the model produces a probability distribution of possible results, such as total project cost or completion date. This allows managers to assess the level of confidence in achieving specific objectives, moving beyond simple best- and worst-case scenarios (Lehman & Groenendaal, 2020; Project Management Institute, 2017). In addition, Allahi et al. (2017) argue that Monte Carlo is more comprehensible and feasible than other methods to estimate contingency reserve in construction projects.

To account for project variability, uncertain parameters are modelled using expert estimates mapped to probability distributions. Two common distributions used for modelling expert opinion are the PERT and the Triangular distributions that can be seen in Figure 2.6. Both are defined by three data points: the minimum, most likely and maximum values (Lehman & Groenendaal, 2020).

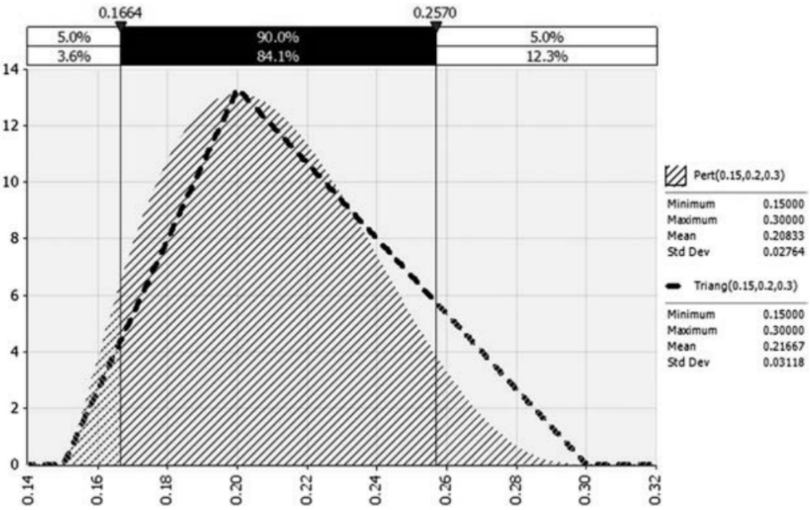


Figure 2.6: Example of PERT and Triangular Distribution retrieved from Lehman and Groenendaal (2020)

The output of a Monte Carlo simulation can be presented as a probability distribution representing the range of possible project costs(Karlsen & Lereim, 2005). The probability distribution curve enables decision-makers to select their "level of coverage", which illustrates the probability that a specific allocated amount will cover all additional costs that arise (Allahi et al., 2017).

While the probability distribution provides an understanding of the overall cost exposure, it does not explain which specific variables drive this uncertainty. To fully comprehend quantitative risk models, Chapman and Ward (2003) emphasise the necessity of sensitivity analysis. This analytical technique determines which individual project risks have the greatest potential impact on project outcomes by correlating variations in the expected outcome with variations in the individual elements of the risk model (Burtonshaw-Gunn, 2009).

The results are frequently visualised using a Tornado Chart, as seen in Figure 2.7 (Lehman & Groenendaal, 2020). This chart can be automatically retrieved as an output from the MCS in @RISK. To construct this chart, the underlying model evaluates how the expected output varies when specific input variables are tested across their extreme values while keeping all other variables stable. By displaying these results as horizontal bars arranged in decreasing order of influence, the chart forms its characteristic "tornado" shape to clearly identify the project's primary risk drivers (Lehman & Groenendaal, 2020). This visualisation provides project managers with guidance on where to focus proactive mitigation efforts to most efficiently reduce uncertainty and ensure project stability (Burtonshaw-Gunn, 2009; Lehman & Groenendaal, 2020).

@RISK can generate four different types of tornado charts to analyse input sensitivity (Lumivero, n.d):

- Change in Output Statistic: Divides input values into a set of bins across their range. For each bin, a particular output statistic is calculated. The magnitude of the change across all bins is then tabulated. This approach is sometimes referred to as the conditional sensitivity method.
- Regression: Constructs a regression equation that best predicts the output as a weighted sum of the inputs. The results are standardized and then ranked according to their magnitude.
- Correlation: Calculates the correlation coefficients between each input and the output and ranks the inputs based on the magnitude of these coefficients. Varies between -1 and 1. Rank-based methods such as Spearman rank correlation are commonly used in project risk analysis because they can identify relationships between variables without assuming linear relationships or normally distributed data (Peleskei et al., 2015). This makes them suitable for Monte Carlo-based analyses where project risks often interact in complex ways.
- Contribution to Variance: A sequential sum of squares technique to determine how much each input contributes to the variance of the output.

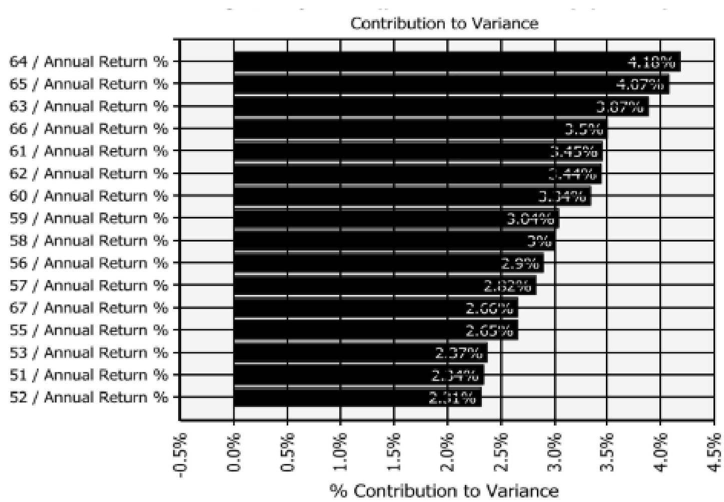


Figure 2.7: Example of a Tornado Chart retrieved from Lehman and Groenendaal (2020)

A critical factor in building a robust Monte Carlo model is addressing the correlations between different cost items and risks. In practice, project risks are rarely entirely independent: a delay or cost overrun in one area often triggers cascading effects in others. If a simulation model assumes that all risks are completely independent, it tends to underestimate the total cost variance and the overall risk exposure of the project (Karlsen & Lereim, 2005).

2.7 Budgeting

Risks and uncertainties often have financial consequences that may affect whether a project remains within budget. For this reason, budgeting is closely linked to risk management. By incorporating uncertainty into the budgeting process, organisations can allocate financial reserves and improve their ability to manage potential cost deviations. According to Project Management Institute (2021), and as illustrated in Figure 2.8, the project budget is developed based on cost estimates for specific project activities. To fully build up the budget, these estimates must be supplemented with reserve funds to account for uncertainty and risks.

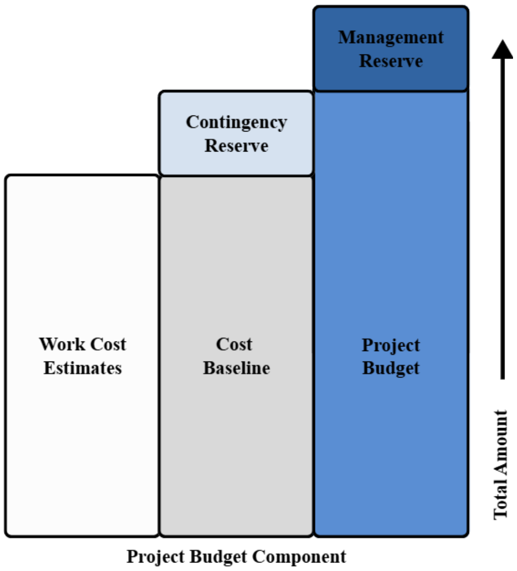


Figure 2.8: The Budget Build adapted from Project Management Institute (2021)

2.7.1 Cost Estimation

Cost estimation is a fundamental process in project management, described by AACE International (2015) as "a process used to predict uncertain future cost". It involves a quantitative assessment of the resources required to complete project activities, including labour, materials, equipment and overhead (Burtonshaw-Gunn, 2009; Project Management Institute, 2021).

The goal of a cost estimate is to establish a realistic baseline for the budget and maximise the probability that the actual outcome aligns with the prediction (AACE International, 2015). According to AACE International (2015), the output of this process ideally includes both an expected cost and a probabilistic cost distribution. In addition, historical reference cost data can be used to improve the reliability of the estimates.

In traditional project management practice, cost estimation is often performed by using deterministic approaches, where costs are expressed as single-point estimates. These estimates typically represent the most likely cost of completing the project based on the defined scope and assumptions. Such estimates are often derived from the project's Work Breakdown Structure, where individual cost elements are calculated and aggregated into a total project cost. However, a limitation of point estimates is that they do not reflect the inherent uncertainty in projects. A single value provides no information about the possible range of outcomes or the likelihood of deviations. Relying solely on deterministic estimates may create a false sense of precision and lead to unrealistic expectations regarding project cost performance (Karlsen & Lereim, 2005).

Karlsen and Lereim (2005) describe this base estimate as a theoretical value where no risk events occur, where the project is assumed to proceed exactly as planned. Since such risk-free conditions rarely exist in reality, this assumption is a limitation of traditional estimating approaches. Chapman and Ward (2003) describe a common issue in practice where uncertainty is not treated explicitly, but is instead embedded directly within individual cost items. To account for potential risks or to protect against future budget reductions, estimators include hidden margins in their base estimates. The authors characterise this behaviour as a "vicious circle", in which estimators inflate their values in anticipation of later downward adjustments by management. Consequently, contingency is implicitly absorbed into the base estimate rather than being managed as a separate and transparent component (Chapman & Ward, 2003). Karlsen and Lereim (2005) argue that in addition to a lack of transparency this approach also introduces the risk of double-counting, since additional contingency reserves may later be added on top of the already inflated base estimates.

2.7.2 Budgeting for Risk Reserves

Management must accept a certain level of uncertainty and risk, as unforeseen expenditures will always arise in projects (Karlsen & Lereim, 2005). To cover these unforeseen conditions and address potential deviations from planned outcomes, additional funds are typically allocated in project budgeting. This financial protection is commonly implemented through two distinct reserves. Although terminology varies in the literature, Project Management Institute (2021) distinguishes between contingency reserves and management reserves, which serve different but complementary roles in managing cost uncertainty.

As illustrated in Figure 2.8, contingency reserves are included within the cost baseline of the project budget. They are managed directly by the project manager and are designated for "Known-Unknowns", discussed in Subchapter 2.1 and shown in Figure 2.1. These represent identified risks where the project team is aware of the uncertainty and has estimated both the probability of occurrence and the potential impact.

Management reserves are instead intended for "Unknown-Unknowns", which is unforeseen events that could not be identified during the risk management process but fall within the scope of the project. Unlike contingency reserves, these are not part of the cost baseline, but are part of the total project budget.

2.7.2.1 Estimating Contingency Reserve

To determine the appropriate funding for a group of risks, the Expected Monetary Value (EMV) method is frequently employed. This is calculated by multiplying the probability (P) of a risk occurring by its potential financial impact (I) (Project Management Institute, 2021):

$$EMV = P \times I$$

The aggregate EMV of all identified risks typically forms the foundation of a project's contingency reserve (Gunde et al., 2025). However, relying solely on this sum is often insufficient as it produces an "average" expected outcome (Chapman & Ward, 2003). To establish a more robust contingency reserve, an additional margin referred to as "allowance" must be added on top of the EMV (Karlsen & Lereim, 2005). To evaluate the combined effect of these uncertainties and determine a realistic reserve, probabilistic tools such as Monte Carlo simulations (as described in 2.6.2) are widely employed (Karlsen & Lereim, 2005; Project Management Institute, 2021). Chapman and Ward (2003) argue that to ensure total project safety, a project should set aside a sufficient contingency reserve to achieve an 80% or 90% chance of staying within budget. This creates a buffer for events that would have a high impact if they happened.

This principle is conceptually aligned with Value at Risk (VaR), a widely applied risk metric in finance. It represents the maximum expected loss at a given confidence level over a specified time horizon. In simple terms, VaR corresponds to a selected percentile of a loss distribution. In financial contexts, it is common to adopt a high confidence level such as P95, reflecting a conservative risk appetite (Acebes et al., 2024). In project management, however, P80 is often considered more appropriate, as it balances risk protection with competitiveness.

The size of the reserve also depends on the organisation's risk tolerance, which refers to the amount or degree of uncertainty and risk exposure that an organisation is willing to accept and withstand in pursuit of its objectives (Project Management Institute, 2024). If the organisation has a low tolerance, even small risks must be budgeted for.

Setting a high confidence level for contingency protects the project, but in practice it also creates a dilemma in the tendering phase. Chapman and Ward (2003) describe how this is particularly evident in fixed-price contracts, where contractors must include a contingency reserve to cover costs for uncertainty and risk. At the same time, competitive procurement often awards the contract to the lowest bidder, which puts pressure on contractors to reduce prices, margins and contingency sums. Contractors are therefore forced to balance the risk of losing the bid against the risk of financial loss if problems occur later on (Burtonshaw-Gunn, 2009; Chapman & Ward, 2003).

Gunde et al. (2025) suggest that if an activity is completed without the risk materialising, the contingency fund allocated for that specific activity should be converted back into the budgeted fund, which optimises resource utilisation.

2.7.2.2 Estimating Management Reserve

Estimating the management reserve differs from estimating the contingency reserve. Management reserves are typically determined using reserve analysis and often rely on heuristics, percentage rules (e.g., 5%-10% of total budget) or historical data from similar projects rather than a bottom-up calculation of specific risks (Chapman & Ward, 2003; Project Management Institute, 2017). It also involves a strategic decision regarding where these funds should be held and there are different opinions in the literature. According to Project Management Institute (2024), management reserves can be managed at different levels in the organisation depending on the structure. At the same time, Val and Chumber (2011) argue that it is typically controlled at a higher organisational level rather than by the individual project team and that it is most effectively managed at the portfolio level. This approach allows the organisation to pool resources for emerging risks instead of tying a buffer to each individual project. Chapman and Ward (2003) support this view and suggest that the management reserve is more effectively assessed and managed at the portfolio level to ensure better capital efficiency across the organisation.

Karlsen and Lereim (2005) specifies that management reserves (referred to as budget reserves) are intended for extraordinary risks, such as contractor bankruptcy or major client-induced scope changes. While the project manager should control the base cost and allowance, the formal authority over the management reserve requires a close dialogue between the project manager and the project owner, and should remain with the project owner or steering group.

2.8 Indicators for Risk Exposure

To evaluate project success and maintain control, Project Management Institute (2021) highlights the importance of using Key Performance Indicators (KPIs). KPIs are measures used to monitor project progress, anticipate trends and make informed decisions based on reliable data.

Project Management Institute (2021) distinguishes between lagging and leading indicators. Lagging indicators, such as schedule variance or budget consumption, look backward at events that have already occurred. In contrast, leading indicators are predictive and forecast future trends and changes, allowing the project team to identify potential performance variances before they reach tolerance thresholds.

Scarlat et al. (2012) introduces the concept of Key Risk Indicators (KRIs) with the role as an early warning system. The author argue that KPIs primarily reflect past and current performance, and show whether project goals have been achieved, while KRIs function as forward-looking indicators that help detect emerging risks and provide early warning signals. This perspective is similar to the idea of leading indicators described by Project Management Institute (2021), where metrics are used to anticipate future performance and support proactive decision-making.

Indicators can also prioritise which individual uncertainties demand the most monitoring. As discussed in Chapter 2.6.2, sensitivity analysis and its visual representation, the tornado chart, serve as an indicator of risk exposure (Burtonshaw-Gunn, 2009; Project Management Institute, 2021). It functions as a prioritisation metric, and signals which inputs drive the greatest variability in the project's expected outcome. This provides the project team with guidance on where to focus mitigation efforts and allocate monitoring resources to achieve the greatest impact on overall project stability (Lehman & Groenendaal, 2020).

At the portfolio level, indicators are important to ensure that collective investments maintain strategic alignment and expected outcomes. De Marco et al. (2018) argue that risk management at this level must act as more than just a control tool and that it should support value generation. To achieve this, they propose the use of specific portfolio-level indicators, such as the Expected Monetary Value Combined (EMVC). The EMVC acts as a leading indicator by forecasting how the aggregated value of open risks (both threats and opportunities) may affect the expected portfolio profit. A negative EMVC value provides an early warning of potential margin erosion, giving management the opportunity to proactively strengthen risk mitigation measures before losses materialise.

2.9 Risk Analysis as Decision Support

Risk analysis functions as a decision-support mechanism that helps organisations manage uncertainty in alignment with their strategic objectives (Chapman & Ward, 2003). Effective risk management requires a clear definition of organisational boundaries for acceptable risk, ensuring that decisions are aligned with the overall strategy. By providing structured input to planning and prioritisation, risk analysis helps project teams and management allocate resources where they create the greatest value (Project Management Institute, 2024; SIS, 2018). A central aspect of this alignment is the concept of risk appetite, which describes the level of uncertainty an organisation is willing to accept in pursuit of desired outcomes (Project Management Institute, 2021).

Risk appetite is determined by risk thresholds, which define the acceptable range of variation around specific objectives and serve as measurable limits for decision-making. For instance, a risk threshold of 10% around a cost objective reflects a higher risk appetite than a threshold of 5% (Project Management Institute, 2021). These thresholds and criteria must reflect the organisation's values, resources and overall capacity to absorb potential impacts (SIS, 2018).

Once individual risks and the overall risk exposure are evaluated against established thresholds, decision-makers must formulate appropriate risk response strategies to maximise positive impacts and minimise negative ones (Project Management Institute, 2021; SIS, 2023). For negative risks, organisations commonly employ proactive strategies such as avoidance (terminating the risk by altering the plan), transfer (shifting the consequence to a third party) or mitigation (taking early action to reduce the probability or severity) (Burtonshaw-Gunn, 2009; Project Management Institute, 2021).

However, when proactive measures are not cost-effective or necessary, an organisation may choose the strategy of risk acceptance (Burtonshaw-Gunn, 2017). Accepting a risk means acknowledging its existence but deliberately keeping it without taking proactive action to change its probability or impact before it occurs. Risk acceptance can take either an active or passive form. Active acceptance involves developing a contingency plan or setting aside financial reserves to be triggered only if the risk event materialises. Passive acceptance, on the other hand, means taking no advance action, leaving the project team to bear the consequences as they occur (Burtonshaw-Gunn, 2009; Project Management Institute, 2021). The decision to accept a risk is often driven by risk efficiency, where the cost of mitigating a risk would be disproportionate to the potential benefit, leading management to take the risk because reducing it would cost more than it is worth. Instead of spending too much to remove the risk, they make informed decisions to take it, with the aim of achieving the best overall results of the project (Chapman & Ward, 2003).

2.10 Organisational Learning and Knowledge Management

SIS (2018) emphasises the iterative nature of risk management and the importance of recording, reporting and learning from experience. Within project environments, this learning process is facilitated by knowledge management, which Edwards et al. (2025) identify as essential for enhancing decision-making and communication. By establishing communities of practice, organisations can ensure that lessons learned are not lost but are instead shared to support future risk management efforts.

However, applying these principles in the construction sector comes with challenges. The industry operates within a complex environment where projects are often constrained by interdependencies and shared resources (Bai et al., 2025). Olsson (2008) argues that traditional risk management processes often focus too heavily on single projects, and fail to foster learning between projects or identify common risk trends across a portfolio. This isolation reinforces the fragmented and siloed nature of knowledge in the sector, highlighted by Amaechi et al. (2025). Fostering a culture of collective learning allows project teams to leverage historical data to illuminate potential future risks, thereby reducing costly rework and expediting decision-making processes (Amaechi et al., 2025). This integration of knowledge management into risk processes is increasingly revolutionised by technological advancements. Amaechi et al. (2025) identify Artificial Intelligence (AI) and Big Data analytics as emerging trends in this domain. Unlike traditional methods, AI-powered systems have the capacity to analyse vast datasets to forecast potential issues with high accuracy. This capability enables organisations to implement preventative measures before risks materialise, facilitating a strategic shift from reactive uncertainty management to a more robust, proactive risk handling approach (Amaechi et al., 2025).

Edwards et al. (2025) also argue that project performance is improved when people communicate with each other and share good practices, lessons learned, relevant experiences, sensible advice or opinions. According to AACE International (2015), the ultimate success of risk management depends on the continuous engagement of the entire project team throughout the project lifecycle. At the end of a project, an important step is to capture and document historical data related to risks and their impacts. Storing this information in a database allows the organisation to build knowledge that can support future projects.

3 Method

The methodological approach adopted in this thesis was used to investigate how project-level risks can be analysed and visualised at the portfolio level. The study was conducted as a case study at VSN and applied a combination of research methods to explore both current practices and analytical modelling approaches. The study is qualitatively driven but the resulting framework incorporates a quantitative simulation.

The qualitative research was grounded in three main data sources: a literature review, document analysis and semi-structured interviews. The research followed an abductive and iterative research approach. An abductive approach is characterised by a movement between theory and empirical observations, where researchers iteratively relate literature to empirical findings in order to develop and refine theoretical understanding, as well as to challenge pre-understandings (Bell et al., 2022). The abductive approach also guided the development of the proposed risk management framework, which was iteratively refined through continuous interaction between theoretical concepts and empirical findings.

3.1 Literature Review

Booth et al. (2026) describe that literature searches often begin with a *scoping search*, which is intended to provide an overview of the existing research within a topic area. Following this recommendation, an initial exploratory search was conducted in order to gain a deeper understanding of risk management.

The literature review was guided by ISO 31000, an international standard for risk management that outlines general principles, terminology and processes for managing risk. In addition, publications and guidelines from the Project Management Institute (PMI) were reviewed. These sources contributed to establishing best practices and practical perspectives on how risk management is typically structured within organisations.

To complement the standards, scientific journal articles were searched through academic databases such as Scopus, Web of Science and Google Scholar. According to Booth et al. (2026), multidisciplinary databases are useful when conducting literature reviews because they provide access to a wide range of research.

Booth et al. (2026) further explain that relevant search terms can be identified by examining frequently used keywords in article titles and abstracts. Based on this approach, several key terms related to the research topic were identified and used to develop search strings. The search strings included combinations of terms such as ”project risk management”, ”portfolio risk management”, ”risk aggregation”, ”project portfolio risk”, “portfolio-level risk analysis”, ”cost analysis” and ”contingency reserve”. Boolean operators such as *AND*, *OR* and *NOT* were used to combine and refine these search terms in the database queries.

When screening search results, Booth et al. (2026) recommend first reviewing article titles to determine potential relevance, followed by reading abstracts when the title alone is insufficient for making a decision. This approach was applied in the selection process to assess whether the publications addressed relevant topics. Another technique described by Booth et al. (2026) is *pearl growing*, where references and citations from relevant articles are used to identify additional studies. This method was also applied during the literature review process.

Preference was given to more recent publications in order to reflect current research developments within the field. However, earlier studies were also included when they provided important theoretical contributions. In addition, articles with a high number of citations were prioritised, as citation frequency was considered an indicator of academic influence and relevance.

3.2 Document Analysis

An internal document analysis was conducted to develop an understanding of how risk management is structured within VSN. The objective was to examine how the organisation described its risk processes and how these are applied during different phases of a project. The review focused on documents related to both the tender phase and the project execution phase in order to capture the full perspective of the project lifecycle.

The internal documents included guidelines, templates for risk registers, reporting formats and written process descriptions. These documents provided insight into how risks were intended to be identified and categorised and how probability and impact were defined within the organisation. The analysis also examined how risk information was documented and how it was communicated between project teams and management levels.

In addition to providing contextual understanding, the document analysis served as a foundation for the subsequent interviews. By reviewing existing documentation in advance, it was possible to identify areas for further clarification and discussion. The findings from the document review therefore informed the development of the interview questions and ensured that the interviews were grounded in the actual organisational processes.

The review was carried out in collaboration with representatives from VSN to ensure that the interpretation of the documents reflected actual organisational practice. The findings also supported the adaptation of the proposed framework so that it aligned with existing processes and organisational conditions.

3.3 Semi-Structured Interviews

To understand how risk management is carried out in practice, qualitative data were collected through semi-structured interviews with respondents at VSN.

3.3.1 Respondents

The selected respondents consisted of project managers and tender engineers, as these roles are responsible for identifying, assessing and managing risks at different stages of the project lifecycle. An overview of the interview participants is presented in Table 3.1, including their roles, years within the company and years of experience in the field. In total, 13 respondents participated in the study.

Table 3.1: Overview of interview respondents

Respondent ID	Role	Years at VSN	Years in the field
R1	Tender Engineer	7	12
R2	Tender Engineer	5	30
R3	Tender Engineer	10	24
R4	Tender Engineer	2	19
R5	Tender Engineer	9	20
R6	Tender Engineer	10	31
R7	Project Manager	9	11
R8	Project Manager	4	5
R9	Project Manager	15	21
R10	Project Manager	1	4
R11	Project Manager	13	21
R12	Project Manager	14	37
R13	Project Manager	6	18

Efforts were made to include participants with different levels of experience and involvement in various types of projects in order to capture a broader perspective of current practices. The respondents were contacted individually and were given the opportunity to voluntarily decide whether they wanted to participate in the interview. Due to confidential handling of all responses, each participant was assigned an anonymous identifier (R1–R13). These identifiers are used throughout the analysis to ensure that individual respondents can not be traced.

3.3.2 Interview Format

The interviews were conducted via Microsoft Teams and lasted approximately 60 minutes. The discussions focused on how risk management is structured and applied within individual projects, as well as how risk information is transferred between the tender phase and project execution. Participants were also invited to reflect on the strengths and limitations of the current approach and to identify potential areas for improvement.

A semi-structured interview format was adopted to ensure that consistent themes were addressed across all interviews while still allowing participants the flexibility to elaborate on their experiences. Semi-structured interviews follow an interview guide, but the interviewer can adjust the order of questions and pose follow-up questions if relevant. According to Flick (2022) semi-structured interviews are suitable when interviewing experts. Two separate interview guides were developed to reflect the different perspectives of tender engineers and project managers. The interview guides are presented in Appendix A and Appendix B.

3.3.3 Compilation of Interviews

The collected material from interviews was analysed using a thematic approach. Bell et al. (2022) define thematic analysis as one of the most common approaches to qualitative data analysis. It focuses on the search for patterns or themes within a dataset, such as interview transcripts. Recurring patterns and themes related to risk identification, assessment practices, information transfer and perceived challenges were identified and categorised.

3.4 Development of a Framework for VSN

The purpose of the proposed framework is to enable a more structured approach to project risk management and to support analysis of risk exposure at portfolio level within VSN. The framework was developed through an iterative research process that combined insights from the literature review, empirical findings from interviews and document analysis and results from exploratory uncertainty analysis.

The empirical findings served as the starting point for the framework development and identified several limitations in current risk management practices within VSN. To address these challenges, relevant theoretical concepts presented in Chapter 2 were used as the foundation for the framework design. However, it should be emphasised that no single existing theoretical model or standardised framework in the literature could be directly applied to the specific organisational context of VSN. Instead, the framework was developed by adapting and combining theoretical perspectives related to probabilistic risk analysis, cost estimation uncertainty, portfolio risk aggregation and organisational learning to fit the organisational context of VSN.

The uncertainty analysis constituted an integrated part of the framework development and was developed simultaneously with the framework itself. It was used to explore possibilities and to support the integration of quantitative perspectives. Together, these elements informed the development of the framework presented in chapter 5. To further support understanding of the framework and illustrate how it may function in practice, an illustrative example is also presented.

3.4.1 Uncertainty Analysis with Monte Carlo Simulation

A model using Monte Carlo simulation was developed to demonstrate how uncertainty in probability and cost estimates can influence total risk exposure at both project and portfolio level. The model was developed in Microsoft Excel using the @RISK add-in software. The analysis was conceptual in nature and aimed to show how uncertainty analysis can be applied within VSN.

Due to confidentiality principles within VSN, historical project-specific data could not be used in the thesis. For this reason, illustrative data were constructed to develop a model and demonstrate how the simulation results can be interpreted, see chapter 5. An overview of the probability distributions used in the analysis is presented in Figure 3.1.

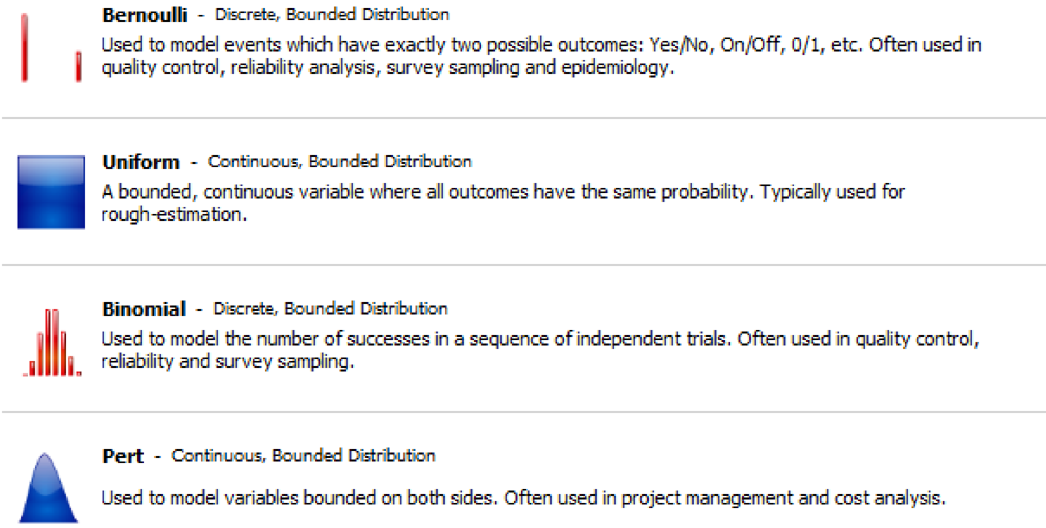


Figure 3.1: Used distributions in model retrieved from @RISK

3.5 AI-disclosure

AI tools, such as ChatGPT, Google Gemini, Notebook LM and Microsoft Copilot were used as support throughout the research process. These tools assisted in brainstorming ideas, refining the text and helping to organise content. AI was not used to replace critical thinking, generate original research findings or influence interpretations and analytical decisions. The authors were responsible for all arguments, data analysis and conclusions. To maintain confidentiality, no sensitive company data regarding VSN or personal information from interviews was shared with external AI tools. However, VSN's internal Copilot environment was used to manage internal information, as it complies with the organisation's security guidelines.

4 Empirical Findings

The empirical findings of this study provide insights into how risk management is structured within VSN and how it is applied in practice. The section begins with a presentation of how the organisation formally defines its internal risk management processes in governing documents and internal guidelines. These documents represent the intended way of working and establish the current baseline for how risk management is expected to be performed within projects.

This formal perspective is complemented by insights from conducted interviews, which provide an overview of how risk management is carried out in practice. The interviews capture how risk-related activities are managed in different project contexts and how project managers and tender engineers perceive these practices. The interviews add depth to the formal description and reflect how procedures are interpreted and applied in real situations.

4.1 Risk Management Based on Internal Guidelines

According to VSN's internal documentation, risk management is a process aimed at ensuring that project objectives are achieved. The process is supported by internal digital tools that structure how risks are identified, assessed and followed up throughout the project lifecycle. The two central governance tools used within the organisation are APV (Tender Process Tool) and PPV (Project Process Tool).

Risk management begins in the tender phase within APV. During this stage, the tender engineer is responsible for identifying and documenting relevant project risks in the Risk and Opportunity List. The assessment is based on a probability and impact map, where each risk is evaluated according to its likelihood of occurrence and its potential financial consequence. In addition, the tender engineer must also determine which risks require a financial provision in the form of a contingency reserve. This means that not all identified risks automatically result in a cost provision. Instead, a professional judgement is made regarding which uncertainties are significant enough to justify allocating contingency in the tender calculation.

If VSN is awarded the contract, responsibility shifts from the tender organisation to a project manager. All risks and opportunities that were identified and documented during the tender phase in APV can be transferred into PPV. Each risk is then supposed to be continuously updated based on actual project development. The project manager evaluates whether previously identified risks are still relevant, whether new risks have emerged, and whether allocated risk money remains sufficient.

4.1.1 The Risk- and Opportunity List

The risk- and opportunity list is structured as a probability-impact matrix. Each identified risk or opportunity is assessed along two dimensions that include the likelihood of occurrence and the estimated financial consequence. Probability is expressed in predefined intervals with a 20% scale and impact is structured in five cost levels as illustrated in Table 4.1. The cost is estimated as a single numerical value based on professional judgement and is subsequently classified by the system into the corresponding predefined cost intervals. Once the information is entered, a marker is automatically placed in the heat map that provides a visual overview of the project's risk exposure. A picture of the probability–impact matrix can be seen in figure 4.1. The structure makes it possible to prioritise risks according to their relative exposure, since a higher probability combined with a higher impact results in greater risk significance.

Table 4.1: Intervals in the probability-impact matrix

Level	Probability (likelihood of occurrence)	Impact (financial consequence)
1	0 - 20%	0 - 19 999 SEK
2	20 - 40%	20 000 - 49 999 SEK
3	40 - 60%	50 000 - 99 999 SEK
4	60 - 80%	100 000 - 249 999 SEK
5	80 - 100%	> 250 000 SEK

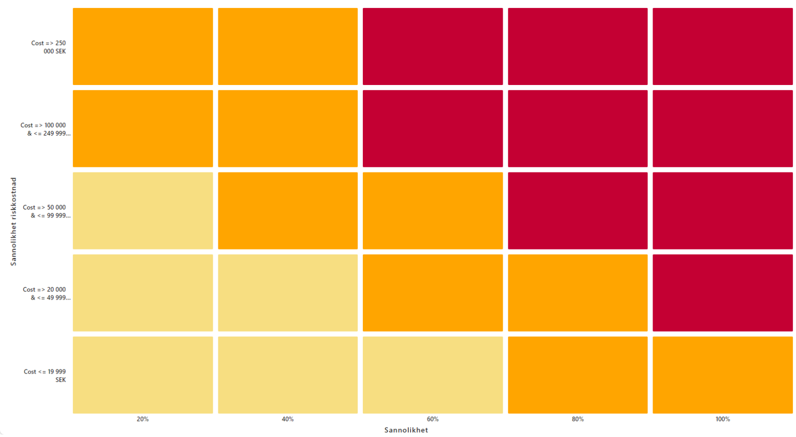


Figure 4.1: Probability-impact matrix retrieved from Vattenfall Services Nordic AB (2026)

The updated risk- and opportunity list was introduced across the entire organisation a few years ago and therefore represents a relatively new governance tool within Vattenfall Services Nordic AB. The introduction aimed to standardise risk assessment practices and strengthen transparency across projects. However, it is still in an early stage of organisational adoption since the tool was recently implemented.

Risk registration occurs directly within the internal system once a risk has been identified. The user enters a name for the risk so that it can be easily recognised in the register. A description is then written to explain what the risk involves, under which conditions it may occur and how it could affect the project. The system also includes a field for preventive actions. Here, potential measures that could reduce the likelihood of the risk occurring can be documented. This makes it possible to link the identified risk to concrete management actions. In addition, it is possible to indicate whether the risk has already been included as a contingency item in the budget estimation.

A risk status must be selected from predefined alternatives presented in figure 4.2. The status reflects the current situation of the risk and is intended to be updated whenever changes occur in the project that affect it. This ensures that the risk register continuously reflects the actual risk situation in the project. The internal governing documentation further states that the risk register should be reviewed and updated at least once per month. In addition, each risk must be assigned to a category and the available options are also shown in figure 4.2.

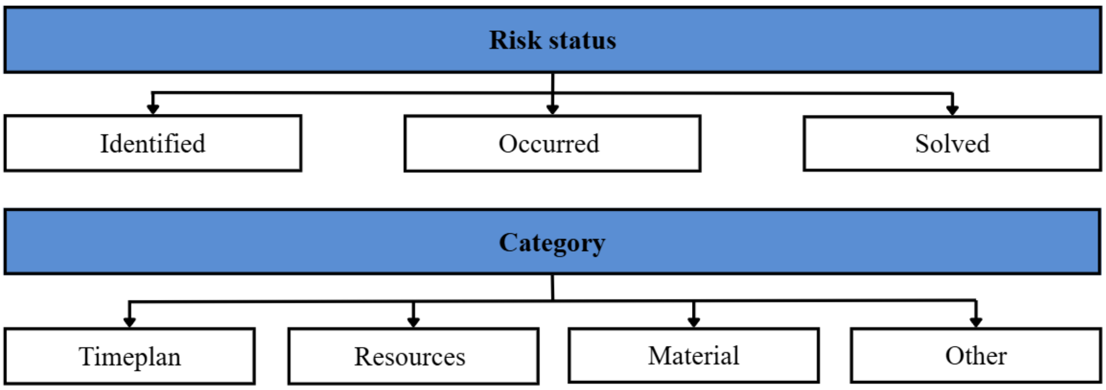


Figure 4.2: Own illustration of options for risk status and category

4.2 Respondents' Perspectives on Risk Management

To understand how risk management is performed in practice, the internal guidelines are complemented with the perspectives of employees involved in project work. The findings are based on interviews with 13 respondents from VSN who work as tender engineers and project managers. The respondents have varying levels of experience, ranging from a few years to more than 20 years, as illustrated in Table 3.1. They participate in projects that differ in size, complexity and contract type, which provides a broad perspective on current risk management practices across the organisation.

The findings are organised thematically according to recurring patterns and topics identified during the analysis to provide a structured presentation. The two respondent groups have different responsibilities and perspectives and the findings build on the respondents' own experiences and reflections. Tender engineers (R1–R6) are mainly responsible for tender preparation, including cost estimation and the initial identification and assessment of project risks. Project managers (R7–R13), on the other hand, are responsible for project execution and work with risk management throughout the project lifecycle.

4.2.1 Risk Identification Practices

According to the respondents, risk identification is mainly based on experience and dialogue between individuals involved in the project, such as tender engineers, project managers and site workers. R1 explains that risks are identified in dialogue with project managers, while R3 describes that identification is based on experience from previous projects. Similar descriptions are provided by R5 and R9, who emphasise discussions with colleagues and the use of prior project experience as a central approach. R10 also highlights the importance of collaboration with colleagues, emphasising the benefits of working in open-plan offices where advice and knowledge can easily be shared.

The respondents further describe that the levels of involvement of different actors in the risk identification process vary. R1, R3 and R4 describe that project managers are often involved during the tender phase, whereas R2 states that risk identification is carried out individually before being presented to others. From the project managers' perspective, R7 and R11 describe that site personnel and technicians are involved in identifying risks. In contrast, R13 identifies risks independently without involving others.

Documentation of risks varies considerably between respondents. R2, R4 and R6 describe that they document risks in Excel-based templates, while R1 and R3 refer to the risk- and opportunity list in APV, although the tool is not always consistently used. R5 explains that risks have previously only been discussed verbally or presented in meetings. Among project managers, R9 and R13 refer to tools in PPV but indicate that these are used to a limited extent. R10 states that the risk and opportunity list in PPV is *"more of an administrative burden than support"*, and R11 explains that smaller risks are often not documented at all.

Several respondents describe challenges related to identifying all relevant risks. R9 states that it is *"impossible to ensure that all risks are identified"*, while R3 explains that certain risks, such as ground conditions, are difficult to assess in advance. R6 similarly notes that *"you do not know everything in advance"*, and R11 describes that risks often become apparent only during project execution.

R8 notes that project risk identification is not supported by a formal list. In addition, R12 explains that HSSEQ risks are supported by predefined lists to help with identification. R6 uses a self-made template for project risk documentation that is reused across projects but continuously adapted to fit specific project conditions.

Respondents also describe areas for improvement in the identification process. R1 suggests the development of checklists for different project types, while R2 emphasises the need for clearer and more user-friendly tools. R5 underlines that the process is highly dependent on individual experience and suggests that more knowledge could be documented. R7 highlights the need to better capture knowledge from site personnel and incorporate it into structured systems. R10 explains the role of experience and training, particularly for less experienced staff, in improving risk identification. In addition, R12 suggests that AI could be used to identify recurring risks and support the process through historical project data.

4.2.2 Risk Analysis Practices

Although structured approaches for risk analysis in the organisation exist, the assessment methods vary between respondents. R1 and R3 describe that they use the risk- and opportunity list in APV, where probability is expressed in percentage intervals. In contrast, R2 and R4 report that they are using simplified 1–5 scales in an independent Excel-based model. Evaluating the probability and consequence of a risk is frequently described as an *"advanced guess"* based almost entirely on gut feeling and past experiences. R1 explains that estimations are often made *"between the thumb and index finger"*, while R8 similarly describes assessments as *"taken from the air"*.

Several respondents describe the assessment process as highly subjective. R5 explains that assessments may depend on the individual, noting that it is influenced by the person's mindset and general risk propensity. R9 agrees, stating that evaluations vary based on experience levels and even the individual's *"daily mood"*.

Respondents such as R2, R7, R12 and R13 emphasise that previous projects serve as a key reference point, where earlier outcomes and experiences are used to estimate how often a risk may occur and what impact it may have. When doing these estimates, R5 notes a tendency within the organisation to overestimate the probability of risks occurring, while estimating the financial consequence is generally considered easier to assess. Furthermore, R6 highlights the boundary between a risk and a pure cost: *"if an event has an 80–90 percent probability of occurring, it should be treated as a direct cost in the calculation rather than a risk"*, which is why R6 only evaluates risks with a 10, 30 or 60 percent probability.

When asked whether they believed their colleagues would make similar assessments, most respondents answered no. R9 gives an example that an inexperienced colleague would likely perceive a particular task as more challenging and thus as a higher risk than an experienced colleague would. R8 confirms this and notes that *"everyone thinks differently"* and that assessments are made based on one's own personal and holistic experiences. An exception from this opinion is R4 and R10, who believe that their closest colleagues would probably make similar evaluations since they share the same workspace and have a close dialogue with the same project manager.

The respondents suggested several improvements to standardise the assessment phase. R1 highlights the lack of clear definitions, questioning what a given probability level represents in practice and calling for guidelines to unify the process. There is also a demand for historical data and statistics to support intuitive assessments. R5 wishes for historical overviews of actual risk occurrences to prevent systematic overestimation.

4.2.3 Contingency Reserve and Cost Estimation Uncertainty

When theoretical risk assessments are translated into a financial contingency reserve in project budgets, respondents describe that the approaches vary. Several respondents describe an approach where contingency reserves are determined by combining probability and consequence. R12 explains that this is calculated by multiplying the estimated cost impact by an assumed probability.

However, alternative approaches are also described. R3 explains that contingency is only assigned when the probability exceeds a certain threshold and that in such cases the full cost of the risk is accounted for rather than a probability-weighted value. Other respondents describe that contingency is sometimes based primarily on potential penalties related to delivery times and project completion.

Regardless of the calculation method, R1, R7, R8 and R13, describe that the determination of contingency reserve is often based on judgement rather than formal calculation. R1 and R7 explain it as based on intuition and *"taken from the hip"*. R6 similarly describes the process as *"an advanced guess"*, highlighting the uncertainty involved in estimating potential costs.

R12 further describes challenges related to probability-based calculations. The respondent explains that if a risk is estimated to cost, for example, 100,000 SEK with a probability of 50%, the resulting contingency reserve would be 50,000 SEK. However, in practice, the risk either occurs fully or not at all, meaning that the project will either result in the full cost or none. This creates situations where the allocated contingency reserve does not correspond to the actual outcome in individual projects, even if the method is applied consistently.

A recurring aspect presented by several respondents is the balance between financial safety and competitiveness. R6 emphasises the difficulty of budgeting a high contingency reserve since this may result in losing the tender. Similarly, R1 explains that identified risks may sometimes be excluded to maintain a competitive price. However, R3 also notes that this goes both ways, since the organisation does not want to win a tender if it is too risky. This is supported by R4, who stresses that the goal is to win the right projects with the correct conditions, rather than just lowering the price solely to win. R12 further describes that organisational requirements for profit margins may also affect the contingency reserve, as margins are sometimes added on top of already uncertain estimates.

As a consequence of uncertainty and difficulties in applying formal contingency reserves, several respondents describe the use of embedded margins. R10 explains that additional costs are sometimes added directly to material estimates based on a *"feeling"* for the project, without being documented as specific risks. R8 similarly describes that extra machine time is included in planning and incorporated into the forecast without being separated as an explicit risk. R11 describes a comparable approach, where time estimates are deliberately increased to create a *"wobble room"* in the project, allowing for the management of smaller uncertainties during execution.

While these embedded margins are described as providing flexibility in project execution, differences are described in how they are viewed. R6 expresses a contrasting perspective, emphasising that all risks should be explicitly documented and separated in the calculation to ensure transparency and maintain control over the estimation. This is supported by R11, who demonstrates a structured approach by clearly documenting all considerations in each calculation.

Uncertainty in cost estimation is described by several respondents, including R3, R6, R9 and R12, as a fundamental challenge. R6 explains that estimates are based on incomplete information, while R3 and R9 describe that external factors are difficult to predict in advance. R12 further explains that time constraints in the tender phase limit the level of detail in cost estimation, resulting in estimates that are based on assumptions rather than detailed analysis. R7 emphasises the importance of early risk identification, stating: *"It is in the tender that you can get paid for identified risks"* while also expressing a desire for greater accuracy at this stage.

The respondents also describe differences in risk management practices between projects based on AB 04 and ABT 06 contracts. R12 explains that in AB 04 (Design-Bid-Build) projects, contractors receive predefined material lists from the client, and quantity errors often result in variations and additional compensation (ÄTA). As a result, contingency reserves are generally not needed. In contrast, ABT 06 (Design-Build) projects require contractors to estimate material needs independently, which introduces greater uncertainty and increases the risk of miscalculations. To manage this uncertainty, contingency reserves are often included. R6 further explains that the early involvement of contractors in ABT 06 projects improves the identification of risks and opportunities, whereas varying quality in client-provided design documents in AB 04 projects can contribute to increased uncertainty.

R13, who only works with framework agreements, explains that they personally use PPV for risks that are not included in the budget. According to R13, the probability of these risks occurring is considered too low, and including them as actual costs would reduce the project's forecasted profit margin in a way that does not reflect the expected outcome of the project. Instead, R13 uses the PPV list as a tool to document and highlight such risks without allocating funds in the budget.

4.2.4 Handover from Tender Phase to Project Phase

When the tender has been won, the project is handed over to a project manager who is responsible for executing it. The handover from the tender phase to the project organisation is according to the respondents carried out through a structured meeting based on a specific checklist or a handover document. R3 describes it as follows: *"We have a separate meeting for the handover. The meeting is usually about one hour, and we go through everything, including risks"*. However, the respondents emphasise that the project manager is often involved in the tender phase, and already has an understanding of the risks. R1 notes that this is the case in *"nine out of ten"* projects.

R12 expresses an opposition to handovers in which the tender engineer has conducted the entire calculation independently. *"I don't really like that kind of handover when the commercial side, the tender engineers, calculate everything themselves and then make a completely clean handover to the project side"*. R12 argues that the project manager should be involved and work through risks together with the tender side, so when the handover happens, the project manager is already *"up to speed on everything"*. R4, R5, and R6 indicate that, since the project manager has already been involved, they rarely receive questions about why a particular contingency reserve was included.

R9 highlights challenges that arise when project managers are not involved in the tender phase or when projects change ownership. In these situations, project managers often lack prior knowledge about the project and its risks and therefore rely on handover templates to understand the project. However, respondents describe several difficulties related to this process. R13 emphasises the challenges of "inherited" projects and states: *"The projects I have inherited have barely been documented at all. It takes a huge amount of time to get familiar with the project"*.

R10 further explains that embedded risk margins make project handovers more difficult. When taking over a project, it can be hard to determine whether previous estimates include additional buffers, such as extra material costs. These margins are often hidden within total cost estimates and may only be known by the person who made the original calculations.

When it comes to framework agreements, there is no such handover since they do not involve a tender phase for each project. Instead, project managers who work with framework agreements (R8, R9, R10, R11, R12 and R13) receive their assignments or project descriptions directly from the clients. Within these agreements, project managers have to accept the projects they are assigned, and the prices are already predetermined through unit rates or EBR codes (Elnätbranschens riktlinjer) that were established when the framework agreement was signed.

4.2.5 Comparison of Estimated Reserves and Actual Costs

According to R7, the contingency reserve is primarily used to cover calculation errors rather than costs resulting from occurred risks. In station projects, the contingency reserves are often consumed during project execution, but respondents explain that it is hard to determine how the funds were actually spent. For example, R6 notes that the contingency reserve is frequently used, but only the overall project outcome in terms of profit or loss is easy to find. This makes it difficult to trace how the contingency reserve contributed to managing uncertainty.

R13 explains that when a risk occurs and leads to additional costs, the impact may become hidden if the project team performs well in other areas and generates extra revenue elsewhere in the project. As a result, the overall project may still show a profit, even though the specific risk caused a financial loss. Consequently, the actual cost and impact of the individual risk often remain invisible.

The tender engineers R1, R2, R3, R5 and R6 state that they do not know if their risk assessments and financial estimates were accurate because they lack feedback after the completed project. R1 explains that they are constantly working on new bids, and do not have the time to ask how previous projects went, adding: *"It is rare to get feedback... You only get feedback if things have gone really bad"*. R4 has not yet had any tenders that has reach completion but expresses an interest in understanding the outcomes later on.

R7 describes a gap where final reports are created but not used by the tender teams: *"There are gaps, so to speak. We make the report, but no one really reads it, unfortunately. The report is meant for them to review, or at least that's how I see it"*. R7 further argues that the first task a tender engineer should undertake when a new tender arrives is to analyse similar historical projects and not simply *"guess again"*. R11 agrees, noting that project managers spend time writing final reports but rarely see that this historical data is used for future estimates. R9 adds that providing feedback is effective when a project manager consistently works with the same tender engineer on recurring projects.

4.2.6 Attitudes Towards Quantitative Risk Analysis Methods

None of the respondents have any prior experience with quantitative risk analysis methods such as Monte Carlo simulations. Despite the lack of experience, the overall attitude toward implementing such tools is highly positive. They also indicate that they would be able to perform such a three-point estimation that is required for Monte Carlo. Respondents R1 and R3 emphasise that a simulation tool should ideally be integrated into existing systems, like APV/PPV, to avoid duplication of work and prevent an increased administrative burden.

Although some experienced respondents note that they might not need or use a simulation tool themselves, they still emphasise that it would be highly valuable for knowledge transfer within the organisation. For instance, R11 mentions that while they personally do not need it, many others would benefit greatly from such a tool. Similarly, R10 points out that while it might not change much for them now that they are experienced, such simulations would be a *"great tool as a newcomer"* when one is uncertain about how to estimate costs. This statement is supported by R12, who sees the tool as a vital way to transfer senior expertise to less experienced staff, and R2, who notes that it would be very helpful for standardising assessments when new employees join the company.

There is also some skepticism from R8, depending on the type of contract. Since R8 only works with framework agreements governed by pre-determined unit rates and EBR codes, adding simulated risk budgets is not practically feasible, as the prices are already locked by the client. Instead of advanced simulations, R8 prefers clearly documented standard figures (schablonsiffror) that dictate exactly how to approach and price specific risk elements.

Several respondents express positive views towards simulations and quantitative tools as support for risk assessment and decision-making. While historical project data is considered an important foundation, respondents also emphasise the value of tools that can provide structure, visualise uncertainty and support reflection. R12 describes a simulation tool as *"incredibly great help"*, particularly if it included a large amount of project history and visualised different scenarios, such as best- and worst-case outcomes.

Similarly, R7 sees strong potential in systems that can support estimates by suggesting standard values for commonly occurring risks rather than relying entirely on new assumptions in each tender. R7 further explains that such tools could provide estimators with something to compare their own *gut feeling* against, which could save time and encourage deeper reflection. In addition, R5 highlights that a system that builds knowledge over time could help the organisation evaluate whether risks are assessed appropriately and consistently in the long term.

When discussing simulations, R1, R7, R11 and R13 mention the potential possibilities of integrating AI. R11 suggests an AI-supported function that can automatically extract relevant data and history from final reports, ensuring that the company learns from past deviations. But at the same time the respondent emphasises the importance of the human factor.

4.2.7 Communication of Risks to Management

Tender engineers primarily communicate risks to management during "bid or no bid" meetings. R1 explains that projects exceeding 10 million SEK are presented using a standardised PowerPoint template that includes identified project risks and the proposed contingency reserve. According to the respondents, management priorities differ during these reviews. R2 explains that higher management is rarely involved in the details of individual projects and instead focuses on aspects such as the project schedule and potential liquidated damages (*"viten"*). R1 and R5 explain that detailed risk assessments from the tender phase are often reduced to financial figures. As a result, management may receive the final estimate without full insight into the uncertainty. In contrast, R6 highlights that management often requests an understanding of the assumptions behind the risk analysis and how the estimates were developed.

R2 and R5 further describe that management sometimes adjusts the contingency reserve after the initial estimate has been made. These decisions are based on judgement, strategic considerations and previous experience. R5 explains that adjustments may depend on how important it is for the organisation to win a specific project, while R2 notes that perceptions of how *"difficult"* a client is expected to be can also influence the decision.

During the execution phase, project managers generally report risks during monthly project control or forecast meetings. The level of detail requested by management appears to vary. R8 and R10 explain that management often focuses more on the overall profit margin forecast than on the specific risks underlying the project. R8 further notes that management places a high level of trust in project managers to handle risks independently and rarely monitors them in detail. Instead, project managers are expected to provide a *"heads up"* if deviations are expected.

Other project managers describe stricter reporting requirements and an increasing demand for greater transparency from higher management. R7 notes a recent shift where higher management requests more detailed insight into project risks, including priced risks, their potential consequences and how they could financially affect the project if they materialise. Similarly, R9 explains that management wants information regarding the probability, consequence and monetary value of risks and notes that projects are not allowed to start if the overall risk level exceeds a certain threshold.

R11 further explains that management formally requires project teams to document risks and opportunities through the PPV system. However, R11 also expresses uncertainty regarding how or if this information is used at a broader portfolio level. According to R11, project managers may feel more motivated to use the system if there were clearer indications that the documented information actively supports decision-making beyond the individual project. The comparability of risk information between projects is also described as limited by several respondents. R4, R7 and R13 explain that differences in documentation practices and storage of information make it difficult to compare risks across projects. In contrast, R1 and R5 describe that risk information could be comparable if centralised systems were used consistently.

4.3 Design Rationale for the Framework

Based on the empirical findings presented in this chapter, several limitations in the current risk management practices at VSN have been identified. To address these challenges and enable a portfolio-level overview of risk exposure, a risk management framework containing a quantitative risk analysis model is proposed. The design of the proposed framework is driven by the following rationales derived from the empirical data:

- **Subjective assessments:** The empirical findings show that current risk evaluations rely heavily on individual intuition, personal experience and informal dialogue. To enable more consistent and comparable risk information across projects, common definitions and standardised assessment principles are proposed.
- **Financial transparency:** The findings indicate that uncertainty is frequently incorporated directly into base cost estimates through embedded margins. This reduces transparency and makes it difficult to distinguish between planned costs and risk-related uncertainty. A clearer separation between different types of uncertainty and risk is therefore suggested.
- **Representation of uncertainty:** Current assessment practices are mainly based on deterministic single-value estimates and assumed percentages. Such approaches provide limited insight into the range of possible outcomes and do not capture statistical variation. A probabilistic approach is therefore proposed to represent uncertainty more realistically.
- **Aggregation of project-level risk information:** Risk information is currently managed primarily at project level, which limits the possibility of obtaining an overview of total portfolio exposure. To enable portfolio-level analysis, it is proposed that project-level risk information should be structured in a consistent way that allows aggregation and comparison across projects.
- **Organisational learning and feedback:** The findings reveal limited feedback between completed projects and future tender processes. Historical experiences and project outcomes are therefore not systematically transferred within the organisation. Continuous feedback and structured use of historical data are proposed to strengthen organisational learning and improve future risk assessments.
- **Alignment with existing work practices:** The empirical findings highlight a concern that new tools could lead to duplication of work and an increased administrative burden. To facilitate implementation and encourage user acceptance, the proposed framework is designed to build upon existing workflows and governance structures.

5

Proposed Framework for Risk Analysis at VSN

This chapter presents the proposed framework for risk management at Vattenfall Services Nordic AB (VSN). The framework was developed to address the variations identified in current risk management practices and to create a more structured approach for handling risks. The empirical findings showed that project risks are currently identified, assessed and documented in different ways depending on the project and the individuals involved. Such variation reduces transparency and makes it difficult to compare risk information across projects or understand the organisation's total risk exposure.

The purpose of the framework is therefore to provide guidance for how risk management can be performed within the organisation. It introduces clearer definitions of risks and uncertainties together with common principles for documentation and assessment. This creates a foundation for combining project-level information and analysing risk exposure from a broader portfolio perspective.

A central part of the framework is a quantitative simulation model developed in Microsoft Excel using the @RISK software. The model demonstrates how uncertainty in probability and cost estimates can be represented and analysed using probabilistic methods. Through Monte Carlo simulation, uncertainty can be quantified and visualised to provide an understanding of potential project outcomes and overall risk exposure at both project and portfolio level.

To demonstrate how the framework can be applied in practice, an illustrative example has been developed and is presented later in this chapter. The example follows the project lifecycle and illustrates how risk information is entered, updated and analysed over time. It also demonstrates how uncertainty from individual projects can be aggregated to support portfolio-level analysis and decision-making.

5.1 Overview of the Framework

An overview of the framework is illustrated in Figure 5.1. The figure also indicates in which sections of the thesis each part of the framework is described in more detail.

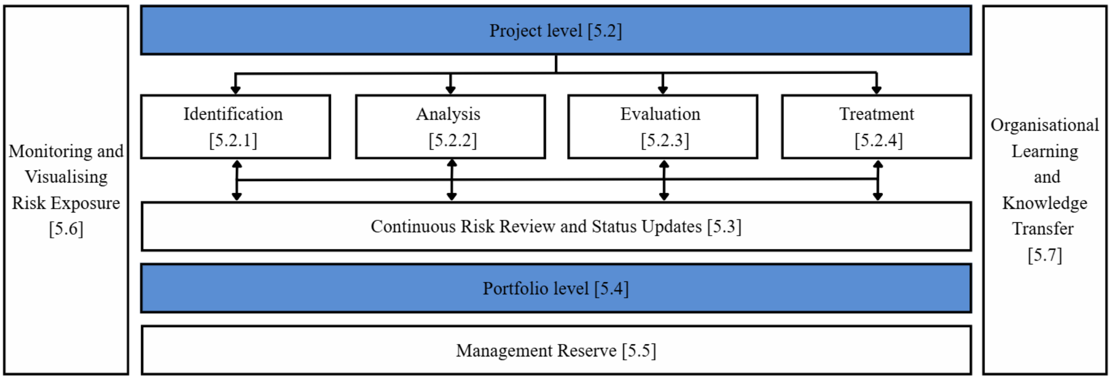


Figure 5.1: Overview of the proposed risk management framework

The framework should be understood as an iterative process where the project-level activities presented in Section 5.2 provide risk information required for portfolio-level aggregation. The framework begins with identification (Subsection 5.2.1) where uncertainties are documented and categorised. This is followed by an analysis stage (Subsection 5.2.2), in which risks are assessed using both qualitative judgement and quantitative methods. The results are then evaluated against defined criteria and translated into the contingency reserve in the evaluation stage (Subsection 5.2.3). The framework also includes risk treatment (Subsection 5.2.4), where sensitivity analysis is used to identify which uncertainties have the greatest influence on the overall project outcome and where mitigation is needed.

In addition, risk information is supposed to be continuously reviewed and updated throughout the project lifecycle to reflect changes in project conditions, as will be described in Section 5.3. This ensures that the risk data remains relevant over time and supports proactive decision-making.

The portfolio-level perspective described in Section 5.4 builds directly upon the standardised project-level information. Through the use of probabilistic modelling and Monte Carlo simulation, uncertainty distributions from individual projects can be aggregated into a combined portfolio distribution. This enables management to analyse the financial risk exposure across multiple projects. Furthermore, it enables management to support decisions related to project selection, prioritisation and resource allocation.

There are also sections that are connected to the overall functionality of the framework. Section 5.5 describes how aggregated uncertainty analysis can support the allocation of management reserves. Section 5.6 further contributes to the overall functionality of the framework by describing how risk information is monitored, visualised and communicated throughout the project lifecycle. The KPIs, visualisation methods and status categories support continuous updates of project data and make it possible to track how the portfolio risk exposure changes over time. In this way, the framework not only supports risk aggregation but also continuous governance and follow-up of uncertainty across projects.

In parallel, the framework promotes knowledge transfer and continuous feedback between projects in order to strengthen organisational learning and support continuous improvement, described in Section 5.7. Information from completed projects is captured and reused to improve future risk assessments.

5.2 Project Level

The framework for the project level is aligned with commonly recognised stages of risk management, including identification, analysis, evaluation and treatment (SIS, 2018). These stages form a continuous process, where risk information is revised as the project develops and new conditions emerge.

5.2.1 Identification

Risk identification is proposed as a structured and data-supported process that combines predefined risk information with project-specific input. The intention is to establish a consistent approach where both recurring and unique risks can be identified in a comparable way across projects. The identification process should start in the tender phase and involve tender engineers, project managers and relevant specialists to ensure that multiple perspectives are considered.

The use of predefined risk checklists forms an important part of the identification stage. These checklists are intended to be developed from historical project data and should reflect commonly occurring risks within similar types of projects. By using such checklists as a starting point, frequently occurring risks are less likely to be overlooked. To improve usability, the checklists should be adapted to specific project types to ensure that the user does not need to review a large number of risks that are irrelevant to the project at hand. At the same time, the process should remain open to the inclusion of new risks. Project-specific conditions need to be incorporated to ensure that the identification process does not become rigid.

Historical risk data is proposed to be stored in a structured and searchable format. Each recorded risk should include information on its assessment and the actual outcome. This enables the data to be analysed and later reused in future projects to obtain more accurate estimates. In the future, the storage of historical project data could potentially enable AI-based tools to identify patterns and suggest relevant risks based on similarities between projects.

As part of the identification process, risks should be classified according to their relationship to cost uncertainty. The classification is inspired by Project Management Institute (2024) and distinguishes between base costs, risks and uncertainties. The framework proposes that risks can be categorised into the four categories: Type A, Type B, Type C and fixed costs as seen in Figure 5.2. Type A, Uncertain-Knowns, refers to known budget cost items where the exact amount is uncertain. These can be described as “hidden costs” within cost estimations. Type B, Known-Unknowns, refers to potential costs that may or may not occur, knowledge exists to estimate both their probability and impact. Type C, Unknown-Unknowns, refers to costs arising from events that cannot be identified in advance, representing unforeseen cost drivers. Fixed costs, Known-Knowns, refer to fixed costs that are known with certainty and therefore do not involve any uncertainty in the cost estimation.

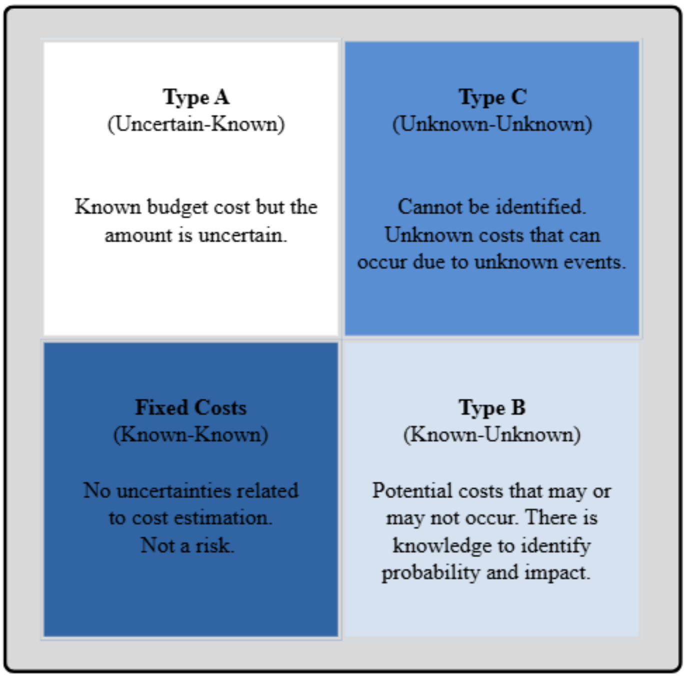


Figure 5.2: Proposed risk classification matrix inspired by Project Management Institute (2024)

By implementing this categorisation, the framework links risk management to the budgeting process, distinguishing between base costs and risk-related allowances. Type A and Type B should be managed through a defined contingency reserve, while Type C should be addressed through a broader management reserve.

All identified items are proposed to be documented using two complementary approaches, depending on their characteristics. Type A represents uncertainties in cost estimation and should be documented in the calculation tool for project budgeting. Type B is event-based and should be documented in the risk and opportunity list in APV/PPV. This distinction creates a clear separation between uncertainties in cost estimation and risk events.

The proposed structure supports a more systematic handling of information by ensuring that different types of inputs are documented in a way that reflects their purpose and use. This creates better conditions for traceability and transparency across projects, while also facilitating the aggregation of information.

Each identified Type A and Type B will also be categorised according to: *Timeplan*, *Resources*, *Materials* and *Other*. These categories are based on VSN's current risk management structure and support consistency with existing processes. This categorisation improves the ability to track, monitor and analyse recurring risk patterns across projects.

5.2.2 Analysis

In the analysis stage, identified risks are assessed and converted into quantified impacts on the project. To ensure a consistent and comparable interpretation of risk, the framework provides guidelines on how both probability and consequence should be assessed.

Probability is expressed using fixed intervals that align with the current structure of the Risk and Opportunity List used in APV/PPV. A further addition in the proposed framework is the inclusion of clearer descriptions of the underlying meaning of each interval. The probability intervals for Type B are presented in Table 5.1. The descriptions provide guidance on how probability should be defined to ensure that similar risks are assessed in a consistent manner across projects.

Table 5.1: Probability intervals for Type B

Probability interval	Classification	Definition
0–20%	Very low	Very rare event. Occurs only under exceptional conditions and is not expected in normal projects.
20–40%	Low	Rare event. Occurs under specific conditions but is not typical.
40–60%	Medium	Possible event. The event is as likely to occur as not.
60–80%	High	Likely event. Occurs in a majority of similar projects.
80–100%	Very high	Very likely event. The occurrence is expected unless conditions change.

The consequence of each identified item is defined using a three-point estimate, as presented in Table 5.2. This structure captures the range of possible outcomes and provides a consistent basis for estimation. The use of three-point estimates also enables the Excel simulation model to represent uncertainty in cost estimates more realistically by accounting for potential variation instead of relying on single-value assumptions.

Table 5.2: Three-point consequence estimation for Type A and Type B

Consequence estimate type	Classification	Definition
Minimum cost	Lower bound	Optimistic but realistic outcome. Represents the lowest expected cost for the item.
Most likely cost	Expected value	Most probable cost based on available information and professional judgement.
Maximum cost	Upper bound	Conservative outcome. Represents the highest expected cost for the item.

Together, the probability intervals in Table 5.1 and the consequence estimates in Table 5.2 define the input data used in the analysis. The framework proposes that items are analysed differently depending on their classification (Type A, B or C), where the classification determines the required input data and how the item is represented in the simulation model.

To ensure a structured analysis of uncertainty, a simulation-based approach should be applied. Monte Carlo simulation is used to represent both variability in consequence and uncertainty in probability. The proposed modelling approach is summarised in Table 5.3.

Table 5.3: Proposed modelling approach for different risk categories

Type	Distribution	Input data
Type A	PERT	Minimum, most likely and maximum consequence
Type B	Uniform + Bernoulli + PERT	Probability interval and three-point consequence estimate
Type C	Not modelled	Managed outside the simulation
Fixed cost	-	Modelled as a one point estimate

Type A risks are modelled using a PERT distribution, where the three-point estimate defines the minimum, most likely, and maximum consequence values. During each simulation iteration, a cost value is sampled from the distribution. By repeatedly sampling across many iterations, the simulation captures the variation in possible outcomes and represents the uncertainty in the estimated risk cost.

Type B risks are modelled using a stochastic approach to capture uncertainty in both the probability of occurrence and the financial consequence. The probability is represented by a uniform distribution within the predefined interval. During each simulation iteration, a probability value is sampled and after that used in a Bernoulli distribution to determine whether the event occurs. The Bernoulli output is then multiplied by the PERT distribution that represents the consequence estimate. This calculation forms the basis of how the simulation determines the cost of each risk. If the event does not occur, the resulting cost becomes zero. If the event occurs, the simulation generates a cost outcome from the consequence distribution.

Type C is excluded from the simulation because it cannot be defined in terms of probability and consequence. Type C are instead proposed to be managed through a separate management reserve. Fixed costs are also included in the simulation model to calculate the total cost of the project. However, since fixed costs by definition do not contain any uncertainty, they are modelled as deterministic single-point estimates.

The Excel model calculates the total project cost by combining the simulated costs of the Type A and Type B risks together with the fixed project costs. For each simulation iteration, a cost outcome is generated for each identified risk based on its assigned distributions. The simulated costs of all risks are then summed and added to the fixed project costs to create one possible project cost outcome. This calculation is repeated across 10,000 iterations, which generates a distribution of possible total project costs. Figure 5.3 illustrates the calculation logic used in the simulation model.

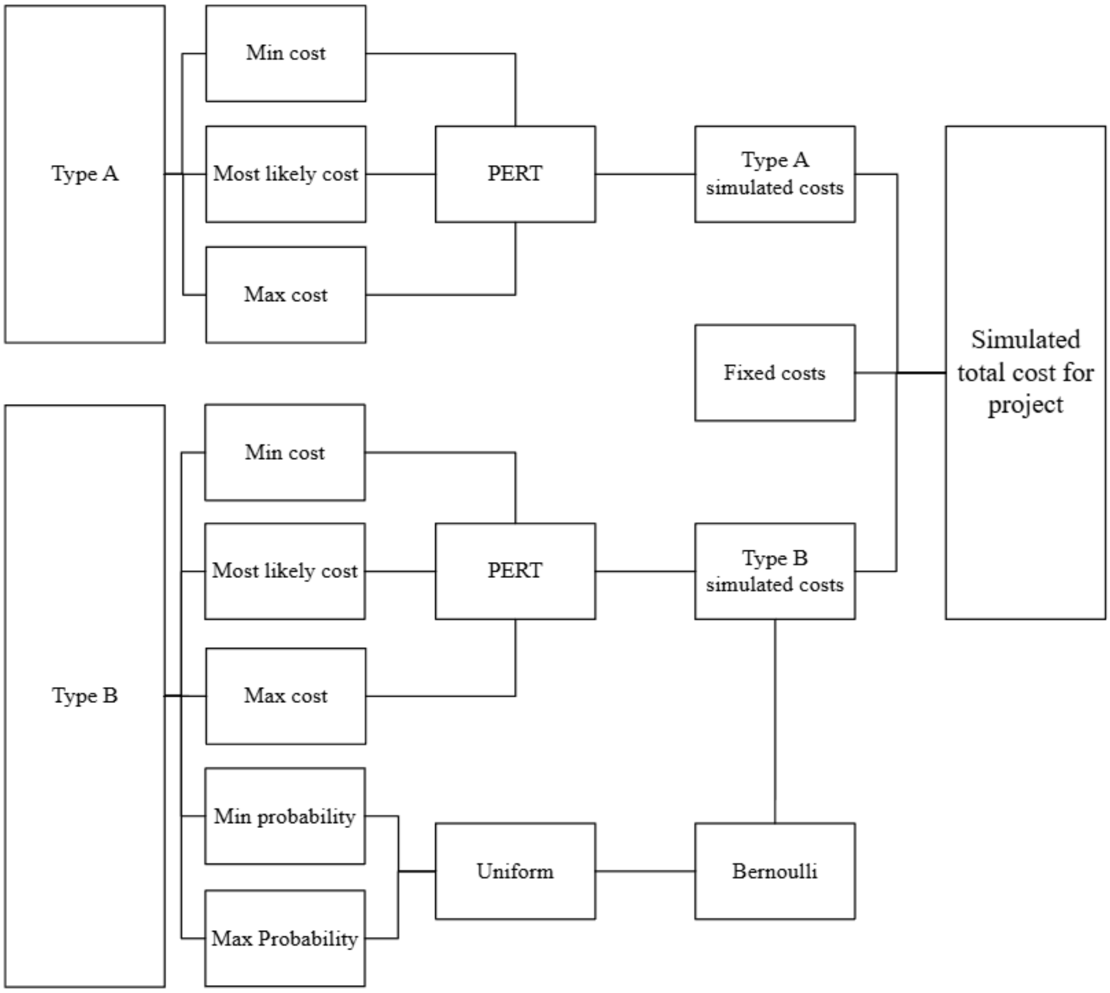


Figure 5.3: Calculation logic for simulated total cost for project

5.2.3 Evaluation

The evaluation stage defines how the results from the risk analysis should be interpreted and translated into project budgeting. It relies on the statistical outputs generated by the Monte Carlo simulation, which provide a probabilistic representation of uncertainty and describe the range of possible project outcomes. The aggregated results from Type A and Type B items form the basis for evaluating the project's total risk exposure.

To ensure consistency, the framework proposes that the evaluation should be based on a selected confidence level. This level should reflect the organisation's risk tolerance and be applied systematically across projects. A recommended approach is to use an 80% confidence level (P80) since it can be assumed to provide a balance between risk coverage and market competitiveness.

Since Type A risks represent uncertainties that are expected to affect the project cost, they should be included directly in the project budget. However, the exact financial consequence remains uncertain. The framework therefore recommends using the most likely estimate as the budgeted value for each Type A item. This establishes a realistic baseline cost while recognising that the actual outcome may differ from the estimate.

It is also during the evaluation stage that the project contingency reserve is decided. The purpose of this reserve is to cover uncertainty beyond the budgeted project costs. This includes situations where Type A risks result in higher costs than expected, as well as costs related to mitigation activities or occurred Type B risks. The contingency reserve is calculated by comparing the simulated total project cost at the selected confidence level with the project baseline. The proposed calculation subtracts the budgeted Type A costs and fixed costs from the simulated total project cost at the P80 confidence level, as expressed in Equation 5.2.3:

$$\text{Contingency Reserve} = P80\ \text{Total} \ - (\text{Budgeted Type A} + \text{Fixed Costs})$$

5.2.4 Treatment

The treatment stage defines how identified risks and uncertainties should be managed in order to reduce overall project uncertainty and support project objectives. The purpose is to ensure that mitigation efforts are directed towards the uncertainties that have the greatest impact on the project outcome.

The framework proposes that treatment decisions are based on the results from the Monte Carlo simulation and the sensitivity analysis presented in the tornado diagram. The tornado diagram visualises which uncertainties have the largest influence on the variation in project cost and therefore identifies the main drivers of uncertainty. This is assessed using Spearman rank correlation, which measures the relationship between individual inputs and the variation in project outcomes, as described in section 2.6.2.

A Spearman rank correlation coefficient close to 1 indicates that an item has a strong positive influence on the variation in project cost, meaning that changes in the input are strongly associated with changes in the project outcome. Uncertainties with high correlation values therefore contribute significantly to the overall project uncertainty and should be prioritised during the treatment stage. By focusing mitigation efforts on these uncertainties, the overall variability in project cost can be reduced, resulting in a more predictable and reliable project outcome. The results therefore support prioritisation by directing attention towards the most critical uncertainties.

For Type B, possible treatment actions may include reducing consequence, reducing probability or accepting the item. An action could also be to eliminate the item by transferring responsibility to an external party, often at an increased cost. It is also possible to eliminate the risk by selecting an alternative solution or by allocating a fixed cost to ensure that the uncertainty is removed.

For Type A, treatment should focus on reducing the spread of the estimate. This can be achieved by improving input data, refining assumptions or selecting solutions with lower variability. In this way, uncertainty is reduced, which leads to a narrower distribution in the analysis.

Treatment activities may be implemented both during the early planning stages of a project and continuously throughout project execution. Early treatment efforts are primarily aimed at reducing uncertainty before project initiation, while ongoing treatment supports continuous adaptation to changing project conditions.

5.3 Continuous Risk Review and Status Updates

Risk management should be treated as a continuous process throughout the project lifecycle. The framework therefore proposes continuous risk review as an integrated process connected to risk identification, analysis, evaluation and treatment. As project conditions change over time, new risks and uncertainties may emerge and previously identified items may change in probability, consequence or expenses. It is therefore important that the framework supports both the identification of new items and the continuous updating of existing ones. To facilitate this process and support the user in maintaining consistent updates, the framework proposes a defined set of status categories.

For Type A, the framework proposes two status categories: *Estimated* and *Known*. Their definition, the required input data from the user and what the model does automatically are described in Table 5.4.

Table 5.4: Proposed status categories for continuous monitoring of Type A

Status	Definition	User input	Model update (automatic)
Estimated	The item remains uncertain and the cost is not yet fully known.	Update the estimated financial consequence if needed.	Updates expected cost based on current estimates. Keeps the item in the current risk exposure.
Known	The cost is fully known and no longer uncertain.	Register expenses.	Sets minimum = most likely = maximum. Treats the item as a fixed cost and removes uncertainty.

As project conditions evolve and affect the probability and consequence of Type B items, their status must be continuously updated. To manage this, the proposed framework categorises Type B items using a defined set of status categories. This supports forward-looking assessments and ensures that identified items can be tracked over time and linked to realised outcomes. A distinction is made between items that remain active, those that are no longer relevant, items mitigated through planned actions and those that have actually occurred. The proposed approach is further explained in Table 5.5.

This distinction is important because these situations represent different implications for both project control and cost follow-up. In particular, it should be possible to distinguish between cases where contingency reserve has been used proactively to reduce or remove a risk, and cases where the risk has occurred and contingency reserve has been used reactively to manage its consequence.

In some cases, an *occurred* Type B item may lead to continued uncertainty regarding the final financial impact. When this is the case, the item should no longer be treated only as an event-based item, but may also give rise to a Type A uncertainty. This means that the occurrence itself is known, while the final consequence remains uncertain. The framework should therefore allow a transition from Type B to Type A when the nature of the item changes during project execution.

Table 5.5: Proposed status categories for continuous monitoring of Type B

Status	Definition	User input	System updates (automatic)
Active	The item remains relevant and may still occur.	Update probability and consequence if needed.	Keeps the item in current risk exposure and the forecast is based on probability and consequence.
Closed	The item is no longer relevant to the project.	No input required.	Sets probability and consequence to zero. Removes the item from the current risk exposure while retaining it for traceability.
Mitigated - Closed	Action has been taken to remove the item before it occurs.	Register mitigation cost.	Sets probability and consequence to zero. Links cost to contingency usage and removes the item from the current risk exposure.
Mitigated - Active	Action has been taken to reduce the item, but it may still occur.	Register mitigation cost and update probability and consequence.	Updates expected cost based on revised values. Keeps the remaining risk in the current exposure and tracks the used contingency.
Occurred - Known cost	The item has occurred and the cost is fully known.	Register actual cost.	Transfers cost to realised outcomes. Removes the item from uncertainty and updates the total project cost.
Occurred - Unknown cost	The item has occurred but the final cost is not yet fully known.	Update the estimated consequence.	Sets probability to 100%. Treats remaining uncertainty as Type A and updates the expected remaining cost.

By applying these status categories, the framework creates a more structured basis for follow-up during project execution. It becomes possible to distinguish between potential exposure, proactive mitigation and realised outcomes, while also improving traceability in how contingency reserve is used over time.

Figure 5.4 illustrates how the model responds to different types of status changes. White indicates that there is no input data needed. Green signifies that the input for the specific item must be manually updated by the project-responsible individual. Red indicates that the system automatically updates the corresponding cells based on the defined logic.

Type	Status	Expenses	Consequence			Probability	
			Min	Most likely	Max	Min	Max
A	Estimated						
	Known		0	0	0		
B	Active						
	Closed	0	0	0	0	0	0
	Mitigated - Active						
	Mitigated - Closed		0	0	0	0	0
	Occurred - Cost known		0	0	0	100%	100%
	Occurred - Cost unknown					100%	100%

Fill in and keep updated
Automatic by the system
Not used for that status

Figure 5.4: Risk status in model and changes in data

5.4 Portfolio Level

The framework standardises how uncertainty is defined across projects by applying a common classification of Type A and Type B and consistent probabilistic modelling principles. As a result, each project generates comparable output data in the form of cost distributions derived from Monte Carlo simulations. These comparable outputs form the basis for portfolio-level aggregation.

At the portfolio level, each project contributes to a probability distribution of the total project cost obtained from its individual simulation. This project-level total combines the simulated outcomes of Type A and Type B together with the fixed costs. As illustrated in Figure 5.5, these project-level distributions are subsequently combined into a single aggregated distribution, which represents the uncertainty across the portfolio.

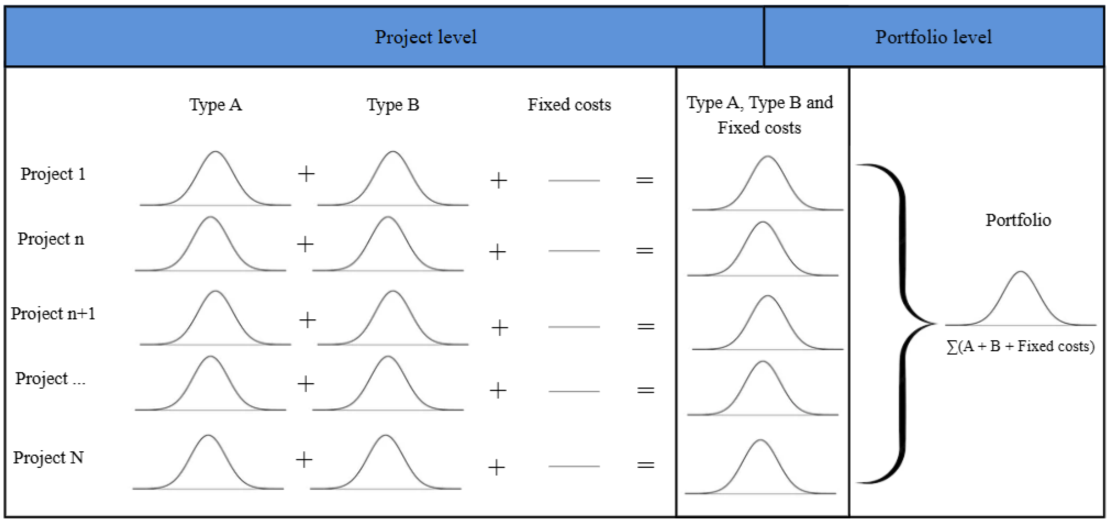


Figure 5.5: Monte Carlo model build-up for portfolio-level aggregation

The portfolio-level simulation enables management to evaluate the portfolio's total financial exposure in probabilistic terms. Instead of relying on single-point forecasts, decision-makers can assess the likelihood of different cost outcomes and evaluate these against the organisation's defined risk tolerance. This provides a forward-looking perspective on portfolio performance and supports more informed strategic decision-making.

5.5 Management Reserve

To protect the organisation against Type C, additional funds must be allocated in the form of a management reserve. Given the administrative effort and governance required to manage formal reserves, it is proposed that a dedicated management reserve is established only for projects exceeding a predefined financial threshold. For smaller or less complex projects, setting aside and governing a formal management reserve may not be cost-effective. For large-scale projects that exceed this threshold, the organisation must make a strategic decision regarding where these funds should be held. As it is currently unspecified which approach aligns best with VSN's overall structure and preference, two alternative strategies are proposed.

- **Alternative 1: Project-Level Allocation**
  The management reserve is included in the project budget but kept separate from the cost baseline. The authority over the reserve lies with the steering group and ensures that funds are used only for extraordinary events.
- **Alternative 2: Portfolio-Level Allocation**
  The management reserve is pooled at the portfolio level. This allows resources to be deployed dynamically to projects facing actual critical issues. It improves capital efficiency, but requires a functioning governance structure to coordinate.

5.6 Monitoring and Visualising Risk Exposure

Risk exposure should be continuously monitored and visualised throughout the project lifecycle since identified risks and available project information change over time. The framework therefore proposes three system-based views that represent different project stages and support follow-up as the project progresses. Together, these views provide a structured overview of changes in the project situation and enable comparison between initial estimates, updated forecasts and actual outcomes. Key performance indicators (KPIs) are also established to evaluate financial uncertainty and present simulation results in a structured format. In addition, the framework proposes a revised heat map structure to visually represent identified Type B risks according to their estimated probability and consequence.

5.6.1 System-Based Views of Risk Exposure

The framework consists of three system-based views that corresponds to different stages of the project lifecycle and are intended to support the user in specific aspects of project risk management. The system-based views include: the *Initial Risk Forecast*, the *Current Risk Forecast* and the *Actual Risk Outcome*.

At the beginning of a project, identified risks are assessed and documented, forming the *Initial Risk Forecast*. This view represents the expected project situation based on identified uncertainties and their estimated probability and consequence. It provides an initial indication of the project's uncertainty profile and serves as the basis for establishing the contingency reserve.

Once the *Initial Risk Forecast* has been completed, that version is saved in the historical risk database. The completed *Initial Risk Forecast* is also automatically transferred to the *Current Risk Forecast*. This avoids the need for project teams to create a new forecast from the beginning and ensures that all previously identified risks and estimates remain available.

During project execution, the *Current Risk Forecast* is continuously updated based on the status logic described earlier. Depending on the selected status, users revise relevant information such as probability, consequence and expenses. Based on these updates, the simulation model automatically recalculates the project forecast and generates an updated estimate of the expected project outcome. The *Current Risk Forecast* therefore reflects the most recent project situation and provides an overview of the remaining uncertainty and expected future costs. Since this view reflects current project conditions, it can also support portfolio-level monitoring of ongoing projects.

At project completion, the final version of the *Current Risk Forecast* becomes the *Actual Risk Outcome*. At this stage, all risks have either occurred or been closed and the final financial impact is known. The *Actual Risk Outcome* represents the third system-based view and enables direct comparison between the original *Initial Risk Forecast* and the realised project outcome. This comparison creates a basis for evaluation and learning and can support improved future estimates and risk assessments.

All information from the three views is stored in a database to preserve historical project data and support future use of project experiences. Figure 5.6 illustrates the relationship between the three system-based views and how information moves throughout the project lifecycle.

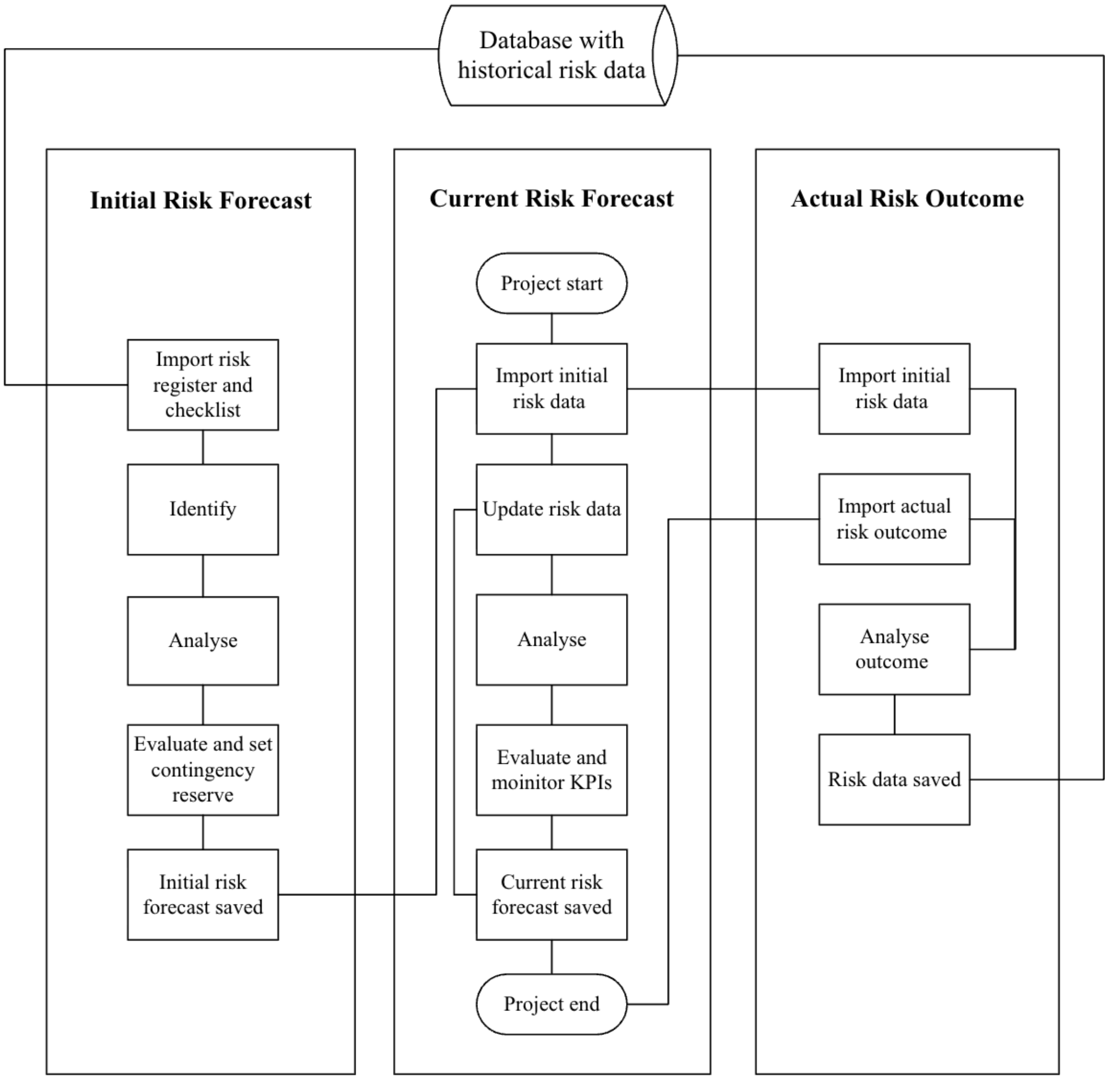


Figure 5.6: Relationship between the three system-based views

5.6.2 Key Performance Indicators

The framework enables the derivation of a set of Key Performance Indicators (KPIs) that support both project-level and portfolio-level decision-making. The KPIs are derived from the *Initial Risk Forecast*, the continuously updated *Current Risk Forecast*, and the *Actual Outcome* at project closure. Together, these indicators provide both forward-looking and backward-looking insights into project risk exposure and financial performance.

The primary output from the simulation model is the probability distribution, which provides the basis for evaluating overall uncertainty. Different confidence levels can be selected depending on the organisation's risk tolerance and decision-making needs. Within the proposed framework, the 80th percentile (P80) has been selected as the primary confidence level.

Although the simulation model can generate a wide range of KPIs, the framework focuses on three financial indicators that provide an overall understanding of forecasted cost development and financial risk exposure. These KPIs are applicable at both project and portfolio level. At portfolio level, the KPIs are calculated using aggregated data from multiple projects simultaneously, thereby providing an overview of the portfolio's combined financial exposure.

- **Estimated Cost at Completion (P80)**
  Represents the forecasted final cost at an 80% confidence level. This means that there is an 80% probability that the final cost will not exceed the estimated amount.
- **Confidence Level of Staying Within Budget**
  Represents the probability that the available budget will be sufficient to complete the project or portfolio. The KPI is determined by comparing the current forecasted cost distribution with the established budget and therefore reflects the current likelihood of remaining within budget considering the remaining uncertainties.
- **Confidence Margin (P80)**
  Represents the difference between the established budget and the estimated final cost at the P80 confidence level. A positive value indicates an expected financial surplus at the selected confidence level, while a negative value indicates that the forecasted cost exceeds the available budget and that additional funding would likely be required.

In addition to the financial KPIs, the portfolio overview aggregates categorical risk data from all individual projects to provide a broader understanding of the risk landscape:

- **Category frequency**
  This metric shows the frequency of risks by the predefined categories (*Timeplan*, *Resources*, *Materials* and *Other*). This allows management to identify which risk types are the most commonly occurring across the entire portfolio.
- **Status frequency**
  This metric shows how many risks are currently *Active*, *Closed*, *Mitigated - active*, *Mitigated - closed*, *Occurred - known* and *Occurred - unknown*, offering an aggregated view of risk progression across the portfolio.

5.6.3 Visualisation of Risk Exposure in a Heat Map

In addition to quantitative indicators and simulation-based analysis, the proposed framework should also include a probability–consequence map in APV/PPV. The purpose of the heat map is to provide a simple and intuitive visual overview of the project's current risk exposure and to complement the tornado chart.

The probability–consequence map should be based on the input data for Type B risks. On the x-axis, risks should be positioned according to their probability of occurrence, divided into five intervals of 20% each. On the y-axis, risks should be positioned according to the *Most Likely* value of their financial consequence. Instead of using fixed monetary intervals, the maximum value on the y-axis should correspond to the total budgeted cost of the individual project. The axis should then be divided into five intervals representing how large a share of the total project budget a single risk may affect.

This approach makes the consequence scale relative to the size of each individual project, which is considered more suitable since projects within VSN vary significantly in size. As a result, the map becomes more meaningful for the project manager compared to if predefined fixed cost intervals were used.

Only risks classified with the statuses *Active* and *Mitigated – active* should be visualised in the heat map since these represent the project's current remaining risk exposure. If the status of a risk changes, the map should automatically update accordingly to ensure that the visualisation always reflects the current project situation.

The heat map is particularly useful for identifying risks with both high probability and high financial impact, thereby supporting prioritisation of mitigation efforts and management attention. An example of the proposed heat map is illustrated in Figure 5.7. Together with the tornado chart and quantitative KPIs, the map contributes to a more comprehensive understanding of project uncertainty and risk exposure.

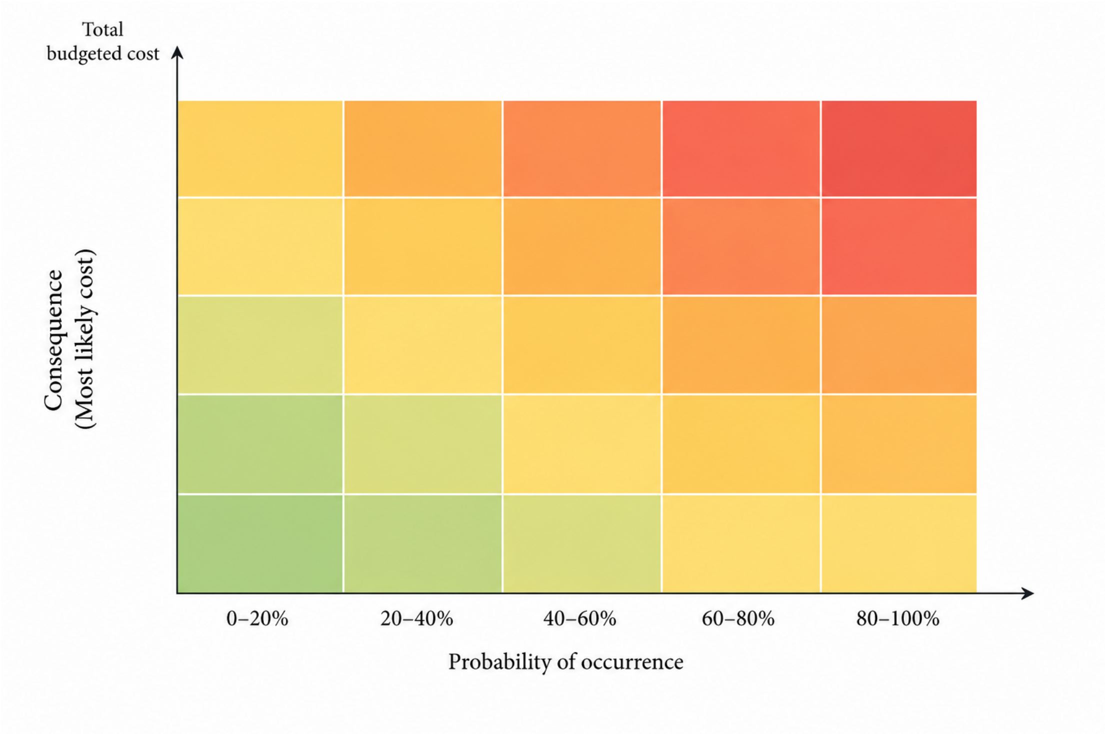


Figure 5.7: Proposed heat map for Type B

5.7 Organisational Learning and Knowledge Transfer

Within the proposed framework, organisational learning is closely linked to the interaction between risk identification, risk forecasting and project outcomes. At project initiation, risks should be identified with support from a risk checklist and data from historical projects. The risk checklist should provide guidance by structuring common risk categories and previously identified risk types, helping practitioners ensure that relevant uncertainties are considered. The historical risk data is a risk register that supports the assessment process by providing information on previous estimates and outcomes.

At project closure, the focus shifts from forecasting to evaluation and learning. The *Actual Risk Outcome* is known and information from the project is used to update the risk register and associated reference data based on risks identified during execution and their realised impacts. This enables comparison between the *Initial Risk Forecast* and the *Actual Risk Outcome*.

By retaining historical versions of risk forecasts and linking them to actual project outcomes, the organisation establishes a structured feedback loop. Insights gained from these comparisons can be used to refine probability and consequence definitions, improve estimation of cost uncertainty, and update risk registers, checklists and supporting guidance material. Over time, this process reduces reliance on individual judgement and enables a consistent, data-driven approach to risk management.

At portfolio level, aggregated information from project risk registers enables the identification of recurring risks, common drivers of deviation and patterns in forecast accuracy across projects. This integration of risk registers therefore plays an important role in organisational learning and transforms individual project experiences into shared knowledge that strengthens future risk identification, forecasting and decision-making.

5.8 Illustrative Example of the Proposed Framework

This section presents an illustrative example to demonstrate how the proposed framework and the Excel-based @RISK model operate in practice. It is designed to demonstrate the underlying modelling logic, the integration of quantitative methods and the interpretation of simulation outputs. The example is divided into two parts, first the project level and then the aggregation of five projects to demonstrate a portfolio-level overview. An overview of all Excel worksheets included in the model is presented in Appendix C and Appendix D.

5.8.1 Illustrative project

The model is structured around the three different views, presented as separate sheets: the *Initial Risk Forecast*, the *Current Risk Forecast* and the *Actual Risk Outcome*. The project is further divided into the three categories of input data: Fixed costs, Type A and Type B. By processing these inputs through a Monte Carlo simulation with 10,000 iterations, this example demonstrates how the framework evaluates probabilistic data through the different project phases to generate a distribution curve of the final project cost and KPIs.

5.8.1.1 Initial Risk Forecast

At the start of the project, a risk checklist is used to support the identification of risks and uncertainties. The illustrative project includes five fixed cost items, five Type A items and five Type B risks in order to demonstrate how the different categories are managed. The illustrative fixed costs are shown in Table 5.6.

Table 5.6: Fixed costs in Project 1

ID	Fixed cost	Cost (SEK)
F1	Fixed cost 1	200 000
F2	Fixed cost 2	100 000
F3	Fixed cost 3	50 000
F4	Fixed cost 4	300 000
F5	Fixed cost 5	500 000
Total		1 150 000

It also includes five Type A in different categories (*Timeplan*, *Resources*, *Materials* and *Other*). Each Type A is defined using a three-point estimate consisting of a minimum, most likely and maximum value, as illustrated in Table 5.7. These uncertainties are modelled using a PERT distribution, capturing the variability around the most likely estimate while limiting the influence of extreme values. Historical data is supposed to help estimators with these values.

Table 5.7: Input data for Type A in Project 1

ID	Uncertain cost	Category	Min (SEK)	Most likely (SEK)	Maximum (SEK)	Budgeted cost (SEK)
A1	Uncertain cost 1	Timeplan	80 000	110 000	200 000	110 000
A2	Uncertain cost 2	Materials	220 000	300 000	430 000	300 000
A3	Uncertain cost 3	Timeplan	140 000	230 000	320 000	230 000
A4	Uncertain cost 4	Other	180 000	200 000	300 000	200 000
A5	Uncertain cost 5	Timeplan	130 000	190 000	270 000	190 000
Total			750 000	1 030 000	1 520 000	1 030 000

Since Type A represents costs that will occur, each item is assigned a cost in the budget. In this illustrative example, this budgeted cost is based on the most likely estimate. This is recommended but may be adjusted by the budget owner. The uncertainty inputs are used for the Monte Carlo simulation, while the budgeted value is necessary for the model build-up.

The illustrative project also includes five Type B in different categories. For each Type B, a probability of occurrence is defined together with a minimum, most likely and maximum cost impact. The probability of occurrence determines whether the risk event is realised in a given simulation iteration. If the event occurs, the associated cost impact is sampled from a PERT distribution.

In the model, the probability is first represented using a uniform distribution generating random values between 0 and 1. This value is then evaluated through a Bernoulli condition based on the specified probability of occurrence for the risk. If the Bernoulli outcome equals 1, meaning that the risk occurs during the simulation iteration, the result is multiplied by the sampled PERT-distributed cost uncertainty. Consequently, the cost impact is only included in iterations where the risk event is realised. The input parameters for the Type B risks are presented in Table 5.8.

Table 5.8: Input data for Type B in Project 1

ID	Risk event	Category	Min (SEK)	Most likely (SEK)	Maximum (SEK)	Probability
B1	Risk 1	Resources	40 000	90 000	170 000	0-20%
B2	Risk 2	Materials	20 000	60 000	100 000	40-60%
B3	Risk 3	Timeplan	25 000	70 000	150 000	0-20%
B4	Risk 4	Other	20 000	50 000	120 000	20-40%
B5	Risk 5	Timeplan	30 000	80 000	100 000	60-80%
Total			135 000	350 000	640 000	

Type A and Type B are then combined and analysed in the MCS with 10,000 iterations. The output is a probability distribution of the total project cost that represents the combined outcome of both types of uncertainty and fixed costs. The resulting probability distribution is presented in Figure 5.8.

The selected confidence level is extracted from the probability distribution and in line with the framework's recommendations, the P80 level was used. At this confidence level, the model indicates a total budget of 2,408,000 SEK. Subtracting the fixed costs and budgeted Type A costs from this value represents the additional contingency required to achieve an 80% probability of staying within the project budget.

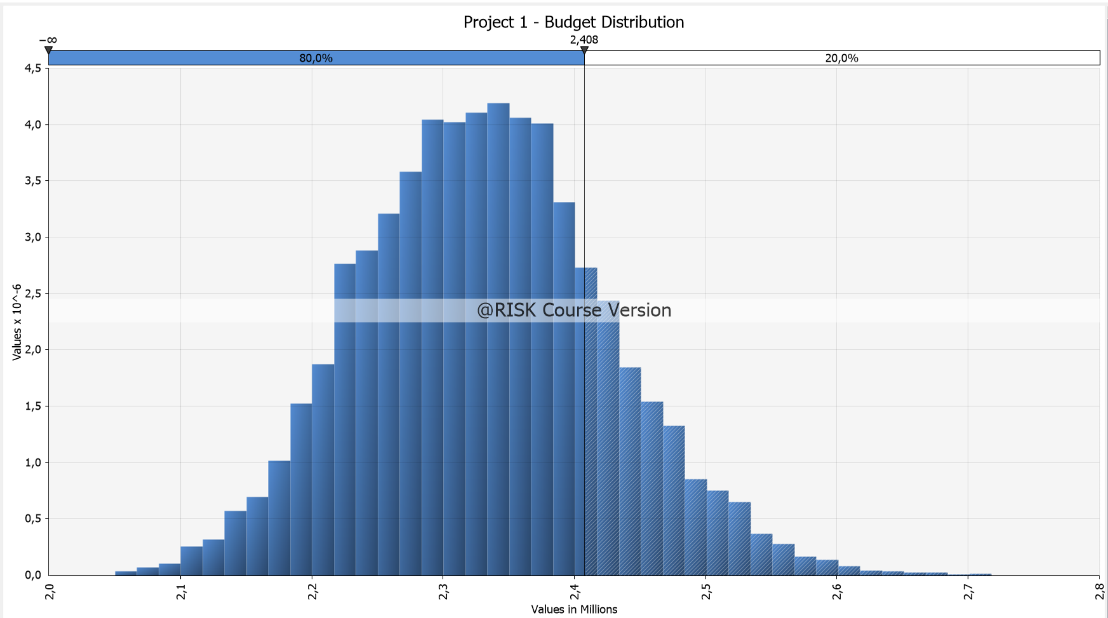


Figure 5.8: Histogram of the total project cost distribution for Project 1, including uncertainty. P80 is indicated by a vertical line

The results indicate that, with a project budget of 2,408,000 SEK, there is an 80% probability that the total project cost will not exceed the available budget. As shown in Table 5.9, this budget includes a contingency reserve of 227,909 SEK. Selecting a different percentile would adjust the size of the contingency reserve accordingly. In addition, choosing a lower contingency reserve increases the probability of a budget overrun. This illustrates how the simulation output can be used to connect uncertainty to decision-making and to align the contingency reserve with the organisation's risk tolerance.

Table 5.9: Summary of budgeted costs in Project 1

ID	Summary of budgeted costs	Cost (SEK)
S1	Total budgeted cost Type A	1 030 000
S2	Tolal budgeted fixed costs	1 150 000
S3	Total budgeted contingency reserve	227 909
Total	Total budgeted costs for project (P80)	2 407 909

At the start of the project, the project budget and contingency reserve are established based on the uncertainty analysis. The contingency reserve is intended to cover situations where a Type A item exceeds its budgeted cost or when a Type B risk occurs. Since the analysis is performed early in the project lifecycle, the level of uncertainty is generally high due to limited available information. If the required contingency reserve becomes excessively large in relation to the fixed project costs, this may indicate that the project involves a high level of uncertainty and financial exposure that is considered unacceptable from a portfolio perspective. In such cases, management may decide not to submit a tender for the project.

In addition to the probability distribution, the Monte Carlo simulation produces a sensitivity analysis, presented as a tornado chart in Figure 5.9. The chart shows which uncertainties have the greatest influence on the total project cost and can therefore support decision-making regarding risk mitigation. In this case, the factor "P1 / A2" (Uncertain cost 2) has the strongest impact on the project outcome.

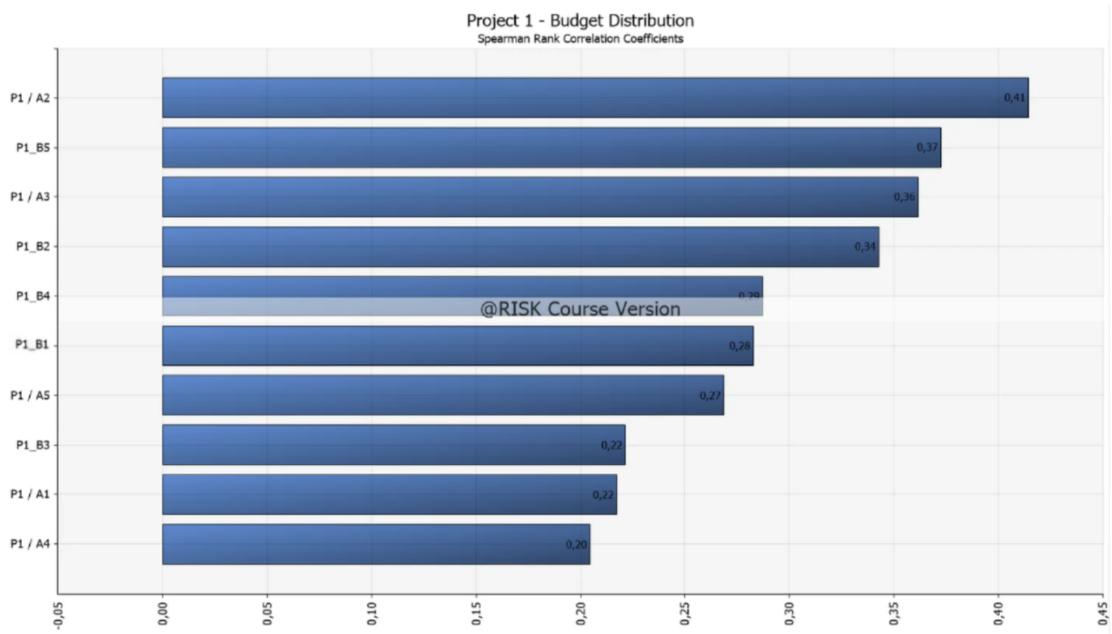


Figure 5.9: Spearman rank correlation coefficient for the budget in project 1

The analysis is based on Spearman rank correlation coefficients, which measures how strongly changes in one variable are associated with changes in another. A higher correlation coefficient indicates that a specific uncertainty has a larger influence on the overall project cost.

However, the sensitivity analysis should only be viewed as a decision-support tool. Although some uncertainties have a greater statistical impact on the results, this does not necessarily mean that they should always be prioritised for mitigation. Other factors, such as mitigation cost, feasibility, and project-specific considerations, must also be taken into account when selecting appropriate risk management actions.

The same type of sensitivity analysis can also be applied at a portfolio level, where the tornado chart illustrates which projects contribute the most to the overall uncertainty of the portfolio. This provides decision-makers with a clearer understanding of which projects have the greatest influence on the portfolio's total cost variability and where mitigation efforts or additional attention may have the largest overall effect.

5.8.1.2 Current Risk Forecast

Once the project has started, all information from the *Initial Risk Forecast* is automatically transferred to the *Current Risk Forecast*. During execution, the project manager should continuously update the project data to reflect the current risk exposure. This includes updating the status, revising the estimated probability and financial consequence as well as registering actual money used.

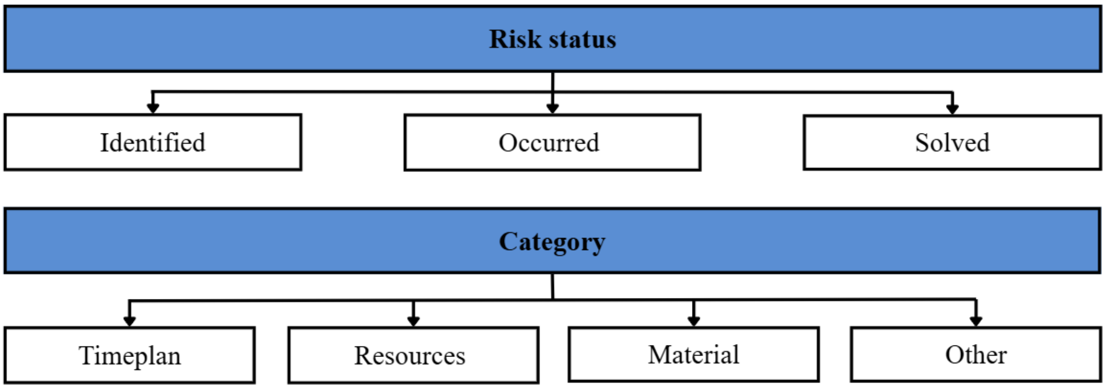
To make the process easier, the user first updates the risk status. Based on the selected status, the system then provides further instructions on what additional information needs to be updated. These instructions follow the logic described earlier in Figure 5.4. The system automatically determines how the calculations should be performed depending on the selected status, ensuring that the risk is treated consistently according to the predefined logic.

Table 5.10 illustrates the different status categories for Type A together with descriptions of the actions required by the user. Table 5.11 presents the same concept for Type B, but with status categories adapted to that type.

Table 5.10: *Current Risk Forecast* with status and user instruction for Type A

ID	Uncertain cost	Category	Status	Instructions for user that depend on status
A1	Uncertain cost 1	Timeplan	Estimated	Keep consequence and expenses updated
A2	Uncertain cost 2	Materials	Estimated	Keep consequence and expenses updated
A3	Uncertain cost 3	Timeplan	Estimated	Keep consequence and expenses updated
A4	Uncertain cost 4	Other	Known	Only update expenses
A5	Uncertain cost 5	Timeplan	Known	Only update expenses

Table 5.11: *Current Risk Forecast* with status and user instruction for Type B



The *Current Risk Forecast* Summary is illustrated in Table 5.12. This provides a snapshot that compares the initial budget against the expenses incurred to date at a specific point in the project's execution.

Table 5.12: *Current Risk Forecast* summary in Project 1

ID	Name	Budgeted cost (SEK)	Expenses (SEK)
S1	Type A	1 030 000	580 000
S2	Type B	0	0
S3	Contingency reserve	227 909	150 000
S4	Fixed costs	1 150 000	500 000
S5	Outside project	0	0
Total	Total	2 407 909	1 230 000

When the updated data are processed through the Monte Carlo simulation, the model generates KPIs to forecast the project's financial outcome. As visualised in the *Current Risk Forecast* KPIs matrix in Table 5.13, changes in the identified uncertainties have affected the probabilistic forecast of the final project cost. As a result, the estimated project cost at an 80 % confidence level has decreased to 2,389,870 SEK. Consequently, the statistical probability that the project will successfully conclude within its established baseline budget improves from the initial 80 % to 86 %, which creates a positive confidence margin (P80) of 20,876 SEK.

Table 5.13: *Current Risk Forecast* KPIs in Project 1

ID	KPI	Cost (SEK)
KPI 1	Estimated cost at completion (P80)	2 389 870
KPI 2	Confidence level of staying within budget	86%
KPI 3	Confidence margin (P80)	20 876

5.8.1.3 Actual Risk Outcome

At project completion, the *Current Risk Forecast* transitions into the *Actual Risk Outcome*. All identified risks have either *Occurred* or been *Closed*, and the financial outcome is known. The framework enables an analysis between this final *Actual*

Risk Outcome and the *Initial Risk Forecast* generated during the tender phase or project initiation. This enables a structured feedback loop to improve organisational learning and knowledge transfer. Practitioners can measure how accurate their estimates were. The insights gained are then used to update the risk register with reference data, which also aims to help future three-point estimates and probability assessments.

5.8.2 Illustrative Portfolio

The illustrative portfolio is constructed by combining the single illustrative project from Section 5.8.1 with four additional illustrative projects, which can be seen in Appendix D. To evaluate the overall risk exposure, the individual project-level distributions, which are obtained from each project's *Current Risk Forecast* are aggregated. This aggregation creates a portfolio-level probability distribution that captures the combined uncertainty across the five projects. The distribution is visually represented in Figure 5.10, which shows the distribution curve for the entire portfolio and highlights the 80% confidence interval (P80).

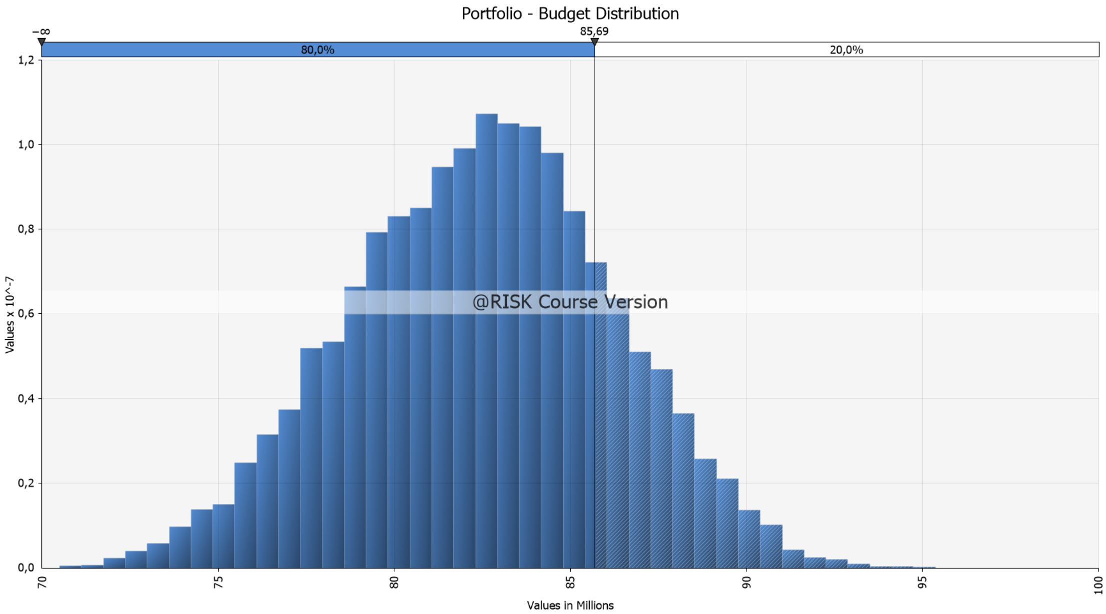


Figure 5.10: Histogram of the total project cost distribution for the portfolio, including uncertainty. P80 is indicated by a vertical line

To provide a detailed breakdown of how each project contributes to this aggregate distribution, Table 5.14 provides a portfolio overview. This table connects the individual project data (P1 - P5) to the total portfolio outcome by showing each project's budgeted cost, estimated cost at completion, confidence level of staying within budget and confidence margin.

Table 5.14: Portfolio overview

Project	Budgeted cost (SEK)	Contingency reserve/ Budgeted cost	Estimated cost at completion (P80), (SEK)	Confidence level of staying within budget	Confidence margin (P80), (SEK)
P1	2 407 909	9%	2 388 682	86%	19 227
P2	5 470 000	8%	5 735 274	38%	-265 274
P3	43 920 000	10%	45 988 069	59%	-2 068 069
P4	12 870 000	3%	13 494 830	61%	-624 830
P5	19 400 000	5%	19 430 818	79%	-30 818
Total	84 067 909	9%	85 685 724	66%	-1 617 815

The simulation shows that the portfolio has a 66% chance of staying within its budget of about 86 million SEK. If management considers this level as risky and wants a safer margin, the results can be used to estimate the needed extra reserve.

The analysis shows a negative confidence margin of about 1.6 million SEK. This means that to increase the confidence level from 66% to 80%, management could set aside an management reserve of 1.6 million SEK. This demonstrates the advantage of using a portfolio-level approach for management reserve (Alternative 2). Instead of adding extra buffer money to each of the five projects individually, the organisation can keep the reserve centrally. This avoids locking capital into projects that may not need it and helps protect their expected profit margins. However, it is up to VSN where they want to allocate this reserve.

The colour coding in Table 5.14 provides a quick visual indication of the portfolio risk situation, where green represents stronger budget confidence and red indicates a higher risk of cost overruns. Although Project P2 has the lowest confidence level, with only a 38% probability of staying within budget, Project P3 has the largest negative confidence margin and therefore contributes the most to the portfolio's overall negative result. This demonstrates that a project with the lowest probability of success does not necessarily have the greatest impact on the portfolio outcome.

The totals from the Portfolio overview are also presented in Table 5.15 as portfolio-level KPIs. These KPIs provide management with a quick and clear overview of the overall portfolio status, making it easier to monitor risk exposure.

Table 5.15: Portfolio KPIs

ID	KPI	Output
KPI 1	Estimated cost at completion (P80), (SEK)	85 685 724
KPI 2	Confidence level of staying within budget	65%
KPI 3	Confidence margin (P80), (SEK)	- 1 617 815

In addition to financial KPIs, the model aggregates categorical risk data across the portfolio to identify trends. Table 5.16 shows the frequency of the different categories (*Timeplan*, *Resources*, *Materials* and *Other*). *Timeplan* is identified as the most commonly occurring risk across the portfolio. This may indicate that the organisation should take action to address this specific risk category.

Table 5.16: Category frequency for Type A and Type B

Category	Frequency
Timeplan	27
Resources	2
Materials	12
Other	9

Most frequent category in the portfolio:	Timeplan

The model can also visualise the frequency of different risk statuses across the portfolio. Table 5.17 shows the frequency of current statuses for all Type A uncertainties and Table 5.18 presents the status frequency for all Type B risks. By visualising the frequency of each status, an overview of the current risk situation is provided, which makes it easier to understand how risks are distributed across the portfolio.

Table 5.17: Status frequency Type A

Status	Frequency
Known	8
Estimated	17

Table 5.18: Status frequency Type B

Status	Frequency
Active	8
Closed	3
Mitigated - Active	4
Mitigated - Closed	5
Occurred - Cost known	3
Occurred - Cost unknown	2

6
Discussion

The discussion of the empirical findings and the proposed framework examines how project risk management can be developed to enable analysis of total risk exposure at portfolio level. The section is structured around four themes that have been chosen because they collectively make it possible to answer the study's research questions. The four themes are:

- Risk Identification and Data Standardisation
- Quantitative Risk Analysis and Contingency Reserve Estimation
- Portfolio Risk Aggregation and Decision Support
- Organisational Learning and Knowledge Transfer

Within these themes, the empirical findings from the internal guidelines and interviews provide an understanding of how risk management is currently performed at VSN. These insights are analysed in relation to the literature, which outlines how risk management, data standardisation and portfolio aggregation are expected to function from an academic perspective. By comparing current practices with these theoretical ideals, a gap becomes evident. The proposed framework is therefore discussed as a practical means of addressing this gap and offers a structured approach to improve how risks are managed across projects.

Following the discussion of these four themes, the chapter concludes by presenting the limitations of the proposed framework and the study, as well as providing suggestions for future research.

6.1 Risk Identification and Data Standardisation

The empirical findings demonstrate that risk identification at VSN is currently an experience-based process driven largely by informal dialogues and individual intuition. Respondents describe varying documentation practices, where some use the centralised APV/PPV tool while others rely on self-made Excel templates or avoid documenting smaller risks. A consequence of this unstructured approach is the use of "embedded margins". Since uncertainties are not systematically identified as distinct risks, estimators deliberately inflate material quantities or add extra machine time to create a "wobble room" during project execution, without documenting these additions explicitly.

ISO 31000 emphasises that risk identification forms the foundation of the entire risk management process since risks that remain unidentified cannot be subsequently analysed or treated (SIS, 2018). The criticality of this stage is further emphasised by the ”influence/information gap” described by Karlsen and Lereim (2005). Early project phases are characterised by high uncertainty but offer the greatest opportunity to influence outcomes and secure necessary financial resources. This theoretical dilemma is clearly reflected in the empirical findings regarding VSN's tender process, where R7 notes that *”it is in the tender that you can get paid for identified risks”*. Failing to identify risks during this phase forces the project to carry unfunded uncertainties into execution.

From a theoretical perspective, this reliance on subjective intuition and embedded margins is problematic. Edwards et al. (2025) warn that unstructured brainstorming without cognitive support often leads to incomplete and biased risk assessments. Furthermore, Sanchez et al. (2009) highlight that when risk management practices depend heavily on individuals, it leads to inconsistent practices across an organisation. In addition, Chapman and Ward (2003) describe the practice of hiding uncertainties within base estimates as a ”vicious circle” that obscures true project risk exposure and introduces a risk of double-counting.

To reduce the reliance on individual ”gut feeling”, the proposed framework replaces unstructured brainstorming with data-supported identification through the introduction of predefined risk checklists. Upon project initiation, a tailored risk checklist containing relevant risks for the specific project type will automatically appear in the system. At this stage, the framework connects to what the literature describes as the programme level. Although VSN does not formally use the term ”programme” within its organisational structure, the proposed framework practically introduces programme-level elements through the categorisation of projects and the use of tailored risk checklists. According to theory, a programme is described as a group of similar or related projects managed in a coordinated way to gain benefits that isolated management would not provide (Piterska & Kramskiy, 2017; SIS, 2023). By grouping similar projects to develop shared risk checklists, the framework implicitly adopts this structure. Grounding these checklists in historical project data provides the necessary support to identify risks more consistently, thereby shifting the organisation towards a proactive approach where knowledge is systematically transferred between projects. However, the framework also allows for the inclusion of project-specific risks, ensuring that new or context-dependent risks can be added when necessary.

Several authors advocate the use of predefined categories and structured frameworks to support a more systematic identification process. For example, Zavadskas et al. (2010) and Edwards et al. (2025) argue that structured classification provides essential cognitive support and improves consistency in risk identification. To apply this practically, the proposed framework uses the categorisation already established in VSN's internal guidelines, classifying risks into *Timeplan*, *Resources*, *Materials* and *Other*. Similarly, Project Management Institute (2024) presents a classification of uncertainties that explicitly distinguishes between knowns and unknowns. Inspired by this literature, the proposed framework mandates a shared organisational taxonomy, requiring all identifiable uncertainties to be classified into either Type A (Uncertain-Knowns) or Type B (Known-Unknowns). While the taxonomy also acknowledges Type C (Unknown-Unknowns), these cannot be proactively classified or quantified during this stage, as no prior knowledge of them exists.

By establishing this classification early in the identification phase, the framework creates a clear boundary between actual fixed costs and uncertainties. This improves transparency and reduces the problematic practice of using embedded margins. This standardisation of the identification stage transforms fragmented project knowledge into comparable data sets, satisfying the prerequisite for subsequent portfolio-level aggregation, which is further discussed in Section 6.3.

6.2 Quantitative Risk Analysis and Contingency Reserve Estimation

The empirical findings reveal that the process of translating identified risks into a contingency reserve at VSN is currently highly subjective. Several respondents describe the allocation of risk budgets as an *"advanced guess"* that is often *"taken from the hip"*. While some estimators attempt to structure this by multiplying the estimated cost impact of a risk by its probability, an approach theoretically known as Expected Monetary Value (EMV), respondent R12 highlights a limitation in this method. Because a specific risk event either materialises fully or not at all during execution, allocating a probability-weighted fraction of the cost (e.g., 50% of a risk's total impact) frequently results in a contingency reserve that fails to match the actual realised outcome. Furthermore, the empirical findings also highlight the tension during the tender phase between financial safety and market competitiveness. Respondents describe a difficult balancing act where including too high a contingency reserve may result in losing the bid, while insufficient contingency reserve exposes the project to a financial risk.

Kwak and Ingall (2009) and Senova et al. (2023) argue that single-point estimates, such as relying on a calculated EMV, create a false sense of precision. These deterministic approaches fail to capture the statistical variance and range of possible outcomes that emerge when multiple uncertainties exist simultaneously. Chapman and Ward (2003) further criticise the simplistic "probability times impact calculation", warning that it treats risk merely as an expected average and ignores overall risk efficiency. To calculate a realistic contingency reserve, the literature suggests using probabilistic methods like Monte Carlo simulation. By mathematically modelling uncertainty, organisations can set their contingency reserve based on a confidence level of staying within budget.

The introduction of this probabilistic approach in the proposed framework resolves the reliance on subjective intuition and single-point calculations. Instead of assessing risks in isolation, the framework mathematically combines the structured input data from both Type A and Type B using Monte Carlo simulation. By running 10,000 iterations, the model generates a probability distribution of possible project costs. This output shifts the decision-making process and estimators can derive the contingency reserve required to achieve a predefined confidence level.

To systematically balance the tension between safety and competitiveness in tenders described by the respondents, the framework proposes an organisational baseline at the 80% confidence level. At this level, the project achieves an 80% probability of not exceeding its budget, providing a buffer against severe impacts while maintaining competitive tender pricing. In addition to defining the total contingency reserve, the framework's quantitative analysis supports targeted risk treatment. By utilising sensitivity analysis and Tornado charts generated from the simulation, the framework ranks the individual risk drivers that contribute most significantly to the project's overall cost variance. This provides project managers with guidance on where to focus proactive mitigation efforts to achieve the greatest impact on project stability.

Another limitation observed in the findings concerns the lack of continuous updates of the project's risk exposure during execution. Once a contingency is set in the tender phase, there is limited follow-up on how the risk level evolves. This implies that changes in project conditions, realised risks, or newly emerging uncertainties are not reflected in an updated assessment of the remaining risk exposure.

From a theoretical perspective, this static approach contradicts the view of risk management as a continuous and iterative process (SIS, 2018). Sanchez et al. (2009) emphasise that uncertainty evolves throughout the project lifecycle and therefore requires ongoing reassessment to remain relevant for decision-making. Without such updates, the connection between risk analysis and project control weakens, as the analysis no longer reflects the actual state of the project.

The proposed framework addresses this limitation by enabling a continuous evaluation through a current risk forecast. By updating the input data as the project progresses and re-running the probabilistic model, the framework provides an updated probability distribution of total project cost. This allows project managers to assess the likelihood that the project will remain within the budget.

6.3 Portfolio Risk Aggregation and Decision Support

As discussed in 6.1, empirical findings indicate that risk information within VSN is currently fragmented, which makes it difficult to achieve a portfolio overview. Higher management primarily evaluates performance through static metrics, such as schedules and expected profit margins. This means that the organisation lacks a structured view of its total exposure to uncertainty.

Teller et al. (2014) show that portfolio management depends on consistent and comparable data across projects. Without such consistency, aggregation does not reflect actual risk exposure. Kock et al. (2020) describe this as a data quality issue, where inconsistent input leads to misleading results and the principle "garbage in, garbage out" applies. In addition, Aven (2016) emphasise that risk assessments must reflect both uncertainty and the strength of underlying knowledge to support informed decisions. ISO 31000 further highlights that risk management should support decision-making at all organisational levels, which requires that risk information remains interpretable beyond the individual project (SIS, 2018).

The empirical findings indicate that this requirement is not fulfilled in the current practice. Risk information is collected within projects but lacks a common structure that allows comparison or aggregation. This limits the ability to understand how individual projects contribute to the organisation's total exposure. It also affects decisions related to new tenders, where additional uncertainty is evaluated without a clear reference to the existing portfolio.

The proposed framework addresses this through the use of standardised and quantitative risk data. Each project generates a probability distribution of total cost based on structured input data and probabilistic analysis. These outputs allow aggregation across projects, where the combined distribution represents the organisation's total financial exposure.

The introduction of the *Current Risk Forecast* strengthens this approach. By updating project data and re-running the analysis, each project produces an updated estimate of the probability of remaining within budget. These project-level forecasts can be combined to form a portfolio-level overview of current risk exposure. This enables management to assess how uncertainty develops over time and how it affects the organisation as a whole.

This aggregated perspective provides a basis for assessing whether the current portfolio aligns with the organisation's risk tolerance. It also allows evaluation of new tenders in relation to existing commitments. By analysing how additional projects affect the overall distribution of outcomes, management can assess whether new uncertainty fits within the current exposure. This creates a direct link between project-level analysis and strategic decisions.

The proposed framework separates Type C from the standard risk analysis. Instead, it suggests that these risks should be managed through a management reserve. Implementing this reserve requires a strategic decision regarding organisational governance. Based on Val and Chumber (2011) and Chapman and Ward (2003), the framework highlights portfolio-level allocation as a highly efficient approach for an organisation like VSN, which manages multiple projects simultaneously. Tying up financial buffers in every individual project reduces the forecasted profit margins and decreases overall capital efficiency. Instead, pooling the management reserve centrally allows management to deploy resources dynamically. Funds are then only allocated to the specific projects if critical, unforeseen issues actually materialise.

However, VSN's governance structure might require the reserve to be maintained within individual project budgets (Alternative 1). If so, the framework emphasises that control mechanisms must be enforced. As supported by Karlsen and Lereim (2005), formal authority over these funds must remain with the project owner or steering group. The framework ensures that VSN can protect its portfolio against major financial shocks while maintaining transparency and cost control.

6.4 Organisational Learning and Knowledge Transfer

The empirical findings indicate that organisational learning within VSN is limited by a lack of structured feedback processes and limited use of historical project data. Risk assessments are often based on individual experience rather than documented knowledge from previous projects. Some tender engineers report that they rarely receive feedback on whether their estimations were accurate or utilised during project execution. Similarly, project managers note that although final project reports are produced, they are not always reviewed. As a result, knowledge remains individual and project-specific instead of being transferred within the organisation. This creates a dependency on experienced individuals and limits the organisation's ability to improve its risk management practices over time.

From a theoretical perspective, this lack of structured learning mechanisms represents a limitation. Olsson (2008) emphasise that traditional risk management practices are often too focused on individual projects, leading to fragmented knowledge and weak feedback loops. This prevents organisations from learning from past experiences and improving future risk assessments. Similarly, Aven (2016) highlights that risk understanding is closely linked to the quality of knowledge, and that learning from previous outcomes is essential for strengthening the basis of future decisions. ISO 31000 further stresses that risk management should be an iterative process, where information is continuously updated and lessons learned are integrated into future activities (SIS, 2018). Without such mechanisms, organisations risk repeating the same mistakes and failing to improve the accuracy of their risk assessments.

The proposed framework addresses these limitations by introducing a structured feedback loop that enables organisational learning. Risk information is systematically captured and updated across three distinct phases: the *Initial Risk Forecast*, the *Current Risk Forecast* and the *Actual Risk Outcome*. By comparing initial estimates and actual project outcomes at project completion, the framework ensures that deviations are identified and analysed. This creates a formal mechanism for evaluating the accuracy of previous assessments and for improving future estimations.

In addition, the framework supports knowledge transfer by structuring and storing risk data into risk registers. This enables historical data to be reused in new projects, reducing reliance on individual experience and supporting less experienced employees in their assessments. The introduction of predefined risk checklists, based on project data, makes sure that knowledge stays within the organisation. Instead of relying on intuition, individuals are guided by structured information that reflects previous project outcomes. This also establishes a foundation for more advanced forms of organisational learning. As highlighted by Amaechi et al. (2025), digital tools and data-driven approaches, including Artificial Intelligence (AI), can play a key role in analysing historical data and identifying patterns across projects. This perspective is supported by several respondents, who emphasise the potential of using automated systems to extract insights from previous projects and improve future risk assessments. The framework focuses on establishing a structured data foundation, which later on enables future integration of such technologies.

By formalising feedback processes and structuring historical risk data, the framework transforms organisational learning from an informal and experience-based activity into a systematic process. The framework strengthens the organisation's ability to learn from past projects, improve the quality of future risk assessments and reduce dependency on individual expertise.

6.5 Limitations and Future Research

The proposed framework presents a few KPIs, which represent only a fraction of the possible metrics that can be extracted from the model. The included KPIs were selected because they give an overview of financial risk exposure. It is up to the organisation to evaluate its specific strategic objectives, risk appetite and governance structures to determine which metrics are the most relevant to retrieve.

This aligns with the principles of ISO 31000, which emphasise that risk criteria and evaluation methods must always be tailored to the organisation's unique internal and external context.

One limitation of the framework concerns the assumption of independence between projects and risks. In practice, dependencies often exist where several projects share common risks or are affected by the same external factors. Karlsen and Lereim (2005) note that such dependencies can influence the overall risk level. This assumption simplifies the model and may underestimate systematic or correlated exposure. While the current assumption of independence simplifies the model and may underestimate systematic exposure, it was considered appropriate given the conceptual purpose of the framework and the current lack of available correlation data. However, when the organisation has a comprehensive historical risk database, the input data in the model can be complemented with correlation coefficients to capture the interdependencies.

Future research should focus on implementing the framework in an integrated system in the organisation. Excel is not optimal for managing and analysing complex project and portfolio risk data. In addition, the framework should be developed to become more user-friendly and easier for practitioners to apply in practice. The intention is that users should put in project and risk data, after which the system automatically generates outputs and provides the user with key performance indicators that are easy to interpret.

Additional research can also examine how the framework performs in practice. It should focus on applying the framework using historical project data in order to evaluate the accuracy and reliability of the probabilistic forecasts and aggregation methods. Furthermore, it would be valuable to implement and evaluate the framework in practice and compare its performance with VSN's current risk management process. Such studies could provide insight into how the framework affects decision-making, risk visibility and portfolio-level uncertainty management in real project environments.

As discussed earlier, transitioning to a more structured and documented approach establishes a data foundation to enable AI to support and simplify the estimation process. AI-based methods can assist practitioners by systematically analysing vast amounts of historical project data, identifying patterns and automatically suggesting risk estimates based on actual previous outcomes. This technological integration would reduce the current reliance on individual judgement and intuition, thereby improving the overall consistency and accuracy of how risks are assessed across the portfolio.

7
Conclusion

This thesis aimed to investigate how risk management practices at the project level can be developed and aggregated to enable analysis of risks at the portfolio level. Based on empirical findings and theoretical principles, the study proposes a framework that shifts risk management from isolated, subjective evaluations to a standardised process. This section presents the conclusions to the research questions outlined in Chapter 1.

7.1 Current Practices of Handling Project Risks

The findings show that the identification, assessment and management of project risks at VSN rely largely on individual experience and informal practices. Although formal tools and guidelines exist, their use varies between projects, which leads to differences in how risks are defined, documented and followed up. Risk identification often takes place through discussions rather than structured processes, and smaller risks are not always recorded. As a result, uncertainty is not consistently represented in a transparent way.

A recurring pattern concerns the use of embedded margins. Instead of documenting uncertainty explicitly, estimators include buffers directly in cost estimates to create flexibility during execution. This indicates that uncertainty is recognised but not systematically documented. Such practices reduce transparency and make it difficult to distinguish between planned costs and uncertainty. They also limit the possibility of comparing risks across projects or of reusing information in future projects.

7.2 Requirements for Aggregating Risk Information

To enable aggregation and analysis of risk exposure at the portfolio level, project-level risk information should be standardised across projects. Without consistent definitions of probability, consequence and risk categories, project-level information cannot be meaningfully combined. Variations in documentation practices and assessment methods lead to differences in how uncertainty is represented, which reduces the reliability of aggregated results.

The quality of the input data is critical to enable accurate aggregation. If risks are not explicitly documented or if uncertainty is embedded within cost estimates, the underlying data does not reflect the actual risk exposure. This limits the usefulness of any aggregation, as the result will not represent the true level of uncertainty. Therefore, reliable aggregation requires that uncertainty is clearly separated from base estimates and consistently recorded.

The findings also highlight the importance of updating information. Aggregated results are only relevant if they reflect the current state of projects. Without continuous updates, portfolio-level assessments risk becoming outdated and disconnected from actual conditions. This reinforces the need for dynamic data that can be revised as projects progress.

7.3 Aggregation of Uncertainty at Portfolio Level

The study shows that uncertainties in project outcomes can be analysed through Monte Carlo simulation by replacing deterministic cost estimates with probabilistic representations of uncertainty. In the proposed framework, Type A (known uncertain costs) are modelled using PERT distributions, while Type B (risk events) are modelled through probability-based occurrence combined with PERT-distributed consequences. This enables the generation of probability distributions representing the total uncertainty of individual projects.

By standardising risk classifications, input parameters and assessment methods across projects, these project-level distributions can be mathematically aggregated into a combined portfolio-level distribution. The resulting portfolio view provides a probabilistic representation of the organisation's total financial risk exposure and enables analysis of uncertainty across multiple projects. The findings therefore demonstrate that standardised risk data together with quantitative uncertainty analysis can support risk aggregation and visualisation of overall risk exposure.

7.4 Use of Risk Information

Structured and quantified risk information can support decision-making at both project and portfolio level. Visual tools such as probability distributions, heat maps and tornado charts provide decision-makers with insights into uncertainty and its potential impact. At project level, probabilistic forecasts and risk exposure indicators provide a basis for estimating contingency reserves, prioritising risk responses and monitoring changes in uncertainty throughout the project lifecycle. At portfolio level, aggregated risk information enables management to assess the organisation's overall risk exposure, evaluate how new tenders affect the portfolio risk profile and support decisions related to resource allocation and risk acceptance. However, the success of the portfolio-level analysis depends on consistent input data at the project level.

The findings also show that risk information can support organisational learning when it is systematically documented, updated and linked to actual project outcomes. By comparing initial forecasts with actual outcomes, organisations can identify recurring risk patterns, improve future estimates and refine risk assessment practices. The proposed framework therefore combines decision support with a structured feedback process that enables project experiences to be transformed into organisational knowledge that strengthens future risk management. This also establishes a foundation for more advanced, data-driven approaches, including the future use of AI to enhance predictive capabilities.

8
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Appendix A - Interview Guide for Tender Engineers

Background

- What is your current role in the organisation?
- How long have you worked in this role?
- What type of projects do you primarily work with?
- How did you learn to work with risks in the organisation, and how confident do you feel in the process?

Identification of Risks in the Tender Phase

- How are risks identified in connection with tenders? Is a risk register used?
- Who participates in the risk identification?
- How do you document project risks?
- Are opportunities identified during the tender phase? How?
- How do you ensure that all relevant risks are captured?
- How many risks are typically identified in a tender?
- Can you give examples of common risks?
- Do you feel that there are risks that are missed or underestimated in the tender phase? Why?
- How can the identification of risks be improved?

Assessment of Probability and Consequence

- How do you assess the probability and consequence of a risk?
- What do you base your assessment on?
- Do you take into account that risks may depend on each other?
- Do you feel that assessments are consistent across projects and between individuals?
- How can the assessment of risks be improved?

How the Contingency Reserve is Determined

- How is the contingency reserve determined in a tender? (the contingency reserve included in the budget)
- What factors influence the size of the contingency reserve?
- How is the risk assessment connected to the contingency reserve that is included?
- What guidelines exist for how large the contingency reserve should be?
- Do you add a general uncertainty margin for aspects not identified as specific risks?
- If yes: How do you determine the size of that margin?
- How do you perceive decision-making regarding the contingency reserve today?
- How could the process around the contingency reserve be improved?

Handover and Follow-up of the Contingency Reserve

- How is the handover of risks from the tender phase to the project organisation carried out?
- How are questions or discussions handled regarding why a certain risk or contingency reserve was included?
- How is the difference between the planned contingency reserve and the actual risk cost analysed?
- What type of feedback do you receive regarding how the contingency reserve was actually used in the project?
- Does a project typically require more or less contingency reserve than estimated?
- In what way do you feel that the organisation learns from past deviations in contingency reserve?

Assessment of Uncertainty and Knowledge of Quantitative Methods

- Have you used quantitative methods, such as simulations or probability-based calculations, in risk analysis or tender work? (e.g., Monte Carlo)
- If yes: How have you used such tools in your work?
- Would you be able to estimate a risk by specifying: minimum, most likely, and maximum possible cost outcome?
- How do you view the possibility of using simulation to analyse risks?
- In what way would such a method affect your work?

Communication to Management

- What type of risk information is requested at higher levels? (management or portfolio level)
- How are risks communicated to management or portfolio level?
- Do you feel that risk information is comparable between projects?

Closing

- Is there anything you would like to add that we have not covered?

Appendix B - Interview Guide for Project Managers

Background

- What is your current role in the organisation?
- How long have you worked in this role?
- What type of projects do you primarily work with?
- What types of contracts do you typically work with?
  Fixed price? Time and material?
- What is the typical project budget?
- At which stages of the project do you work with risks? (Do you participate in the tender phase?)
- How did you learn to work with risks in the organisation, and how confident do you feel in the process?

Handover from Tender to Project

- How is the handover of risks from the tender phase to the project organisation carried out?
- What do you know about how the contingency reserve in a project was determined?
- How is the risk assessment connected to the contingency reserve that is included?
- How are questions or discussions handled regarding why a certain risk or contingency reserve was included?
- How do you perceive decision-making around the contingency reserve today?
- How could the process around the contingency reserve be improved?
- Do you feel that there are risks that are missed or underestimated in the tender phase? Why?

Identification of Risks in the Project

- How are risks identified? Is a risk register used?
- Who participates in the risk identification?

- How do you document risks?
- Do you also identify opportunities? How?
- How do you ensure that all relevant risks are captured?
- How many risks are typically identified?
- Can you give examples of common risks?
- At what points in the project do you update the risk list? How often?
- How can the identification of risks be improved?

Assessment of Probability and Consequence

- How do you assess the probability and consequence of a risk?
- What do you base your assessment on?
- Do you take into account that risks may depend on each other?
- Do you feel that assessments are consistent across projects and between individuals?
- How can the assessment of risks be improved?

Follow-up of the Contingency Reserve

- Do you feel that the contingency reserve covers all risks that occur?
- What do you usually use the contingency reserve for?
- Do you use the contingency reserve when you mitigate a risk?
- Does the project usually require more or less contingency reserve than estimated?
- How often is additional contingency reserve needed to cover costs from occurring risks?
- What do you do when you identify a new risk that you believe should be covered by the contingency reserve?
- What do you do if an unidentified risk occurs (i.e., one without an allocated reserve)?
- What happens if the contingency reserve is not used, or if it is insufficient?
- How is the difference between planned risk reserve and actual risk cost analysed?
- How do you provide feedback to the tender engineer about how the risk reserve was actually used in the project?
- In what way do you feel that the organisation learns from past deviations in contingency reserve?

Assessment of Uncertainty and Knowledge of Quantitative Methods

- Do you feel that the estimated cost of a risk corresponds with the actual outcome when the risk occurs?
- Is the cost usually higher or lower than estimated?
- How often do estimated costs not match the final outcome?
- Have you used quantitative methods, such as simulations or probability-based calculations, in risk analysis?
- If yes: How have you used such tools in your work?
- Would you be able to estimate a risk by specifying: minimum, most likely, and maximum possible outcomes as a cost?
- How do you view the possibility of using simulation to analyse risks?
- In what way would such a method affect your work?

Communication to Management

- How are risks reported in status reports?
- What type of risk information is requested at higher levels? (management or portfolio level)
- How are risks communicated to management or portfolio level?
- Do you feel that risk information is comparable between projects?

Closing

- Is there anything you would like to add that we have not covered?

Appendix C - Excel Sheets for Project 1

This appendix presents the Excel simulation model developed for the illustrative project 1, with the three views *Initial Risk Forecast*, *Current Risk Forecast*, *Actual Risk Outcome* and Actual Risk Outcome Comparison with Initial Risk Forecast.

The worksheets are separated by a gray divider line into to parts:

- User inputs: The fields located on the left side of the worksheet represent the parameters that the user manually enters and updates, such as probability intervals and three-point consequence estimates.
- Simulation: The sections to the right of the vertical gray divider line represent the probabilistic operations, distribution formatting and calculations that the model generates automatically based on the predefined simulation logic.

Project 1 - Initial Risk Forecast

Output
Distribution
Formula

KPI - Project Summary

ID	KPI	Output
KPI 1	Estimated cost at completion (P80), (SEK)	2 407 909
KPI 2	Confidence level of staying within budget	80%
KPI 3	Confidence margin (P80), (SEK)	0

Budget - Project Summary

ID	Summary of budgeted costs	Cost (SEK)
S1	Total budgeted cost Type A	1 030 000
S2	Total budgeted fixed costs	1 150 000
S3	Total budgeted contingency reserve	227 909
Total	Total budgeted costs for project (P80)	2 407 909

Type A - Uncertain Costs

ID	Uncertain cost	Category	Min (SEK)	Most likely (SEK)	Maximum (SEK)	Budgeted cost (SEK)
A1	Uncertain cost 1	Timeplan	80 000	110 000	200 000	110 000
A2	Uncertain cost 2	Materials	220 000	300 000	430 000	300 000
A3	Uncertain cost 3	Timeplan	140 000	230 000	320 000	230 000
A4	Uncertain cost 4	Other	180 000	200 000	300 000	200 000
A5	Uncertain cost 5	Timeplan	130 000	190 000	270 000	190 000
Total			750 000	1 030 000	1 520 000	1 030 000

Type B - Risk Events

ID	Risk event	Category	Min (SEK)	Most likely (SEK)	Maximum (SEK)	Probability
B1	Risk 1	Resources	40 000	90 000	170 000	0-20%
B2	Risk 2	Materials	20 000	60 000	100 000	40-60%
B3	Risk 3	Timeplan	25 000	70 000	150 000	0-20%
B4	Risk 4	Other	20 000	50 000	120 000	20-40%
B5	Risk 5	Timeplan	30 000	80 000	100 000	60-80%
Total			135 000	350 000	640 000	

Fixed Costs

ID	Fixed cost	Cost (SEK)
F1	Fixed cost 1	200 000
F2	Fixed cost 2	100 000
F3	Fixed cost 3	50 000
F4	Fixed cost 4	300 000
F5	Fixed cost 5	500 000
Total		1 150 000

Simulation Output

Output from simulation	Cost (SEK)
Simulated total cost Type A	971 895
Simulated total cost Type B	57 198
Simulated Type A and Type B	1 029 093
Simulated total costs	2 179 093

Confidence level	Cost (SEK)
Confidence level Type A without contingency reserve	31%
Confidence level Type A with contingency reserve	100%
Confidence level Type B with contingency reserve	94%
Confidence level project	80%

Type A - Simulation Data

Simulated Cost (PERT)	Confidence level budgeted cost
92 031	37%
351 925	44%
175 456	50%
180 489	30%
171 993	47%
971 895	31%

Type B - Simulation Data

Min Probability	Max Probability	Simulated cost (PERT)	Simulated probability (UNIFORM)	Simulated probability (BERNOULLI)	Simulated Cost of Risk Event
0%	20%	138836,0449	11%	0%	0
40%	60%	45177,91141	41%	0%	0
0%	20%	57197,76909	15%	100%	57197,76909
20%	40%	33274,07914	36%	0%	0
60%	80%	56581,28535	72%	0%	0
					57 198

Project 1 - Current Risk Forecast

KPI - Project Summary

ID	KPI	Output
KPI 1	Estimated cost at completion (P80), (SEK)	2 388 682
KPI 2	Confidence level of staying within budget	86%
KPI 3	Confidence margin (P80), (SEK)	19 227

Project Information

Budgeted cost	2 407 909

Type A - Uncertain Costs

ID	Uncertain cost	Category	Status	Instructions for user that depends on status
A1	Uncertain cost 1	Timeplan	Estimated	Keep consequence and expenses updated
A2	Uncertain cost 2	Materials	Estimated	Keep consequence and expenses updated
A3	Uncertain cost 3	Timeplan	Estimated	Keep consequence and expenses updated
A4	Uncertain cost 4	Other	Known	Only update expenses
A5	Uncertain cost 5	Timeplan	Known	Only update expenses
Total				

Consequence

Min (SEK)	Most likely (SEK)	Maximum (SEK)
80 000	110 000	200 000
220 000	300 000	430 000
140 000	230 000	320 000
180 000	200 000	300 000
130 000	190 000	270 000
750 000	1 030 000	1 520 000

Expenses

Expenses drawn from budget	Expenses drawn from contingency reserve	Expenses drawn from outside project	Total expenses for Type A item
80000			80000
100000			100000
100000			100000
100000			100000
200 000			200000
580000	0	0	580000

Type A - Simulation Data

Min (SEK)	Most likely (SEK)	Maximum (SEK)	Simulated Cost (PERT)
80 000	110 000	200 000	123 214
220 000	300 000	430 000	338 037
140 000	230 000	320 000	269 023
100 000	100 000	100 000	100 000
200 000	200 000	200 000	200 000
740 000	940 000	1 250 000	1 030 274

Type B - Risk Events

ID	Risk event	Category	Status	Instructions for user that depends on status
B1	Risk 1	Timeplan	Active	Keep consequence and probability updated
B2	Risk 2	Materials	Mitigated - Closed	Fill in expenses
B3	Risk 3	Timeplan	Mitigated - Active	Fill in expenses and keep consequence and probability updated
B4	Risk 4	Other	Occurred - Unknown cost	Keep consequence updated
B5	Risk 5	Timeplan	Closed	No need to do anything
Total				

Consequence

Min (SEK)	Most likely (SEK)	Maximum (SEK)
40 000	90 000	170 000
20 000	60 000	100 000
25 000	70 000	150 000
20 000	50 000	120 000
30 000	80 000	100 000
135 000	350 000	640 000

Probability

Min Probability
0-20%
40-60%
0-20%
20-40%
60-80%

Expenses

Expenses drawn from budget	Expenses drawn from outside project	Total expenses for Type B item
		0
50 000		50000
100000		100000
		0
		0
150000	0	150000

Type B - Simulation Data

Min (SEK)	Most likely (SEK)	Maximum (SEK)	Min Probability	Max Probability	Simulated cost (PERT)	Simulated probability (UNIFORM)	Simulated probability (BERNOULLI)	Simulated Cost of Risk Event
40 000	90000	170 000	0%	20%	100063,7401	1%	0%	0
0	0	0	0%	0%	0	0%	0%	0
25 000	70000	150 000	0%	20%	90017,87509	17%	0%	0
0	0	0	0%	0%	0	0%	0%	0
0	0	0	0%	0%	0	0%	0%	0
65 000	160 000	320 000						0

Fixed costs

ID	Fixed cost	Budgeted cost (SEK)	Expenses (SEK)
F1	Fixed cost 1	200 000	
F2	Fixed cost 2	100 000	
F3	Fixed cost 3	50 000	
F4	Fixed cost 4	300 000	
F5	Fixed cost 5	500 000	500000
Total		1 150 000	500000

Project Summary

ID	Name	Budgeted cost (SEK)	Expenses (SEK)	Budget left (SEK)	Estimated final cost (SEK)	Estimated remaining cost (SEK)	Confidence level of staying within budget	Estimated cost at completion (P80), (SEK)	Estimated remaining cost needed for P80	Confidence margin (P80), (SEK)
S1	Type A	1 030 000	580 000	450 000	1 030 274	450 274	89%	1 006 282	426 282	23 718
S2	Type B	0	0	0	0	0	0%	94 099	94 099	-94 099
S3	Contingency reserve	227 909	150 000	77 909	150 000	0	100%	150 000	0	77 909
S4	Fixed costs	1 150 000	500 000	650 000	1 150 000	650 000	100%	1 150 000	650 000	0
S5	Outside project	0	0	0	0	0	100%	0	0	0
Total	Total	2 407 909	1 230 000	1 177 909	2 330 274	1 100 274	86%	2 388 682	1 158 682	19 227

Project 1 - Actual Risk Outcome

Type A - Uncertain Costs

ID	Uncertain cost	Category	Status	Instructions for user that depends on status
A1	Uncertain cost 1	Timeplan	Known	Only update expenses
A2	Uncertain cost 2	Materials	Known	Only update expenses
A3	Uncertain cost 3	Timeplan	Known	Only update expenses
A4	Uncertain cost 4	Other	Known	Only update expenses
A5	Uncertain cost 5	Timeplan	Known	Only update expenses
Total				

Consequence

ID	Min (SEK)	Most likely (SEK)	Maximum (SEK)
A1	80 000	110 000	200 000
A2	220 000	300 000	430 000
A3	140 000	230 000	320 000
A4	180 000	200 000	300 000
A5	130 000	190 000	270 000
Total	750 000	1 030 000	1 520 000

Expenses

ID	Expenses drawn from budget	Expenses drawn from contingency reserve	Expenses drawn from outside project	Total expenses for Type A item
A1	110 000			110000
A2	300 000			300000
A3	230 000			230000
A4	200 000			200000
A5	190 000	50 000		240 000
Total	1 030 000	50 000	0	1080000

Type A - Simulation Data

ID	Min (SEK)	Most likely (SEK)	Maximum (SEK)	Simulated Cost (PERT)
A1	110 000	110 000	110 000	110 000
A2	300 000	300 000	300 000	300 000
A3	230 000	230 000	230 000	230 000
A4	200 000	200 000	200 000	200 000
A5	190 000	190 000	190 000	190 000
Total	1 030 000	1 030 000	1 030 000	1 030 000

Type B - Risk Events

ID	Risk event	Category	Status	Instructions for user that depends on status
B1	Risk 1	Timeplan	Closed	No need to do anything
B2	Risk 2	Materials	Occured - Known cost	Fill in expenses
B3	Risk 3	Timeplan	Occured - Known cost	Fill in expenses
B4	Risk 4	Other	Occured - Known cost	Fill in expenses
B5	Risk 5	Timeplan	Closed	No need to do anything
Total				

Consequence

ID	Min (SEK)	Most likely (SEK)	Maximum (SEK)
B1	40 000	90 000	170 000
B2	20 000	60 000	100 000
B3	25 000	70 000	150 000
B4	20 000	50 000	120 000
B5	30 000	80 000	100 000
Total	135 000	350 000	640 000

Probability

ID	Min Probability
B1	0-20%
B2	40-60%
B3	0-20%
B4	20-40%
B5	60-80%
Total	

Expenses

ID	Expenses drawn from budget	Expenses drawn from outside project	Total expenses for Type B item
B1			
B2	100 000		100000
B3	76825	100000	176825
B4		110000	110000
B5			0
Total	176825	210000	386825

Type B - Simulation Data

ID	Min (SEK)	Most likely (SEK)	Maximum (SEK)	Min Probability	Max Probability	Simulated cost (PERT)	Simulated probability (UNIFORM)	Simulated probability (BERNOULLI)	Simulated Cost of Risk Event
B1	0	0	0	0%	0%	0	0%	0%	0
B2	0	0	0	100%	100%	0	100%	100%	0
B3	0	0	0	100%	100%	0	100%	100%	0
B4	0	0	0	100%	100%	0	100%	100%	0
B5	0	0	0	0%	0%	0	0%	0%	0
Total	0	0	0						0

Fixed costs

ID	Fixed cost	Budgeted cost (SEK)	Expenses (SEK)
F1	Fixed cost 1	200 000	200000
F2	Fixed cost 2	100 000	100000
F3	Fixed cost 3	50 000	50000
F4	Fixed cost 4	300 000	300000
F5	Fixed cost 5	500 000	500000
Total		1 150 000	1150000

Project Summary

ID	Name	Budgeted cost (SEK)	Expenses (SEK)
S1	Type A	1 030 000	1 030 000
S2	Type B	0	0
S3	Contingency reserve	227 909	226 825
S4	Fixed costs	1 150 000	1 150 000
S5	Outside project	0	210 000
Total	Total	2 407 909	2 616 825

Project 1 - Actual Risk Outcome Comparison with Initial Risk Forecast

KPI - Project Summary

ID	KPI Name	Cost (SEK)
KPI 1	Budgeted cost	2 407 909
KPI 2	Actual cost	2 616 825
KPI 3	Variance (SEK)	- 208 916
KPI 4	Variance (%)	-9%

Type A - Uncertain Costs

ID	Uncertain cost	Status	Budgeted cost	Expenses (SEK)	Variance (SEK)	Variance (%)
A1	Uncertain cost 1	Known	110 000	110000	0	0%
A2	Uncertain cost 2	Known	300 000	300000	0	0%
A3	Uncertain cost 3	Known	230 000	230000	0	0%
A4	Uncertain cost 4	Known	200 000	200000	0	0%
A5	Uncertain cost 5	Known	190 000	240000	-50 000	-26%
Total			1 030 000	1080000	-50 000	-5%

Type B - Risk Events

ID	Risk event	Status	Expenses (SEK)
B1	Risk 1	Closed	0
B2	Risk 2	Occured - Known cost	100000
B3	Risk 3	Occured - Known cost	176825
B4	Risk 4	Occured - Known cost	110000
B5	Risk 5	Closed	0
Total			386825

Fixed costs

ID	Fixed cost	Budgeted cost (SEK)	Expenses (SEK)	Variance (SEK)	Variance (%)
F1	Fixed cost 1	200 000	200000	0	0%
F2	Fixed cost 2	100 000	100000	0	0%
F3	Fixed cost 3	50 000	50000	0	0%
F4	Fixed cost 4	300 000	300000	0	0%
F5	Fixed cost 5	500 000	500000	0	0%
Total		1 150 000	1150000	0	0%

Project Summary

ID	Name	Budgeted costs (SEK)	Expenses (SEK)	Variance (SEK)	Variance (%)
S1	Type A	1 030 000	1 030 000	0	0%
S2	reserve	227 909	226 825	1 084	0%
S3	Fixed costs	1 150 000	1 150 000	0	0%
S4	Outside project	0	210 000	-210 000	
S5	Total	2 407 909	2 616 825	-208 916	-9%

Appendix D - Excel Sheets for the Portfolio

This appendix presents the Excel simulation models developed for *Current Risk Forecast* of illustrative projects 2, 3, 4, 5 and the illustrative portfolio.

The worksheets are separated by a gray divider line into to parts:

- User inputs: The fields located on the left side of the worksheet represent the parameters that the user manually enters and updates, such as probability intervals and three-point consequence estimates.
- Simulation: The sections to the right of the vertical gray divider line represent the probabilistic operations, distribution formatting and calculations that the model generates automatically based on the predefined simulation logic.

Project 2 - Current Risk Forecast

KPI - Project Summary

ID	KPI Name	Cost (SEK)
KPI 1	Estimated cost at completion (P80)	5 735 274
KPI 2	Confidence level of staying within budget	38%
KPI 3	Confidence margin (P80)	-265 274

Project Information

Budgeted cost	5 470 000

Type A - Uncertain Costs

ID	Uncertain cost	Category	Status	Instructions for user that depend on status
A1	Uncertain cost 1	Schedule	Estimated	Keep consequence and expenses updated
A2	Uncertain cost 2	Materials	Estimated	Keep consequence and expenses updated
A3	Uncertain cost 3	Schedule	Estimated	Keep consequence and expenses updated
A4	Uncertain cost 4	Other	Known	Only update expenses
A5	Uncertain cost 5	Schedule	Known	Only update expenses
Total				

Consequence

Min (SEK)	Most likely (SEK)	Maximum (SEK)
1 000 000	1 200 000	1 300 000
600 000	800 000	1 000 000
1 000 000	1 200 000	1 300 000
180 000	200 000	300 000
400 000	600 000	70 000
3 180 000	4 000 000	3 970 000

Expenses

Expenses drawn from budget	Expenses drawn from contingency reserve	Expenses drawn from outside project	Total expenses for Type A item
800000			800000
40000			40000
600000			600000
100000			100000
200 000			200000
1740000	0	0	1740000

Type A - Simulation Data

Min (SEK)	Most likely (SEK)	Maximum (SEK)	Simulated Cost (PERT)
1 000 000	1 200 000	1 300 000	1 200 361
600 000	800 000	1 000 000	880 288
1 000 000	1 200 000	1 300 000	1 236 530
100 000	100 000	100 000	100 000
200 000	200 000	200 000	200 000
2 900 000	3 500 000	3 900 000	3 617 179

Type B - Risk Events

ID	Risk event	Category	Status	Instructions for user that depend on status
B1	Risk 1	Schedule	Active	Keep consequence and probability updated
B2	Risk 2	Materials	Mitigated - Closed	Fill in expenses
B3	Risk 3	Schedule	Mitigated - Active	Fill in expenses and keep consequence and probability updated
B4	Risk 4	Other	Occurred - Unknown cost	Keep consequence updated
B5	Risk 5	Schedule	Closed	No need to do anything
Total				

Consequence

Min (SEK)	Most likely (SEK)	Maximum (SEK)
1 000 000	1 200 000	1 300 000
50 000	60 000	700 000
25 000	70 000	150 000
210 000	250 000	300 000
60 000	80 000	100 000
1 345 000	1 660 000	2 550 000

Probability

Min Probability	Max Probability
0%	20%
0%	20%
0%	20%
20%	40%
40%	60%

Expenses

Expenses drawn from budget	Expenses drawn from outside project	Total expenses for Type B item
		0
50 000		50000
100000		100000
300 000	500000	800000
		0
450000	500000	950000

Type B - Simulation Data

Min (SEK)	Most likely (SEK)	Maximum (SEK)	Min Probability	Max Probability	Simulated cost (PERT)	Simulated probability (UNIFORM)	Simulated probability (BERNOULLI)	Simulated Cost of Risk Event
1 000 000	1 200 000	1 300 000	0%	20%	1266775.618	19%	0%	0
0	0	0	0%	20%	0	8%	0%	0
25 000	70 000	150 000	0%	20%	44088.56242	13%	0%	0
0	0	0	20%	40%	0	35%	100%	0
0	0	0	40%	60%	0	43%	100%	0
1 025 000	1 270 000	1 450 000						0

Fixed costs

ID	Fixed cost	Budgeted cost (SEK)	Expenses (SEK)
F1	Fixed cost 1	600 000	
F2	Fixed cost 2	200 000	
F3	Fixed cost 3	50 000	
F4	Fixed cost 4	70 000	
F5	Fixed cost 5	100 000	500000
Total		1 020 000	500000

Project Summary

ID	Name	Budgeted cost (SEK)	Expenses (SEK)
S1	Type A	4 000 000	1 740 000
S2	Type B	0	0
S3	Contingency reserve	450 000	450 000
S4	Fixed costs	1 020 000	500 000
S5	Outside project	0	500 000
Total	Total	5 470 000	3 190 000

Budget left (SEK)	Estimated final cost	Estimated remaining cost
2 260 000	3 617 179	1 877 179
0	0	0
0	450 000	0
520 000	1 020 000	520 000
-500 000	500 000	0
2 280 000	5 587 179	2 397 179

Confidence level of staying within budget	Estimated cost at completion (P80), (SEK)	Estimated remaining cost needed for P80	Confidence margin (P80), (SEK)
100%	3 558 605	1 818 605	441 395
57%	260 243	260 243	-260 243
100%	450 000	0	0
100%	1 020 000	520 000	0
0%	500 000	0	-500 000
38%	5 735 274	2 545 274	-265 274

Project 3 - Current Risk Forecast

KPI - Project Summary

ID	KPI Name	Cost (SEK)
KPI 1	Estimated cost at completion (P80)	45 988 069
KPI 2	Confidence level of staying within budget	59%
KPI 3	Confidence margin (P80)	-2 068 069

Project Information

Budgeted cost	43 920 000

Type A - Uncertain Costs

ID	Uncertain cost	Category	Status	Instructions for user that depend on status
A1	Uncertain cost 1	Resources	Estimated	Keep consequence and expenses updated
A2	Uncertain cost 2	Resources	Estimated	Keep consequence and expenses updated
A3	Uncertain cost 3	Materials	Estimated	Keep consequence and expenses updated
A4	Uncertain cost 4	Materials	Estimated	Keep consequence and expenses updated
A5	Uncertain cost 5	Other	Estimated	Keep consequence and expenses updated
Total				

Consequence

Min (SEK)	Most likely (SEK)	Maximum (SEK)
1 000 000	2 000 000	5 000 000
600 000	800 000	1 000 000
1 000 000	1 200 000	1 300 000
4 000 000	5 000 000	10 000 000
10 000 000	20 000 000	25 000 000
16 600 000	29 000 000	42 300 000

Expenses

Expenses drawn from budget	Expenses drawn from contingency reserve	Expenses drawn from outside project	Total expenses for Type A item
1 000 000			1 000 000
600 000			600 000
1 000 000			1 000 000
4 000 000			4 000 000
1 000 000			1 000 000
7600000	0	0	7 600 000

Type A - Simulation Data

Min (SEK)	Most likely (SEK)	Maximum (SEK)	Simulated Cost (PERT)
1 000 000	2 000 000	5 000 000	2 114 667
600 000	800 000	1 000 000	752 318
1 000 000	1 200 000	1 300 000	1 092 173
4 000 000	5 000 000	10 000 000	8 194 136
10 000 000	20 000 000	25 000 000	20 069 152
16 600 000	29 000 000	42 300 000	32 222 446

Type B - Risk Events

ID	Risk event	Category	Status	Instructions for user that depend on status
B1	Risk 1	Schedule	Active	Keep consequence and probability updated
B2	Risk 2	Schedule	Active	Keep consequence and probability updated
B3	Risk 3	Schedule	Occurred - Known cost	Fill in expenses
B4	Risk 4	Materials	Active	Keep consequence and probability updated
B5	Risk 5	Materials	Active	Keep consequence and probability updated
Total				

Consequence

Min (SEK)	Most likely (SEK)	Maximum (SEK)
1 000 000	1 200 000	1 300 000
600 000	800 000	1 000 000
1 000 000	1 200 000	5 000 000
3 000 000	3 000 000	4 000 000
60 000	80 000	1 000 000
5 660 000	6 280 000	12 300 000

Probability

Min Probability	Max Probability
20%	40%
0%	20%
60%	80%
20%	40%
40%	60%

Expenses

Expenses drawn from budget	Expenses drawn from outside project	Total expenses for Type B item
		0
		0
2000000		2000000
		0
		0
2000000	0	2000000

Type B - Simulation Data

Min (SEK)	Most likely (SEK)	Maximum (SEK)	Min Probability	Max Probability	Simulated cost (PERT)	Simulated probability (UNIFORM)	Simulated probability (BERNOULLI)	Simulated Cost of Risk Event
1 000 000	1 200 000	1 300 000	20%	40%	1219708,525	35%	100%	1219708,525
600 000	800 000	1 000 000	0%	20%	761284.3081	8%	0%	0
0	0	0	60%	80%	0	66%	100%	0
3 000 000	3 000 000	4 000 000	20%	40%	3117577.345	30%	100%	3117577.345
60 000	80 000	1 000 000	40%	60%	142350.5547	51%	100%	142350.5547
4 660 000	5 080 000	7 300 000						4 479 636

Fixed costs

ID	Fixed cost	Budgeted cost (SEK)	Expenses (SEK)
F1	Fixed cost 1	10 000 000	9000000
F2	Fixed cost 2	200 000	
F3	Fixed cost 3	50 000	
F4	Fixed cost 4	70 000	
F5	Fixed cost 5	100 000	
Total		10 420 000	9000000

Project Summary

ID	Name	Budgeted cost (SEK)	Expenses (SEK)
S1	Type A	29 000 000	7 600 000
S2	Type B	0	0
S3	Contingency reserve	4 500 000	2 000 000
S4	Fixed costs	10 420 000	9 000 000
S5	Outside project	0	0
Total	Total	43 920 000	18 600 000

Budget left (SEK)	Estimated final cost	Estimated remaining cost
21 400 000	32 222 446	24 622 446
0	4 479 636	4 479 636
2 500 000	2 000 000	0
1 420 000	10 420 000	1 420 000
0	0	0
25 320 000	49 122 083	30 522 083

Confidence level of staying within budget	Estimated cost at completion (P80), (SEK)	Estimated remaining cost needed for P80	Confidence margin (P80), (SEK)
46%	31 843 998	24 243 998	-2 843 998
22%	3 260 259	3 260 259	-3 260 259
100%	2 000 000	0	2 500 000
100%	10 420 000	1 420 000	0
100%	0	0	0
59%	45 988 069	27 388 069	-2 068 069

Project 4 - Current Risk Forecast

KPI - Project Summary

ID	KPI Name	Cost (SEK)
KPI 1	Estimated cost at completion (P80)	13 494 830
KPI 2	Confidence level of staying within budget	61%
KPI 3	P80 funding gap	-624 830

Project Information

Budgeted cost	12 870 000

Type A - Uncertain Costs

ID	Uncertain cost	Category	Status	Instructions for user that depend on status
A1	Uncertain cost 1	Schedule	Estimated	Keep consequence and expenses updated
A2	Uncertain cost 2	Materials	Estimated	Keep consequence and expenses updated
A3	Uncertain cost 3	Schedule	Estimated	Keep consequence and expenses updated
A4	Uncertain cost 4	Other	Known	Only update expenses
A5	Uncertain cost 5	Schedule	Known	Only update expenses
Total				

Consequence

Min (SEK)	Most likely (SEK)	Maximum (SEK)
1 000 000	1 200 000	1 300 000
600 000	8 000 000	9 000 000
1 000 000	1 200 000	1 300 000
180 000	1 200 000	1 300 000
400 000	900 000	1 300 000
3 180 000	12 500 000	14 200 000

Expenses

Expenses drawn from budget	Expenses drawn from contingency reserve	Expenses drawn from outside project	Total expenses for Type A item
800000			800000
40000			40000
600000			600000
100000			100000
200 000			200000
1740000	0	0	1740000

Type A - Simulation Data

Min (SEK)	Most likely (SEK)	Maximum (SEK)	Simulated Cost (PERT)
1 000 000	1 200 000	1 300 000	1 116 862
600 000	8 000 000	9 000 000	7 177 557
1 000 000	1 200 000	1 300 000	1 170 157
100 000	100 000	100 000	100 000
200 000	200 000	200 000	200 000
2 900 000	10 700 000	11 900 000	9 764 576

Type B - Risk Events

ID	Risk event	Category	Status	Instructions for user that depend on status
B1	Risk 1	Schedule	Active	Keep consequence and probability updated
B2	Risk 2	Materials	Mitigated - Closed	Fill in expenses
B3	Risk 3	Schedule	Mitigated - Active	Fill in expenses and keep consequence and probability updated
B4	Risk 4	Other	Occurred - Unknown cost	Keep consequence updated
B5	Risk 5	Schedule	Closed	No need to do anything
Total				

Consequence

Min (SEK)	Most likely (SEK)	Maximum (SEK)
1 000 000	1 200 000	1 300 000
50 000	60 000	700 000
25 000	70 000	150 000
210 000	250 000	300 000
60 000	80 000	100 000
1 345 000	1 660 000	2 550 000

Probability

Min Probability	Max Probability
0	0
0%	20%
0%	20%
20%	40%
40%	60%

Expenses

Expenses drawn from budget	Expenses drawn from outside project	Total expenses for Type B item
		0
50 000		50000
100000		100000
		0
		0
150000	0	150000

Type B - Simulation Data

Min (SEK)	Most likely (SEK)	Maximum (SEK)	Min Probability	Max Probability	Simulated cost (PERT)	Simulated probability (UNIFORM)	Simulated probability (BERNOULLI)	Simulated Cost of Risk Event
1 000 000	1 200 000	1 300 000	0%	0%	1053307.501	0%	0%	0
0	0	0	0%	20%	0	3%	0%	0
25 000	70 000	150 000	0%	20%	111263.8514	15%	0%	0
0	0	0	20%	40%	0	22%	0%	0
0	0	0	40%	60%	0	55%	0%	0
1 025 000	1 270 000	1 450 000						0

Fixed costs

ID	Fixed cost	Budgeted cost (SEK)	Expenses (SEK)
F1	Fixed cost 1	2 000 000	
F2	Fixed cost 2	200 000	
F3	Fixed cost 3	50 000	
F4	Fixed cost 4	70 000	
F5	Fixed cost 5	100 000	500000
Total		2 420 000	500000

Project Summary

ID	Name	Budgeted cost (SEK)	Expenses (SEK)
S1	Type A	10 000 000	1 740 000
S2	Type B	0	0
S3	Contingency reserve	450 000	150 000
S4	Fixed costs	2 420 000	500 000
S5	Outside project	0	0
Total	Total	12 870 000	2 390 000

Budget left (SEK)	Estimated final cos	Estimated remaining cost
8 260 000	9 764 576	8 024 576
0	0	0
300 000	150 000	0
1 920 000	2 420 000	1 920 000
0	0	0
10 480 000	12 334 576	9 944 576

Confidence level of staying within budget	Estimated cost at completion (P80), (SEK)	Estimated remaining cost needed for P80	Confidence margin (P80), (SEK)
54%	10 846 767	9 106 767	-846 767
63%	245 035	245 035	-245 035
100%	150 000	0	300 000
100%	2 420 000	1 920 000	0
100%	0	0	0
61%	13 494 830	11 104 830	-624 830

Project 5 - Current Risk Forecast

KPI - Project Summary

ID	KPI Name	Cost (SEK)
KPI 1	Estimated cost at completion (P80)	19 430 818
KPI 2	Confidence level of staying within budget	79%
KPI 3	P80 funding gap	-30 818

Project Information

Budgeted cost	19 400 000

Type A - Uncertain Costs

ID	Uncertain cost	Category	Status	Instructions for user that depend on status
A1	Uncertain cost 1	Schedule	Estimated	Keep consequence and expenses updated
A2	Uncertain cost 2	Materials	Estimated	Keep consequence and expenses updated
A3	Uncertain cost 3	Schedule	Estimated	Keep consequence and expenses updated
A4	Uncertain cost 4	Other	Known	Only update expenses
A5	Uncertain cost 5	Schedule	Known	Only update expenses
Total				

Consequence

Min (SEK)	Most likely (SEK)	Maximum (SEK)
1 000 000	1 200 000	1 300 000
600 000	800 000	1 000 000
3 000 000	3 200 000	3 300 000
180 000	200 000	3 000 000
4 000 000	6 000 000	7 000 000
8 780 000	11 400 000	15 600 000

Expenses

Expenses drawn from budget	Expenses drawn from contingency reserve	Expenses drawn from outside project	Total expenses for Type A item
800000			800000
40000			40000
600000			600000
100000			100000
200 000			200000
1740000	0	0	1740000

Type A - Simulation Data

Min (SEK)	Most likely (SEK)	Maximum (SEK)	Simulated Cost (PERT)
1 000 000	1 200 000	1 300 000	1 218 044
600 000	800 000	1 000 000	805 287
3 000 000	3 200 000	3 300 000	3 239 923
100 000	100 000	100 000	100 000
200 000	200 000	200 000	200 000
4 900 000	5 500 000	5 900 000	5 563 254

Type B - Risk Events

ID	Risk event	Category	Status	Instructions for user that depend on status
B1	Risk 1	Schedule	Active	Keep consequence and probability updated
B2	Risk 2	Materials	Mitigated - Closed	Fill in expenses
B3	Risk 3	Schedule	Mitigated - Active	Fill in expenses and keep consequence and probability updated
B4	Risk 4	Other	Occurred - Unknown cost	Keep consequence updated
B5	Risk 5	Schedule	Mitigated - Closed	Fill in expenses
Total				

Consequence

Min (SEK)	Most likely (SEK)	Maximum (SEK)
1 000 000	1 200 000	1 300 000
50 000	60 000	700 000
25 000	70 000	150 000
210 000	250 000	3 000 000
60 000	80 000	100 000
1 345 000	1 660 000	5 250 000

Probability

Min Probability	Max Probability
0	0
0%	20%
0%	20%
20%	40%
40%	60%

Expenses

Expenses drawn from budget	Expenses drawn from outside project	Total expenses for Type B item
		0
	500 000	500000
1000000		1000000
	5000000	5000000
		0
1000000	5500000	6500000

Type B - Simulation Data

Min (SEK)	Most likely (SEK)	Maximum (SEK)	Min Probability	Max Probability	Simulated cost (PERT)	Simulated probability (UNIFORM)	Simulated probability (BERNOULLI)	Simulated Cost of Risk Event
1 000 000	1 200 000	1 300 000	0%	0%	1153805.109	0%	0%	0
0	0	0	0%	20%	0	10%	0%	0
25 000	70 000	150 000	0%	20%	91339.4907	17%	0%	0
0	0	0	20%	40%	0	37%	100%	0
0	0	0	40%	60%	0	50%	0%	0
1 025 000	1 270 000	1 450 000						0

Fixed costs

ID	Fixed cost	Budgeted cost (SEK)	Expenses (SEK)
F1	Fixed cost 1	7 000 000	
F2	Fixed cost 2		
F3	Fixed cost 3		
F4	Fixed cost 4		
F5	Fixed cost 5		500000
Total		7 000 000	500000

Project Summary

ID	Name	Budgeted cost (SEK)	Expenses (SEK)
S1	Type A	11 400 000	1 740 000
S2	Type B	0	0
S3	Contingency reserve	1 000 000	1 000 000
S4	Fixed costs	7 000 000	500 000
S5	Outside project	0	5 500 000
Total	Total	19 400 000	8 740 000

Budget left (SEK)	Estimated final cost	Estimated remaining cost
9 660 000	5 563 254	3 823 254
0	0	0
0	1 000 000	0
6 500 000	7 000 000	6 500 000
-5 500 000	5 500 000	0
10 660 000	19 063 254	10 323 254

Confidence level of staying within budget	Estimated cost at completion (P80), (SEK)	Estimated remaining cost needed for P80	Confidence margin (P80), (SEK)
100%	5 561 055	3 821 055	5 838 945
63%	459 224	459 224	-459 224
100%	1 000 000	0	0
100%	7 000 000	6 500 000	0
0%	5 500 000	0	-5 500 000
79%	19 430 818	10 690 818	-30 818

Portfolio Overview

Information

Projects in the portfolio:	5
Total portfolio budget:	84 048 682

KPI Portfolio

ID	KPI	Output
KPI 1	Estimated cost at completion (P80), (SEK)	85 685 724
KPI 2	Confidence level of staying within budget	65%
KPI 3	Confidence margin (P80), (SEK)	- 1 637 042

Category Frequency

	Category	Frequency
	Timeplan	27
	Resources	2
	Materials	12
	Other	9

Most occurring risk in portfolio: Timeplan

Status Frequency Type A

	Status	Frequency
	Known	8
	Estimated	17

Status Frequency Type B

	Status	Frequency
	Active	8
	Closed	3
	Mitigated - Active	4
	Mitigated - Closed	5
	Occurred - Cost known	0
	Occurred - Cost unknown	2

Portfolio - Simulation Data

Project	Budgeted cost (SEK)	Contingency reserve/ Budgeted cost	Simulated total Cost (SEK)	Estimated cost at completion (P80), (SEK)	Confidence level of staying within budget	Confidence margin (P80), (SEK)
P1	2 388 682	9%	2 303 951	2 388 682	86%	19 227
P2	5 470 000	8%	5 478 117	5 735 274	38%	-265 274
P3	43 920 000	10%	38 991 074	45 988 069	59%	-2 068 069
P4	12 870 000	3%	13 946 426	13 494 830	61%	-624 830
P5	19 400 000	5%	19 063 254	19 430 818	79%	-30 818
Total	84 048 682		79 782 822	85 685 724	65%	-1 637 042

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