Second-order effects of risks on cost estimates and project planning

Master Thesis Report

Construction Management & Engineering

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Delft University of Technology

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by

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Preface

This master thesis report was written to fulfil the graduation requirements of the Construction Management & Engineering Master's program at TU Delft. This research consists of seven months of work on preparation, research and writing. In these seven months, I had the opportunity to enjoy doing research, conducting interviews, developing a new methodology and turning it all into a report.

I would like to thank everyone who supported me during this research and contributed to the result. First, I would like to thank Witteveen+Bos for providing a graduation spot where I could conduct this research. I would particularly like to thank Erik Schulte Fischedick and Mehmet Uzun for their daily guidance and support based on their knowledge of the thesis topic. I would also like to thank John Heintz for his day-to-day guidance and for keeping this research on track through his experience in doing research. Furthermore, I would like to thank Erfan Hoseini for his support during this study and his specialised knowledge of the topic, which increased the quality of the research. I would also like to thank Marcel Hertogh for steering this committee and putting the research in the right direction. Finally, I would also like to thank Dura Vermeer and Royal BAM Group for giving interviews, which greatly helped this research.

S. Efftink - 4729811
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Summary

Despite many attempts to improve, cost overruns and delays remain problematic in large construction and infrastructure projects. A cost overrun occurs when the final costs of a project exceed the initial estimates and agreements made with the client. A project delay is an overrun of the time initially estimated and agreed upon with the client. The main contributors to these issues are project complexity, optimism bias and strategic misrepresentation, scope changes, poor project management, uncertainty and risk, and inadequate contingency plans. From the design phase, creating an accurate cost estimate and planning appears to be quite complex, partly because projects face risks with second-order effects. In contrast to first-order effects that result directly from a risk, second-order effects are the indirect impacts that can disrupt the entire project.

Figure 1 gives an example of a scope change in a project. The direct consequence is that the design must be adjusted, which incurs costs and delays. The second-order effects of design changes are often underestimated, such as applying for new permits or making new calculations. These can cause further delays, which in turn affect other project activities. The entire project becomes disrupted, leading to even more costs and delays.

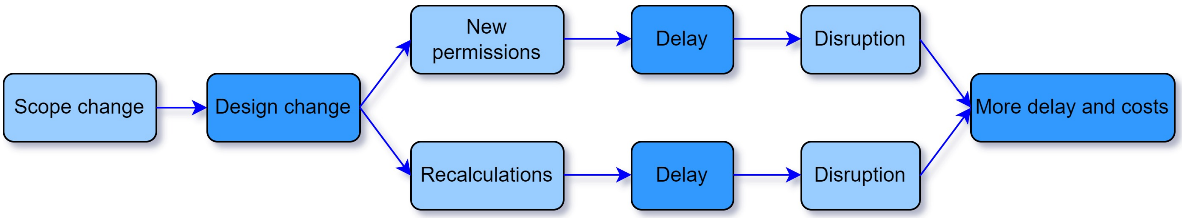

Figure 1: Example of Second-Order Effects

Current project management methods fall short of identifying and quantifying second-order effects of risks in the construction and infrastructure sector. Therefore, this research aims to make project managers aware of the second-order effects of risks, identify their causes and consequences, and provide advice on how to better identify and quantify them. An improved method for estimating risks with second-order effects will be developed in the process. This will be done using the Double Diamond design process model, which consists of four phases. In the first phase, second-order effects of risks are reviewed in the literature, and interviews with experts in the field are conducted to capture them as accurately as possible. In the second phase, all collected data is analysed. These include writing a conclusion of the literature review and transcribing and coding the interviews to obtain their results. A programme of requirements that the new method must meet to be an improvement is also drawn up in this phase. This method will be developed in the third phase before being delivered in the fourth phase and assessed by experts in an expert panel. This research, by going through this process, will answer the research question:

How can construction and infrastructure project managers effectively identify and assess the impact of second-order effects of risks on cost estimates and project planning during the design phase?

Using the literature, a definition of the first-order effect and second-order effect of risks was drawn up. Interview respondents were asked to review, improve and, if necessary, complete these established definitions during the interviews. This answers sub-research question 1:

What are second-order effects of risk?

First-order effects of risks are the direct and foreseeable consequences of a risk in a construction or infrastructure project often identified in a risk analysis session. Preventive or corrective measures can be taken to reduce the likelihood or impact of these risks. First-order risk effects are simple, quantifiable consequences and can be directly linked to a cause, possibly leading to increased costs or delays.

Second-order effects of risks are the indirect effects that follow from the initial risk or arise from a corrective or preventive measure. These effects can be more significant, possibly multiplying the original impact by a multiple. They can affect project activities that were not directly affected, making these activities more expensive or delayed due to disruptions. Second-order effects are edge effects, ripple effects, chain effects, cumulative effects, disruptive effects, and cascade effects that can influence the dynamics of project schedules and cost estimates in a compounded way.

From interviews with cost experts, project managers and risk managers from various contractors complemented by the literature review, sub-research question 2 can be answered:

How are second-order effects of risks currently dealt with?.

Risks are identified during a risk analysis session using the RISMAN method. A probability and impact are attached to the identified risks using ranges with pessimistic and optimistic values. In cost estimates, a monetary amount is linked to the risks and in planning, a duration. Next, a Monte Carlo Simulation is performed on the schedule and estimate from which a total project duration or project cost can be obtained at a distribution of probabilities. Finally, based on expert judgement, both an additional reservation in the cost estimate (also called the non-object-specific risk contingency) and buffers in the schedule are added. Although this reservation can be calculated in various mathematical and probabilistic ways, this does not appear to happen in practice. Interview respondents were familiar with second-order effects of risks but did not seem to unanimously agree on where in the 'Standaard systematiek voor kostenramingen 2018' they should be budgeted. In this way, they gave different answers:

- Direct costs to be further detailed
- Object-specific risks
- Non-object-specific risks
- Non-object-specific contingency
- No specific place, second-order effects not taken into account

Another issue that emerged during the interviews is that contractors sometimes offer somewhat more competitive prices in an estimate than consultants. This has to do with the contractor having to consider the market. In other words, the contractor sometimes has to offer sharper prices in an estimate than is realistic in order to win projects. The consultant, who has an independent position, will always try to give the best advice and make the estimate as realistic as possible. Furthermore, clients appear not to require complex mathematical models for calculating the non-object-specific risk contingency and correlating risks because they do not understand these methods properly, as indicated during interviews.

To better understand the causes and consequences of second-order effects, the interviews with cost experts, project managers and risk managers sought examples of the occurrence of risks with second-order effects in practice. All examples were collected, categorised, and processed into categories of causes or consequences. This allows answering sub-research question 3:

What are the causes and consequences of second-order effects of risks?.

Causes are categorised into unexpected soil conditions, Black Swans, design changes, accidents, miscalculations and slow procedures. Consequences are categorised to new studies, design changes, recalculations, material (price) changes, disruptions, damage recovery, scarcity of machinery and personnel, seasonal operations and new regulations.

The literature study and interviews have made it clear where the challenges lie regarding identifying and quantifying risks with second-order effects. These were translated into a list of requirements that a new method must meet to improve the current method. This programme of requirements consists of incorporating second-order effects of risks, regularly updating the cost and planning, conducting a multi-disciplinary risk analysis session, being understandable to the client and saving time.

The method developed is based on the theory by (Zuccaro et al., 2018) of cascading effects, which is normally applied in the natural disaster sector. It has been translated to be applicable in the construction and infrastructure sector. The method consists of Equation 1 run through six steps, as shown in Figure 2:

$$D(s,t) = H \times E \times V \times \alpha \tag{1}$$

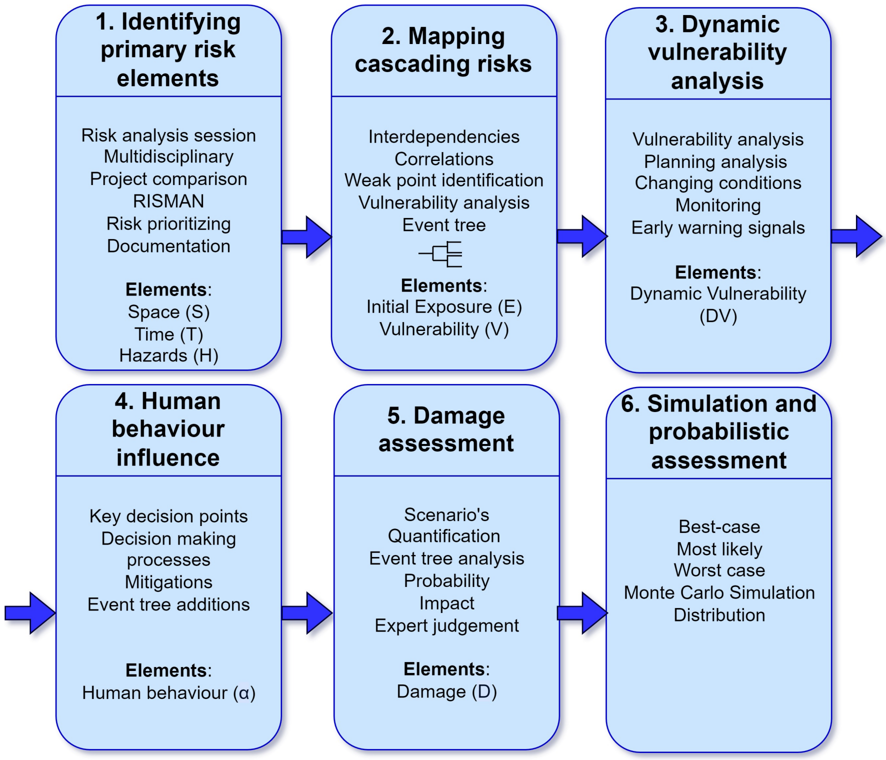

Figure 2: Overview new method

1. *Identification of primary risk factors:* In the first step, a risk analysis session is used to establish a list of potential risks. This risk analysis session focuses on identifying risks with second-order effects using the RISMAN method. This risk analysis session is carried out multidisciplinary and considers similar completed projects. These sessions are extensively documented to build a database. Elements S (specific project location and surrounding areas), T (project timeline) and H (risk file) are captured in this step.
2. *Cascading risk mapping:* In this step, dependencies and correlations between risks and second-order effects are clearly presented through an event tree. In this step, elements E (weaknesses of the project) and V (sensitivity of project components) should be considered.
3. *Dynamic vulnerability analysis:* Assess how vulnerabilities of project components may be evaluated during a project. Update these vulnerabilities continuously based on real-time data and early warning signals as indicators of emerging problems. These dynamic sensitivities are used to define element DV.
4. *Influence human behaviour:* Key decision points (element α) are indicated in this step, where the decision-making process should be extensively documented. Mitigation plans for negative impacts can be added in this step.
5. *Damage assessment:* After the entire event tree has been drawn up with all elements incorporated, the impact can be expressed in time and money (Element D). Based on historical data and expert assessments, all branches of the event tree will be quantified with probabilities and consequences. This will include best case, worst case and most likely value.

6. *Simulation and probabilistic assessment:* In the final step, a Monte Carlo Simulation is performed. After running 10,000 iterations, a distribution of different total costs and project duration can be obtained at different probabilities of success.

After establishing the new method, sub-research question 4 can be answered:

How should the 'Standaard Systematiek voor Kostenramingen 2018' be adjusted to improve incorporation of second-order effects of risks?

Using the new method, the identification of risks is likely to be more complete and second-order effects of risks will be more clearly identified. In the SSK-2018, object-specific or non-object-specific risks should be clearly described and substantiated so that cost experts and project managers know exactly what has been estimated. This description will include the second-order effects of risks where reference can be made to the arms of the event tree. The non-object-specific risk contingency can most likely be adjusted downwards as more risks with second-order effects will be identified in this way in the risk dossier. However, this remains to be seen from upcoming tests and practical examples.

As validation, the new method was assessed by an expert panel according to a prepared assessment form. The expert panel indicated that the new method may be of higher quality and clarity because it contains a structured approach, which is important for acceptance and application to real projects. The new method improves accuracy in risk identification, quantification, and clarity on second-order effects, making it more understandable and practical for clients. However, the method also seems to have drawbacks. According to the expert panel, the new method will likely take more time to implement and apply. Also, due to the complexity of the method, training needs to be given to experts to retrain them, which will cost time and money.

Further research should show how more accurate cost estimates are with the new method than with the current method. It should also measure exactly how much time both methods cost in using them. This follow-up research could subsequently be used to make a trade-off between the new and current methods.

Samenvatting

Kostenoverschrijdingen en vertragingen vormen, ondanks vele pogingen om dit te verbeteren, nog steeds een probleem in grote constructie- en infrastructuur projecten. Men spreekt van een kostenoverschrijding als de uiteindelijke kosten van een project hoger uitvallen dan initieel geschat en afgesproken is met de opdrachtgever. Een vertraging van een project is een overschrijding van de tijd die initieel is geschat en is afgesproken met de opdrachtgever. De grootste bijdragers hieraan zijn complexiteit van projecten, optimisme vooroordeel en strategische misrepresentatie, scopewijzigingen, matige project management, onzekerheid en risico en inadequate reserveplannen. Vanuit de ontwerpfase blijkt het vrij complex om een nauwkeurige kostenraming en planning te maken omdat projecten te maken hebben met risico's met tweede-orde effecten. Tweede-orde effecten zijn, in tegenstelling tot eerste-orde effecten die beschreven worden als het directe gevolg van een optredend risico, het indirecte gevolg dat het project ontregelt.

In Figure 3 wordt een voorbeeld gegeven van een scopewijziging aan een project. Het directe gevolg is dat het ontwerp gewijzigd moet worden waar kosten aan verbonden zitten. Wat vaak slecht in te schatten is zijn de tweede-orde effecten die deze ontwerpwijziging met zich meebrengen zoals het aanvragen van nieuwe vergunningen of het maken van nieuwe berekeningen. Deze kunnen weer voor vertragingen zorgen die weer van invloed zijn op andere projectactiviteiten. Het hele project raakt hierdoor ontregeld wat leidt tot nog meer kosten en vertragingen.

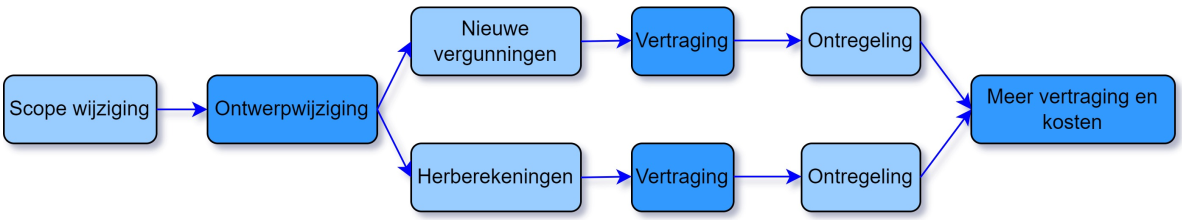

Figure 3: Voorbeeld optreden tweede-orde effecten

Huidige projectmanagementmethodes komen te kort bij het identificeren en kwantificeren van tweede-orde effecten van risico's in de constructie- en infrastructuursector. Het doel van dit onderzoek is daarom om projectmanagers bewust te maken van tweede-orde effecten van risico's, de oorzaken en gevolgen ervan vast te stellen en advies te geven over hoe ze beter geïdentificeerd en gekwantificeerd kunnen worden. Hierbij wordt er een verbeterde methode ontwikkeld voor het schatten van risico's met tweede-orde effecten. Dit zal gedaan worden aan de hand van de Double Diamond ontwerpprocesmodel die bestaat uit vier fasen. In de eerste fase wordt er in de literatuur gekeken naar tweede-orde effecten van risico's en interviews met experts in het vakgebied afgenomen om tweede-orde effecten zo goed mogelijk in beeld te brengen. In de tweede fase wordt alle verzamelde data geanalyseerd. Zo wordt er een conclusie van de literatuurreview geschreven en worden de interviews getranscribeerd en gecodeerd om hieruit resultaten te verkrijgen. Ook wordt er in deze fase een programma van eisen opgesteld waaraan de nieuwe methode moet voldoen om een verbetering te zijn. Deze methode wordt in de derde fase ontwikkeld om het vervolgens in de vierde fase op te leveren en te laten beoordelen door deskundigen in een expert panel. Dit onderzoek zal door dit proces het doorlopen antwoord geven op de onderzoeksvraag:

Hoe kunnen constructie- en infrastructuurprojectmanagers op een effectieve manier de impact identificeren en kwantificeren van tweede-orde-effecten van risico's op kostenramingen en projectplanning tijdens de ontwerpfase van het project?

Met behulp van de literatuur is er een begrip opgesteld voor het eerste-orde effect en het tweede-orde effect van een risico. Vervolgens is er aan interviewrespondenten gevraagd om deze opgestelde begrippen tijdens de interviews te beoordelen, verbeteren en aanvullen. Hiermee wordt sub-onderzoeksvraag 1 beantwoord:

Wat zijn tweede-orde effecten van risico's?

Eerste orde effecten van risico's zijn de directe en voorzienbare gevolgen van een risico in een constructie- of infrastructuurproject die kenbaar worden gemaakt in een risicoanalysesessie. Vaak worden er preventieve of corrigerende maatregelen genomen om de waarschijnlijkheid of impact van deze risico's te verminderen. Risico-effecten van eerste orde zijn eenvoudige gevolgen die kwantificeerbaar zijn en direct kunnen worden gekoppeld aan een oorzaak, mogelijk leidend tot een toename in kosten of vertraging.

Tweede-orde effecten van risico's zijn de indirecte effecten die volgen uit het initiële risico of die voortkomen uit een corrigerende of preventieve maatregel. Deze effecten kunnen significanter zijn en mogelijk de oorspronkelijke impact vermenigvuldigen met een veelvoud. Ze kunnen van invloed zijn op projectactiviteiten die niet direct werden beïnvloed, waardoor deze activiteiten duurder worden of vertraging oplopen door verstoringen. Effecten van de tweede orde zijn randeffecten, rimpeleffecten, kettingeffecten, cumulatieve effecten, verstorende effecten en cascade-effecten die de dynamiek van planningen en kostenramingen van een project op een samengestelde manier kunnen beïnvloeden.

Vanuit interviews met kostendeskundigen, projectmanagers en risicomanagers van verschillende aannemers aanvullend met de literatuurstudie kan sub-onderzoeksvraag 2 worden beantwoord:

Hoe wordt er momenteel omgegaan met tweede-orde effecten van risico's?.

Momenteel worden risico's tijdens een risicoanalysesessie geïdentificeerd volgens de RISMAN methode. Vervolgens wordt er een waarschijnlijkheid en impact gekoppeld aan de geïdentificeerde risico's door middel van bandbreedtes met pessimistische en optimistische waarden. In kostenramingen wordt er een geldbedrag gekoppeld aan de risico's en in planningen een tijdsduur. Daarna wordt er een Monte Carlo Simulatie uitgevoerd op de planning en raming waaruit er een totale projectduur of projectkosten verkregen kan worden bij een verdeling van de waarschijnlijkheid. Ten slotte worden, op basis van een deskundigenoordeel, zowel een extra reservering in de kostenraming (ook wel de niet benoemde object overstijgende risicoreservering genoemd) als buffers in de planning toegevoegd. Hoewel deze reservering op verschillende wiskundige en probabilistische manieren berekend kan worden blijkt dit in de praktijk niet te gebeuren. Respondenten van interviews waren bekend met tweede-orde effecten van risico's maar bleken het niet unaniem eens te zijn over op welke plaats in de Standaard Systematiek voor Kostenramingen 2018 deze begroot zouden moeten worden. Zo gaven ze verschillende antwoorden:

- Directe kosten nader te detailleren
- Object-gebonden risico's
- Object-overstijgende risico's
- Object-overstijgende risicoreservering
- Geen specifieke plaats, er wordt geen rekening gehouden met tweede-orde effecten

Wat ook naar voren kwam tijdens de interviews is dat aannemers soms wat scherpere prijzen aanbieden in een raming vergeleken consultants. Dit heeft te maken met dat de aannemer rekening moet houden met de markt. Dat wil zeggen dat de aannemer soms scherpere prijzen moet aanbieden in een raming dan dat realistisch is om zo projecten voor zich te kunnen winnen. De consultant, die een onafhankelijke positie heeft, zal altijd proberen het beste advies te geven en de raming zo realistisch mogelijk maken. Verder blijken opdrachtgevers complexe wiskundige modellen voor het berekenen van de niet benoemde object overstijgende risicoreservering en het correleren van risico's niet te eisen omdat zij zelf deze methodes niet goed begrijpen, zoals aan werd gegeven tijdens interviews.

Om beter inzicht te krijgen in de oorzaken en gevolgen van tweede-orde effecten is er tijdens de interviews met kostendeskundigen, projectmanagers en risicomanagers gevraagd naar voorbeelden van het optreden van risico's met tweede-orde effecten in de praktijk. Alle voorbeelden zijn vervolgens verzameld en gecategoriseerd, en verwerkt tot categorieën van oorzaken of gevolgen. Zo kan er antwoord worden gegeven op sub-onderzoeksvraag 3:

Wat zijn de oorzaken en gevolgen van tweede-orde effecten van risico's?.

De oorzaken zijn gecategoriseerd tot onverwachte grondcondities, Black Swans, ontwerpwijzigingen, ongelukken, misrekeningen en langzame procedures. De gevolgen zijn gecategoriseerd tot nieuwe onderzoeken, ontwerpwijzigingen, herberekeningen, materiaal (prijs) wijzigingen, verstoringen, schade herstel, schaarste van machines en personeel, seizoensgebonden activiteiten en nieuwe regelgevingen.

Doormiddel van de literatuurstudie en de afgenomen interviews is duidelijk geworden waar de uitdagingen liggen omtrent het identificeren en kwantificeren van risico's met tweede-orde effecten. Deze zijn vertaald naar een programma van eisen waar een nieuw opgestelde methode aan moet voldoen om een verbetering te zijn ten opzichte van de huidige methode. Dit programma van eisen bestaat uit het integreren van tweede-orde effecten van risico's, het regelmatig updaten van de kosten en de planning, het uitvoeren van een multidisciplinaire risicoanalysesessie, het beter te begrijpen zijn voor de opdrachtgever en het besparen van tijd.

De ontwikkelde methode is gebaseerd op de theorie van cascade-effecten van Zuccaro die normaalgesproken wordt toegepast in de natuurrampen sector. Deze is omgeschreven om in de constructie- en infrastructuursector van toepassing te kunnen zijn. De methode bestaat uit Equation 2 die in zes stappen doorlopen wordt, zoals te zien is in Figure 4:

$$D(s,t) = H \times E \times V \times \alpha \tag{2}$$

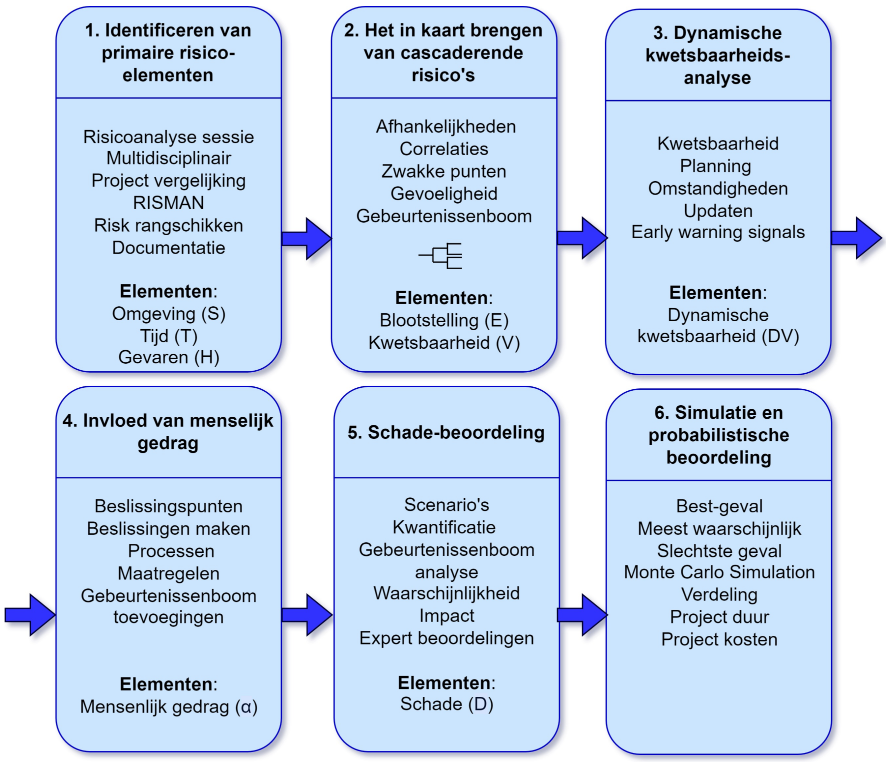

Figure 4: Overzicht nieuwe methode

1. *Identificatie van primaire risicofactoren:* In de eerste stap wordt met behulp van een risicoanalysesessie een lijst met mogelijke risico's opgesteld. In deze risicoanalysesessie ligt de nadruk op het identificeren van tweede-orde effecten waarbij de RISMAN methode wordt gebruikt. Deze risicoanalysesessie wordt multidisciplinair uitgevoerd waarbij er ook gekeken wordt naar vergelijkbare afgeronde projecten. Deze sessies worden uitgebreid gedocumenteerd om een database

op te bouwen. De elementen S (specifieke projectlocatie en omliggende gebieden), T (projecttijdlijn) en H (risicodossier) worden in kaart gebracht in deze stap.

2. *Cascaderende risico's in kaart brengen:* In deze stap worden afhankelijkheden en correlaties tussen risico's en tweede-orde effecten overzichtelijk weergegeven doormiddel van een gebeurtenissenboom. In deze stap moet er gekeken worden naar element E (zwakke punten van het project) en V (gevoeligheid van projectonderdelen).
3. *Dynamische kwetsbaarheidsanalyse:* Beoordeel hoe gevoeligheden van projectonderdelen zich kunnen evalueren tijdens een project. Update deze kwetsbaarheden voortdurend op basis van real-time data en early warning signals als indicatoren voor opkomende problemen. Met deze dynamische gevoeligheden wordt element DV gedefinieerd.
4. *Invloed menselijk gedrag:* Belangrijke beslispunten (element α) worden aangeduid in deze stap waarbij het besluitvormingsproces uitgebreid gedocumenteerd moet worden. Mitigatieplannen voor negatieve gevolgen kunnen in deze stap worden toegevoegd.
5. *Schadebeoordeling:* Na dat de gehele gebeurtenissenboom is uitgewerkt met alle elementen erin verwerkt kan de impact in tijd en geld worden uitgedrukt (Element D). Op basis van historische data en expertbeoordelingen zullen alle takken van de gebeurtenissenboom gekwantificeerd worden met kansen en gevolgen. Hierin zal het beste geval, slechtste geval en meest waarschijnlijke waarde worden opgenomen.
6. *Simulatie en probabilistische beoordeling:* In de laatste stap wordt er een Monte Carlo Simulatie uitgevoerd. Na het runnen van 10.000 iteraties kan er een distributie van verschillende totaalkosten en totale duur van het project verkregen worden bij verschillende waarschijnlijkheden van slagen.

Na het opstellen van de nieuwe methode kan sub-onderzoeksvraag 4 worden beantwoord:

How should the 'Standaard Systematiek voor Kostenramingen 2018' be adjusted to improve in- corporation of second-order effects of risks?

Door gebruik te maken van de nieuwe methode wordt het identificeren van risico's waarschijnlijk vollediger en worden tweede-orde-effecten van risico's duidelijk in kaart gebracht. In de SSK-2018 moeten de object gebonden of object overstijgende risico's duidelijk omschreven en onderbouwd worden zodat kostendeskundigen en project managers precies weten wat er geraamd is. In deze omschrijving zullen dan ook de tweede-orde effecten van risico's genoemd worden waarbij er verwezen kan worden naar takken van de gebeurtenissenboom. De niet benoemde object-overstijgende risicoreservering kan hoogstwaarschijnlijk naar beneden worden bijgesteld aangezien meer risico's met tweede-orde effecten op deze manier benoemd zullen worden in het risico dossier. Echter moet dit nog blijken uit komende testen en praktijkvoorbeelden.

Als validatie is de nieuwe methode beoordeeld door een expert panel volgens een opgesteld beoordelingsformulier. Het expert panel geeft aan dat de nieuwe methode van hogere kwaliteit en duidelijkheid kan zijn omdat het een gestructureerde methode bevat wat belangrijk is voor de acceptatie en toepassing op reële projecten. de nieuwe methode verbeterd de nauwkeurigheid bij risico identificatie en kwantificatie en de duidelijkheid over tweede-orde effecten, wat het begrijpelijker en praktischer maakt voor opdrachtgevers. Echter lijkt de methode ook nadelen te bevatten. Volgens het expert panel gaat de nieuwe methode waarschijnlijk meer tijd kosten door het implementeren en het toepassen ervan. Ook moet er door de complexiteit van de methode trainingen gegeven worden aan experts om deze bij te scholen, wat tijd en geld gaat kosten.

Verder onderzoek moet uitwijzen hoe nauwkeuriger kostenramingen worden met de nieuwe methode vergeleken met het huidige methode. Ook moet precies gemeten worden hoeveel tijd beide methodes kosten in het gebruik ervan. Dit vervolgonderzoek zou vervolgens gebruikt kunnen worden om een afweging te maken tussen het gebruik van de nieuwe methode en het huidige.

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Nomenclature

Abbreviations

Abbreviation	Definition
AHP	Analytical Hierarchy Process
CIF	Cost, Insurance and Freight
CPM	Critical Path Method
DDP	Delivery Duty Paid
FOB	Free On Board
FOSM	First-Order Second-Moment
L-Value	Lowest Value
P&G	Preliminary and General
PDF	Probability Distribution Functions
PERT	Program Evaluation and Review Technique
PMC	Product-Market Combination
RCF	Reference Class Forecasting
SSK-2018	Standaardsystematiek voor Kostenramingen 2018
T-Value	Top-Value
WBS	Work Breakdown Structure

1
Introduction

The success of a construction project depends on multiple factors. Many studies have examined the success factors of construction projects in which two factors are not missing from any study, namely time and money (Silva et al., 2016). Although time and money are found to be the two most important success criteria, it is still common for projects to go over budget and exceed schedule. Only 8% of construction projects manage to complete the project within the specified time frame, while 9 out of 10 construction projects face budget overruns. This gives a combined total of 98% of large construction projects to overrun in costs or face delays (Morad, 2023).

Major contributors to budget overruns and delays arise from the earlier project phases where poor methods of cost estimation and poor project scheduling and planning are high up in the list (Larsen et al., 2016) (Xie et al., 2022) (Enshassi et al., 2009) (Odeh & Battaineh, 2002)(Arditi et al., 1985) (Frimpong et al., 2003) (Daoud et al., 2023). Cost estimation and project planning in early project phases are challenging because of:

- *Lack of information:* The earlier in the project the cost estimation and planning is made, the less information is available. Less information makes it more difficult to estimate and schedule (Castro Miranda et al., 2022) accurately.
- *Uncertainty and risks:* In the earlier project phases, many things are still uncertain. This makes it difficult to give an accurate cost estimate. A form of uncertainty is risks. Risk comes in different forms in the construction industry. They prove difficult to assess and are a major problem while estimating costs and planning a project in the construction industry. (Ojo & Odediran, 2015)

When estimating risks related to time and money, a major challenge lies in fully quantifying the risk. Current estimating techniques and planning methods consider risk a stand-alone activity where a given probability of an event may result in more money or time. However, risks are much more complex than a stand-alone activity. The occurrence of a risk can result in certain activities coming to a standstill, with all its costs and delays involved. Also, a risk can trigger another risk, possibly bringing other costs and delays, such as second-order effects. These second-order effects of risks can be explained with an example from a conducted interview:

> *"A project manager estimated the cost of a pump at €100.000. This concerned only the purchase value. It later turned out that that pump had to be transported to an offshore platform and then installed. The total cost came to nearly a million"*

This research will attempt to better define, understand, identify, and quantify these second-order effects of risks, which will improve cost estimation techniques and planning methods.

2
Problem Definition

This chapter presents the problem definition. First, a problem statement is expressed, followed by the relevance for practice and science alongside the research gap. After this, the scope is explained, and the research questions are presented.

2.1. Problem Statement

It was clear from the introduction that projects in the construction and infrastructure sector continue to overrun the budget and are often delayed. It also became clear that contributing factors such as estimating costs or planning mostly arise at the earlier project stages. These include factors such as low experience in the design team, inadequate methods of cost estimate and deficient project scheduling and planning, highlighted in many studies (Daoud et al., 2023) (Larsen et al., 2016) (Xie et al., 2022) (Enshassi et al., 2009) (Odeh & Battaineh, 2002) (Arditi et al., 1985) (Frimpong et al., 2003). Uncertainties, risks and lack of information are factors that make an accurate cost estimate and project planning in the design phase challenging (Torp & Klakegg, 2016) (Castro Miranda et al., 2022) (Ojo & Odediran, 2015). One of the challenges regarding estimating risks under uncertainty is that second-order effects might occur. This means that besides the direct impact of an occurred risk, an indirect impact may also arise, triggering another risk event (Abdel-Monem et al., 2022). This can create a ripple or cascading effect, which will be further explained in section 4.3. From this, the following problem statement emerges:

"Despite many attempts to carefully include risk in cost estimates and project planning, the construction and infrastructure industry still faces cost (over/under) estimates and delays, resulting partly from failing to identify and quantify second-order effects of risk carefully. Second-order effects from risk events can trigger unforeseen costs and disrupt the overall project timeline, ultimately impacting project success."

2.2. Relevance

This section looks for knowledge gaps in practice and science to support the relevance of this research. First, the practical relevance will be explained using exploratory interviews with sector experts. Second, the scientific relevance will be determined based on literature highlighting the knowledge gaps.

2.2.1. Practical relevance

In project and budget planning, estimating risks is crucial and challenging. This involves identifying risks through analysis and considering their likelihood and potential impacts. However, not all consequences can be directly quantified in monetary terms, such as the delays and operational disruptions caused by unforeseen events. The literature describes these as first/second-order, cascading, ripple, or knock-on effects, among other terms. To account for such uncertainties, a non-object-specific risk contingency, typically 5-10% of baseline costs, is added to budgets using methodologies like 'Standaard Systematiek voor Kostenramingen 2018' (SSK-2018). However, this percentage, often based on the estimator's experience and intuition, may not accurately cover the significant additional costs that some risks can bring (Expert of Witteveen+Bos, Personal Communication, December 15, 2023) (Expert of Witteveen+Bos, Personal Communication, February 9, 2024).

2.2.2. Scientific relevance

In risk management, understanding and mitigating the primary effects of risks is often a straightforward process. However, the complexity arises when managing second-order effects, the indirect impacts that arise from the primary impact. These secondary effects are often less predictable and can impact a project differently, leading to unforeseen problems. In a project environment, for example, a primary risk may delay the project's timetable. At the same time, second-order effects may include increased costs, reduced team morale and even reputation damage to the organisation (Cooper & Lee, 2009) (Nasirzadeh et al., 2008) (Hassan & Peco, 2021) (Hanna et al., 1999). Since there are so many challenges in estimating second-order effects of risks, it is helpful to do more research on this to improve understanding of their dynamics and impact.

2.3. Scope

This research focuses on the risk estimations in the design phase of large construction and infrastructure projects in the Netherlands, where cost estimates of risks and project planning are critical components of project success. An overview of all project phases can be found in Figure 2.1. The scope of this study further focuses on projects where the SSK-2018 calculation method has been or will be applied.

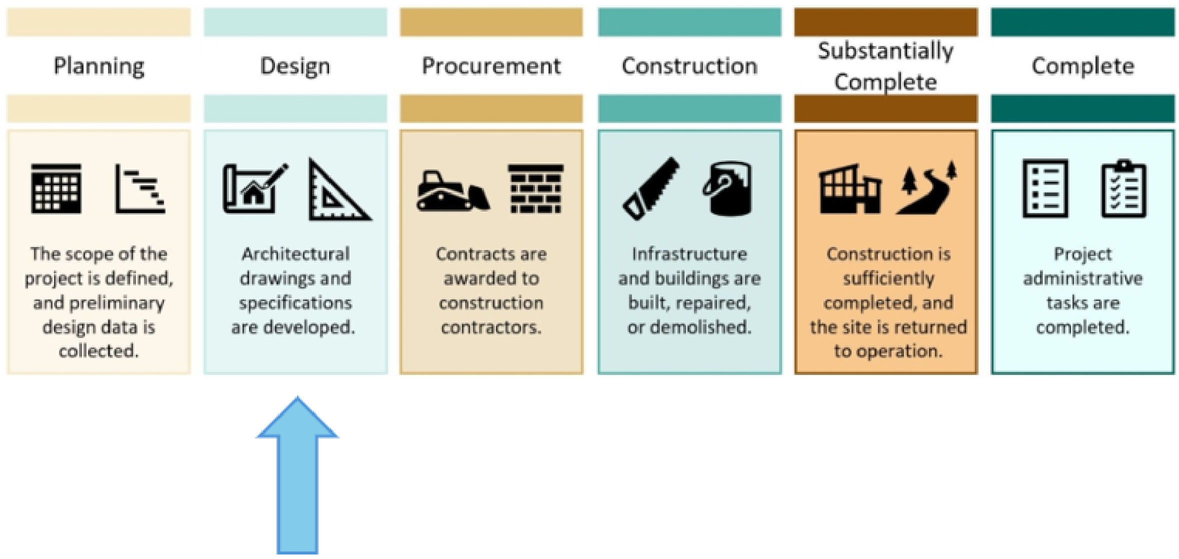

Figure 2.1: Project phases of construction and infrastructure projects ("Projects in action", 2023)

In addition, only projects where the UAV-gc contract form has been used are considered as this contract form is best aligned with the SSK-2018 (CROW, 2018). Concerning risks, this research will focus on both known and unknown risks. Besides, an event can have different effects. For example, there are time-related, cost-related, productivity-related and other related effects (Sun & Meng, 2009). This study focuses on effects related to time and money. Lastly, liability has been excluded from this study because the focus is on the problem's technical aspects, and the problem's legal aspect is less well suited to the author's knowledge.

2.4. Research questions

The main research question that will be answered in this research reads as follows:

How can construction and infrastructure project managers effectively identify and assess *the impact of second-order effects of risks on cost estimates and project planning during the design phase?*

This main research question will be answered by using the following sub-questions:

1. *What are the second-order effects of risks?*
2. *How are second-order effects of risks currently dealt with?*
3. *What are the causes and consequences of second-order effects of risks?*
4. *How should the 'Standaard Systematiek voor Kostenramingen 2018' be adjusted to improve incorporation of second-order effects of risks?*

2.5. Research goal

This study aims to reduce over-/underestimates and delays in construction and infrastructure projects. This will be done by focusing on improving cost and planning estimates of risks with second-order effects. To achieve this, the second-order effects of risk will be studied more closely by conducting interviews and developing a new method to improve their identification and quantification, which can be used to complement or adjust current methods.

3
Methodology

The British Design Council emphasises design as a process that leads to creating solutions with functional, aesthetic, and emotional values. It's significant to code the design process to make it visible and tangible. The Double Diamond model represents this codified process. This model is structured around four phases: Discover, Define, Develop, and Deliver (Kochanowska & Gagliardi, 2022). This chapter starts by explaining the Discover phase, where a great understanding of user needs is studied, followed by the Define phase, where the challenge found in the Discover phase is defined. After that, the Develop phase focuses on generating and testing potential solutions. Lastly, the solution is refined and tuned for implementation in the Deliver phase. In Figure 3.1, the schematic representations of the Double Diamond Design method can be found. An overview of the methodology can be seen in Figure 3.2.

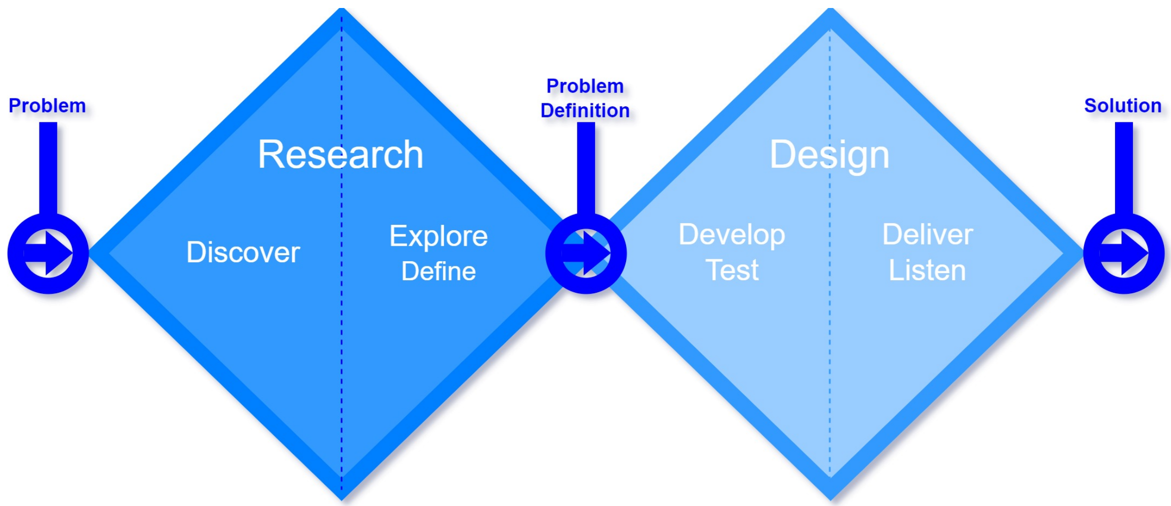

Figure 3.1: The Double Diamond design process model (Ayre, 2023)

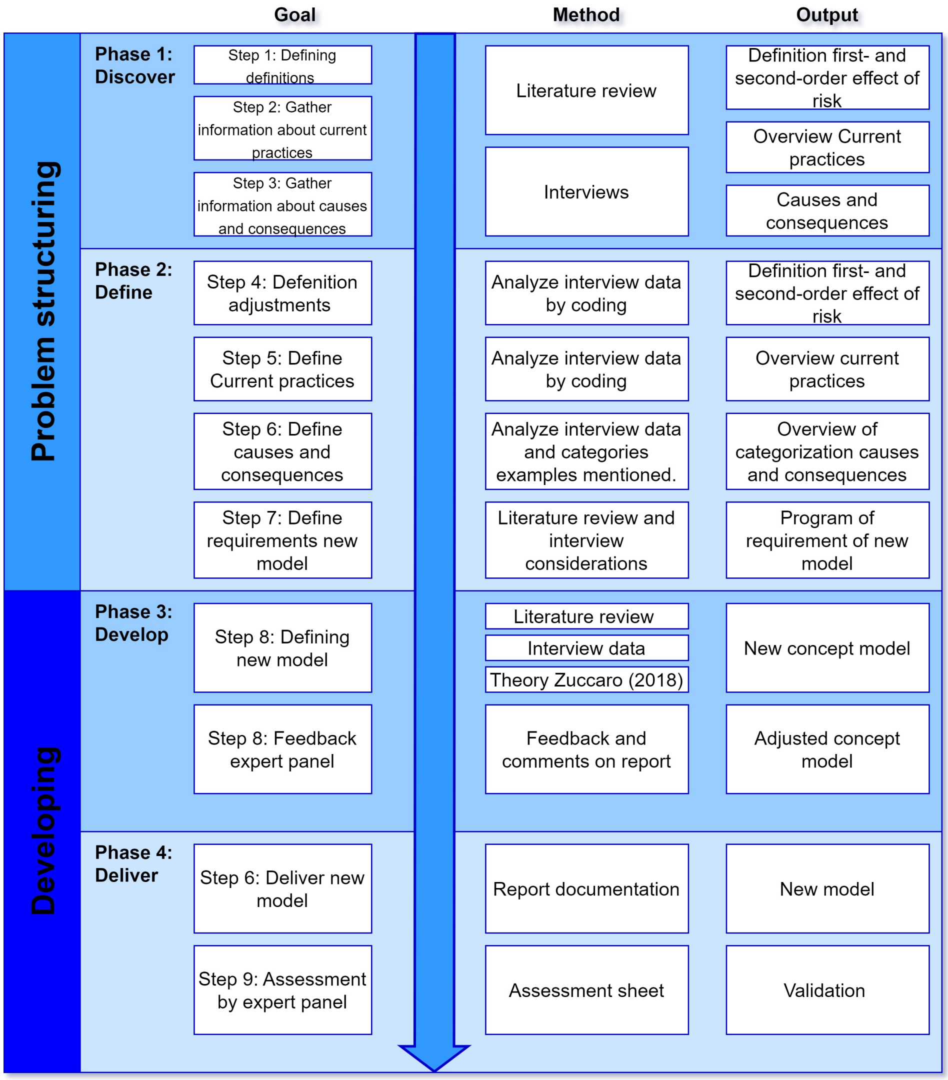

Figure 3.2: Methodology overview

3.1. Discover

The Discover phase identifies and quantifies the second-order effects of risks in construction- and infrastructure projects. This involves an extensive literature review and semi-structured interviews. The diagram's lines of Figure 3.1 spread out and broaden, representing a receptiveness to data and creativity. This research aims to improve the identification and estimate of the second-order effects of risks in the design phase. This is done by improving the understanding of the second-order effects of risks.

The baseline knowledge for this research topic is provided during the literature review. In addition, the literature review should theoretically answer sub-question 1: *What are the second-order effects of risks?* To achieve this, the following topics are thoroughly examined using existing literature:

- Budget overruns and delays
- Cost estimate and project planning
- Risk management
- First and second-order risks effects
- Contingency reserve

In addition to the literature review, 10 interviews are conducted. To go into depth during an interview, a semi-structured interview is chosen. The advantages of a semi-structured interview are as follows:

- In addition to verbal responses, non-verbal answers such as gestures and facial expressions can also become apparent during an interview (Kakilla, 2021).
- Although the respondent is free to answer the questions, the interviewer can still steer the interview by asking different questions on different topics (Kakilla, 2021).

Other possible interview strategies are less suitable. Unstructured interviews are not useful in this situation because of the need to find answers to certain topics and questions. In addition, structured interviews are also unsuitable because it's recommended to give the interviewee space to tell a bit more than just the answer to the question to get a better overview of the topics.

The consultancy & Engineering firm Witteveen+Bos is divided into product-market combinations (PMC) (Witteveen+Bos, 2023). This means that within the company, different groups of people perform a particular service (Scribbr, 2023). So, the company has several PMCs, of which an overview is shown in Figure A.5. The topic of second-order effects of risks intersects with two groups of PMC Construction Management, namely Project Management and Cost Management. For this reason, three interviews are conducted with experts from the Cost Management group and two experts from the Project Management group. Three project managers of certain contractors are also interviewed to get better insights into the practical side of the topic. Lastly, an arbitrator will be interviewed because this job sees many arbitration cases pass by where second-order effects or risks are the issue.

The interview with the experts covers sub-questions 2: *How are second-order effects of risks currently dealt with?* and sub-question 3: *What are the causes and consequences of second-order effects of risks?*. Besides answering sub-questions 2 and 3, semi-structured interviews with experts provide better insight into the definition of second-order effects of risks, especially the practical side. This will allow sub-question 1 to be completed and refined. The interviews cover topics such as first- and second-order effects definitions, dealing with second-order effects, causes, and consequences. During the interviews, questions are asked to discover potential new topics. The topic list with sample questions for the interviews is shown in Appendix E.

3.2. Define

In the Define phase, all the data gathered is studied, and conclusions and findings are defined. This phase is about *'connecting the dots, spotting patterns, hunting for insight and understanding emotions'* (Kochanowska & Gagliardi, 2022). The diagram's lines, as can be seen in Figure 3.1, come together and intersect at a critical moment in the process. In this phase, interviews are analysed, and the data obtained from the literature review is processed to answer sub-questions 1, 2, and 3.

After the interviews were conducted, they were transcribed using the transcribe function in Microsoft Word. In Microsoft Word, audio can be recorded or uploaded, and the program generates a transcript. This transcript is checked based on the audio fragment. Errors in the transcript were removed. After all errors are removed, a clear transcript is generated that distinguishes between different speakers and time intervals.

Following this, the data is analysed through coding. There are different ways of coding: a top-down, deductive, theoretical process and a bottom-up, inductive, data-driven process (Swain, 2018). Deductive coding consists of a set of predetermined codes derived from the literature review and research questions that are tested in the interview data (Crabtree & Miller, 2023). With inductive coding, codes are actually created from the interview data (Strauss, 2017).

In this study, it is essential to see whether information from the literature is confirmed in the interviews. In addition, it is also interesting to be open to additional information to gain new insights possibly. Therefore, this study uses a hybrid method of inductive and deductive coding. This means highlighting all important information from the interview data to attach one of the following codes to it:

- Definition of first- and second-order effects of risks
- Dealing with second-order effects of risks

- Causes
- Consequences
- Additional information

New codes emerged from all the additional information codes, such as consultant vs contractor, culture change, and client requirements. These were tested in follow-up interviews. After all the interviews are coded, the analysis determines whether specific patterns are visible in the interviews and whether information is confirmed in multiple interviews. In this way, results are obtained, and sub-questions 1, 2, and 3 are answered. A comparison with the literature will be made as well. A list of important concepts and themes from the literature is compared with a list from the interviews. It examines why certain concepts and themes do or do not match the literature.

The Define phase ends with a program of requirements for a new method for approaching the problem defined in this phase. This program of requirements is prepared from the interview data complemented by the literature. It considers what is possible, what is desirable and what needs to be improved.

3.3. Develop

The Develop phase follows after the problem has been adequately identified and defined. In this phase, through inspiration and a better understanding of the problem from the previous phases by creativity complementary with inventing, experimenting, iterating and testing, a possible solution to the problem is found that potentially meets the user's needs (Kochanowska & Gagliardi, 2022). The diagram once more spreads out and expands, representing a readiness to generate a multitude of possible solutions, as can be seen in Figure 3.1

The literature shows that the method described by Zuccaro et al. (2018) has not yet been applied to the cascading effect of risks in construction projects, making it possible to gain new insights. This theory is incorporated in a new method to better identify and quantify risks with accompanying second-order effects, allowing sub-question 4 to be answered: *How should the 'Standaard Systematiek voor Kostenramingen 2018' be adjusted to incorporate second-order effects of risks in calculating contingency?* The theory by Zuccaro et al. (2018) is based on the Elementary Brick model, in which risk elements are analysed piece by piece to get a complete picture of the cascading effects, considering the interdependence and dynamic nature of risks.

Implementing this theory involves continuous assessments and advice by an expert panel. An expert panel is a group of experts who help make choices, actions, and recommendations based on their expertise and intuition- (of Sustainability & Environment, 2005). In this study, the expert panel consists of three experts from the company Witteveen+Bos. In the Develop phase, the expert panel can help with the following areas:

- *Applicability:* Making the theory by (Zuccaro et al., 2018) applicable to the construction and infrastructure sector.
- *Providing feedback:* Experts can continuously provide feedback to the method in the development phase to achieve the best result.
- *Validation:* Validation of certain assumptions and choices can be made by experts of the expert panel, ensuring realistic data will be used. In addition, the final method can be assessed by using an assessment sheet to determine if the method is usable or if some adjustments are needed before it is usable.

Expert assessments were chosen to validate the new method. A deliberate decision was made not to apply the new method to a case study where the project's before-and-after cost calculations are known. One reason is that clients are reluctant to share data on this.

3.4. Deliver

The Deliver phase involves further solution development and further testing through iterations. This phase results in a detailed description of the solution and a plan for its implementation (Kochanowska & Gagliardi, 2022). The diagram's lines in Figure 3.1 lines come together once more and intersect at the process's concluding point. The expert panel helps in this phase by initially assessing the new methodology. After that, the expert panel gives recommendations to improve the method. In this way, the expert panel validates the new method designed in this study. All experts on the expert panel complete an assessment form, which can be found in Appendix D. The experts assess the current risk identification and quantification methods for final comparison. The results will be presented in chapter 7.

4
Literature review

This literature review investigates the causes of cost overruns and delays in construction and infrastructure projects and defines the second-order effects of risks. It also considers how risks are calculated in cost estimates and project planning and how this can be improved.

4.1. Cost overruns and delays

This section analyses cost overruns and delays. It also discusses the contributors to these issues and explains burn rate and disruption.

4.1.1. Contributors

To understand budget overruns and delays due to risks in construction projects, it is first necessary to look at the literature in general and what is already known about them. A definition of cost overrun or budget overrun is given by Morad (2023): *"Cost overrun in construction refers to the situation where the actual costs incurred during a project exceed the initial budget or estimated costs agreed upon with the client."* (Morad, 2023)

Delay in construction and infrastructure projects is defined by Assaf and Al-Hejji (2006): *"The time overrun either beyond completion date specified in a contract, or beyond the date that the parties agreed upon for delivery of a project"* (Assaf & Al-Hejji, 2006)

Cost overruns and delays in construction and infrastructure projects are common globally (Flyvbjerg, Skamris Holm, & Buhl, 2003) (Flyvbjerg et al., 2004) (Cantarelli et al., 2012) (Cantarelli et al., 2013). Budget overruns are a worldwide phenomenon affecting different types of infrastructure projects. According to several studies, even nine out of ten large projects face budget overruns (Flyvbjerg, 2013). Railway projects face a 45% budget overrun on average, fixed-link projects have to deal with a 34% increase in costs and road projects experience 20% budget overruns on average (Flyvbjerg, Skamris Holm, & Buhl, 2003). Morad (2023) found that only 8% of construction projects meet the agreed deadline which means 92% of construction projects are delayed. This gives a combined total of 98% of the construction projects that are delayed or face cost overruns (Morad, 2023)

In addition, a distinguish can be made between different project types when it comes to budget overruns and delays:

- *Project size and complexity:* Larger projects face greater challenges regarding managing time and money as these projects deal with more complex operations. This can lead to an increased probability of budget overruns and scheduling delays (Daoud et al., 2023) (Atapattu et al., 2023).
- *Time constraints:* Projects with time pressure are crucial to project success. The pressure to meet deadlines can lead to rushed work and compromises in quality that cause further cost overruns and delays (Atapattu et al., 2023).

Several factors are mentioned to be responsible for these budget overruns and delays:

- *Complexity of projects:* Large-scale infrastructure projects are complex due to including several stakeholders, complicated designs and comprehensive timelines. This complexity makes it difficult to estimate costs accurately during the design phase, resulting potentially in cost overruns and delays (Flyvbjerg, Skamris Holm, & Buhl, 2003) (Flyvbjerg et al., 2018) (Bruzelius et al., 2002).
- *Optimism bias and strategic misrepresentation:* The literature shows that project managers tend to underestimate costs and overestimate benefits, which is called optimism bias or strategic misrepresentation (Flyvbjerg, Bruzelius, & Rothengatter, 2003) (Flyvbjerg, Skamris Holm, & Buhl, 2003) (Flyvbjerg et al., 2004) (Flyvbjerg, 2007) (Cantarelli et al., 2013) (Flyvbjerg, 2013) (Flyvbjerg et al., 2018) (Flyvbjerg, Bruzelius, & Rothengatter, 2003). Optimism bias and strategic misrepresentation can lead to underestimating time and costs, resulting in delays and budget overruns. This will affect project performance and the overall success of a project. Causes for these phenomena are incomplete information, overconfidence and deadline pressure (Chadee et al., 2021).
- *Scope creep:* Scope changes are modifications, additions or deletions to the original project scope defined at the start of the project. These can be initiated by several causes, such as stakeholder requests, changed project needs, external influences, and risk occurrences (Tariq et al., 2020). Changes in the scope of projects can lead to increased costs and delays when made during the execution phase of the project (Flyvbjerg et al., 2018) (Flyvbjerg, Bruzelius, & Rothengatter, 2003) (Flyvbjerg, Skamris Holm, & Buhl, 2003).
- *Poor project management:* Weaknesses in areas of project management and governance structures such as poor contract management and lack of accountability can result in challenges of cost estimates and project planning (Flyvbjerg, Skamris Holm, & Buhl, 2003) (Bruzelius et al., 2002).
- *Uncertainty and risk:* Uncertainty and risks contribute significantly to cost overruns and delays. Risks prove to be hard to estimate, especially when second-order effects, lock-in effects, disruption, ripple effects, cascading effects, cumulative impact or indirect impact must be included in estimating costs and planning (Flyvbjerg, Bruzelius, & Rothengatter, 2003) (Flyvbjerg, Skamris Holm, & Buhl, 2003) (Flyvbjerg, 2007) (Cantarelli & Flyvbjerg, 2013).
- *Inadequate contingency planning:* Contingency reserve seems not always that accurate. They are often estimated based on the experience and intuition of the cost estimator (Hoseini et al., 2020) (Flyvbjerg, Skamris Holm, & Buhl, 2003).

While cost overruns and delays are often seen as unfavourable, they can also have benefits. For example, cost overruns can be a cause of quality costs incurred. These are costs that improve the quality of the project outcome, which cannot necessarily be seen as something negative (Joemmanbaks et al., 2017). Under quality costs, one could understand different components such as improved sustainability, social value creation, economic stimulation and improved safety.

Much research has already been done in the literature on optimism bias and strategic misrepresentation, scope creep, project complexity, the benefits of cost overruns and delays, and poor project management. However, little is known about the phenomenon of second-order effects of risks on cost estimates and project planning, including contingency planning. Understanding these contributors to cost overruns and delays is crucial.

4.2. Cost estimate and project planning

This section provides a literature-based explanation of how a project's budget and schedule are established and which methodologies can be used to determine this. First, the budget, in general, will be explained before zooming in on the contingency reserve and management reserve.

4.2.1. Project costs

Burke (2013) found that the following components can be considered when estimating the cost of a project in the United Kingdom:

- Direct costs

- Indirect costs
- Labour costs
- Material and equipment costs
- Transport costs
- Preliminary and general (P&G) costs
- Project office costs
- Project team costs

Direct costs are costs directly linked to a specific project or activity, including management salaries, labour, materials and equipment. They also cover specific project services. Direct costs can be allocated to a project, making them easier to estimate, track and control. Indirect costs are not directly linked to specific projects but are necessary for company operations. These include salaries for senior management, sales, marketing, and administrative staff; wages for support services like maintenance and cleaning; and costs for office supplies, computers, and maintenance parts. Other indirect costs cover training, insurance, and facilities. To cover these costs, companies apply an extra charge to their services. Effective management of these costs is crucial to prevent profit loss (Burke, 2013).

The Critical Path Method (CPM) is created to address the cost due to changes in time. So, when a project is delayed, the question is, how will the cost change? To determine this, all the time-related costs should be considered, such as rent increases, employee labour rate increases, and productivity reductions. The labour rate is determined by summing various costs like salary, associated labour costs, overhead contributions, and profit margins divided by total working hours. Estimating potential costs, such as sick days or downtime, is essential to arrive at an accurate hourly labour rate. For overtime, the calculation simplifies the increased wage and contributions to variable costs and profit, assuming no lost time. However, client charges for overtime often reflect a higher multiplier of the employee's overtime pay (Burke, 2013).

Material and equipment costs, or procurement costs, are calculated by adding a percentage (commonly between 10% and 20%) to the purchase price. They are the costs that are made by necessary goods and services. Transport costs vary based on delivery terms between supplier and client. Ex-Works means the buyer handles all costs from the supplier's location. Free on Board (FOB) means the supplier loads the goods and covers export fees, but the buyer takes over once the goods are packed, paying for transport and import duties. Cost, Insurance and Freight (CIF) includes the supplier covering delivery and insurance to the destination, with the buyer handling import duties. Delivered Duty Paid (DDP) sees the supplier responsible for all costs and risks to the buyer's doorstep. Quoting beyond Ex-Works, like FOB or CIF, and even DDP, can make offers more appealing internationally, necessitating detailed cost analysis for accurate and competitive pricing. Project office costs, or project management fees, are often outlined in a distinct contract as part of the overall project budget. These also include various related costs that fluctuate throughout different project stages. The team might consist of part-time members, either contracted or borrowed from other departments. With a historical cost database, the project management fee can typically be estimated at 6% to 10% of the project's total value (Burke, 2013).

Specific costs known as P&G's are accounted for separately for construction projects requiring on-site work. These include setting up and dismantling the site, supervising, insurance, bonds, renting plants and equipment, providing site facilities like huts and toilets, ensuring security, supplying utilities, creating temporary roads and signage, scaffolding, lighting, worker accommodation, travel, training, materials handling, and waste removal. These costs should cover overhead and profit margins and care should be taken to avoid double counting expenses that might be covered by the client (Burke, 2013).

In Figure 4.1, it can be seen how the project budget is established. This consists of the management reserve and the baseline cost, which is further explained in subsection 4.2.4. The contingency reserves are further described in subsection 4.2.3, and the work package cost estimates comprise the baseline cost or control accounts. Work package cost estimates include the activity contingency reserve and activity cost estimates (Stackpole, 2013).

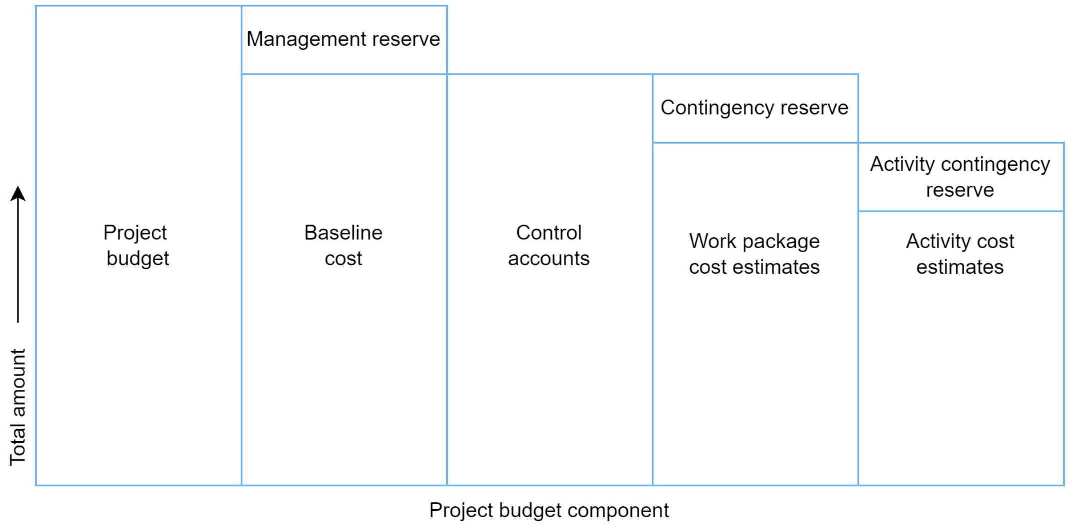

Figure 4.1: Project budget components (Stackpole, 2013)

Although Burke (2013) focused primarily on projects in the United Kingdom and Figure 4.1 comes from the book by Stackpole (2013) from the USA, there are some similarities but indeed some differences with the build-up of project costs in the Netherlands. An overview of how the project budget is structured according to the Standaardsystematiek voor Kostenramingen 2018, a Dutch project estimate method, can be found in Figure 4.2. An overview of this in Excel can be found in Appendix A, Figure A.6.

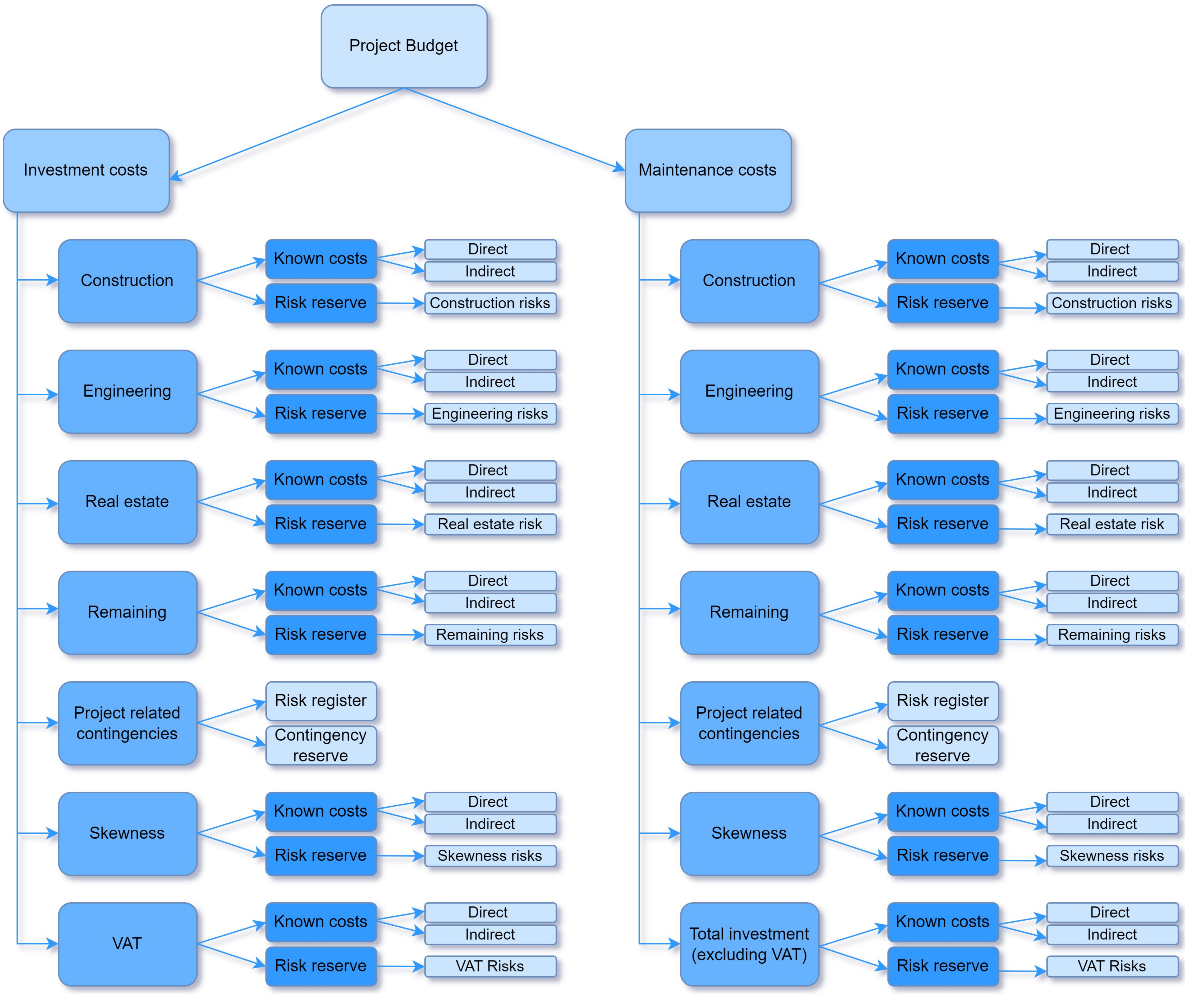

Figure 4.2: Project Budget based on SSK-2018 (CROW, 2018)

The budget overview separates investment costs and maintenance costs. Investment costs represent the cost of an object or activity, while maintenance costs represent the cost of maintaining those objects or activities. Both components are divided into so-called cost categories and cost groups. The cost categories are the object costs of construction, engineering, real estate, remaining, project-related contingencies, skewness, and VAT costs. The cost groups after that divide the cost categories into known costs, consisting of direct and indirect costs and risk reserves (CROW, 2018).

Construction costs include the costs of physically realising the objects in this category. These construction costs may include man-hours, equipment, material, rental, and subcontractor costs. *Engineering costs* refer to the 'brain-work costs' in engineering related to organisation, environment, legal and economics. The acquisition and use of land on which real estate is constructed are called *real estate costs*. This includes costs such as site preparation and preconditioning of projects. The *remaining costs* include those that do not belong to any of the above categories. This may, for example, be the moving of cables and compensation for loss unrelated to real estate. The *project-related contingencies* consist of known risks resulting from a risk analysis and unknown risks. Known risks are calculated with probability times impact, while unknown risks are calculated with an additional percentage of the investment and maintenance costs, also called the contingency reserve. More about known and unknown risks can be found in subsection 4.3.2. *Skewness* is the difference between costs determined deterministically and those estimated probabilistic. Lastly, each cost item can be specified as a *VAT* percentage. If no VAT is charged, this box remains empty in the estimate (CROW, 2018).

4.2.2. SSK-2018

A commonly used method for producing cost estimates in the Netherlands is the Standaardsystematiek voor Kostenramingen 2018 (SSK-2018). The method is designed for the civil engineering sector in its full breadth, i.e. above-ground and underground work. The SSK-2018 ensures reasonable cost control within project engineering, contains a format for preparing cost estimates in a standard manner every time, has a guide for dealing with risks and includes an option for providing concrete substantiation for estimates (CROW, 2018). Using systems engineering, cost estimates are generated following Figure 4.3.

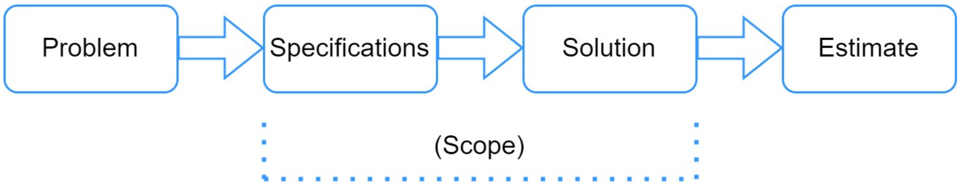

Figure 4.3: Systems Engineering and cost estimates (CROW, 2018)

According to the SSK-2018, after the solution is prepared, it will be divided into objects to create a clear object tree. An object is defined as '*an object assembled from materials and parts into a whole*'. Costs can then be attached to all objects, as can be seen in Figure 4.2. A somewhat more difficult part of the estimate process is estimating risks. The first step is to identify as completely as possible all risks that could occur in a project. This will be done using the RISMAN method, which is further explained in subsection 4.3.1. After applying this method, an overview of all known risks will be obtained. In the SSK-2018, there are three places to estimate risks: object-specific, non-object-specific, and non-object-specific risk contingency. The total risk reserve can be obtained by adding these three cost items together. After linking the risks to the (non-) objects, the risks can be calculated in a deterministic way using the following formula based on expert judgement (CROW, 2018):

$$Risk = Probability \times impact$$

In the SSK-2018, an example is provided to explain this: In a cost estimate, the probability of 'unexpected archaeological finding' is 5% with an impact of €200.000, the risk will be calculated as follows (CROW, 2018):

$$Risk = 5\% \times €200.000 = €10.000$$

Nevertheless, this method of estimating risks does not seem to be able to estimate the possible entire impact correctly. By calculating the probability times impact, only a part of the risk event is included in the estimate. Second-order risk events, as defined in section 4.3, can also cause high costs in the cost estimate. This underestimation of costs can be well explained through an example:

> *"Transporting tunnel elements across the sea is critical to constructing an underwater tunnel. The primary risk identified in such projects often revolves around the potential loss of a tunnel element during transit, leading to it sinking to the sea bottom. Traditional risk assessments might focus solely on the tangible loss, such as the cost of the concrete material. However, this approach overlooks significant secondary effects, such as project delays. These delays can arise from the time required to produce and transport a replacement element, which may have far-reaching consequences on the project timeline and overall costs, potentially exceeding the initial loss of the concrete itself. This example highlights the importance of considering both first and second-order impacts in risk estimates to ensure comprehensive project planning and management" (Expert of Witteveen+Bos, Personal Communication, February 29, 2024).*

So, it turns out it is impossible and too expensive to know and estimate all the risks. Nevertheless, it is known that there will be risks that are yet unknown. These so-called known-unknown risks will be further explained in subsection 4.3.2. This is considered in the SSK-2018 by reserving an additional percentage of work package cost estimates, as seen in Figure 4.1. This percentage, also called the contingency reserve, is based on the experience and intuition of the cost estimator (CROW, 2018). In addition to calculating this percentage deterministically, there are other methods to calculate this contingency reserve, presented graphically in Figure 4.4 of subsection 4.2.3.

4.2.3. Contingency reserve

In the reading of Mishra and Judson (2023), the following definition is established for the contingency reserve:

"A contingency reserve is a time or money allocated in the schedule or cost baseline for known risks with active response strategies"

So, the contingency reserve serves as a buffer to address unforeseen events or circumstances that may impact the project's execution. It is essential to ensure that project costs and execution planning remain realistic and adequate to handle unexpected cost increases or delays. It is an addition to the budget to better deal with risks and uncertainties and thus keep the project within budget. The value of this contingency reserve is based on a risk analysis and assessment of potential risks that could influence the project (Mishra & Judson, 2023). Multiple methods to determine the contingency reserve are divided into three categories: deterministic, probabilistic and modern mathematical (Bakhshi & Touran, 2014). An overview of these methods can be seen in Figure 4.4.

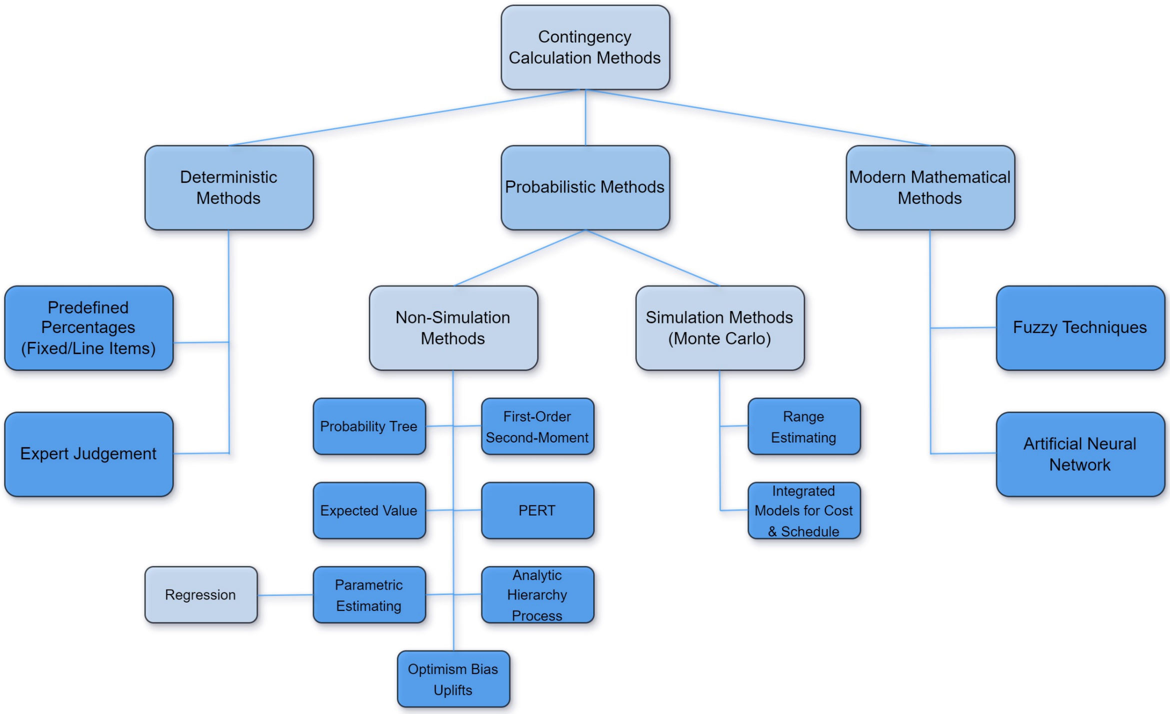

Figure 4.4: Contingency Calculation Methods (Bakhshi & Touran, 2014).

In earlier days, deterministic methods for calculating the contingency reserve have been used. The contingency reserve was established as a percentage of the baseline costs of a project based on intuition, experience, and historical data. This method is still the most commonly used but is difficult to reason about or defend (Baccarini, 2006). It is also one of the reasons why projects still go over budget (Hartman, 2000) since it appears to be not accurate enough. The two deterministic methods to determine the contingency reserve can be *predefined percentage*, meaning that it is a fixed number at particular companies, or *expert judgement*, meaning that the expert doing the cost estimate is allowed to prepare this percentage based on his intuition and experience (Bakhshi & Touran, 2014) (Hoseini et al., 2020). Expert judgement is one of the methods to establish the contingency reserve used in the

SSK-2018 (CROW, 2018). Using *historical data* to determine the contingency reserve needs final cost data from past projects to calculate the average cost overrun. This method uses historical project data to identify typical cost overruns and sets the contingency reserve accordingly. This data-driven method is more defensible and can provide more realistic outcomes when enough data is available. However, cost experts face the problem of this data not being sufficiently present. Clients often do not want to share the data of entire projects, making it difficult (Expert of Witteveen+Bos, Personal Communication, February 29, 2024).

In probabilistic methods, uncertainties are statistically incorporated into the contingency reserve. These methods give probability distribution functions (PDF) to cost components. Probabilistic methods can be divided into two categories: Simulation methods (Monte Carlo) and Non-Simulation Methods (Ammar et al., 2023). The first non-simulation method is the *probability tree*. This method provides an overview of risks and their associated impact by adding up those of all individual risks. The disadvantage of this method is that it is a lot of work and thus takes a lot of time to do when there are many risks involved in a project (Bakhshi & Touran, 2014). The second non-simulation method is *First-Order Second-Moment (FOSM)*, which calculates the standard deviation and mean of a function based on the first-order linear approximation (Bakhshi & Touran, 2014). Another one is the *Expected Value method* that calculates the risk by multiplying the probability and the impact of the risks established in the risk register. Multiple risks are added together by calculating the expected value for each individual risk and then summing these values. A disadvantage of this method is that positive risks may be missed (Ammar et al., 2023). To avoid an automatic increase in the contingency reserve due to the number of risks, it is important to consider dependencies and correlations between risks. This can be done by adjusting the probabilities for overlapping risks and using techniques like Monte Carlo simulations to account for combined risk effects. *The Program Evaluation and Review Technique (PERT)* defines risks based on their optimistic cost, most likely and pessimistic cost based on historical data (quantitative) or expert knowledge (qualitative). This can then be used to calculate the mean and standard deviation. However, this method is relatively expensive and inaccurate in large, complex projects. *Parametric Estimating* connect the output (cost overrun) and the input (different risk factors) by using historical data. This method can be applied easily but has the limitation of a hard, understandable relationship between input and output. When there is a linear relationship between inputs and outputs, regression can be applied to this in the earlier project phases when little information is known. A disadvantage is that many assumptions must be made, making the method less reliable (Ammar et al., 2023). *Analytical Hierarchy Process (AHP)* identifies risk factors and sub-factors in work packages of the work breakdown structure. The overall risk for each work package will be calculated using the AHP. In this way, the inconsistency of expert judgement will be reduced, but it requires experienced data (Bakhshi & Touran, 2014)(Ammar et al., 2023). The last non-simulation model is the *Optimism Bias Uplifts*. This approach prevents the underestimation of costs in transportation projects by using historical data. Finished projects will be categorised into groups, and an uplift will be applied to the project budget. This method is also called *Reference Class Forecasting (RCF)* (Ammar et al., 2023)(Bakhshi & Touran, 2014).

Simulation methods combine expert judgement and analytical techniques. These methods are commonly used when models are complex or impractical. This method uses random sampling to estimate a range of outcomes. *Range Estimating* is a process used to estimate the probability of cost variations in a project and to determine the contingencies needed to cover these potential variations. It uses Monte Carlo simulation to model the impact of identified critical cost items, relying on expert judgement and historical data to establish a range of possible outcomes. This method helps provide the appropriate level of confidence that the project budget can accommodate unexpected changes in costs (Humphries, 2009) (Ammar et al., 2023)(Bakhshi & Touran, 2014). This method can also be used in the SSK-2018 but is not mandatory. *Integrated Models for Cost & Schedule* determines the contingency reserve by combining cost with schedule. By applying Monte Carlo simulations to the project schedule, the model calculates the contingency reserve considering the potential extra costs and delays (Hulett, 2016).

Two methods are categorised under Modern Mathematical Methods, of which *Fuzzy Techniques* is the first. The contingency reserve in construction and infrastructure projects using Fussy Techniques is determined by combining the dynamic and time-dependent nature of risks, including probabilities, opportunities and risk responses. Risks can be translated into linguistic terms that can be translated into fuzzy numbers. This data is thereafter placed into the model to obtain a simulation of the impact of risks and risk response strategies. The advantage is that in this method, the risk response strategies are thus included in the contingency reserve setup (Fateminia, 2023b). The other and last method concerns *Artificial Neural Network*. Artificial Neural Networks determine the contingency reserve by combining regression and classification to predict variable costs. This method helps to plan for unexpected project changes by learning from historical data of past projects. In this way, the method can help to predict future needs, making the contingency reserve more accurate. A disadvantage of this method is that it needs a lot of data before it works well (Chen & Hartman, 2000).

4.2.4. Management reserve

Fateminia (2023a) found a definition for the management reserve:

"The management reserve is an amount of project budget that is reserved to handle unforeseen events."

As seen in Figure 4.1, the management reserve adds to the baseline costs and the project budget. It was found by Ahmadi-Javid et al. (2020) that cost estimates of uncertain risks can be categorised into two groups: unknown-unknowns and known-unknowns. These terms will be further explained in subsection 4.3.2. Unknown-unknown risks should be budgeted in the management reserve, while known-unknown risks are budgeted in the contingency reserve (Ahmadi-Javid et al., 2020). Traditional methods calculate the management by applying an additional percentage over the baseline project costs. New methods include historical data in the determination of the management reserve. Similar projects will be found using a k-nearest neighbour algorithm and a genetic algorithm to optimize the selection of these projects (Lee et al., 2017). The SSK 2018 includes the management reserve as a separate element in the project-related contingencies or as a buffer on top of the detailed cost estimate to provide additional flexibility to deal with these types of unforeseen challenges.

4.2.5. Project planning

Project planning concerns drawing up a detailed road map that includes clear instructions to the project team on activities that need to be completed, the timeline for these activities and the required resources to achieve the defined project outcome efficiently (Mantel & Shafer, 1985). Proper project planning is important to achieve project success (Dvir et al., 2003) (Serrador, 2013) (Irfan et al., 2021). Failure to complete the project scope within the predetermined time frame can cause problems, which are referred to as delays. Delay is defined as an event that extends the required contractual time to complete the work (Stumpf, 2000). The impact of a delay, also known as a schedule overrun, is defined by Mohamad (2010) as the extension of the project's completion time. The project manager must ensure that the project is executed within the established time frame and that all stakeholders are satisfied (Zwikael, 2009). A Work Breakdown Structure (WBS) will first be drawn up to create proper project planning. In a WBS, the entire project is divided into activities and sub-activities. In the later stages of the project, when more information is available, the schedule is represented in an accurate precedence diagram that can eventually be represented in a Gantt Chart (Pellerin & Perrier, 2019).

Planning methods and tools can be divided into two categories: resource-driven planning and time-driven planning. Resource-driven scheduling is defined as a schedule driven by available resources such as line-of-balance and Last Planner System methods. Time-driven scheduling is the more traditional way of scheduling project activities where duration and dependencies are estimated. Examples of time-driven scheduling are CPM and PERT (Memon & Zin, 2010) (AlNasseri, 2015) (Kenley & Seppänen, 2006) (Demeulemeester & Herroelen, 2006). These methods are already included in most planning programmes.

Commonly used project planning programmes in the Netherlands are Microsoft Planning and Primavera P6. Microsoft Project is a software programme created for project managers to develop planning, assign resources to tasks, track progress, manage budgets and analyze workloads. Microsoft Project is project management software that calculates project budgets by evaluating the cost of resources (such as labour, equipment and materials) assigned to tasks. These resources can be used for multiple projects through a shared pool, and costs are calculated based on the speed and availability of each resource as defined in their schedules. Although it can create complex schedules with methods such as critical paths and event chains, it cannot estimate resource output, limiting its use for production with strict material constraints. The software supports extensive customisation capabilities, provides different access levels for different user roles, and visualises project progress through Gantt charts (Wale, 2015).

Planning in Primavera P6 consists of the following steps. First, an Enterprise Project Structure (EPS) is created, which organises all projects in a company into a hierarchical structure. The subsequent step is developing a WBS that breaks down the projects into more minor elements. After this, activities are defined based on start and end dates. Then, relationships between activities are added to the activities. These can be Finish to Start (FS), Start to Start (SS), Finish to Finish (FF) and Start to Finish relationships. After associating the relationships to the activities, the schedule is created where a project duration can be obtained from the schedule (Mahure & Ranit, 2018).

For probabilistic planning, durations are given for all activities: optimistic, pessimistic, and most likely. Then, these values can be thrown into a Monte Carlo Simulation, which is run 10,000 times. From this, a schedule is then generated with a P85 value. This means the schedule can be determined with 85% certainty (Sergey et al., 2020).

In addition to calculating a schedule probabilistic, risks are also considered by applying buffers (Zarghami & Zwikael, 2023). There are three different types of buffers, of which an overview can be found in Figure 4.5:

- *Resource buffer:* The resource buffer can be described as a system or strategy for prioritising resources efficiently to ensure that all necessary resources are prepared and available precisely when needed for tasks that are crucial to the project's timeline (Vanhoucke & Vanhoucke, 2016).
- *Feeding buffer:* A series of safeguards designed to shield segments of the critical chain from disruptions (Vanhoucke & Vanhoucke, 2016).
- *Project buffer:* A dedicated safeguard specifically designed to secure the project's completion date (Vanhoucke & Vanhoucke, 2016).

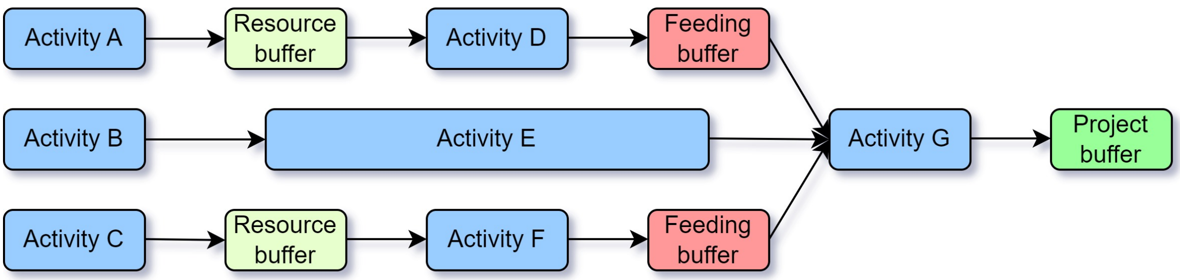

Figure 4.5: Buffers (Leijten, 2023)

4.3. Risks

In this section, specific components concerning risk are studied. For example, it examines the risk management method RISMAN, distinguishes between known and unknown risks, and examines first- and second-order effects of risks.

4.3.1. RISMAN

RISMAN stands for risk management and is a method that can be applied to projects. The following aspects play a role in its implementation (CROW, 2018):

- *Making risks explicit and managing them:* The identification and disclosure of risks ensures that risk awareness is enhanced, allowing for better choices in risk management.
- *Dealing with risks proactively:* Preparing measures for these known risks is proactive rather than acting only after risks have already occurred.
- *Managing risk more consciously:* Applying the RISMAN method improves risk awareness and prevents project blindness.

The RISMAN method consists of five steps and can be described as a cyclical process, as can be seen in Figure 4.6

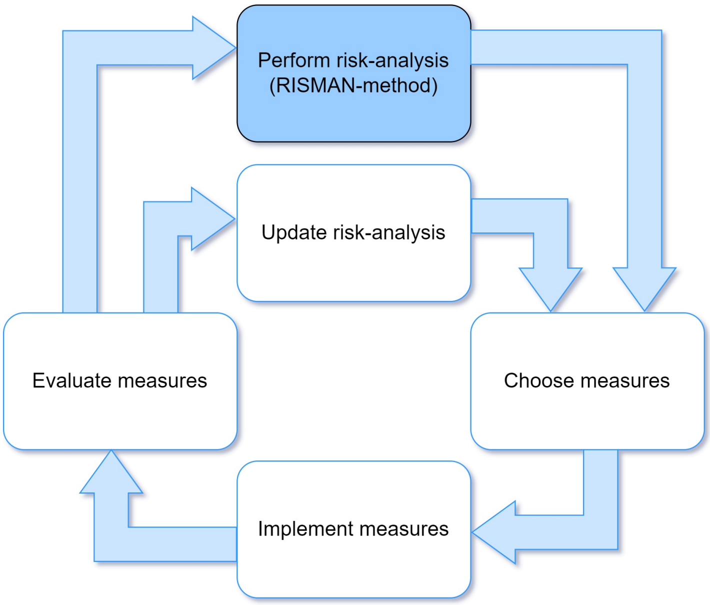

Figure 4.6: RISMAN method (Van den Bunt et al., 2013)

The first step is to conduct a comprehensive risk analysis. This involves looking at the project from different points of view. Consider the following points of view:

- Political/Governmental
- Financial/Economical
- Legal
- Technical
- Organisational
- Geographic/Spatial
- Societal

The risk analysis results in an overview of all risks, including potential measures and the probability and impact of the risk. The second step is to establish management measures. Based on the expected effect of the measure and the associated costs, the project management determines which measures will be related to which risks. The third step is to implement the measures where the person in charge ensures that the measures are implemented. In the fourth step, the management measures are evaluated. This involves checking whether the measures have had the desired effect. The final step consists of updating the risk analysis. The obtained list of risks must be updated because the corresponding measures have eliminated risks. New risks may also be added to the list during this process (CROW, 2018).

4.3.2. Known and unknown risks

On February 12, 2002, Secretary of Defence Donald Rumsfeld made the famous comment concerning the limitations of intelligence reports (Shermer, 2024):

”There are known knowns. These are things we know that we know. There are known unknowns. That is to say, there are things that we now know we don’t know. But there are also unknown unknowns. These are things we do not know, we don’t know.”
Donald Rumsfeld

Figure 4.7: Risk classification (Bhadra, 2021)

Risks can be classified into four categories: known-known, unknown-known, known-unknown and unknown-unknown, as can be seen in Figure 4.7. When the management knows and understands the risk, it is about *known-known risks*. These risks often come up in risk analysis and are known to management, meaning there are corresponding measures. *Unknown-known risks* are, in fact, the result of poor risk analysis. These risks are known but did not arise during the risk analysis (Bhadra, 2021). *Known-unknown risks* are often experienced, but it's challenging to understand their full impact and effects because of insufficient risk management. While it's possible to calculate these risks, it remains uncertain when and to what degree they occur (Perera & Higgins, 2017) (Granger, 2010). In the literature, the budget of known-unknown risks in cost estimates is also called the contingency reserve, which is already explained in subsection 4.2.3 (Institute, 2000) (Lee et al., 2017) (Walker et al., 2017) (Hoseini et al., 2020). The management reserve, as explained in subsection 4.2.4, serves as a buffer to cover costs related to *unknown-unknown risks* (Lee et al., 2017) (Eldosouky et al., 2014). In risk management practices, unknown-unknown risk events are also called black swans (Aven, 2013).

In the SSK-2018, known-known risks are incorporated in the risk reservation resulting from the risk analysis. Known-unknown risks are not explicitly budgeted in the SSK-2018 but should be minimised as much as possible through knowledge sharing and experience within the team to avoid cost overruns. The contingency reserve in the SSK-2018 should ensure that costs for known unknowns should be covered. Unknowns are estimated by adding an additional buffer in the contingency reserve or adding an additional percentage over the total project cost. The SSK-2018 suggests being flexible in dealing with unknown unknowns and proposes an adaptive project management approach (CROW, 2018).

However, the SSK-2018 does not necessarily distinguish between known and unknown risks. The method considers the estimate from uncertainties distinguishing three types: decision uncertainties, normal knowledge uncertainties and future uncertainties, as seen in Figure 4.8. Decision uncertainties have to do with the possible consequences of decisions made by the client. Several variants of executing the scope are considered, all of which are estimated separately. The client chooses one of the variants that is referenced and considered as the scope for the following project phases. In this process, the client tends to apply opportunism and strategic misrepresentation, as described in section 4.1, which the cost expert should pay close attention to. Also, the client could choose to include an additional budget in the estimate that may result from scope changes. This additional budget is commonly determined by considering the cost differences of different scope variants (CROW, 2018).

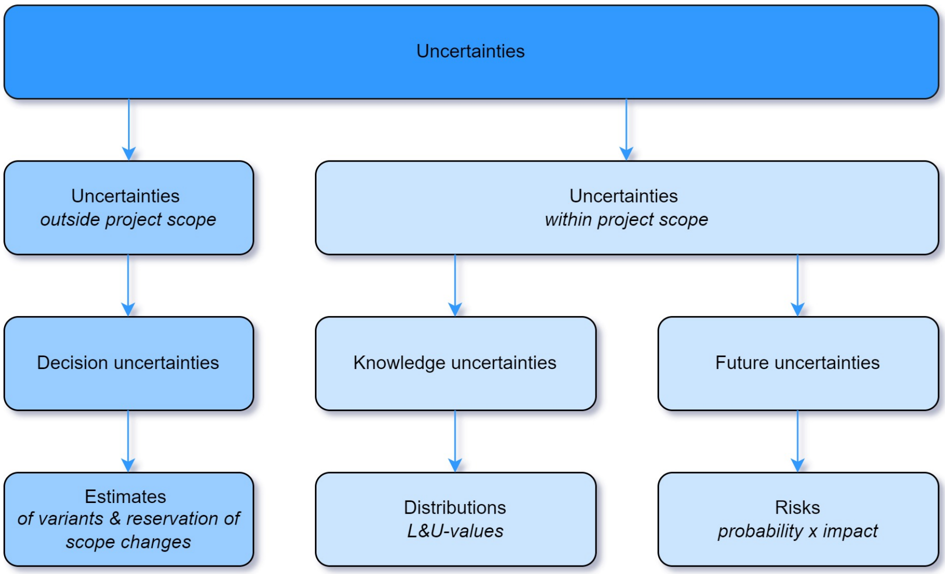

Figure 4.8: Uncertainties within and outside project scope (CROW, 2018)

Normal uncertainties consist of knowledge uncertainties and future uncertainties. Knowledge uncertainties exist due to the lack of information, such as specific quantities and prices of an object. Here, the most likely value (T-value or top value) is often taken into account, but the lowest value (L-value) and the highest value (U-value) are also included. Future uncertainties refer to risks that may occur. The goal is to identify these as completely as possible by applying the RISMAN method described in subsection 4.3.1 (CROW, 2018).

In short, risks are known potential outcomes with estimable probabilities, while uncertainties are unknown potential outcomes without predictable probabilities. Unknowns include known unknowns (identified risks with uncertain impacts) and unknown unknowns (unforeseen risks). The distinction between risk and uncertainty lies in quantifying and predicting outcomes. While risks are linked to known potential outcomes and their causes, uncertainties are linked to unknown outcomes and the inability to predict or link probabilities to these outcomes because of the lack of information.

4.3.3. First and second-order

The phenomenon of first- and second-order risk effects can be found in the literature under different names while referring to more or less the same issue. For example, the secondary impact of changes refers to how any changes made in a project can make the work that didn't change more expensive (Cooper & Lee, 2009). Change orders are directly related to schedule compression, trade stacking, sequence of work, overmanning and multiple-shift work, and negative morale impact, which could be considered second-order effects (Hanna et al., 1999). Cooper and Lee (2009) speaks of a first and secondary impact where the secondary impact can become as much as 2, 3 or 4 times as high as the first impact. A TU Delft professor who researched second-order effects found that the visible cost of a change or modification to the scope of work is called first-order, and the impact on the cost and/or time to perform unchanged work (or other modified work) is called disruptive of disruptive effects, which are also called second-order effects (Prof. of TU Delft, Personal Communication, March 5, 2024). Current risk analysis techniques do not account for the interactions or interrelationships between risks and don't cover the full effect of risks. They fail to consider the indirect and secondary effects of risks. A first risk can trigger other risks due to their interrelationship, resulting in a cumulative effect greater than the sum of individual risks (Nasirzadeh et al., 2008). When an activity causes another activity to occur, one may also speak of a ripple effect (Thomas & Oloufa, 1995). The ripple effect is defined as its cumulative growth in, for example, time or costs (Lucko et al., 2021) (Lishner & Shtub, 2023). Furthermore, the phenomenon is described, among other terms, as knock-on effects (Reichelt & Lyneis, 1999) (Bai et al., 2014), cumulative impact (Ibbs, 2013) (Reichard & Norwood, 2001), disruption (Kikwasi, 2012) (Finke, 1998) and cascading effects (Guo et al., 2019) (Pescaroli & Alexander, 2018).

When these different yet quite similar definitions and explanations of the second-order effect of risks (or other designations) are put together, the following two definitions can be obtained:

- *First-order effects* of risks are the direct impact of a risk in a construction or infrastructure project. These are specific, straightforward consequences that are usually quantifiable and can be directly linked to a cause, possibly leading to an increase in cost or delay. These risks are estimated by calculating the probability times impact in cost estimates.
- *Second-order effects* of risks is the indirect impact that follows from the initial risk. These effects can be more significant, potentially multiplying the initial impact by up to four times. They can affect project activities that were not directly affected, making these activities more expensive due to disruptions. Second-order effects include ripple, knock-on, cumulative, disruptive and cascading impacts that can affect project dynamics, schedules and cost estimates in a compounded manner. These risks are budgeted for in cost estimates by including a contingency reserve in the estimate.

4.3.4. Early warning signals

Early warning signals are indicators that occur before an eventual risk or cascade of risks occurs. They can be used as a tool to identify risks before they start causing a significant problem. Several early warning signals appear in construction and infrastructure projects (van Werkhoven, 2022):

- *Leading indicators:* Indicators that occur earlier than the problem itself, such as project schedule adherence, budget performance and team morale.
- *Stakeholder feedback and informal discussions:* Early warning signals can emerge during stakeholder conversations, such as small talk at coffee corners or during appointments.
- *Materialisation of risks:* When a risk occurs, it can also serve as an early warning signal that other risks may occur due to the initial occurrence risk. This is also known as a cascade of risk.
- *Themes identified via Cause-end-Effect analysis:* Errors in tender documents, lack of data at tender phase, inexperienced client organisation.
- *Increase in RISMAN score:* An adjustment in the RISMAN score indicates that project conditions are changing.
- *Risk analysis:* During risk analysis, early warning signals can be identified, providing a systematic approach to understanding the dynamics of risks (van Werkhoven, 2022).

4.4. Cascading effects analyses

Construction processes have an interconnected relationship (Ma et al., 2021) (Williams, 2017). This means that when a risk occurs, this interconnected relationship with other risks can also cause these risks to occur, eventually leading to a cascade of risks (Guo et al., 2019). So, companies should not calculate risk only by calculating the probability times costs because this will result in underestimating total risk cost and the contingency reserve. This is due to the interrelated nature of risks (Vegas-Fernández, 2022).

Pescaroli and Alexander (2018) highlights the importance of including compound, interconnected, interacting and cascading risks into cost estimate methodologies to allow for more accurate estimates. By including these terms in cost estimates, risks and their effects on costs are better understood. Traditional cost estimate methodologies fail to include these risks in construction and infrastructure projects. Compound risks can be identified as a combination of natural hazards that create an extreme impact. Climate change is an example of an extreme impact resulting from multiple minor hazards, such as pollution and emissions. Interconnected and interacting risks are correlated, resulting in often a collective effect, such as when heavy rainfall can result in flooding. Cascading risks are related to the sequence of effects where the trigger event leads to a cascade of events. The low impact of a trigger event can eventually cause it to have a high impact due to its cascading effect (Pescaroli & Alexander, 2018).

A theoretical model for the cascading effects of disasters is established in the reading of Zuccaro et al. (2018). The main goal of this theoretical framework is to provide a structured approach for analysing and understanding the interconnected nature of risks in disaster events. This includes modelling cascading events, risk assessment and impact evaluation, uncertainty management, scenario development, and simulation, and enhancing emergency planning (Zuccaro et al., 2018). This theoretical framework has not yet been applied to the cascading effect of risks in construction and infrastructure projects, but this could lead to interesting outcomes. When this theoretical model is applied to the cascading effect of risks in construction and infrastructure projects, the following parts could benefit:

- *Improve risk identification and assessment:* By considering the cascading effects of risks, cost estimators can identify broader risks that could influence project cost estimates.
- *Risk mitigation:* When the cascading effect of risks is better identified, decision-making about mitigating risks and managing the costs can be done more effectively.
- *Cost estimate and planning:* Integrating the cascading effect of risks into cost estimate and project planning could help experts in the field to incorporate the direct and indirect costs and delays of risks into the cost estimates and project planning, leading to more accurate project estimates.

Ma et al. (2021) found an integrated framework for analysing safety risk factors in construction projects using machine learning and the cascading effects concept. The article suggests that future research should focus on the impact of risk factors on project resources and costs, considering the cascading effects of risks (Ma et al., 2021).

4.5. Conclusion

The literature review highlights the challenges involved in construction and infrastructure projects. It reveals that cost overruns and delays are globally common in these projects due to project complexity, optimism bias, scope creep, poor project management, uncertainty and risk alongside inadequate contingency planning. The last one mentioned proves to be a significant challenge because it is difficult to quantify the impact of second-order effects of risks in cost estimates and project planning during the design phase. This challenge makes it difficult to accurately estimate the cost and schedule of a project, which will often result in cost overruns and delays. To effectively manage these second-order effects, the direct and indirect effects of project risks in terms of cost and time must be more completely understood. Current risk management practices, such as RISMAN, SSK-2018 and project planning establishments, should consider incorporating the interconnected nature of project risks into these techniques. In natural disaster management, cascading effects have already been comprehensively studied and quantified. These methods could provide outcomes for construction and infrastructure projects. If done correctly, risk identification and assessment could be improved to reduce budget overruns and delays.

The continuation of this research will focus on how project managers now deal with the second-order effects of risks, focusing on identifying and estimating them in terms of time and money. In addition, it is helpful to gather information about the causes of second-order effects and their consequences in terms of time and money. Finally, investigate whether cascading effects analysis of natural disasters can provide new insights into the construction and infrastructure sector by better identifying and quantifying the interconnected nature of project risks.

Lastly, a list of important concepts and themes can be generated based on the literature review. This list can then be compared with important and frequently used interview themes and concepts to reach conclusions. The list with themes and concepts generated from the literature review can be found in Table C.1 of Appendix C

5

Interview Results

This chapter presents and explains the interview results through quotes and paraphrases. First, the topic of first- and second-order effects of risks is covered, after which dealing with second-order effects is discussed. Causes and consequences are discussed after that. This is followed by the section highlighting the difference between consultant and contractor. Finally, the sections on culture change and client requirements are covered.

5.1. First and second-order effects of risks

During the interview, respondents were first asked whether they were familiar with the first-order and second-order effects of risks. Nearly every respondent felt familiar with the concept. Respondents indicated that first-order risk effects refer to the risks that have been foreseen and that result from a risk analysis session. This involves the direct impact of a risk that can often be linked directly to its cause. Commonly, measures are established for these risks: preventive and corrective. Preventive measures are those taken before a risk event has occurred. It can reduce the probability or consequence of a risk. Corrective measures are measures taken after a risk event has occurred. This means that damage will be reduced in this way (Bretveld, 2020). Respondents indicated that first-order risks are estimated by calculating probability times the impact in cost estimates and by doing probabilistic planning with buffers. Sometimes, particular consequence and probability classes are also associated with these risks to speed up and simplify the estimation process.

> *”Well, I would describe the first-order effect as the risks you have in view. The second-order effect is that something that you didn’t quite foresee then happens that makes it all completely out of control.”*

> *”The first-order effect is the direct consequence of an occurring risk. The second-order effect is that the occurrence of this risk has further consequences for other parts of the project that you did not consider.”*

> *”The first-order effect is just purely the occurrence of the risk that has a direct cost, and the second-order effect is the consequence when things interact in terms of disruption.”*

Respondents were asked to assess the concepts defined in subsection 4.3.3. They indicated almost complete agreement with the established concept, with some additions and modifications suggested. Second-order risk effects, also referred to by respondents as the indirect impacts, second-order risks, secondary risks and fringe effects, are the risks that you did not fully foresee. These turn out to have more consequences than thought in advance, causing things to get completely out of hand. These risks affect other project parts and stem from an original risk. The second-order effect is also called the effect whereby project activities no longer fit the bill, causing a chain reaction of accumulations of events. In addition, some respondents indicated that risks resulting from a measure also belong to second-order effects. In cost estimates, these risks are partly included in the probability times consequence reservation and partly estimated by applying a percentage over the object exceeding risk reservation, also called the contingency reserve. In planning activities, these risks are considered by calculating the planning probabilistic, whereby risks can be correlated to each other and by adding buffers at critical locations.

When this feedback is applied to the established concepts from the literature, shown in subsection 4.3.3, combined concepts can be obtained that are based on the literature and interview data from experts in the field. By carefully studying impacts, first-order and second-order effects can be distinguished.

First-order effects of risks are the direct impact of a risk in a construction or infrastructure project that arises from a risk analysis session. Often, preventive or corrective measures are taken to reduce the probability or impact of these risks. First-order risk effects are straightforward consequences that are usually quantifiable and can be directly linked to a cause, possibly leading to an increase in cost or delay. These risks are estimated by calculating the probability times impact in cost estimates (known costs, object-specific or non-object-specific in SSK-2018). Planning activities consider these effects by calculating them as probabilistic and adding buffers at critical locations. An example can be obtained from the situation of a crane falling over on construction sites. In this case, the direct impact is repairing the damage and the cost of rebuilding the crane.

Second-order effects of risks are the indirect impacts that follow from the initial risk or arise from a corrective or preventive measure. These effects can be more significant, potentially multiplying the initial impact by multiple times. They can affect project activities that were not directly affected, making these activities more expensive or delayed due to disruptions. Second-order effects include fringe effects, ripple, knock-on, cumulative, disruptive and cascading impacts that can affect project dynamics, schedules and cost estimates in a compounded manner. These risks are budgeted for in cost estimates by including them in the (in)direct foreseen costs and/or in the contingency reserve. In planning activities, these risks are considered by calculating the planning probabilistic whereby risks can be correlated to each other and by adding buffers at critical locations.

Although all respondents more or less agreed with the definition established, the vagueness of the definition of second-order effects of risks lies in distinguishing between direct impact and indirect impact. To clarify this separation, examples must be analysed thoroughly. Definitions like first- and second-order effects of risks should be seen as a new term for the effects described above. By defining second-order effects, project managers are advised to look beyond the immediate consequences of risks, which leads to a more comprehensive risk assessment. Besides, the understanding that second-order effects can lead to compounded impact can help project managers create more robust-to-risk planning. The definition of second-order effects mentioned above isn't fixed because it can be adjusted and refined based on new experiences, environments and findings. This is a crucial part of the concept to allow project managers to iteratively improve their understanding of and deal with these risks based on actual project outcomes versus theoretical models. In practice, this means that the definition or second-order effects can be used as a way to tackle challenges.

5.2. Dealing with second-order effects of risks

Another topic covered during the interviews was dealing with the second-order effects of risk. This mainly involved identifying and quantifying these effects. The topic specifically involved estimating costs, planning and how a contractor deals with these effects during a project. To Identify first and second-order effects of risks, a risk analysis session is always carried out first according to the RISMAN method, as explained in subsection 4.3.1. This results in a list of identified risks that emerged during this session and were found in similar projects.

> *"I think RISMAN is always used in the Netherlands"*
>
> *"We also always look at similar projects. And what have been the risks there and also the occurred risks?"*

Interviews reveal that the RISMAN method is often applied by different disciplines separately, while a multidisciplinary approach would be more beneficial. This means it is preferable to have people with different knowledge and specialisations at the table when developing a risk dossier. So, having the right people present during such a session would be advantageous, such as contract managers, planners, cost experts and commissioning managers. Measures are thereafter taken for the main risks:

preventive or corrective, as explained in section 5.1.

> *"Actually, the impact and consequences are estimated too mono-disciplinary. But if you estimate it multidisciplinary, you get 50 risks, which is also a prayer without end."*

Following this, the probability and impact will be determined. Most of the respondents indicated that the impact in the SSK-2018 only includes the first-order effect of the risk. Some respondents indicated that the second-order effect should also be calculated in this impact, but this rarely happens or is a rough estimate. This is because respondents indicated that these effects are often underestimated and not clearly included in an estimate.

> *"Second-order effects are commonly underestimated".*

Respondents gave different answers to the question of where second-order effects of risks should be estimated in the SSK-2018, namely:

- *Direct costs to be further detailed:* This cost element refers to the costs directly associated with a construction or infrastructure project but not yet fully specified at the time of cost estimation. This cost item includes elements that are essential to the project but for which the specific details and exact cost have yet to be determined. Consider items that require further investigation or definition before a precise estimate can be made. This may include materials, labour and other direct expenses that are critical to the completion of the project but whose details are not yet fully known at the time the estimate is prepared (CROW, 2018).

  > *"If you follow the SSK-2018, then of course you will see that you included it in an item. Then you include it in the indirect costs further detail."*

- *Object-specific risks:* This refers to the amount to absorb unforeseen costs that can be directly linked to specific parts of projects (objects). This reserve is intended as financial coverage against risks uncovered by a project risk analysis. These risks are reasonably predictable within the scope of the project or the work involved (CROW, 2018).

  > *"Those are the object-specific risks in which you can put that."*

- *Non-object-specific risks:* This reservation includes risks that cannot be specifically assigned to particular project components (objects) but affect the entire project or even multiple projects. These include economic changes, regulatory changes or other external factors that may affect the project's cost. Thus, this component is general and intended to cover unexpected costs exceeding normal project risks (CROW, 2018).

  > *"Sometimes it is more convenient just to include the second-order effect of risk at the non-object-specific risks because then it ties in neatly with the risk register, and then these are all the risks."*

- *Non-object-specific contingency (contingency reserve):.* Respondents who indicated that they consider second-order effects by applying a contingency reserve said that this number is often set at 10% but can be raised or lowered based on expert judgement. When many risks are identified in a risk analysis session, the number can be adjusted downward, and when few risks are identified, the number can be adjusted upward. In addition, the project phase determines the amount of this number. Respondents indicated that the later in the project, the lower this number will be.

  > *"Indeed, I think they should be in the contingency part of one's risk reservation. The unknown non-object specific risk contingency."*

- *No specific place:* Some respondents indicated that second-order effects of risk are not specifically considered in the estimation.

  > *"There is actually no specific place in the SSK-2018 to estimate second-order effects."*

After establishing a list of risks during a risk analysis session, respondents indicate that bandwidths are applied to the risks with an optimistic value and a pessimistic value. Next, this list is placed into a Monte Carlo Simulation tool like Risicoraming, where a cost total can be obtained. Commonly, a cost total is obtained with an 85% chance of being met, P85 also called ("Risicoraming", n.d.).

“Where the principle is that we want to have a P85 probabilistic schedule when we start a work.”

Respondents did agree that risks in cost estimates are not correlated with each other and do not account for risks’ cascading effects. Correlating risks means applying interdependencies to different risks. Risks do not often occur in isolation. One risk event can influence the likelihood or impact of another risk. For example, a delay in material delivery can cause a remote probability of timeline overruns, increasing the likelihood of extended labour and equipment usage (Tran & Bypaneni, 2016).

“Sometimes we do, but most of the time we don’t.”

“No, risks are not correlated to each other in cost estimates, but in practice, it does appear that risks are generally correlated to each other.”

Respondents who indicated that second-order effects are budgeted in the contingency reserve also said that a 10% contingency is taken as the default in the design phase of a project. Based on expert judgement, this number is sometimes adjusted up or down. When the expert saw that few risks emerged during a risk analysis, the contingency reserve was adjusted to a higher value and vice versa. Experts with little experience often do not dare to adjust this number, so it often remains at 10%. The interviews reveal that other methods of calculating this number are hardly used in practice.

“Usually, it’s 10 %, but that can vary. Some project managers don’t vary that. It’s actually based on expert judgement.”

Unlike cost estimates, correlating risks could be done for project planning activities, according to interviews. Respondents agreed on how risks were taken into account in planning activities. Activities are assigned a certain range with optimistic and pessimistic durations, just like cost estimates. Probabilistic estimation tools such as Primavera P6 and Microsoft Project make this possible. Risks can be correlated with these tools, making chain reactions visible in the planning process. Sometimes, only probabilistic planning is done, and only the top five risks are included. In this way, it can be said that the planning has been calculated probabilistic when, in fact, this has only been done for the top five risks. However, Monte Carlo Simulations are often preferred over correlating risks. Clients often require Monte Carlo simulations because this process costs less time and, therefore, less money. There is a time frame of about 2 weeks for making a closed schedule analysis where risks are correlated.

“So you can link a risk to multiple activities, and then you can indicate it in the planning program that if the risk occurs in one activity, then it also occurs in the other activity.”

In addition to calculating probabilistic planning using Monte Carlo Simulations based on a range of activity durations, the risk is also considered by including buffers on the project’s critical path. Although respondents indicated that these buffers are really only meant for the contractor, sometimes the client also uses them. When placing buffers, the main focus is on where there are milestones and fines associated with activities.

“A buffer in the work is to accommodate contractor delays. In principle, the client is not allowed to use that.”

In addition to dealing with second-order effects in cost estimation and planning, other interesting aspects arose during the interviews. First, it came up that good preparation is half the job. This means that performing good reviews on a risk analysis is important. According to respondents, work should always be reviewed by someone else or an external party. This can prevent errors, reducing second-order effects. You need people who will ask strange questions to come to a complete risk analysis in which second-order effects are integrated as well as possible. Unfortunately, these pursuits often cost more time and money, and the workload is too heavy to complete properly.

“Good preparation is half the job”

“So let a third party check the estimate. Do you guys have thought about everything? You need to do a lot more real deep dive reviews, that also takes time and that also costs money.”

Also, having a lot of experience at the table is an important aspect of preparing a risk analysis, and it is good to include this experience as early in the project as possible. Respondents indicate that experts with more experience provide a more complete risk dossier with more second-order effects included.

In practice, it appears that cost experts are often not involved in estimating risks, which can lead to problems. This can be well explained using an example mentioned in an interview:

> *"A project manager estimated the cost of a pump at €100.000. This concerned only the purchase value. It later turned out that that pump had to be transported to an offshore platform and then installed. The total cost came to nearly a million"*

An overview of the process of generating the project schedule and cost estimate, taking into account second-order effects of risks, which can be obtained from the interviews, can be found in Figure A.4.

5.3. Causes and consequences

Another topic that emerged during the interviews was the causes and consequences of second-order effects of risk. To properly identify these effects, as many examples as possible were collected. This involved asking about the cause (trigger event) and its consequences. What emerged mostly was that second-order effects can have much larger consequences in terms of time and money.

> *"Those can be pretty large, yes."*

> *"Giga"*

> *"Overall so what I just said actually„ second-order effects are much larger, right?"*

Respondents speak of a consequence several times greater than the original risk. To provide a better understanding of second-order effects, all examples mentioned in the interviews have been categorized and shown figuratively in Figure 5.1, Figure 5.2, Figure 5.3, Figure 5.4, Figure 5.5 and Figure 5.6. All the examples mentioned in the interviews are presented by keywords in Table B.1 of Appendix B and thereafter categorized. In the figures, the cause (trigger event) is given in blue, and the consequences (first- and second-order effects) are given in light blue.

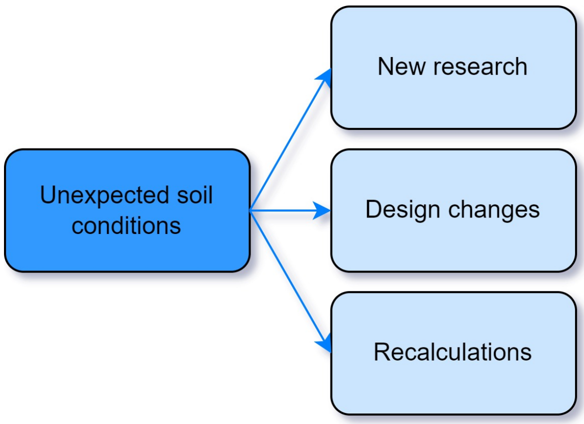

Figure 5.1: Unexpected soil conditions

One cause of second-order effects was an unexpected soil condition, as can be seen in Figure 5.1. As described by an interviewee, during one project, a layer of Kedichem, a soft clay soil that is too weak to build on, was found in the soil. Finding this layer in the ground meant that investigations had to be redone. As a result, construction work was halted for a considerable time, meaning machines and man-hours had to be hired for longer. In addition, adjustments had to be made to the design. These also had to be recalculated, which took a lot of time and money. In this example, the first-order effect directly results from discovering the unexpected soil condition during the project. The direct consequence of finding the soft clay soil (Kedichem), which is unsuitable for building on it, was that soil investigations had to be redone. This effect is directly linked to the initial discovery of the soft clay layer. The second-order effect of having to redo investigations is that the project was put on hold for a while, which meant that machinery and workforce had to be hired for longer than planned. The design changes required with accompanying recalculations also accounted for much of the extra cost and time.

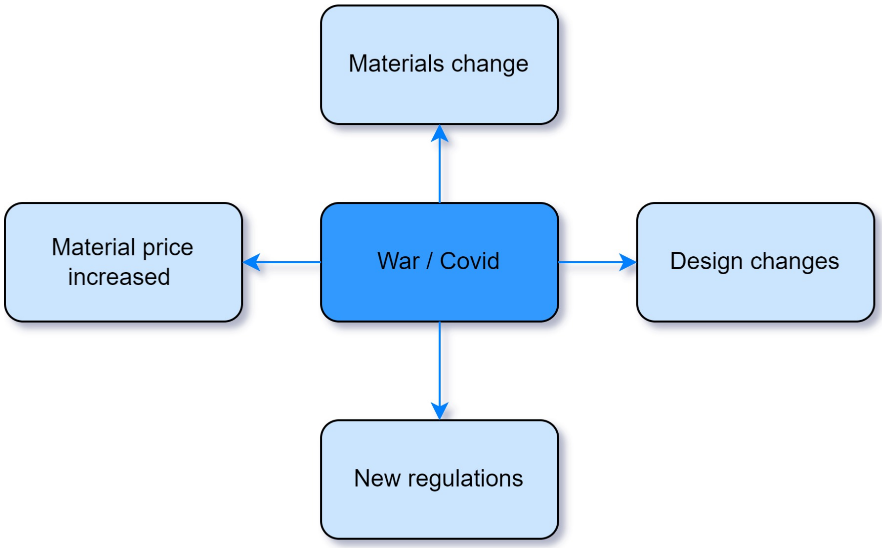

Figure 5.2: War/COVID-19

Other examples that emerged during the interviews concerned the category of Black Swans, as explained in subsection 4.3.2 and shown in Figure 5.2. Examples such as COVID-19 and the war in Ukraine were mentioned in this category. Respondents indicated that due to these unexpected circumstances, materials became more expensive or even unavailable and regulations changed. As a result, materials sometimes had to be replaced and the original design had to be modified. Specific calculations had to be redone because the design had to be changed.

> *"Unexpected occurrences, right? For example, we had that COVID-19 story where we couldn't get materials from China anymore. We needed the materials anyway, so we would get them from Portugal or Turkey. These are slightly different materials and prices anyway, which made the project more expensive but also required a change in design."*

> *"Because of the war in Ukraine, raw materials became more expensive, which led to adjustments in the design."*

The first-order effects of the Black Swans, like COVID-19 and the war in Ukraine, are materials becoming more expensive or even unavailable and, in addition, regulatory changes, as are the direct consequences of the unexpected, large-scale disruptions. The second-order effect stems from the original disruptions, which caused adjustments to the design to be made. Materials had to be replaced because they became too expensive or even unavailable. Calculations had to be redone by replacing the material, resulting in more time and money.

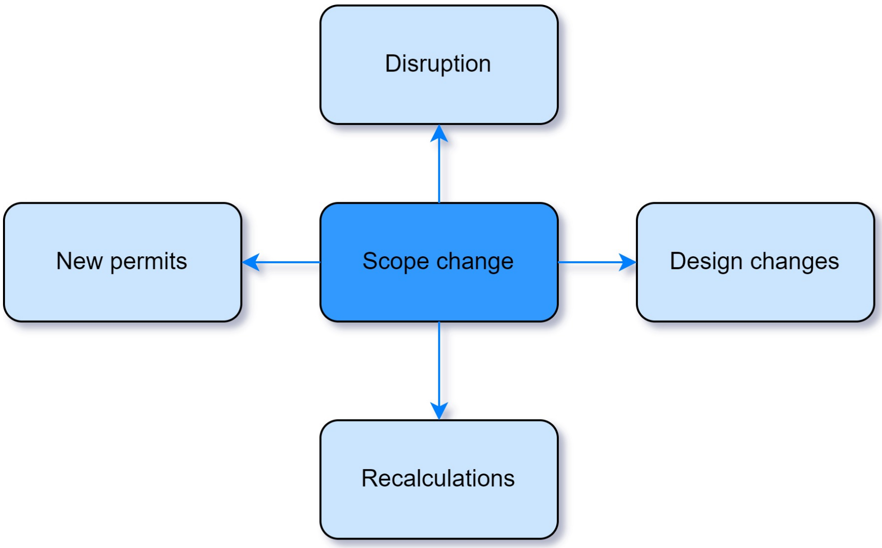

Figure 5.3: Scope change

Scope changes, as can be seen in Figure 5.3, have a large share in causing second-order effects.

> *"Well, scope changes are actually a very important one in that."*

For example, one mentioned in an interview that the request to make a wall a little longer was accepted, but the consequences were not carefully considered. There was already construction where the extension was supposed to be, so the whole design had to be changed. As a result, the design had to be redone, the calculations redone, the permits reapplied, and disruption occurred in the project.

> *"You very easily decide to make the wall a little longer, but then don't think about the possibility that there was a whole structure in the place where you made that wall longer and what impact that would have on the rest of the environment."*

Extending a wall in a construction project entails the first-order effect of changing the design. As a result, second-order effects such as longer production processes, material and design recalculations, permit applications and project disruptions thereafter occur.

Another example mentioned in an interview is that changes in essential product types can cause second-order effects, such as the production process taking longer because working methods must be changed. In addition, changes in materials may result in design changes, which may require recalculations. In addition, scope changes often involve reapplying for permits, resulting in delays and money. Ultimately, all of this will cause activities to come to a halt, causing hired machinery and manpower to come to a halt, leading to an overall disruption and an increase in time and money.

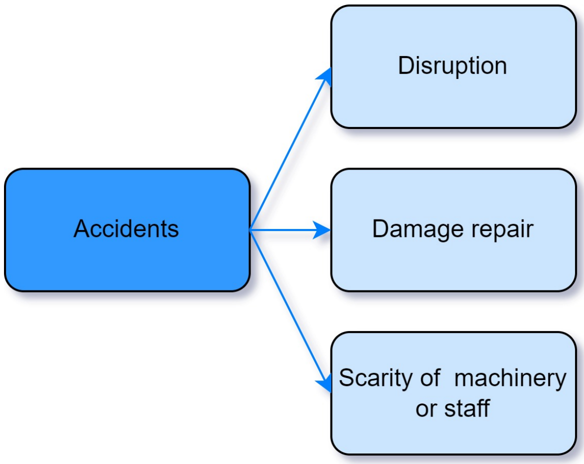

Figure 5.4: Accidents

In Figure 5.4, the consequences of the trigger-event accidents are represented. During an interview, an example was mentioned about a crane falling over. A cost estimate calculated only the cost of rebuilding the crane. However, it turned out that the crane had fallen over on part of the structure. So this also had to be repaired. In addition, it turned out that this was a particular type of crane, of which there are not many in the Netherlands, so the construction work was halted for a while because we had to wait for the availability of another crane. This caused a disruption of the entire construction process. In this example, the first-order effect of the crane falling over is that the crane must be rebuilt. This is the direct consequence of the accident. The second-order effects are the further consequences of the crane collapse, like the structure's damage, special crane availability issues and overall project disruption.

> *"It may be a special crane where there are not many of them, and so are always fully booked. This causes you further delays and disrupts the project."*

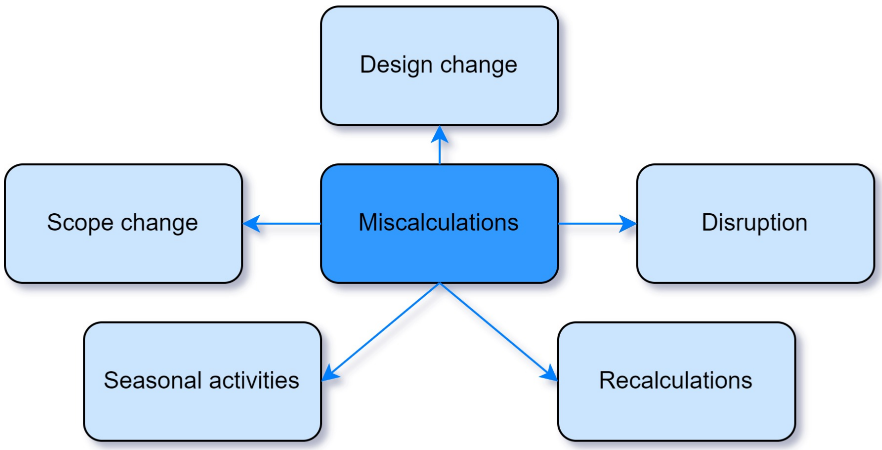

Figure 5.5: Miscalculations

Miscalculations, as shown in Figure 5.5, are another category under which some examples could be placed. One example mentioned in an interview revealed that a building appeared not to be earthquake-proof. As a result, the basement had to be filled with cross-bracing, which can be considered the first-order effect. This basement was intended to be a car parking garage. Because of the cross-connections, this parking garage could no longer be used, so the project scope had to be changed, and the parking garage had to be relocated. This eventually led to all kinds of other adjustments that cost a lot of time and money (second-order effects).

> *"As a result, it had to be completely redesigned. The basement had to be filled with cross-connections when it was actually supposed to serve as a parking garage. This is no longer usable and must be placed elsewhere."*

Another example mentioned in an interview involves the misplacement of pipes and cables underground. As a result, additional pipes and cables had to be placed underground, doubling excavation costs, transportation costs and acceptance costs (first-order effect). In addition, the weaving company had to make an extra cavity, which had constructive consequences: the concrete could, therefore, be poured a week later, which also delayed other activities (second-order effect).

> *"The price of that pipe is easy to estimate, but the consequence for the braiders on the job who still have to cut the rebar is more difficult. Then, another structural engineer has to calculate what extra reinforcement needs to be put in. Does it have constructive consequences? So this cannot be realised in 1 day; this will take a week. As a result, the concrete could also only come in a week later, disrupting the whole planning."*

A design error cited as an example also led to many second-order effects. For example, the spacing of a weir had to be moved two meters outward due to a drawing error, which can be considered the first-order effect. As a result, the river had to be dammed up, causing many works to go in vain. What came along with this is that the breeding season of a certain bird species arrived, so construction had to be halted for a time. Seasonal activities are also a second-order effect that is not always considered. Besides the fact that seasonal activities often involve nature, weather can also play a role in this, such as storm seasons.

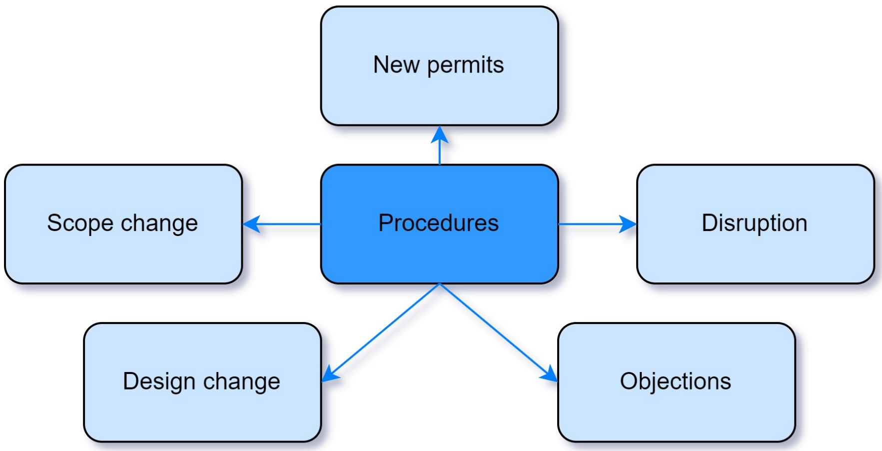

Figure 5.6: Procedures

Procedures can also be trigger-events of second-order effects, as shown in Figure 5.6. This includes complaints from residents, changes in regulations and subsidies, late decision-making, and permits not being granted. For example, during one interview, a respondent told of a project that was subject to objections and appeals. As a result, the project plan had to be modified. Because this took some time, the FLORON study, which focused on protecting and conserving wild plants in the Netherlands, had expired and had to be reapplied for. FLORON coordinates research on the distribution of wild plants in the Netherlands ("FLORON", n.d.). All in all, this caused even more significant delays, creating a major disruption. The first-order effect is the direct result of the objections and appeals from the residents regarding the project. This led directly to the requirement to adjust the project plan. The second-order effects are the conduct of the FLORON study, which thus has to be redone, and further project delays causing disruption.

> *"It may be that the FLORON survey has expired, and suddenly the blue tit has moved into the area."*

In addition to the examples mentioned, other points have emerged during the interviews regarding the causes and consequences of second-order effects:

- *Incurring costs to accelerate:* There may be certain deadlines and penalties associated with activities. So, during the project, these must be met; otherwise, additional costs in the form of fines will be incurred. To avoid this, contractors often choose to incur additional costs to avoid fines and meet the milestones. In this case, the fines exceed the additional costs incurred to expedite the project.

  > *"Because eventually, you have to try to meet the schedule, so you're going to accelerate. You're going to incur additional costs to accelerate. For example, what often happens is that extra formwork, extra shifts are used to meet the schedule; this is cost-prohibitive."*

- *Not mapping the entire consequence:* Interviews show that project managers struggle to identify the full consequence. For example, they forget some consequence categories or do not consider that new consequences may arise with certain consequences. Also, estimates often fail to describe the consequence or describe it poorly. It is then not clear to what extent second-order effects are included.

  > *"What exactly do you put in the amount of impact? I think you have to label it very clearly, and I also often realise that it's not very smartly defined. The impact is 1.5 million. Then what that 1.5 million represents is not described very smartly."*

5.4. Consultant vs contractor

In addition to the previous topics that involved defining first- and second-order effects, identifying how they are currently dealt with, and attempting to outline the causes and consequences, other topics were also explored during the interviews, starting with the consultant's comparison with the contractor. There is a difference between contractors and consultants regarding willingness to budget for high (risk) contingencies. An interviewer, for example, indicated that.

> *"Consultants always strive for the best advice, ensuring that they can provide the most realistic cost estimate or schedule, including a realistic risk reservation."*

Contractors do this as well, to a certain degree. One respondent about deliberately not wanting to estimate all the risks in a risk reserve:

> *"The market also plays a role because sometimes you know quite well how something is. But if you put down the real story, then you have nothing."*

From this, it can be concluded that, unlike consultants, contractors have to deal with the market and competition. Sometimes, offering prices just a little more competitively is necessary to win projects.

5.5. Culture change

Another interesting aspect that came up several times was that experts sometimes do not dare to include a high contingency or time reservation in a cost estimate or planning. In fact, high contingency is rarely appreciated. Respondents feel that this requires a culture change within companies so that they do not shy away from the truth. For example, one respondent proverbially let it be known that you get shot down if you estimate a high contingency or that a high contingency is simply dismissed:

> *"If you really want to bring out those second-order effects during a risk analysis session, you need to have people at the table who think out of the box and start asking weird questions. And that should also be a culture in the company that you don't get shot down, so to speak."*

> *"I think sometimes they know, but kind of brush it off."*

5.6. Client requirements

The client also plays a significant role in how companies deal with the second-order effects of risk. For example, a client wants to include only the top five discrete risks in the risk estimate.

> *"Yes, an executive agency, for example, that says no, we don't require those bandwidths on activities. So, they only model the top five discrete risks. Yes, then you get the check mark that you've done probabilistic planning; just the filter little input of uncertainties is included."*

Although risks can be correlated in some cost estimation and planning programs, this is often not done. One reason for this is that clients do not require it. In fact, clients demand project management methods that are understandable to themselves. Complex correlated models are often not understood by clients and, therefore, have no added value for them. If the client doesn't demand it while executing these complex models, it costs more time and money, and the conclusion not to do it is quickly made. This is evidenced by quotes from several respondents:

> *"If we have several hundred cost experts in the Netherlands, how many of them are statically literate and understand how correlation modelling works?"*

> *"Clients often require conform-SSK-2018, and it therefore represents risks completely independently."*

In response to a question why correlations between risks are often not chosen when there are certain programs in which this can be done:

> *"One reason for that is that many cost experts and planners are often a little smarter than the clients, project managers and directors. They are often much deeper into the details of statistics and modelling. If you get lost in this, the client no longer understands you. So, if you develop complex models to do everything we know we should be doing, you just don't get it sold to the client. And by that, I'm not saying the customer is stupid because they're not; they just haven't had the training to understand this."*

5.7. Conclusion

The interviews highlight that respondents are familiar with the concepts of first- and second-order effects. Although the definitions may sometimes differ slightly, an attempt is made to combine the definitions of the literature with the definitions of experts during the interviews. The dealing with second-order effects seems to vary quite a bit. For example, second-order effects appear to be challenging to identify because there is not enough experience at the table during risk sessions or because these risk sessions are conducted mono-disciplinary. In contrast, multidisciplinary ones would be more complete. Respondents did not unanimously agree on where second-order effects should be included in a cost estimate:

- Direct costs to be further detailed
- Object-specific risks
- Non-object specific risks
- Non-object-specific risk contingency
- No specific place

Respondents indicated cost estimates could be more accurate if risks are correlated. Although there are programs in which risks can be correlated, this is rarely done because it costs too much time and money or simply because the client does not require it. Preference is often given to Monte Carlo Simulations without correlation. Second-order effects are considered in planning by calculating them probabilistic using bandwidths and Monte Carlo Simulation in which correlations between risks are sometimes made. Buffers are then added to the critical paths. Trigger events for the occurrence of second-order effects can be categorised into:

- Unexpected soil conditions
- Black Swans
- Scope Change
- Accidents
- Miscalculations
- Procedures

There also appears to be a difference in how consultants and contractors prepare cost estimates and schedules because contractors sometimes deal with a complex market. In addition, the culture in the construction and infrastructure sector is not yet such that high contingencies in cost estimates are highly valued, often causing deliberate underestimates.

When Table C.1 of Appendix C is studied, interesting similarities and differences can be found:

- *Similarities in definition:* Respondents generally agreed with the literature's established definition for first- and second-order effects. Some respondents indicated that risks after applying a control measure also belong to second-order effects. This is, therefore, included in the definition.
- *Cost estimates:* Although it was suggested in the literature that second-order effects are budgeted for in the contingency reserve, this does not always appear to be the case in practice.
- *Bandwidths:* Although there is little discussion in the literature about applying bandwidths before Monte Carlo Simulations are used, this often appears to be done in practice.
- *Causes and consequences:* There is limited research in the literature on categorising causes and effects of second-order effects. In the interviews, several examples emerged that could be categorised into general causes and effects.
- *Culture change:* Experts sometimes do not dare to include a high contingency or time reservation in a cost estimate or planning. In fact, high contingency is rarely appreciated. Respondents feel that this requires a culture change within companies so that they do not shy away from the truth.
- *Contractor vs consultant:* Although consultants and contractors both want to make the best estimate possible, contractors have to deal with the market and competition where they sometimes have to adjust prices, and this is not always realistic. This means that contractors sometimes offer too low prices, which they know they cannot meet to win the project.
- *Client requirements:* Although risks can be correlated in estimates and schedules, clients do not always demand this because they do not understand the difficult models.

5.8. Program of requirements

Now that it has become clear what second-order effects or risks are and how they are currently dealt with in terms of cost estimates and project planning, together with the categorisation of causes and consequences, the requirements for a new method for improving current project management practices can be examined:

- *Integration of second-order effects:* Develop a method that considers second-order effects of risk in the form of cascading effects that account for interdependencies and potential cascading effects in construction projects when estimating costs. According to Table C.1, both the literature and the interviews point to the presence of cascading effects, ripple effects, domino effects and compound effects. This underlines the importance of developing a method comprehensively considering second-order effects and their interdependencies. The new method should, therefore, ensure that second-order effects are identified as much as possible to be subsequently quantified. The process of identification needs to be improved compared to the current method.
- *Regular cost planning updates:* Ensure that cost estimates are regularly updated to reflect the current risk landscape, as this dynamic addition is critical for managing unexpected changes in project execution. Concepts such as cost/budget/planning/time overrun, delay and scope creep-/changes are common in both the literature review and interviews, emphasising the requirement for dynamic and regular updates to cost estimates.
- *Multidisciplinary risk analysis sessions:* When identifying hazards during a risk analysis, it is essential to look from multiple disciplines to get as complete a picture as possible of all potential threats.
- *Understandable:* Clients appear to find current correlation application methods too challenging to understand, so they do not require them when projects are undertaken. Using a more understandable method will make it easier for clients to understand, allowing them to start demanding it and making cost estimates and schedules more accurate.
- *Time-saving:* Cost estimators and project managers said correlating risks in estimates is too complicated and time-consuming. Therefore, a new method should be time-saving over existing methods.

6
Method Development

Previous chapters have shown that estimating second-order effects of risk is challenging. While estimation methods exist to correlate risks and partially capture second-order effects, they are not commonly used due to the limitations of these methods. Since it is clear from the interviews and literature review that including second-order effects in cost estimates is needed to make the estimate more accurate, this chapter develops a new method to accomplish this potentially. This method will focus on the entire estimation process, whereas many risks with second-order effects as possible will first be identified and then subsequently quantified. This chapter starts with an introduction to the proposed method that includes the theory by Zuccaro et al. (2018), after which the steps are explained in how the new method functions. This method was fine-tuned based on interim feedback from the expert panel.

6.1. Introduction

The construction and infrastructure sector proves to be complex, dealing with risks that can significantly impact project planning and cost estimates. The literature review and interviews suggest that traditional risk management methods fall short in considering these risks' dynamic and correlated nature, which can lead to unexpected cascading effects.

To potentially tackle this problem, this chapter develops a method that includes the cascading effect theory of Zuccaro et al. (2018). This method attempts to improve the identification and quantification of risks and their second-order effects in the design phase of construction and infrastructure projects to make cost estimates more accurate and improve overall project management regarding risks. Usually, this theory would be applied in the natural disaster sector, where cascading effects of damage from natural disasters are better identified and quantified through this method. However, using this theory to the cascading effects of risks in construction and infrastructure projects will lead to new insights and improvements in cost estimate accuracy since the literature review shows that risks are correlated in practice and that cascading effects can occur due to risks in construction and infrastructure projects.

The theory by Zuccaro et al. (2018) is based on the Elementary Bricks model, which includes the following elements:

- Space (S)
- Time (T)
- Hazards (H)
- Initial Exposure (E)
- Vulnerability (V)
- Dynamic Vulnerability (DV)
- Influence of Human Behaviour (α)
- Damage (D)

These elements are used to calculate the damage of cascading disasters using formula Equation 6.1 (without α) or Equation 6.2 (with α). The elements in the formula should be multiplied by each other. By visualising the potential cascading effects of natural disasters and their impact using an event tree, the method could help in a more thorough analysis of how an initial natural disaster can propagate throughout an environment, intensifying vulnerabilities and leading to increased damage.

$$D(s,t) = H \times E \times V \tag{6.1}$$

$$D(s,t) = H \times E \times V \times \alpha \tag{6.2}$$

This chapter develops a new method with step-by-step explanations, from identifying risks to estimating risks in cost estimates, which incorporated the theory by Zuccaro et al. (2018), complemented by other essential areas of improvement discovered in literature review and interviews. In this process, the elements from natural disaster applications have been translated into elements applicable to construction and infrastructure projects. An overview of this translation can be found in Figure 6.1.

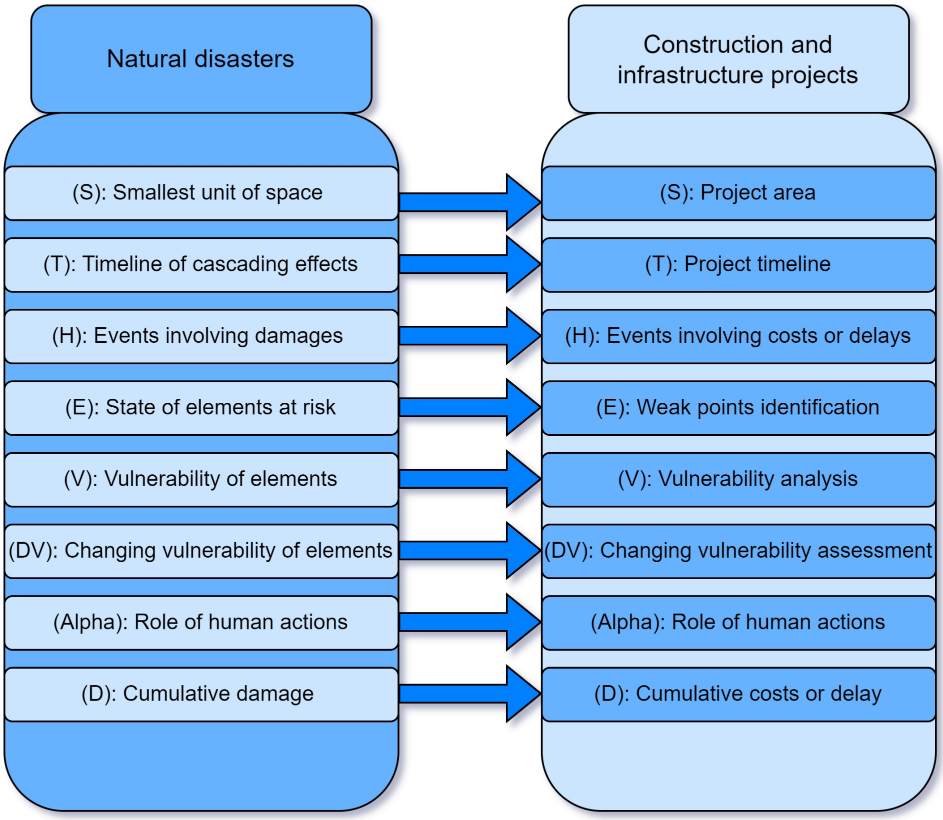

Figure 6.1: Translation from natural disasters to construction and infrastructure projects risks.

An overview of the new method is created, which can be found in Figure 6.2. In the following sections, every step of the new method will be discussed in which each step explains what needs to be done and how the theory by Zuccaro et al. (2018) relates to construction and infrastructure projects. In this, examples will be given to clarify and show practical applications, demonstrating how cost estimates regarding risks can be made more accurately. It also explains how second-order effects play a role in this. Ultimately, this chapter represents a framework that project managers can use to identify and quantify risks, which potentially could complement the widely used cost estimation methodology in the Netherlands, the SSK-2018.

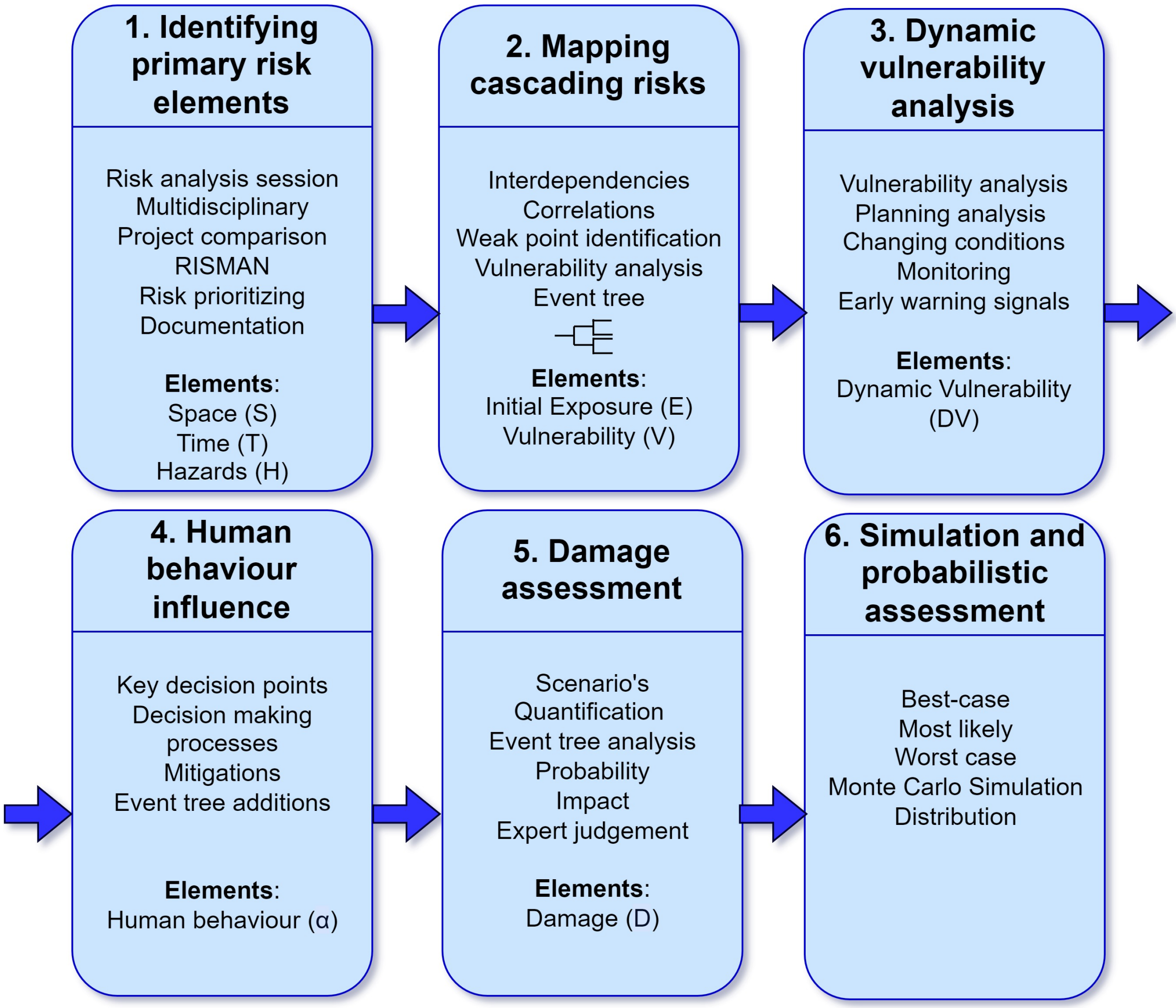

Figure 6.2: Method overview

6.2. Method steps

The six steps explained in this section correspond to the steps in the theory by Zuccaro et al. (2018) and are complemented where necessary to improve the identification and quantification of risks involving second-order effects. Each step explains which elements need to be identified, how this can be done and how it relates to the construction and infrastructure sector.

6.2.1. Identifying primary risk elements

The first step in the method is to generate a list of primary risks. This should be done through a risk analysis session. During a risk analysis session, a few things should be emphasised:

- *Second-order effects:* At the start of the risk analysis session, the session leader should help remind everyone that second-order effects might occur so that as many of these effects as possible should be identified at this stage. This will also help identify second-order effects in the following steps because awareness is created with this announcement.
- *Multidisciplinary:* According to interview respondents, the risk analysis session should be carried out multidisciplinary as it will lead to a more complete risk dossier. So, having the right people present during such a session would be advantageous, such as contract managers, planners, cost experts and commissioning managers, instead of only project managers. In addition, having a few people with much experience present during this session is crucial.
- *Project comparison:* Risk dossier preparation includes comparing similar projects. Consider the

example of building a bridge over a highway; the risk dossier of prior projects with bridges over a road should always be compared. Interviews revealed that clients are not often willing to share data on completed projects, making it difficult to compare projects with many similar projects. Still, it is beneficial to compare projects with the available data.

- *RISMAN:* The RISMAN method will be used in preparing a risk dossier, as explained in subsection 4.3.1. This method will ensure a structured approach and proper risk identification that is mostly used in the Netherlands.
- *Prioritise risks:* Create awareness of the probability and impact of the identified risks using a risk matrix like Table 6.1. Provide scores for likelihood (e.g., rare, unlikely, possible, likely, almost certain) and impact (e.g., negligible, minor, moderate, major, critical). After that, multiply the probability and impact to prioritise risks by magnitude. This can help in becoming aware of which risks are significant and which are minor. This allows a focus on the bigger risks when time is limited.
- *Documentation:* Ensure that justifications for assessing probability and impact are clearly documented somewhere so that it is clear exactly what was budgeted and estimated and why. This will avoid double estimation of risks in both the identified risks and the contingency reserve.

Table 6.1: Risk Matrix

Probability	**Impact**				
	Negligible	**Minor**	**Moderate**	**Major**	**Critical**
Rare	Low	Low	Medium	High	High
Unlikely	Low	Medium	Medium	High	High
Possible	Medium	Medium	High	High	High
Likely	Medium	High	High	High	High
Almost Certain	High	High	High	High	High

During this step, the elements Space (S), Time (T) and Hazards (H) should be defined.

- *Space (S): Specific project site and surrounding areas.* This element concerns the entire project area. Consider geographical, environmental and logistical factors that may bring risks. Make sure to go to the project site to analyse the condition of the project, including the existing infrastructure, access roads and potential environmental hazards.
- *Time (T): Initial project phase.* This element concerns the entire project duration. Create a clear project timeline starting from the planning phase and running through to the complete phase, as shown at Figure 2.1. Include the timing of external factors such as seasonal activities, seasonal weather patterns, peak construction periods or other time-dependent trigger events as described in Table B.1, which may affect the project.
- *Hazards (H): Risk dossier.* This element covers all identified risks, including second-order effects. The list of risks arising from a risk analysis session, as described at the beginning of subsection 6.2.1, is included in this element. This element can be expressed as the additional costs or delays associated with the identified risk event.

6.2.2. Mapping cascading risks

The second step is to map the cascading events. This starts with identifying dependencies and correlations and considering all consequences of a risk's occurrence so that as many second-order effects as possible are included in the cost estimate. This involves thoroughly analysing the project's critical path to understand how tasks and activities correlate. This starts with identifying the Initial Exposure (E) and Vulnerability (V) elements. Together, these elements serve as an indication of how severe the impact of a risk is going to be when it occurs.

- *Initial Exposure (E): Weak points identification.* This element assesses the initial state of the project to identify weaknesses that may be affected by the identified hazards (H). This involves considering project documentation, site conditions and initial project planning with the critical path to identify vulnerable areas. In doing so, consider which second-order effects could head forward due to the identified weaknesses. This element can be expressed as a value between 0 and 1, based on the degree of exposure to the identified risk, where 0 represents no exposure and 1 represents the maximum exposure.

- *Vulnerability (V): Vulnerability analysis.* This element analyses the sensitivity of different project components to the identified hazards. Consider material quality, construction techniques and historical data from similar projects. Again, consider which second-order effects could head forward due to the identified vulnerability. This element can be expressed as a value between 0 and 1, based on the degree of vulnerability to the identified risk, where 0 represents no vulnerability and 1 represents the maximum vulnerability.
- *Event tree creation:* Next, the cascading events are visualised through an event tree. Zuccaro et al. (2018) suggests using the program yWORKS-yED for this purpose, which is a widely available commercial software.

The following step is to create an event tree. Start by listing the initial risks (Hazards, H) and map out possible sequential risks that can be triggered from them. Determine the transition probability to the next event, based on the exposure and vulnerability scores, for each node in the event tree. To explain the process in this subsection more clearly, an example can be used to walk through it again. Imagine a scenario where a design error is identified in the foundation plan:

1. The first step is identifying the Initial Exposure (E). The initial state of the project is that the project is in, for example, the design phase, and the foundation plan is being finalised. The weakness in this is that the design team can discover a potential error in the load-bearing calculations for the foundations. The exposure to the risk is high because the calculation error could lead to serious problems during construction. So, a value of 0.8 can be assumed in this situation.
2. The second step is to determine the Vulnerability (V). This starts with analysing the sensitivity. The sensitivity of the project to this error is significant because the foundation is crucial for the structural integrity of the building. Factors such as the quality of materials used, historical data from similar projects, and the complexity of the design increase the vulnerability. Therefore, in this situation, a value of 0.7 can be assumed for the vulnerability.
3. The last step is to create an event tree. This event tree starts with the initial risk (Hazard, H): design error in the foundation plan. Following this, two options may arise as an example: the design error is discovered before construction starts (low probability) or not discovered before construction starts (high probability). Suppose the error is discovered before construction starts. In that case, this could lead to a redesign (high probability), which could lead to an extension of the project schedule and additional costs in terms of extended labour and equipment rental times. If the error is not detected before construction begins, it can have larger consequences with multiple cascading effects. The next event could be that the foundation of the construction proceeds with errors and subsequently encounters problems in the form of fractures or imbalances (medium chance). This requires construction to be stopped for investigation. This investigation may then reveal that design errors have been made (high probability). The next event is that a redesign has to take place (high probability). This eventually leads to increased costs and delays because approval must be obtained first and because the project has been on hold for a while. In addition, extra costs are incurred because of extended labour and equipment rental times. An example of what this event tree will look like is shown in Figure 6.3.

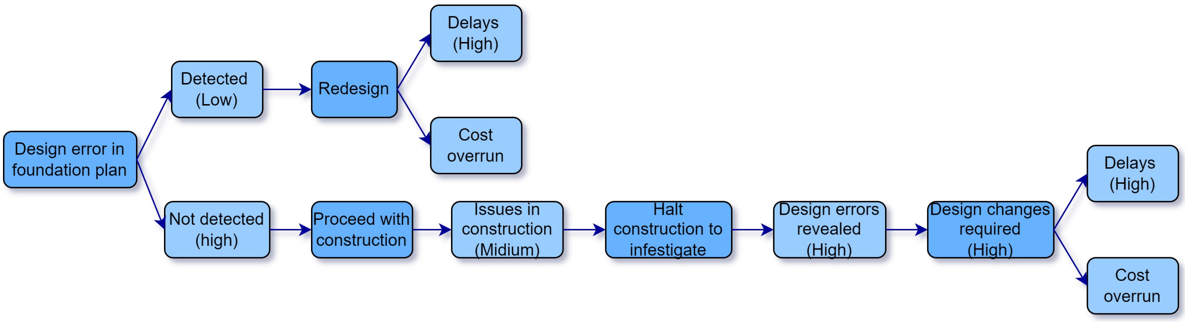

Figure 6.3: Event tree example

6.2.3. Dynamic vulnerability analysis

The next step aims to identify how damage (in cost and time) in one phase can increase vulnerability and cause further delays in other phases. This process should performed based on the following steps:

1. *Identify Dynamic Vulnerabilities (DV):* This element assesses how vulnerabilities develop as the project proceeds. Here, factors such as schedule dependencies, resource allocation and project phase dependencies should be considered carefully.
2. *Changing vulnerability assessments:* It is essential to update vulnerability assessments as new issues appear continuously. In doing so, real-time data will be used to reflect the project's current state and sensitivity to cascading effects.
3. *Monitoring and adapting to change:* When cascading effects might occur, it should be ensured to keep track of it. One way to do this is to monitor early warning signals, as explained in subsection 4.3.4. The following early warning signals should be considered: Leading indicators, stakeholder feedback and informal discussions, the materialisation of risks, themes identified through cause-and-effect analysis, and increased RISMAN score and risk analysis (van Werkhoven, 2022). Make sure the contingency plans are based on the identified vulnerabilities by monitoring early warning signals and adjusting the contingency to mitigate the impact of these cascading effects.

To better explain the step discussed in this subsection, an example will be used where a delay in material delivery occurs.

1. The first step is to establish the project's current state. Suppose the project is in the earlier construction phase, and a material of great importance has been delayed for two weeks. The delay in the delivery of the material affects the project planning in the current phase and creates an increased risk of further delays in subsequent project phases. This delay can lead to a cascade of risks, impacting the project planning and multiple tasks. For example, If steel for the foundation is delivered two weeks late, the structural work will also be delayed by three weeks due to cascading effects. This will delay the overall project timeline by four weeks, considering additional buffer time for unforeseen issues.
2. The second step is to adapt vulnerability assessments continuously. This involves looking at the data each time on the status of material delivery and the progress of the construction phases. If the material delay is even longer than anticipated, the risk assessments should be updated to reflect increased vulnerability in tasks dependent on the delayed material. For example, if the steel for the foundation is delayed, subsequent tasks for the foundation should also be delayed.
3. Next, the progress of all tasks and flags should be delayed using project management tools like Microsoft Project and Primavera P6. Contingency plans can be adjusted based on the impact of delays.

6.2.4. Human behaviour influence

The method includes the potential impacts of human actions in this step. Although the scope of this research is not to mitigate risks, this step is included in the method because it is also included in the method by Zuccaro et al. (2018). The process of including human behaviour influence in the method can be described in four steps:

1. *Identify key decision points (α):* This element includes the human decision-making points that can majorly impact the project. An example could be to include new safety measures or to rearrange tasks in the project planning to reduce delays. Second-order effects should be considered when making these decisions.
2. *Describe decision-making processes:* Describe decision-making processes accurately where it is essential to document who makes the decisions, how they are made and what factors they influence. Examples of factors may include expertise, risk forbearance and stakeholder influence.
3. *Include in risk models:* Include human behaviour in event trees and probabilistic assessment.
4. *Develop mitigation strategies:* Make plans to counter potential negative impacts of human behaviour.

To explain in more detail the step discussed in this subsection, an example is used where new safety regulations are introduced during project implementation:

1. First, the key decision points have to be identified. The new arrangements have been announced mid-project. The key decision point for the project manager is whether to implement the new arrangements immediately or delay the implementation a bit. The impact is that there could be potential delays if the new regulations are complex and training needs to be provided to employees.
2. The second step is to represent the decision-making process. Here, the factors that can influence the choice are project planning, cost challenges and risk of non-compliance penalties. Stakeholders who influence in this context are project managers, safety officers and regulatory agencies. In this, two scenarios can be outlined: immediate implementation or delayed implementation of employee training programmes
3. The event tree should, in this case, include the scenario that the new regulation is included immediately or the scenario that the new regulation is delayed. Probabilities should then be linked to this based on historical data and/or expert judgement. Since the interviews show that clients are reluctant to share project data, expert judgement will (partly) be needed to assess impact and probability.
4. An example here could be employee training sessions or regular safety checks to ensure compliance.

6.2.5. Damage assessment

This step calculates the time and money impacts resulting from cascading events. This is crucial as it translates the identified risks, exposure, (dynamic) vulnerability, and human behaviour into tangible costs and delays, which can be factored into project planning and cost estimates.

This process starts by identifying the cascading events alongside any other second-order effects. Then, each path in the event tree should be analysed for its potential consequences. Each initial impact is quantified by calculating the costs and delays, along with additional labour, material costs, and any other direct costs. Then, all secondary impacts are quantified the same way as the initial impact. For example, a delay in the delivery of materials (initial impact) may possibly lead to extended rental periods for equipment (secondary impact) and increased labour costs due to overtime (secondary impact). Historical data and expert judgement should be used to quantify these impacts. It is helpful in this process to consider multiple scenarios with different potential impacts so that worst-case, best-case and most likely outcomes can be considered. These can then be put into a Monte Carlo simulation to get an accurate estimate of the outcome. This will be explained in more detail in the next step. Ultimately, all impacts of the cascading events must be combined to obtain a comprehensive view of the total damage in terms of costs and delays.

Again, this step will be explained using an example. Consider a design error in a construction project, as shown in Figure 6.4. In doing so, the following cascading events can be identified:

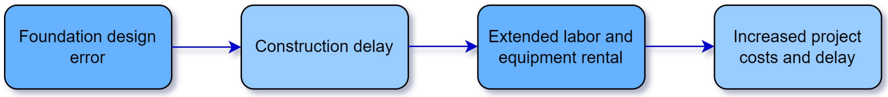

Figure 6.4: Example foundation design error

The initial impact will subsequently be quantified where vulnerability and exposure are already included in these values. For example, the redesign foundation plan costs €60,000, and the delay due to this is three weeks. Next, the secondary impacts can also be quantified. take as an example that extended equipment rental costs €6,000 per week and for 3 weeks therefore €18,000. Additional labour costs €4,000 per week for 3 weeks = €12,000.

Historical data shows that similar projects add an additional €25,000 in unforeseen costs during the redesign. In addition, expert judgement indicates that with a 30% probability, further delays due to soil instability will occur, adding an additional €15,000. From this example, a best-case, most likely and worst-case scenario can then be calculated as has been done in Equation 6.3, Equation 6.4 and Equation 6.5.

Best-case scenario:

$$€60,000 \text{ redesign} + €30,000 \text{ labor and rental} = €90,000 \tag{6.3}$$

Most likely scenario:

$$€90,000 + \text{ unforeseen costs } €25,000 = €115,000 \tag{6.4}$$

Worst-case scenario:

$$€115,000 + \text{ soil instability } €15,000 = €130,000 \tag{6.5}$$

After that, probabilities can be given to each scenario through Monte Carlo Simulations:

- Best-case: 55%
- Most likely: 35%
- Worst-case: 20%

In the end, the total impact can be calculated:

$$\text{Expected cost} = (0.55 \times €90,000) + (0.25 \times €115,000) + (0.2 \times €130,000) = €104,250 \tag{6.6}$$

6.2.6. Simulation and probabilistic assessment

Simulation and probabilistic assessment are essential in assessing potential risks involving cascading effects in construction and infrastructure projects. This step will predict and quantify the established scenarios considering the interactions of risks. The goal is to use expert elicitation to obtain refinement of the probabilities of event transitions in the previous step. After all probabilities and impacts have been determined, the event tree can be put into a Monte Carlo Simulation to calculate the uncertainties and inter-dependencies of the identified risks. During Monte Carlo Simulations, the following steps are made:

- Random values are assumed for the different situations of the event tree: optimistic, most likely and pessimistic. These values are based on the probability distributions.
- Project outcome is simulated 10,000 times.
- A distribution of different outcomes is generated by using this iteration.

Several software tools support Monte Carlo Simulations, with risicoraming.nl already being used in SSK-2018 (“Risicoraming”, n.d.). Interesting values can be obtained from the Monte Carlo Simulation, such as the mean (expected value), standard deviation (variability) and outcomes at certain confidence levels.

6.3. Integration into SSK-2018

Including the risk analysis results and event tree outcomes in initial cost estimates and contingency plans is essential to ensure the potential consequences of cascading effects and any other second-order effects are sufficiently considered. This step includes adjusting project budgets and project planning based on the identified risks and their probabilistic assessments. A detailed guide to performing this step is provided. The aim is to incorporate the findings from the risk analysis session and Monte Carlo Simulations into the cost estimates and base the budget and planning on them.

- *Review and incorporate risk analysis results:* Collect all data resulting from risk identification, event trees, dynamic vulnerability analysis, human behavioural influence, damage assessment and Monte Carlo simulations.
- *Adjust initial cost estimates:* Start by adjusting the project's baseline cost estimate. Ensure that the identified risks are linked to the appropriate components they affect. Here, the Monte Carlo simulation results are used to obtain the desired value from the range of possible outcomes considered.
- *Documentation:* Make sure to clearly describe how the risk assessments have been established. This way, other project managers and clients will know what the budget is based on.
- *Contingency reserve adjustments:* Practice should reveal how much the contingency reserve needs to be adjusted. If cascading effects of risks are linked to specific parts of the project, they will no longer be budgeted for using a contingency reserve. As a result, the contingency reserve could likely be adjusted downwards. However, this remains to be seen in practice. It is, therefore, important that projects are clearly monitored and that all information is recorded, documented and shared.

6.4. Comparison current handling and new method

To indicate the differences and similarities between the current and new method, Figure A.4 should be compared with Figure 6.2. The first similarity is that both methods focus on risk identification first using the RISMAN method. Furthermore, both methods perform Monte Carlo simulations to calculate the estimate probabilistic, where the impact and probability of risks are determined based on expert judgement. Lastly, both methods emphasise the importance of extensively documenting all actions and choices made.

Besides similarities, there are also significant differences between the two methods. The first difference is about second-order effects. The current method underestimates second-order effects and does not clearly show how they can be considered. Moreover, respondents do not know precisely where to estimate second-order effects in the current method. The new method includes second-order effects by displaying them as an event tree and using the Elementary Bricks model to identify and quantify them systematically. The second difference is correlating risks. Although risks could be correlated to each other in the current method, this is not required by the client because it is too time-consuming and difficult to understand. The new method may be easier to understand, so that correlating risks may lead to more accurate cost estimates. The third difference is the inclusion of human behaviour influence in the method. The current method does not show human decisions to be included in the method, while the new method addresses this. The fourth difference is that the risk analysis session in the current method is often conducted mono-disciplinary while the new method recommends doing it multidisciplinary. The final difference is in visualising cascading effects in an event tree. The current method does not require this, but the new method allows the estimation of risks to be displayed more clearly.

7 Validation

This chapter validates the developed method, potentially improving the identification and quantification of risks and their second-order effects on construction and infrastructure projects. Members of the expert panel were asked first to assess the current method of identification and quantification using the listed assessment form, which can be found in section D.1. The expert panel was subsequently asked to assess the new method developed, as explained in chapter 6. This is done using a more or less similar assessment form, which can be found in section D.2. The assessment consists of four parts: identifying risks, quantifying risks, identifying and quantifying second-order effects, and a free-fill option on possible improvements. The scores on the scale represent the following values: 1 = very low, 2 = low, 3 = average, 4 = high and 5 = very high.

7.1. Objective

Validation aims to evaluate the new method developed. Validation in construction- and infrastructure method development is important for several reasons:

- *Ensuring quality and credibility:* Validation in research and method development ensures quality and credibility (Lucko & Rojas, 2010).
- *Accuracy in results:* By validating research findings and practices, researchers can ensure the accuracy of their results. (Lucko & Rojas, 2010).
- *Applicability:* Validation helps determine whether the newly established method applies to real-world scenarios. (Lucko & Rojas, 2010).
- *Meeting program of requirements:* Validation helps determine whether the method meets the established program of requirements.

7.2. Results

The results of the first assessment are presented in Figure 7.1, Figure 7.2 and Figure 7.3. The results are shown using a bar chart to clearly outline how the new method scores compared to the current method. Although this study has been carried out qualitatively so far, comparing how respondents feel about certain aspects of both methods in terms of scores from 1 to 5, which can be seen as a quantitative assessment, is useful (Elo et al., 2014). The scores should be considered as a comparison between both methods.

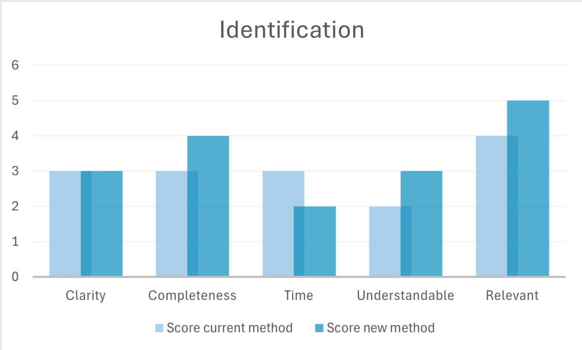

Figure 7.1: Expert panel assessment 1: identification

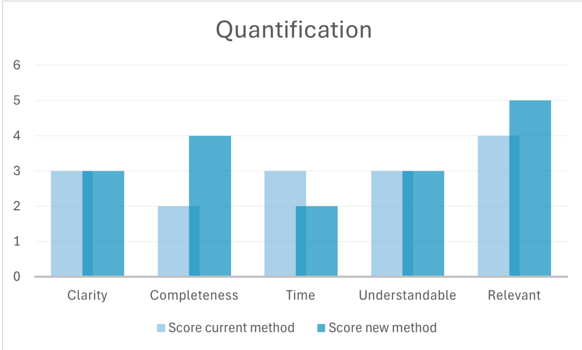

Figure 7.2: Expert panel assessment 1: quantification

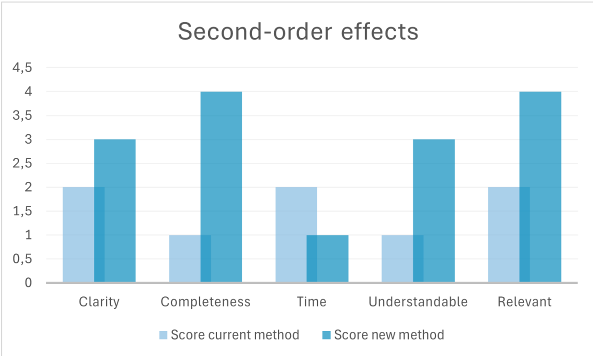

Figure 7.3: Expert panel assessment 1: second-order effects

The assessment form, which can be found in subsection D.3.1, reveals that clarity scores equally well when identifying and quantifying but that clarity regarding second-order effects is nevertheless somewhat clearer with the new method. Completeness regarding risk identification scores slightly higher under the new method than under the current method. This difference is even marginally more significant when quantifying risks. According to Expert 1's assessment, second-order effects are included much more entirely in the new method than in the current method. According to Expert 1's assessment, the current method takes less time to identify and quantify risks than the new method. However, the new method takes much more time when discussing second-order effects. For the client, the new method is easier to understand than the current method as it scores higher on identification, equal on quantification, and much better on second-order effects. When assessing the relevance of construction and infrastructure projects, the new method scores just a little better, especially regarding second-order effects.

It further states that the current method's strength is that it involves expert judgement, which can be done quickly and effectively. The current method's weakness is that the second-order effects of risks are not properly accounted for in the estimation. The strength of the new method is that it has been explained step-by-step, allowing for structured implementation. A disadvantage of the new method is that it will likely take more time than the current method and that cost experts need to be trained to understand and apply it. Furthermore, it is recommended by Expert 1 that the most common situations of second-order effects, more or less described in section 5.3, should be included in the method to form a new way of working.

The results of the second assessment are presented in Figure 7.4, Figure 7.5 and Figure 7.6. The results, again, are shown using a figure to clearly outline how the new method scores compared to the current method. Although this study has been carried out qualitatively so far, comparing how respondents feel about certain aspects of both methods in terms of scores from 1 to 5, which can be seen as a quantitative assessment, is useful (Elo et al., 2014). The scores should be considered as a comparison between both methods.

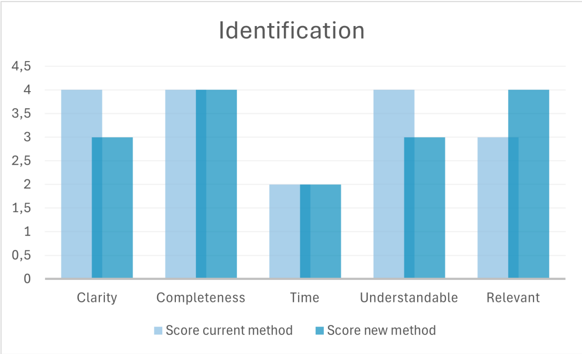

Figure 7.4: Expert panel assessment 2: identification

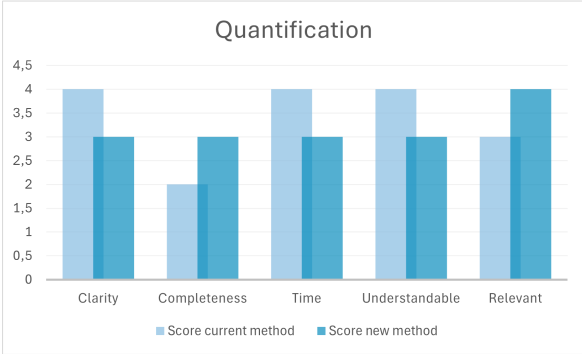

Figure 7.5: Expert panel assessment 2: quantification

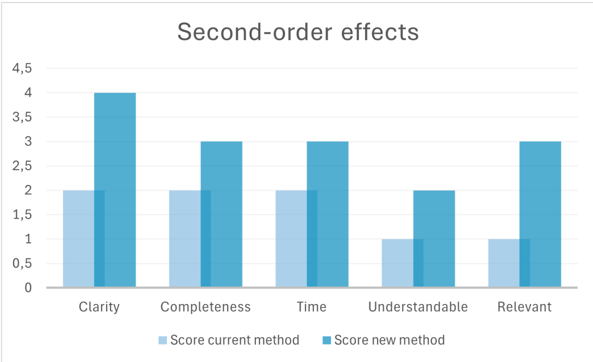

Figure 7.6: Expert panel assessment 2: second-order effects

The assessment form filled in by Expert 2, which can be found in subsection D.3.2, reveals that clarity scores better with the current method for quantifying and identifying risks, but the new methods score higher regarding second-order effects. The new method scores higher than the current method on completeness both in quantification and second-order effects. The completeness concerning identification is equal, according to Expert 2. The time it takes to identify risks will be more or less the same in both methods, while quantification seems to take slightly more time in the current method. Regarding second-order effects, this will take longer with the current method than with the new method, indicated Expert 2. The new method seems a bit more difficult for the client to understand when it comes to identifying and quantifying risks. On the contrary, if second-order effects are specifically considered, it seems clearer to the client. Finally, the new method seems relevant to construction and infrastructure projects. This is reflected in higher scores for identification, quantification and second-order effects.

Expert 2 indicated that the strengths of the current method are that everyone in the Netherlands uses the SSK-2018, and highly skilled risk managers are needed to Identify and quantify risks. The weaknesses of the current method lie in that the consequence classes of the RISMAN method are often not proportionate to the total project size. This makes the outcome of a good risk management process less valuable. This can be explained by a quote:

> *"After all the efforts in recent months, the risk quantification came out with a risk reservation of less than 1%. It was then decided to keep 15% anyway. So then you might as well not quantify risks at all."*

The strength of the new method is that it scores higher than the current method in many aspects, as shown in the figures. However, due to the unfamiliarity of this method, implementing it and the overall process are expected to take more time. Furthermore, according to Expert 2, the new method still seems quite complex, and a good balance is needed between simplicity and predicting reality.

Recommendations for further development of current methods lie in the early involvement of a cost expert in the project. The recommendation for the new method is to apply it to an actual project. This has already been done for different versions of the SSK to compare the results. So, the new method could also be added to this list to see how it actually scores compared to other methods.

The results of the second assessment are presented in Figure 7.7, Figure 7.8 and Figure 7.9. The results, again, are shown using a figure to clearly outline how the new method scores compared to the current method. Although this study has been carried out qualitatively so far, comparing how respondents feel about certain aspects of both methods in terms of scores from 1 to 5, which can be seen as a quantitative assessment, is useful (Elo et al., 2014). The scores should be considered as a comparison between both methods.

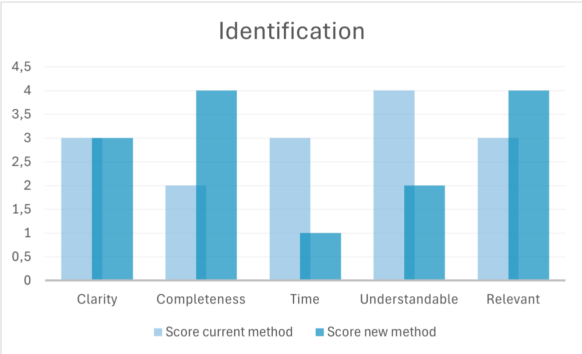

Figure 7.7: Expert panel assessment 3: identification

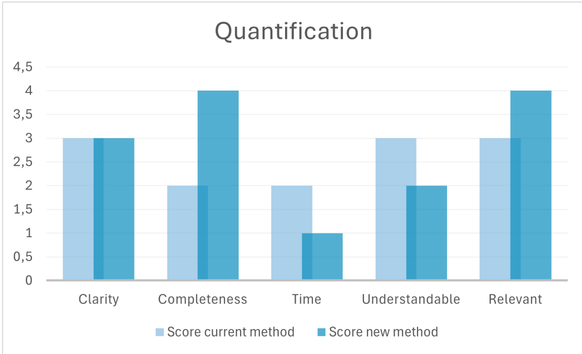

Figure 7.8: Expert panel assessment 3: quantification

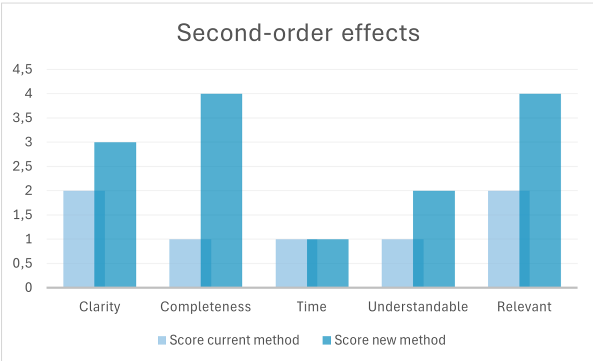

Figure 7.9: Expert panel assessment 3: second-order effects

The assessment form filled in by Expert 3, which can be found in subsection D.3.3, reveals that in terms of clarity, the new method scores are equal compared to the current method based on identification and quantification but that second-order effects emerge more clearly. Expert 3 indicates that the new method is more complete in all aspects than the current one. The scores show that the new method takes quite a bit more time to identify and quantify. The time regarding second-order effects will be about the same, indicates Expert 3. The current method appears a little easier to understand when it comes to identifying and quantifying risks. However, the new method seems to be somewhat easier to understand regarding second-order effects. In addition, the new method appears to be more relevant than the current one.

According to Expert 3, the current method's main strengths are that it is known to the entire civilian world and is, therefore, straightforward. Its weaknesses are its limited integration and comprehensiveness in understanding 'all' risks. Hence, the right specialists must be at the table, but this is not always guaranteed. There may also be too much freedom in completing the SSK-2018, resulting in missing, incomplete, or duplicated risks.

Expert 3 indicates that the strength of the new method is that it incorporates a more integrated approach. With second-order effects included, the impact of risks is more fully and explicitly understood. This forces experts to think a little longer about the risks and highlights the human part more explicitly. The integrated approach could ensure that duplication of risks is avoided. Ultimately, this method could provide a more complete picture. The weakness of the new method is that it seems more complex, making it particularly suitable for larger projects. In addition, a high level of knowledge regarding risk management must be present in both the client and the contractor. In addition, the risk estimation process becomes more intensive, which may increase the likelihood of errors.

> *"You might not be able to see the wood for the trees"*

Expert 3 indicated that the new method's further development should focus on making it more effective while keeping it simple.

7.3. Conclusion

The expert panel indicates that the new method is of higher quality and credibility because it establishes a structured methodology, which is essential for acceptance and application to real-life projects. Furthermore, the expert panel confirms that the new method brings improved accuracy in identifying and quantifying risks and more clarity regarding second-order effects compared to the current method. The new method is generally more understandable to the client, especially regarding second-order effects, enhancing its practical utility in project management.

Although the new method is given a comparatively favourable score on many aspects compared to the current method, there also seems to be a disadvantage to the new method concerning time. More time seems to be needed to adopt and implement the new method. In addition, the complexity of the new method may become a problem. Training sessions are required in order to update experts on their knowledge and counter this complexity. This will also cost time and money.

According to the program of requirements, as established in section 5.8, the new method should comply with integrating second-order effects. From the scores of second-order effects, it can be concluded that this requirement is incorporated in the new method. The regular cost and planning updates and the multidisciplinary risk analysis sessions are integrated into the method, so they can also be ticked off. Whether the new method is easier to understand or not, opinions differ. The expert panel unanimously agreed that including second-order effects in the new method is more understandable. However, the new method seems more challenging to understand in terms of the identification and quantification of risks in general. As a result, it cannot be fully concluded that this requirement is included in the new method. Also, regarding how much time the new method takes compared to the current method, it can be concluded that there is no improvement in the new method. The expert panel indicates that they expect the new method to take more time to use but also to train experts to understand the method.

8
Discussion

This chapter reflects on the results from the literature review, conducted interviews, and the method developed alongside the validation. Furthermore, limitations are discussed, and recommendations are given for further research and practical implications.

8.1. Literature review

It is significant to emphasise that the concept for first-order and second-order effects, obtained in subsection 4.3.3, is created by combining several concepts that mean more or less the same phenomenon. Second-order effects are already mentioned in some papers. Still, the literature review shows that terms such as ripple, knock-on, cumulative, disruptive, and cascading effects are also used to indicate more or less the same phenomenon. Therefore, an attempt has been made to establish an overarching term for all these described synonyms, which can help better identify and quantify risks.

8.2. Interviews

Different synonyms were used for the same phenomenon during the interviews as in the literature. Terms such as secondary and fringe effects were often mentioned, so these synonyms were also added to the concept drawn up for first- and second-order effects based on the literature review and the interviews with experts. Although all respondents more or less agreed with the defined terms, the dividing line between first- and second-order effects seems to be more of a grey area. This is mainly because it is difficult to determine when something is a direct effect and when it is an indirect effect. Collecting more examples and a quantitative research approach will help represent this dividing line more clearly.

An interesting finding from the interviews is that experts in the field gave different answers regarding how second-order effects should be estimated in the SSK-2018. It is worth highlighting that the respondents had different job titles and experiences and worked for various companies such as consultancy and engineering firms, contractors and universities. The literature review and interviews did reveal that second-order effects of risks are an under-emphasised topic within risk estimation. As respondents' experiences and functions varied immensely in the interviews, this might have led them to give different answers on where second-order effects should be estimated in the SSK-2018. Because the issue of second-order effects is so under-addressed, experts in the field could also have created their way of accounting for this phenomenon after all. Experts were familiar with the phenomenon but gave different answers about where these costs should be included in the SSK-2018.

On the causes and consequences presented in section 5.3, the point of discussion is that these categorised causes and consequences concern only the examples mentioned in the interviews conducted. This covers only a sample of 10 interviews conducted with cost experts, project managers, contractors, and arbitrators. More examples should be considered to establish more valuable categorised causes and consequences. This will be discussed further in section 8.4 and subsection 8.5.1.

Furthermore, there can also be a discussion on the willingness always to provide the most realistic estimate possible. The interviews reveal that this can differ between the consultant, who indicated that he always strives for an accurate estimate, and the contractor, who sometimes has to estimate while considering the market. By market, it means the pressure to produce a competitive bid. In other words, the contractor sometimes has to adjust the estimate slightly to win over a project. Consultants, in contrast, have an advisory role and have no direct interest in the execution of a project. Their primary role is to provide objective advice and ensure the accuracy of their estimates. Contractors are often directly involved in project execution and frequently have to compete on price to win contracts. This can lead to pressure to estimate. Also, it is usually not accepted by the company to budget for many risks in an estimate because the total cost will be too high. This may indicate that the culture within companies rejects high-risk reservations. In addition, experts say they could make estimates somewhat more accurate by using complex mathematical models. However, interviews also show that clients do not require this as they do not understand these complex mathematical models.

8.3. Method development and validation

A key point that emerged in validating the method is that the new method could potentially lead to improvements in identifying and quantifying risks, especially second-order effects. Still, it will likely take longer than current methods because working out all possible scenarios in an event tree is time-consuming. To leave the trade-off between making the best possible estimate and the time spent on it to the expert, possible 'shortcuts' in the method could be explored. While further research remains to reveal how much more accurate an estimate becomes with each step of the method, it may be possible to see if steps can be skipped to save time in the process. Although steps 1, 2, 5 and 6 cannot be removed from the method because the method will not work without these steps, one can consider leaving steps 3, 4 or both out of the method. In Appendix A, the different method steps are shown with 'shortcuts'. Figure A.1 represents the method without step 3, Figure A.2 show this without step 4 and Figure A.3 does this for the method without steps 3 and 4.

Furthermore, it is essential to realise that the reviews only contain the assessments of the expert panel, which consists of three experts. In addition, experts from the expert panel indicated that linking grades to current project management methods and the new method developed was complicated. As mentioned earlier, the grades should only be interpreted to clarify which method is more significant in a particular aspect. So, the grades cannot accurately represent the quantity of one method that is significantly better.

Finally, the probability and impact of the method are based on expert judgement complemented by the comparison with previous projects. For now, expert judgement seems the most appropriate method, as clients are often not open to sharing data on completed projects. This makes it challenging to build a database that can serve as substantiation for choices of impact and probability. It is advisable to build up a database of completed projects with the substantiation of specific decisions to use in the future. Building up enough data could lead to more accurate probability and impact values than those based on expert judgement.

8.4. Limitations

This section will discuss this research's limitations. First, the scope limitations will be given, and then the method limitations will be addressed.

8.4.1. Scope limitations

To keep this research within the available time, a scope was created that entails limitations. Risk liability has not been included in this research. Risk liability can significantly affect how a person views risk. In the case of liability, a link can be made to contract forms. This study only examined UAV-gc contract forms. Other contract forms involve different laws and regulations, influencing a person's view of risks. Moreover, this study only considered projects in which the SSK-2018 methodology was used to estimate costs. This method is only used in the Netherlands. Costs will be calculated in other ways outside the country. As a result, this study is particularly representative of projects in the Netherlands. Lastly, this study only considered the effects of risks related to time and money. As indicated in the literature review, there are also other effects, such as productivity losses, that can, in turn, affect the entire project.

8.4.2. Method limitations

Semi-structured interviews ensure that mainly the pre-established topics are covered, leaving other potentially interesting issues unaddressed. This could be avoided by conducting part of the interviews based on the open-interview method. In addition, sample size and selection are a limiting factor. Conducting interviews with a limited number of experts may prevent the full breadth of perspectives from being captured. Another method limitation is the use of hybrid coding. Using a hybrid version of coding when analysing interviews may introduce biases. This is because it partly searches for specific topics. Finally, using a small expert panel limits its results. The panel's expertise, while valuable, might not cover all the essential aspects.

8.5. Recommendations

This section will discuss recommendations for further research and practice.

8.5.1. For further research

This study can be used for follow-up research in several areas:

- *Quantitative research:* This study was particularly conducted qualitatively. However, it could be of great value to approach a similar study quantitatively. In this way, more examples could be collected regarding the causes and consequences of second-order effects, possibly leading to new categories. In addition, an expanded expert panel with more assessments could also provide more valuable conclusions regarding assessing the new method and further developments.
- *Testing & Implementation:* Although experts in the field have assessed the method, this assessment is no complete guarantee of how the method will actually perform in implementation. Several tests should reveal how accurate a cost estimate can become using the new method compared to the current one. This will also involve looking at how much more precise an estimate becomes while omitting steps three and/or four of the method. This process should include how much extra time the new method takes compared to the current one. In this way, a cost-benefit analysis can be carried out, for example, showing whether the method can be of value to the construction and infrastructure sector when it comes to estimating risks.
- *Incorporate liability:* Liability was not included in this study. Including liability could potentially lead to new insights as stakeholders will act accordingly.

8.5.2. For practice

Recommendations for practice are distinguished based on the target audiences: Crow knowledge platform (SSK-2018 developers), consultants, clients, and contractors.

- *Crow knowledge platform:* Crow knowledge platform, the developers of the SSK-2018, could consider incorporating the method established in this research into the SSK-2018. In section 6.3, it is described how this can be done. In short, all data resulting from risk identification, event trees, dynamic vulnerability analysis, human behaviour influence, damage assessment and Monte Carlo simulations should be included in the estimate. In addition, the SSK-2018 should provide space to substantiate cost estimates so everything can be properly documented. Further testing will demonstrate to which extent the contingency reserve needs to be adjusted when using the new method. Because the new methodology is likely to identify more risks with second-order effects, the commonly used value for the contingency reserve could potentially be adjusted downwards as unidentified risks are captured by this contingency reserve.
- *Consultants & Engineering Firms:* Consultants and engineering firms should continue making the most realistic estimates possible, as they have an advisory role. In doing so, it is beneficial to encourage improvements in current methods by providing space for research and graduation projects in this direction. With the results of these studies, they could advise the developers of current cost estimation methods on possible improvements. Also, consultants and engineering firms can use the results of this study as a justification for specific cost estimates where, specifically, many second-order effects have been identified and quantified. Substantiation with this

research would help clients better understand why certain costs were budgeted. Besides, cost experts should clearly document where second-order effects are included in the estimate. The justification of the estimate is essential. Finally, engineering and consultancy firms should build an organised database where all projects can be clearly traced and show which second-order effects have occurred in the projects. This can help in risk analysis sessions where comparisons to other projects are made. In future, this would also allow both the impact in time and money and the probability of occurrence of risks to be based on the database. Expert judgement could thus be replaced by data-driven substantiation. To realise this, all parties involved in a project need more transparency regarding the occurrence of risks.

- *Contractors:* For contractors, ensuring a culture change within the company is recommended. This means employees should not be 'shot down' if they include a significant risk reservation in the budget, while in practice, this proves to be necessary. Also, like consultants and engineering firms, contractors can use the results of this study as a justification for specific cost estimates where, specifically, many second-order effects have been identified and quantified. Substantiation with this research would help clients better understand why certain costs were budgeted. Besides, cost experts should clearly document where second-order effects are included in the budget and show how this was done. The justification of a budget is essential. Finally, contractors should also create a database to quickly retrieve the risks encountered on different projects to improve risk analysis sessions.
- *Clients:* Clients should delve more into hard-to-understand cost estimation methods and associated mathematical methods as it can be concluded that they do provide improvements in cost estimates. When they understand these methods, they could consider requiring these methods from the contractor and consultancy & engineering firms. In this way, the overall cost estimation process will be improved in which everyone is interested. In addition, clients should be more transparent in sharing information on risks encountered in projects. Indeed, cost estimators and project managers can learn a lot from this, and a database can be built that can serve as a foundation for estimates and planning.

9 Conclusion

The literature review, along with the interviews and the method developed, answer the sub-questions, which combined answer the main question:

> *How can construction and infrastructure project managers effectively identify and estimate the impact of second-order effects of risks on cost estimates and project planning during the project design phase?*

From the literature, an understanding of the first-order effect and the second-order effect of risk has been developed, and this has been reviewed and improved during interviews with experts in the sector. This answers sub-research question 1: *What are the second-order effects of risks?*

First-order effects of risks are the direct and foreseeable consequences of a risk in a construction or infrastructure project often identified in a risk analysis session. Preventive or corrective measures can be taken to reduce the likelihood or impact of these risks. First-order risk effects are simple, quantifiable consequences and can be directly linked to a cause, possibly leading to increased costs or delays.

Second-order effects of risks are the indirect effects that follow from the initial risk or arise from a corrective or preventive measure. These effects can be more significant, possibly multiplying the original impact by a multiple. They can affect project activities that were not directly affected, making these activities more expensive or delayed due to disruptions. Second-order effects are edge effects, ripple effects, chain effects, cumulative effects, disruptive effects, and cascade effects that can influence the dynamics of project schedules and cost estimates in a compounded way.

From interviews with cost estimators, project managers, arbiters and risk managers from various contractors, supplemented with the literature study, an answer can be given to sub-research question 2: *How are second-order effects of risks currently being handled?* Risks are identified during a risk analysis session that is carried out mono-disciplinary using the RISMAN method and making comparisons to similar projects. Next, likelihood and impact are assigned to the identified risks through ranges with pessimistic and optimistic values. In cost estimates, an amount of money is linked to the risks and the duration of schedules. Following this, the schedule and estimate are put into a Monte Carlo Simulation, yielding a total project duration or project costs with an often chosen 85% probability. However, some clients select other values, such as the P50 value. Finally, based on expert judgement, an additional reservation is added to the cost estimate and buffers in the schedule. Although this reservation can be calculated mathematically and probabilistic, this does not happen in practice. Although respondents from interviews were familiar with the second-order effects of risks, they did not unanimously agree on where in the SSK-2018 these should be budgeted:

- Direct costs to be detailed further
- Object-specific risks
- Non-object-specific risks
- Non-object-specific risk contingency

- No specific place, second-order effects not taken into account

This indicates that respondents are unsure where second-order effects should now be estimated in the SSK-2018. According to respondents, proper documentation, including well-substantiated estimates, is currently poorly done.

During the interviews with cost estimators, project managers, and risk managers, examples of second-order effects were requested. All examples were then collected, categorised, and placed under the terms causes or consequences. This allows for an answer to sub-research question 3: *what are the causes and consequences of second-order effects of risks?* The causes are categorised into unexpected ground conditions, Black Swans, design changes, accidents, miscalculations, and slow procedures. The consequences are categorised into new investigations, design changes, recalculations, material (price) changes, disruptions, damage repair, scarcity of machinery and personnel, seasonal activities, and new regulations.

What also emerged from the interview results was that estimates are not always carried out in the best and most realistic way possible. Indeed, this is different for consultants, contractors, and clients. The interviews show that consultants always strive to produce the most realistic estimates that meet the client's requirements since they have an advisory role. However, the client's requirements often state that risks do not need to be correlated in cost estimates, while experts indicate that correlations between risks exist in practice. Clients usually do not understand complex mathematical and correlation methods well, so they do not require this from the contractor. From this, it can be concluded that estimates could be performed more accurately, which is currently not done due to client requirements. In addition, respondents from contractor companies indicated that a cost estimate sometimes has to consider the market. In other words, they estimate certain things more positively than reality to win a project. As a result, estimates can also sometimes appear unrealistic.

Through literature study and conducted interviews, it has become clear where the challenges lie regarding identifying and assessing the second-order effects of risks. This has been transformed into a program of requirements, which can be found in section 5.8. A new method has been developed to identify and quantify risks and second-order effects to address these challenges. The method is based on the theory by (Zuccaro et al., 2018) of cascade effects, typically applied in the natural disaster sector, adapted for application in the construction and infrastructure sector during the risk identification and quantification in the design phase. After establishing the method, sub-research question 4 can be answered: *How should the 'Standaard Systematiek voor Kostenramingen 2018' be adjusted to incorporate second-order effects of risks in calculating contingency?* By using the new method, described chapter 6, identifying risks is likely to become more complete and second-order effects of risks are clearly mapped out through an event tree. These can subsequently be estimated in the SSK-2018. In the SSK-2018, object-specific or non-object-specific risks should be clearly described so that cost estimators and project managers precisely understand the basis of an estimate. This description should also include the second-order effects of risks. The non-object-specific risk contingency, which usually consists of risks that couldn't be identified and thus serves as a contingency reserve, can likely be adjusted downwards since risks with second-order effects will, with the use of the new method, be covered in the category of (non-)object-specific risks in the SSK-2018 estimate, as can be seen in Figure 9.1. However, this still needs to be confirmed through upcoming practical examples. Furthermore, it is also worth emphasising that even with the use of the new method, not all existing risks with second-order effects can be identified. The new method only serves as an improvement on the current method.

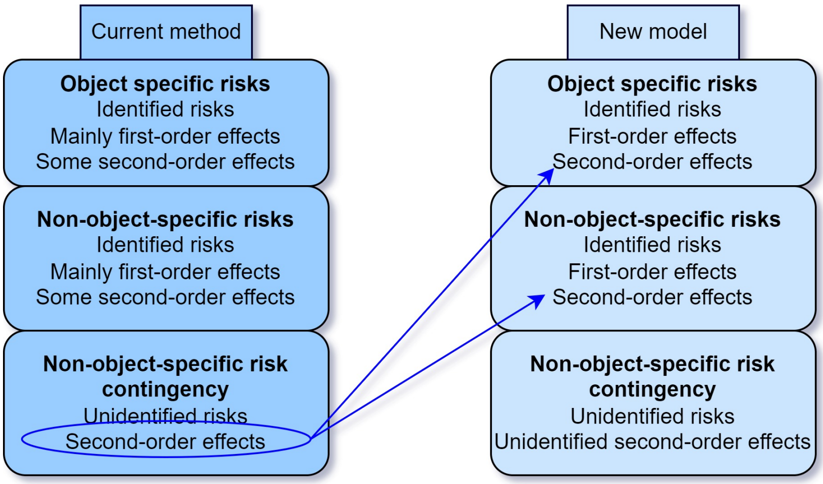

Figure 9.1: SSK-2018 risk reservation of current method compared to new method

The expert panel indicates that the new method is of higher quality and credibility because it establishes a structured methodology, which is essential for acceptance and application to real-life projects. Furthermore, the expert panel confirms that the new method brings improved accuracy in identifying and quantifying risks and more clarity regarding second-order effects compared to the current method. The new method is generally more understandable to the client, especially regarding second-order effects, enhancing its practical utility in project management. Although the new method is given a positive score on many aspects compared to the current method, there also seems to be a disadvantage to the new method concerning time. More time seems to be needed to adopt, implement and use the new method. In addition, training sessions are necessary to update experts on their knowledge and enable them to understand the new method. This will also cost time and money. Lastly, experts on the expert panel indicated that the new method only applies to large projects, whereas risk reservation is not addressed as profoundly in smaller projects. In larger projects, a bit more budget is available to go deeper into this risk reservation. Indeed, in smaller projects, risks are sometimes not identified but are only included as a percentage of the total budget.

Further research should reveal how accurate cost estimates can be with the new method compared to the current one. It should also measure precisely how much extra time both will take. Subsequently, this follow-up research could be used to make a trade-off on whether the new method is helpful for practice.

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A
Additional images

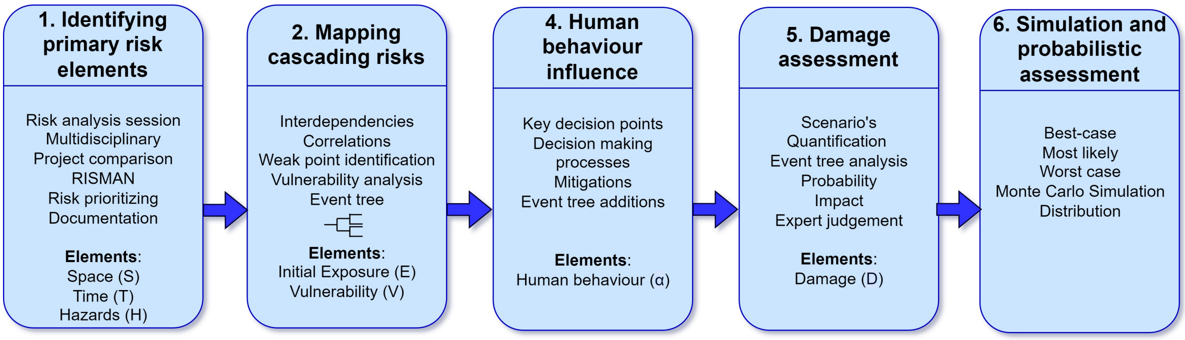

Figure A.1: Model steps without step 3

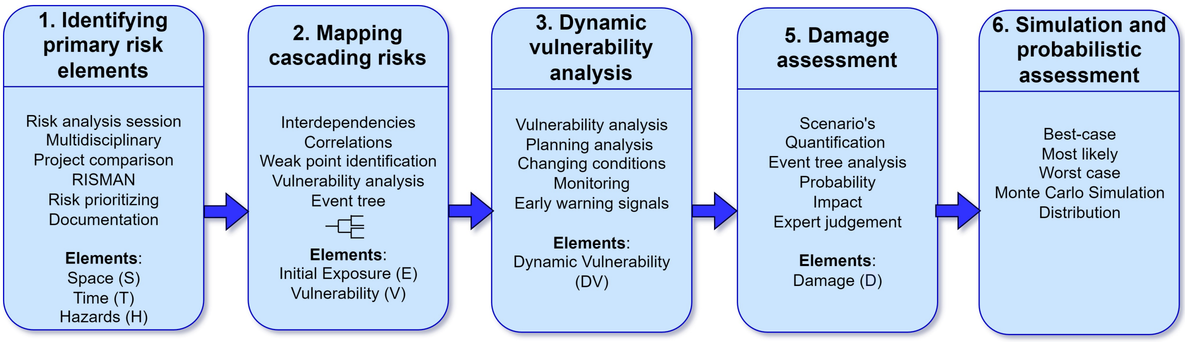

Figure A.2: Model steps without step 4

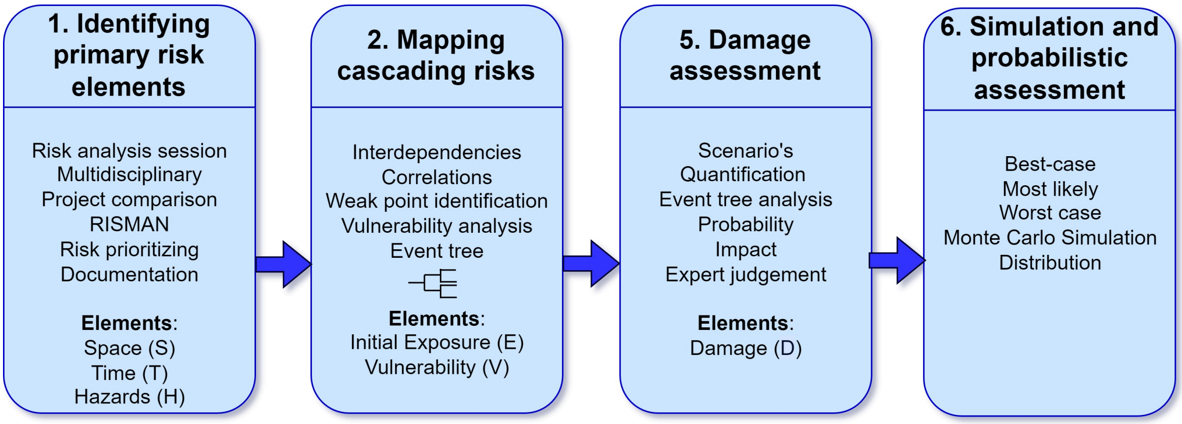

Figure A.3: Model steps without step 3 and 4

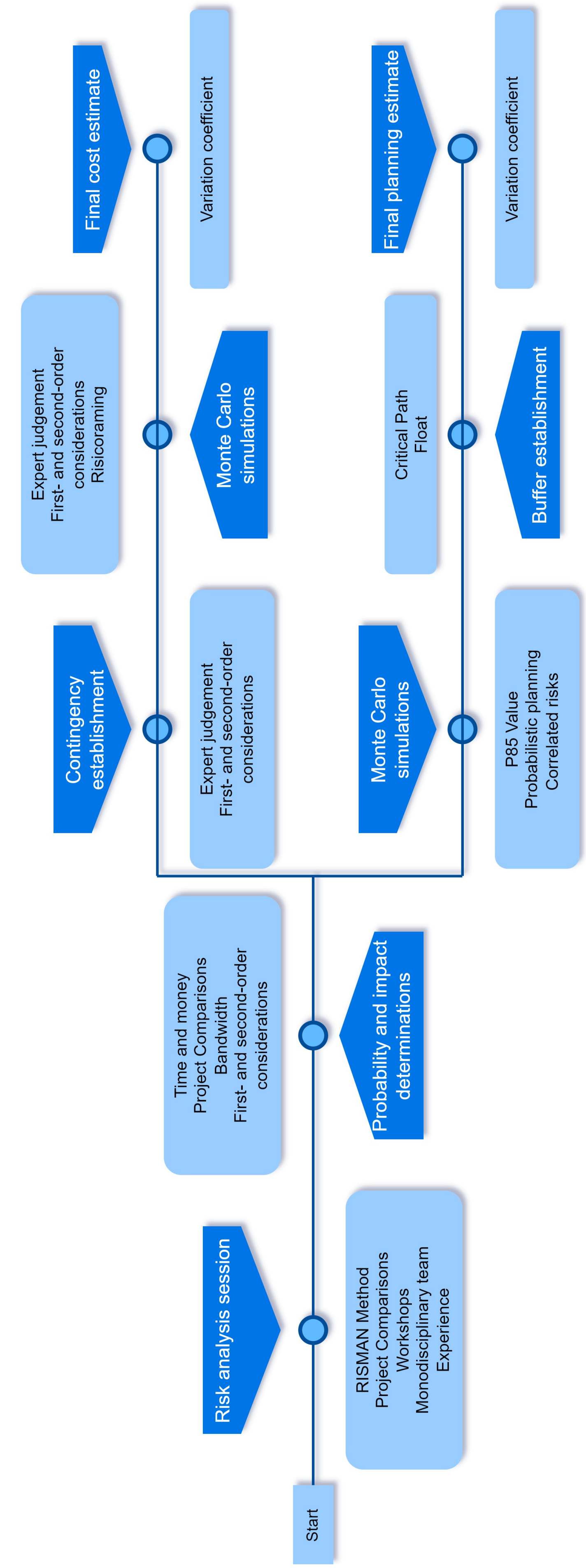

Figure A.4: Cost and planning estimates activities according to interview data

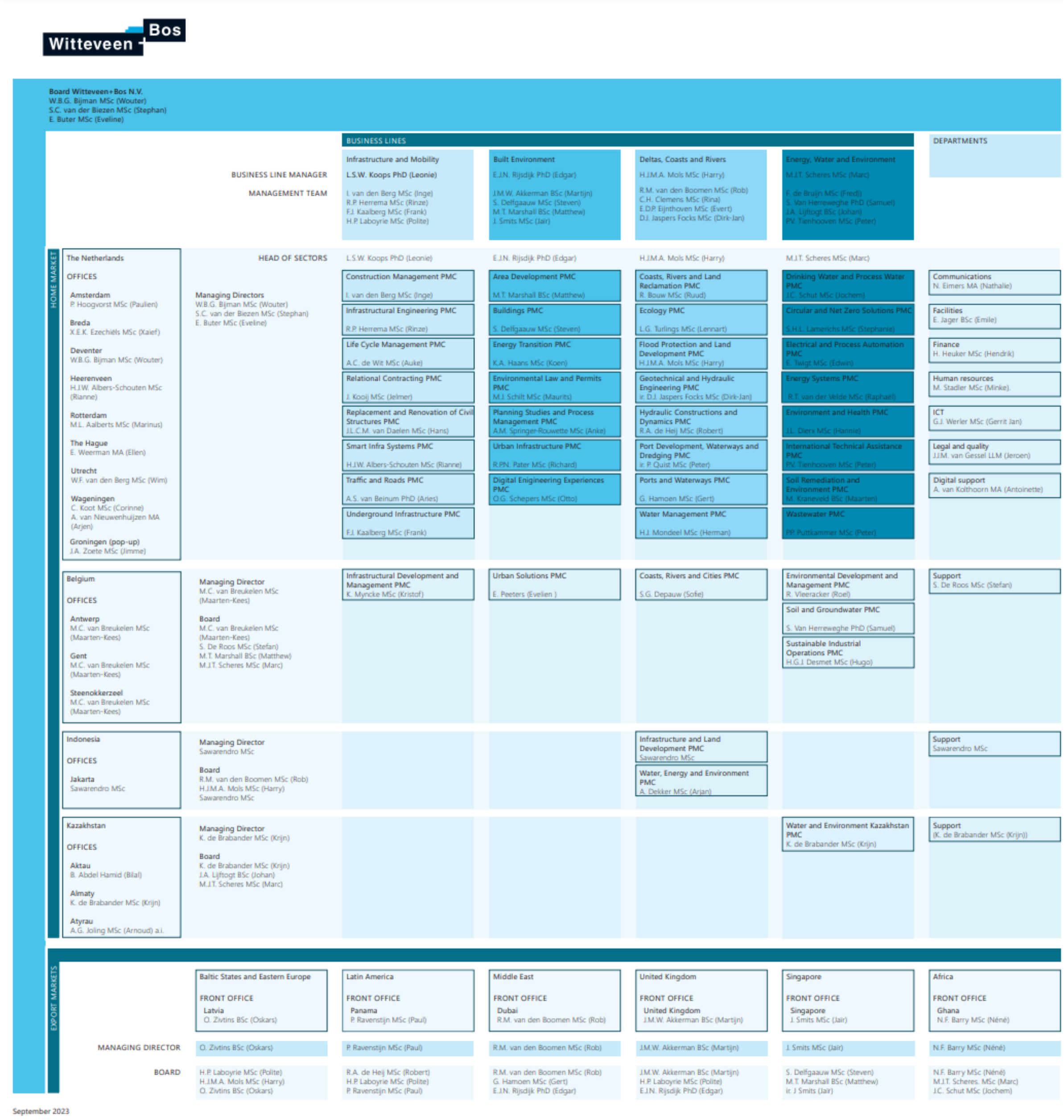

Figure A.5: Witteveen+Bos organic structure (Witteveen+Bos, 2023)

Client:	0	Price level:	jan 2024		Date:	03-04-2024		
Project:	0	Version:	01		Project code:	13xxxx		
	Project summary	Status:	Ongecontr.		Author:			
code	**description**					**Known costs**	**Contingency**	**Total**
				Direct costs	**Indirect costs**			
		Direct costs Known	**Direct costs Preliminaries**					
	INVESTMENT COSTS							
BK01	Object 1	€ -	€ -	€ -	€ -	€ -	€ -	€ -
BK02	Object 2	€ -	€ -	€ -	€ -	€ -	€ -	€ -
BK03	Object 3	€ -	€ -	€ -	€ -	€ -	€ -	€ -
INV.BK	**TOTAL CONSTRUCTION COSTS**	**€ -**	**€ -**	**€ -**	**€ -**	**€ -**	**€ -**	**€ -**
INV.ENG	**TOTAL ENGINEERING**	**€ -**	**€ -**	**€ -**	**€ -**	**€ -**	**€ -**	**€ -**
INV.VK	**TOTAL REAL ESTATE**	**€ -**	**€ -**	**€ -**	**€ -**	**€ -**	**€ -**	**€ -**
INV.OBK	**TOTAL REMAINING COSTS**	**€ -**	**€ -**	**€ -**	**€ -**	**€ -**	**€ -**	**€ -**
INV.SUB	**SUBTOTAL INVESTMENT COSTS**	**€ -**	**€ -**	**€ -**	**€ -**	**€ -**	**€ -**	**€ -**
INV.OOR	Project related contingencies						€ -	€ -
INV.DET	**INVESTMENT COSTS DETERMINISTIC**	**€ -**	**€ -**	**€ -**	**€ -**	**€ -**	**€ -**	**€ -**
INV.VER	Skewness						€ -	€ -
INV.EXCL	**INVESTMENT COSTS PROBABILISTIC (Mu-value)**					**€ -**	**€ -**	**€ -**
INV.BTW	VAT					€ -	€ -	€ -
INV	**INVESTMENT COSTS VAT**	**€ -**	**€ -**	**€ -**	**€ -**	**€ -**	**€ -**	**€ -**
	Bandwidth: with 70% certainty investment costs excluding taxes lie between exclusief VAT between					*€ -*	*and*	*€ -*
	Variation coëfficiënt (estimated) ±						*40%*	
	Risks in relation to known costs							

Figure A.6: SSK-2018 overview Excel (CROW, 2018)

B

Categorizing causes and consequences

Table B.1: Categorizing causes and consequences mentioned in interviews

Cause	Category	Consequence	Category
Unexpected soil conditions (Kedichem layer found)	Soil Conditions	Research + recalculations needed Recalculations	Design Adjustments Recalculations
Validity of research/permits	Design Adjustments	Complaints from residents	Procedures
War	Black Swan	Raw materials more expensive	Design Adjustments
Different legislation and subsidies	Material Changes	Design Adjustments	Different legislation and subsidies
Covid	Black Swan	Materials not available	Substitute material (other country)
Redesign	Materials	Design Adjustments	Laboratory tests (wave load too high)
Research	Design Adjustments	No regulations regarding floors on pile	Legislation and subsidies
Discussion with fire department	New taxes that were not foreseen	Design adjustments	Design Adjustments
Additional pump capacity requested (extra spray capacity added)	Scope Change	Greater sediment transport	Mussel banks affected
Merg study delayed by a year	Miscalculation	Building not earthquake-resistant	Miscalculation
Basement full of cross bracing	Parking garage no longer usable	Scope Change	Disorganization
Disruption of construction process	Disorganization	Decrease in production	Production decrease
Low availability of people or suppliers	Scarcity	Activities take longer	Disorganization
Continued on next page			

Table B.1 – continued from previous page

Cause	Category	Consequence	Category
Delay	Delay	Other activities delayed	Disorganization
Obstacle in your work	Miscalculation	Schedule delayed by 2 weeks	Other activities cannot start
Subcontractor has no time	Schedule further delayed	Disorganization	Scarcity
Crane falls over	Accident	Repair damage	Only one crane available (specific type)
Massive time and cost overrun	Repair damage	Scarcity	Disorganization
Scope change: wall longer	Scope Change	Construction already on site to extend wall	Much more time and money
Design Adjustments	Disorganization	Change in essential product type	Scope Change
Production takes longer	Process and method change	Not excavating	Higher costs and more time
Material Changes	Recalculations	Design Adjustments	Disorganization
Cables and pipes in the wrong place	Miscalculation	Extra pipe to be made	Excavating twice as much
Transportation costs twice as much	Acceptance costs twice as much	Rebar workers make extra openings in reinforcement	Structural consequences
Concrete poured a week later	Design Change	Recalculations	Disorganization
Extra safety measure	Scope Change	Safety measure introduces new risk	Arm lost
Change project team	Scope Change	Requirements for equipment (Rules and Regulations)	Scope Change
Pricing yourself out of the market and unable to deliver		Leaking construction pit	Damage
Disruption of water purification	Repair damage	Decision-making too late	Procedures
Validity of research expires	Procedures	Objection and appeal on permits	Adjust plan
Floron research expired	Reapply for permit	Delay	Design Change
New research and tests	New permits	Disorganization	Drawing error
Miscalculation	Space requirement 2m outward	River raised	Many works need to be redone
Design Change	Disorganization	Permits no longer valid	Replanting studies
UTA Staff present longer	New permit	Research again	UTA Staff present longer
Sheet pile does not reach depth	Miscalculation	Extra work	Season missed
Material stays longer	Design Changes	Seasonal activities	Piles not at depth
Miscalculation	Longer driving / other system / pressing	More expensive setup	Disorganization

Continued on next page

Table B.1 – continued from previous page

Cause	Category	Consequence	Category
Design processes take longer	Procedures	Disorganization	More man-hours
Delays	Permits not obtained	Discussion on requirements with clients	New permits
Objections	More man-hours	Disorganization	Diving takes longer
Scarcity of man-hours	Scarcity	Divers are scarce	More work for divers
More hours	Disorganization	Extra costs to speed up	Speeding up
Storm season	Seasonal activities	Extra delay	Disorganization

C

Checklist concept and themes literature review and interviews

Table C.1: Concepts and themes presence in literature review and interviews

Concepts and Themes	Literature Review	Interviews
Cost/budget/schedule/time overrun	✓	✓
Delay	✓	✓
Optimism bias	✓	✓
Strategic misrepresentation	✓	✓
Scope creep/changes	✓	✓
Poor project management	✓	
Uncertainty/risk	✓	✓
Inadequate contingency planning	✓	
(In)direct costs	✓	✓
SSK-2018	✓	✓
Probability X impact	✓	✓
First/Second order effect	✓	✓
Contingency reserve	✓	✓
Management reserve	✓	
Work Breakdown Structure	✓	
Gantt Chart	✓	✓
Microsoft Planning	✓	✓
Primavera P6	✓	✓
Expert Judgement	✓	✓
RISMAN	✓	✓
(Un)known risks	✓	✓
Identification	✓	
Quantification/estimation	✓	
Risk analysis	✓	✓
Secondary impact	✓	✓
Schedule compression	✓	✓
Disruption	✓	✓
Interrelationship	✓	✓
Correlation	✓	✓
Trigger event	✓	✓
Consequences	✓	✓

Continued on next page

Table C.1 – continued from previous page

Concepts and Themes	Literature Review	Interviews
Ripple effect	✓	✓
Cumulative effect	✓	✓
Knock-on effects	✓	✓
Cascading effects	✓	✓
Compounded	✓	✓
Unexpected soil conditions		✓
Accidents		✓
New research		✓
Material (price) change		✓
New regulations/permits		✓
Client requirements		✓
Measures		✓
Probabilistic planning		✓
Buffers		✓
Bandwidths		✓
Monte Carlo Simulations		✓
Scarety of Machinery or staff		✓
Black swans		✓
Miscalculations		✓
Design changes		✓
Seasonal activities		✓
Culture change		✓
Contractor vs consultant		✓
Accelerating costs		✓
Damage repair		✓
Procedures		✓
Recalculations		✓

D

Assessment sheets

D.1. Assessment sheet current model

Personal Data

Date:
Name:
Job title:
Work experience:

Goal

The goal of this assessment form is to understand the applicability and quality of the current model for identifying and quantifying risks.

Method

The assessment form asks to rate certain aspects of the current model. In doing so, the following scores can be given (consider 1 as negative and 5 as positive):

- Very low
- Low
- Average
- High
- Very high

Assessment Sheet

Identification

	1	2	3	4	5
How clear is the process for identifying risks?					
How complete is the process for identifying risks?					
How much time does the process take to identify risks? (1= very much time, 5= very little)					
How understandable is this process to the client?					
How relevant is this process to construction and infrastructure projects?					

Quantification

	1	2	3	4	5
How clear is the process for quantifying risks?					
How complete is the process for quantifying risks?					
How much time does the process take to quantify risks? (1= very much time, 5= very little)					
How understandable is this process to the client?					
How relevant is this process to construction and infrastructure projects?					

Tweede-orde effecten van risico's

	1	2	3	4	5
How clear is the process to identify and quantify second-order effects of risks?					
How complete is the process to identify and quantify second-order effects of risks?					
How much time does the process take to identify and quantify second-order effects of risks? (1= very much time, 5= very little)					
How understandable is this process to the client regarding identifying and quantifying second-order effects of risks?					
How relevant is this model for identifying and quantifying second-order effects of risks?					

Feedback and Areas for Improvement

- **What are the main strengths of the model?**

  ____

- **What are the main weaknesses of the model?**

  ____

- **Further recommendations or comments for the further development of the model?**

  ____

D.2. Assessment sheet new model

Personal Data

Date:
Name:
Job title:
Work experience:

Goal

The goal of this assessment form is to understand the applicability and quality of the new model developed in the master thesis of Stan Efftink for identifying and quantifying (second-order effects of) risks.

Method

The assessment form asks to rate certain aspects of the current model. In doing so, the following scores can be given (consider 1 as negative and 5 as positive):

- Very low

- Low
- Average
- High
- Very high

Assessment Sheet

Identification

	1	2	3	4	5
How clear is the process for identifying risks?					
How complete is the process for identifying risks?					
How much time does the process take to identify risks? (1= very much time, 5= very little)					
How understandable is this process to the client?					
How relevant is this process to construction and infrastructure projects?					

Quantification

	1	2	3	4	5
How clear is the process for quantifying risks?					
How complete is the process for quantifying risks?					
How much time does the process take to quantify risks? (1= very much time, 5= very little)					
How understandable is this process to the client?					
How relevant is this process to construction and infrastructure projects?					

Tweede-orde effecten van risico's

	1	2	3	4	5
How clear is the process to identify and quantify second-order effects of risks?					
How complete is the process to identify and quantify second-order effects of risks?					
How much time does the process take to identify and quantify second-order effects of risks? (1= very much time, 5= very little)					
How understandable is this process to the client regarding identifying and quantifying second-order effects of risks?					
How relevant is this model for identifying and quantifying second-order effects of risks?					

Feedback and Areas for Improvement

- **What are the main strengths of the model?**

  ____

- **What are the main weaknesses of the model?**

  ____

- **Further recommendations or comments for the further development of the model?**

  ____

D.3. Assessment sheet answers

This appendix will present the completed assessment forms.

D.3.1. Assessment expert 1

This subsection shows the assessment sheets of expert 1.

Assessment expert 1 current model

Persoonlijke gegevens

Datum gesprek:	
Naam:	Expert 1
Functie:	
Werkervaring:	

Doel

Het doel van dit beoordelingsformulier is om inzicht te verkrijgen in de toepasbaarheid en kwaliteit van het huidige model voor het identificeren en kwantificeren van risico's.

Werkwijze

In het beoordelingsformulier wordt er gevraagd om bepaalde aspecten van het opgestelde model te beoordelen. Hierbij kunnen de volgende scores worden gegeven (beschouw 1 als negatief en 5 als positief):

- Erg laag
- Laag
- Gemiddeld
- Hoog
- Erg hoog

Beoordelingsformulier

Identificatie

	1	2	3	4	5
Hoe duidelijk is het proces om risico's te identificeren?				x	
Hoe volledig is het proces om risico's te identificeren?				x	
Hoeveel tijd kost het proces om risico's te identificeren? (1=heel veel tijd 5= heel weinig)				x	
Hoe begrijpelijk is dit proces voor de opdrachtgever?		x			
Hoe relevant is dit proces voor constructie en infrastructuur projecten?					x

Kwantificatie

	1	2	3	4	5
Hoe duidelijk is het proces om risico's te kwantificeren?				x	
Hoe volledig is het proces om risico's te kwantificeren?		x			
Hoeveel tijd kost het proces om risico's te kwantificeren? (1=heel veel tijd 5= heel weinig)				x	
Hoe begrijpelijk is dit proces voor de opdrachtgever?			x		
Hoe relevant is dit proces voor constructie en infrastructuur projecten?					x

Tweede-orde effecten van risico's

	1	2	3	4	5
Hoe duidelijk is het proces om tweede-orde effecten van risico's te identificeren en kwantificeren?		x			
Hoe volledig is het proces om tweede-orde effecten van risico's te identificeren en kwantificeren?	x				
Hoeveel tijd kost het proces om tweede-orde effecten van risico's te identificeren en kwantificeren? (1=heel veel tijd 5= heel weinig)			x		
Hoe begrijpelijk is dit proces voor de opdrachtgever omtrent het identificeren en kwantificeren van tweede-orde effecten van risico's?	x				
Hoe relevant is dit model voor het identificeren en kwantificeren van tweede-orde effecten van risico's?		x			

Feedback en verbeterpunten

Wat zijn de belangrijkste sterke punten van het model?
Op basis van expert judgement wat snel/efficiënt kan

Wat zijn de belangrijkste zwakke punten van het model?
Tweede-orde effecten worden niet of niet goed genoeg meegenomen in de raming en planning

Verdere aanbevelingen of opmerkingen voor de doorontwikkeling van het model?

Assessment expert 1 new model

Persoonlijke gegevens

Datum gesprek	
Naam	Expert 1
Functie	
Werkervaring	

Doel

Het doel van dit beoordelingsformulier is om inzicht te verkrijgen in de toepasbaarheid en kwaliteit van het opgestelde model dat ontwikkeld is in de master thesis van Stan Efftink. Het opgestelde model is een methode om risico's te identificeren en kwantificeren in kostenramingen.

Werkwijze

In het beoordelingsformulier wordt er gevraagd om bepaalde aspecten van het opgestelde model te beoordelen. Hierbij kunnen de volgende scores worden gegeven (beschouw 1 als negatief en 5 als positief):

- Erg laag

- Laag
- Gemiddeld
- Hoog
- Erg hoog

Beoordelingsformulier

Identificatie

	1	2	3	4	5
Hoe duidelijk is het proces om risico's te identificeren?				x	
Hoe volledig is het proces om risico's te identificeren?					x
Hoeveel tijd kost het proces om risico's te identificeren? (1=heel veel tijd 5= heel weinig)	x				
Hoe begrijpelijk is dit proces voor de opdrachtgever?		x			
Hoe relevant is dit proces voor constructie en infrastructuur projecten?					x

Kwantificatie

	1	2	3	4	5
Hoe duidelijk is het proces om risico's te kwantificeren?				x	
Hoe volledig is het proces om risico's te kwantificeren?					x
Hoeveel tijd kost het proces om risico's te kwantificeren? (1=heel veel tijd 5= heel weinig)	x				
Hoe begrijpelijk is dit proces voor de opdrachtgever?		x			
Hoe relevant is dit proces voor constructie en infrastructuur projecten?					x

Tweede-orde effecten van risico's

	1	2	3	4	5
Hoe duidelijk is het proces om tweede-orde effecten van risico's te identificeren en kwantificeren?		x			
Hoe volledig is het proces om tweede-orde effecten van risico's te identificeren en kwantificeren?					x
Hoeveel tijd kost het proces om tweede-orde effecten van risico's te identificeren en kwantificeren? (1=heel veel tijd 5= heel weinig)	x				
Hoe begrijpelijk is dit proces voor de opdrachtgever omtrent het identificeren en kwantificeren van tweede-orde effecten van risico's?		x			
Hoe relevant is dit model voor het identificeren en kwantificeren van tweede-orde effecten van risico's?					x

Feedback en verbeterpunten

Wat zijn de belangrijkste sterke punten van het model?
Meer stapsgewijs (dus meer gestructureerd aan de slag)

Wat zijn de belangrijkste zwakke punten van het model?
Kost waarschijnlijk veel meer tijd
De eerste keren zullen lastig zijn omdat het een andere manier van werken is

Verdere aanbevelingen of opmerkingen voor de doorontwikkeling van het model?
Meest mogelijke voorkomende situaties al meegeven in je onderzoek (een basis vormen voor nieuwe manier van werken identificeren en kwantificeren van (tweede-orde effecten) risico's

D.3.2. Assessment expert 2
This subsection shows the assessment sheets of Expert 2.

Assesment expert 2 current model

Persoonlijke gegevens

Datum gesprek	
Naam	Expert 2
Functie	
Werkervaring	

Doel
Het doel van dit beoordelingsformulier is om inzicht te verkrijgen in de toepasbaarheid en kwaliteit van het huidige model voor het identificeren en kwantificeren van risico's.

Werkwijze
In het beoordelingsformulier wordt er gevraagd om bepaalde aspecten van het opgestelde model te beoordelen. Hierbij kunnen de volgende scores worden gegeven (beschouw 1 als negatief en 5 als positief):

- Erg laag
- Laag
- Gemiddeld
- Hoog
- Erg hoog

Beoordelingsformulier
Identificatie

	1	2	3	4	5
Hoe duidelijk is het proces om risico's te identificeren?				x	
Hoe volledig is het proces om risico's te identificeren?					x
Hoeveel tijd kost het proces om risico's te identificeren? (1=heel veel tijd 5= heel weinig)	x				
Hoe begrijpelijk is dit proces voor de opdrachtgever?		x			
Hoe relevant is dit proces voor constructie en infrastructuur projecten?	x				

Kwantificatie

	1	2	3	4	5
Hoe duidelijk is het proces om risico's te kwantificeren?				x	
Hoe volledig is het proces om risico's te kwantificeren?	x				
Hoeveel tijd kost het proces om risico's te kwantificeren? (1=heel veel tijd 5= heel weinig)				x	
Hoe begrijpelijk is dit proces voor de opdrachtgever?		x			
Hoe relevant is dit proces voor constructie en infrastructuur projecten?	x				

Tweede-orde effecten van risico's

	1	2	3	4	5
Hoe duidelijk is het proces om tweede-orde effecten van risico's te identificeren en kwantificeren?	**x**				
Hoe volledig is het proces om tweede-orde effecten van risico's te identificeren en kwantificeren?	**x**				
Hoeveel tijd kost het proces om tweede-orde effecten van risico's te identificeren en kwantificeren? (1=heel veel tijd 5= heel weinig)	**x**				
Hoe begrijpelijk is dit proces voor de opdrachtgever omtrent het identificeren en kwantificeren van tweede-orde effecten van risico's?	**x**				
Hoe relevant is dit model voor het identificeren en kwantificeren van tweede-orde effecten van risico's?	**x**				

Feedback en verbeterpunten

Wat zijn de belangrijkste sterke punten van het model?

Iedereen in Nederland gebruikt SSK en er zijn hooggeleerde risicomanagers nodig om risico's te inventariseren en te kwantificeren.

Wat zijn de belangrijkste zwakke punten van het model?

De gevolgklassen die vaak gebruikt worden in de RISMAN methode staan veelal niet in de juiste verhouding tot de totale projectomvang (voorziene kosten). Hierdoor is de uitkomst van een zogenaamd goed risicomanagement proces ineens minder waardevol. Na alle inspanningen van de afgelopen maanden kwam uit de kwantificering een risicoreservering < 0.09% "laten we toch maar 15% aanhouden". Dan kun je dus net zo goed geen risico's kwantificeren.

Verdere aanbevelingen of opmerkingen voor de doorontwikkeling van het model?

Zorg voor goed risicomanagement in je project. Net als een kostendeskundige liefst vroegtijdig betrokken. Dit is geen 'bijrol' van een projectleider of projectmanager die een klein Excel lijstje maakt met wat algemeenheden over risico's.

Assesment expert 2 new model

Persoonlijke gegevens

Datum gesprek	
Naam	Expert 2
Functie	
Werkervaring	

Doel

Het doel van dit beoordelingsformulier is om inzicht te verkrijgen in de toepasbaarheid en kwaliteit van het opgestelde model die ontwikkeld is in de master thesis van Stan Efftink. Het opgestelde model is een methode om risico's te identificeren en kwantificeren in kostenramingen.

Werkwijze

In het beoordelingsformulier wordt er gevraagd om bepaalde aspecten van het opgestelde model te beoordelen. Hierbij kunnen de volgende scores worden gegeven (beschouw 1 als negatief en 5 als positief):

- Erg laag
- Laag
- Gemiddeld
- Hoog
- Erg hoog

Beoordelingsformulier

Identificatie

	1	2	3	4	5
Hoe duidelijk is het proces om risico's te identificeren?				x	
Hoe volledig is het proces om risico's te identificeren?					x
Hoeveel tijd kost het proces om risico's te identificeren? (1=heel veel tijd 5= heel weinig)	x				
Hoe begrijpelijk is dit proces voor de opdrachtgever?		x			
Hoe relevant is dit proces voor constructie en infrastructuur projecten?					x

Kwantificatie

	1	2	3	4	5
Hoe duidelijk is het proces om risico's te kwantificeren?				x	
Hoe volledig is het proces om risico's te kwantificeren?		x			
Hoeveel tijd kost het proces om risico's te kwantificeren? (1=heel veel tijd 5= heel weinig)		x			
Hoe begrijpelijk is dit proces voor de opdrachtgever?		x			
Hoe relevant is dit proces voor constructie en infrastructuur projecten?					x

Tweede-orde effecten van risico's

	1	2	3	4	5
Hoe duidelijk is het proces om tweede-orde effecten van risico's te identificeren en kwantificeren?		x			
Hoe volledig is het proces om tweede-orde effecten van risico's te identificeren en kwantificeren?		x			
Hoeveel tijd kost het proces om tweede-orde effecten van risico's te identificeren en kwantificeren? (1=heel veel tijd 5= heel weinig)		x			
Hoe begrijpelijk is dit proces voor de opdrachtgever omtrent het identificeren en kwantificeren van tweede-orde effecten van risico's?	x				
Hoe relevant is dit model voor het identificeren en kwantificeren van tweede-orde effecten van risico's?		x			

Feedback en verbeterpunten

Wat zijn de belangrijkste sterke punten van het model?

Op veel punten scoort het nieuwe model beter. Grootste nadeel is natuurlijk de onbekendheid met deze methode. Daarom zal het in het begin meer tijd kosten om de risico's goed te kwantificeren.

Wat zijn de belangrijkste zwakke punten van het model?
Als een methode té complex is en het niet breed gedragen wordt geïmplementeerd dan blijven er helaas veel projecten mis gaan met te hoge budgetoverschrijdingen (door een te lage risicoreservering). De kunst is de juiste balans te vinden tussen eenvoud en zo goed mogelijk de werkelijkheid te voorspellen.

Verdere aanbevelingen of opmerkingen voor de doorontwikkeling van het model?
Het fictieve project dat we met onze vakvereniging gebruikten om de uitkomsten van verschillende softwarepakketten te vergelijken (bij de verschillende versies van SSK) zouden we opnieuw kunnen gebruiken met de verbeterde modellering van tweede orde effecten van risico's om vervolgens de uitkomsten van de simulaties beter te bestuderen.

D.3.3. Assessment expert 3

This subsection shows the assessment sheets of Expert 3.

Assesment expert 3 current model

Persoonlijke gegevens:

Datum gesprek	
Naam	Expert 3
Functie	
Werkervaring	

Doel:

Het doel van dit beoordelingsformulier is om inzicht te verkrijgen in de toepasbaarheid en kwaliteit van het huidige model voor het identificeren en kwantificeren van risico's.

Werkwijze:

In het beoordelingsformulier wordt er gevraagd om bepaalde aspecten van het opgestelde model te beoordelen. Hierbij kunnen de volgende scores worden gegeven (beschouw 1 als negatief en 5 als positief):

- Erg laag
- Laag
- Gemiddeld
- Hoog
- Erg hoog

Beoordelingsformulier:

Identificatie	**1**	**2**	**3**	**4**	**5**
Hoe duidelijk is het proces om risico's te identificeren?			x		
Hoe volledig is het proces om risico's te identificeren?		x			

Hoeveel tijd kost het proces om risico's te identificeren? (1=heel veel tijd 5= heel weinig)			x		
Hoe begrijpelijk is dit proces voor de opdrachtgever?				x	
Hoe relevant is dit proces voor constructie en infrastructuur projecten?		x			
Kwantificatie	**1**	**2**	**3**	**4**	**5**
Hoe duidelijk is het proces om risico's te kwantificeren?			x		
Hoe volledig is het proces om risico's te kwantificeren?		x			
Hoeveel tijd kost het proces om risico's te kwantificeren? (1=heel veel tijd 5= heel weinig)	x				
Hoe begrijpelijk is dit proces voor de opdrachtgever?				x	
Hoe relevant is dit proces voor constructie en infrastructuur projecten?		x			
Tweede-orde effecten van risico's	**1**	**2**	**3**	**4**	**5**
Hoe duidelijk is het proces om tweede-orde effecten van risico's te identificeren en kwantificeren?		x			
Hoe volledig is het proces om tweede-orde effecten van risico's te identificeren en kwantificeren?	x				
Hoeveel tijd kost het proces om tweede-orde effecten van risico's te identificeren en kwantificeren? (1=heel veel tijd 5= heel weinig)	x				
Hoe begrijpelijk is dit proces voor de opdrachtgever omtrent het identificeren en kwantificeren van tweede-orde effecten van risico's?	1				
Hoe relevant is dit model voor het identificeren en kwantificeren van tweede-orde effecten van risico's?		2			

1 sterk afhankelijk van kennis opdrachtgever/medewerker
2 sterk afhankelijk van aard en omvang van het project

Feedback en verbeterpunten:

Wat zijn de belangrijkste sterke punten van het model?

- Eenvoud
- Inmiddels bekend in de civiele wereld

Wat zijn de belangrijkste zwakke punten van het model?

- Beperkte integraliteit en volledigheid om inzicht te krijgen in "alle" risico's
- Bij het identificeren en kwantificeren bestaat een grote mate van vrijheid ondanks tools als RISMAN etc. Gevolg is dat kans relatief groot is dat risico's (of tweede-orde effecten van risico's) ontbreken of benoemde risico's onvolledig zijn
- Zitten de juiste gegadigden/specialisten aan tafel. Hoe wordt dit geborgd.

Verdere aanbevelingen of opmerkingen voor de doorontwikkeling van het model? Zoals vanmorgen besproken

Assesment expert 3 new model

Persoonlijke gegevens

Datum gesprek
Naam Expert 3
Functie
Werkervaring

Doel

Het doel van dit beoordelingsformulier is om inzicht te verkrijgen in de toepasbaarheid en kwaliteit van het opgestelde model die ontwikkeld is in de master thesis van Stan Efftink. Het opgestelde model is een methode om risico's te identificeren en kwantificeren in kostenramingen.

Werkwijze

In het beoordelingsformulier wordt er gevraagd om bepaalde aspecten van het opgestelde model te beoordelen. Hierbij kunnen de volgende scores worden gegeven (beschouw 1 als negatief en 5 als positief):

- Erg laag
- Laag
- Gemiddeld
- Hoog
- Erg hoog

Beoordelingsformulier

** sterk afhankelijk van OG aard en omvang project*

Identificatie	1	2	3	4	5
Hoe duidelijk is het proces om risico's te identificeren?			x		
Hoe volledig is het proces om risico's te identificeren?				x	
Hoeveel tijd kost het proces om risico's te identificeren? (1=heel veel tijd 5= heel weinig)	x				
Hoe begrijpelijk is dit proces voor de opdrachtgever?		x			
Hoe relevant is dit proces voor constructie en infrastructuur projecten?				x	

Kwantificatie	1	2	3	4	5
Hoe duidelijk is het proces om risico's te kwantificeren?			x		
Hoe volledig is het proces om risico's te kwantificeren?				x	
Hoeveel tijd kost het proces om risico's te kwantificeren? (1=heel veel tijd 5= heel weinig)	x				
Hoe begrijpelijk is dit proces voor de opdrachtgever?		x			
Hoe relevant is dit proces voor constructie en infrastructuur projecten?				x	

Tweede-orde effecten van risico's	1	2	3	4	5
Hoe duidelijk is het proces om tweede-orde effecten van risico's te identificeren en kwantificeren?			x		
Hoe volledig is het proces om tweede-orde effecten van risico's te identificeren en kwantificeren?				x	
Hoeveel tijd kost het proces om tweede-orde effecten van risico's te identificeren en kwantificeren? (1=heel veel tijd 5= heel weinig)	x				
Hoe begrijpelijk is dit proces voor de opdrachtgever omtrent het identificeren en kwantificeren van tweede-orde effecten van risico's?	1				
Hoe relevant is dit model voor het identificeren en kwantificeren van tweede-orde effecten van risico's?	2				

1 sterk afhankelijk van kennis opdrachtgever/medewerker
2 sterk afhankelijk van aard en omvang van het project

Feedback en verbeterpunten

Wat zijn de belangrijkste sterke punten van het model?

- Meer integrale benadering
- Gevolgrisico's worden vollediger en explicieter inzichtelijk gemaakt (tweede orde effecten)
- Verplicht om wat langer na te denken over risico's
- Menselijk aandeel wordt expliciet(er) belicht
- Integrale aanpak voorkomt wellicht dubbelingen van risico's en geeft een vollediger beeld

Wat zijn de belangrijkste zwakke punten van het model?

- Complexe(re) benadering lijkt me daarom vooral (of alleen) geschikt voor “grote” projecten
- Er moet een relatief hoger kennisniveau aangaande risicobeheersing aanwezig zijn (bij OG en ON)
- Actualiseren van risico’s (risicodossier) wordt intensiever waardoor grotere kans op “fouten” onvolledigheid door de bomen het bos niet meer zien etc.

Verdere aanbevelingen of opmerkingen voor de doorontwikkeling van het model?

- Zoals vanmorgen besproken ________________

E

Topic lists and interview questions

In this appendix, the topic lists, alongside some sample interview questions, are represented by arbiters, project managers, contractors and cost experts.

E.1. Interview arbiter

Algemene inleiding

1. Wat is uw functie en ervaring in constructie- en infrastructuurprojecten?

Identificatie van Tweede-orde Effecten

1. Bent u bekent met het fenomeen van 1e en 2e orde effecten van risico's?
2. In het geval van geen herkenning de volgende begrippen toelichten:
    - **Eerste-orde-effecten van risico's** zijn de directe gevolgen van een risico in een bouw- of infrastructuurproject. Dit zijn specifieke eenvoudige gevolgen die meestal kwantificeerbaar zijn en direct kunnen worden gekoppeld aan een oorzaak wat mogelijk leidt tot een toename in kosten of vertraging. Deze risico's worden geschat door de kans vermenigvuldigd met de impact te berekenen in de kostenramingen.
    - **Tweede-orde-effecten van risico's** zijn de complexere en indirecte gevolgen die voortvloeien uit het oorspronkelijke risico. Deze effecten kunnen aanzienlijk groter zijn dan oorspronkelijke impact. Ze kunnen van invloed zijn op projectactiviteiten die niet direct werden beïnvloed terwijl ze wel kunnen resulteren in meer tijd of geld. Effecten van de tweede orde worden ook wel ripple-effecten, kettingreacties, cumulatieve effecten, verstorende effecten en cascade-effecten genoemd die de projectplanningen en kostenramingen op een nog grotere manier kunnen beïnvloeden. Deze risico's worden meestal gebudgetteerd in de kostenramingen door een reserve voor onvoorziene uitgaven op te nemen in de raming.
3. Hoe definieert u eerste en tweede-orde effecten van risico's in de context van arbitragezaken?
4. Kunt u voorbeelden geven van eerste en tweede-orde effecten die u bent tegengekomen in uw projecten?
5. Welke methoden of processen zijn effectief gebleken bij het identificeren van deze tweede-orde effecten tijdens de ontwerpfase van projecten?

Huidige Aanpak van Tweede-orde Effecten

6. Hoe worden tweede-orde effecten van risico's momenteel aangepakt in de constructie- en infrastructuur sector volgens uw ervaring in arbitragezaken?
    - Is dit effectief?

Oorzaken en Gevolgen

7. Wat beschouwt u als de belangrijkste oorzaken van tweede-orde effecten van risico's in uw projecten?
    - (Denk hierbij aan trigger-events)
8. Wat zijn de gevolgen van tweede-orde effecten van risico's?
    - (Denk hierbij aan het optreden van deze effecten)
    - (En het effect van het matig plannen ervan)

Aanpassingen aan de Standaard Systematiek voor Kostenramingen 2018 (SSK-2018)

9. Hoe gaat de SSK-2018 om met second-order effects of risks?
10. Denkt u dat dit een goede aanpak is?
11. Zijn er wijzigingen die u zou aanbevelen in de SSK-2018 om beter om te gaan met tweede-orde effecten van risico's?
    - (Denk hierbij aan het identificeren en ramen)
12. Hoe denkt u over het ramen van risico's als kettingen in plaats van losstaande activiteiten?

Beheer van Tweede-orde Effecten

13. Welke aanbevelingen heeft u voor projectmanagers om tweede-orde effecten van risico's beter te identificeren, ramen en plannen?

Slotvragen

14. Heeft u verder nog aanbevelingen of opmerkingen omtrent tweede-order effecten van risico's?

E.2. Interview contractor

Algemene inleiding

1. Wat is uw functie en ervaring in constructie- en infrastructuurprojecten?

Identificatie van Tweede-orde Effecten

1. Bent u bekend met 1e en 2e orde effecten van risico's?
2. Hoe definieert u eerste en tweede-orde effecten van risico's in de context van uw projecten?
3. In het geval van geen herkenning de volgende begrippen toelichten:
    - **Eerste-orde effecten van risico's** zijn de directe en voorzienbare impact van een risico in een bouw- of infrastructuurproject dat voortkomt uit een risicoanalyse-sessie. Vaak worden maatregelen genomen om de waarschijnlijkheid of impact van deze risico's te verminderen preventief of corrigerend. Eerste-orde risico-effecten zijn directe gevolgen die kwantificeerbaar zijn en direct gekoppeld kunnen worden aan een oorzaak wat kan leiden tot een verhoging van de kosten of vertraging. Deze risico's worden geschat door de waarschijnlijkheid maal de impact in kostenramingen te berekenen. Bij het plannen van activiteiten worden deze effecten meegenomen door ze probabilistisch te berekenen en buffers op kritieke locaties toe te voegen.
    - **Tweede-orde effecten van risico's** zijn de indirecte gevolgen die volgen op het initiële risico of die ontstaan uit een maatregel correctief of preventief. Deze effecten kunnen significant groter zijn mogelijk het initiële effect meerdere keren vermenigvuldigend. Ze kunnen projectactiviteiten beïnvloeden die niet direct getroffen waren waardoor deze activiteiten duurder worden en langer duren door verstoringen. Tweede-orde effecten omvatten randeffecten, rimpel-, domino-, cumulatieve, verstorende en cascaderende impact. Deze risico's worden

gebudgetteerd in kostenramingen door deze zo goed mogelijk in de benoemde risico's en daarnaast een reserve voor onvoorziene uitgaven in de raming op te nemen. In de planning worden deze risico's meegenomen door de planning probabilistisch te berekenen waarbij risico's aan elkaar gekoppeld kunnen worden en door buffers op het kritieke pad toe te voegen.

4. Kunt u voorbeelden geven van eerste en tweede-orde effecten die u bent tegengekomen in uw projecten?

Huidige Omgaan met Tweede-orde Effecten

5. Hoe identificeert u tweede-orde effecten van risico's?
6. Welke methoden of processen gebruikt u momenteel om tweede-orde effecten van risico's te identificeren en te kwantificeren?
7. Hoe gaat u om met tweede-orde effecten van risico's?
   - Gebruikte methodes / tools?
   - Wat gebeurt er tijdens het optreden ervan?
   - Wat als de bouw stil staat? Hoe anticipeert u hier op? Wat kost dat? Voor wie zijn deze kosten?

Oorzaken en Gevolgen

8. Wat beschouwt u als de belangrijkste oorzaken van tweede-orde effecten van risico's in uw projecten?
   - Denk hierbij aan trigger-events
9. Wat zijn de gevolgen van tweede-orde effecten van risico's? (in tijd en geld)
   - Denk hierbij aan het optreden van deze effecten
   - En het effect van het matig plannen ervan

Aanpassingen aan de huidige methodes

10. Zijn er wijzigingen die u zou aanbevelen aan de huidige project management methodes om beter om te gaan met tweede-orde effecten van risico's?
    - Denk hierbij aan het identificeren, ramen en plannen ervan
    - Zijn er obstakels die dit moeilijk maken?

Slotvragen

11. Heeft u verder nog aanbevelingen of opmerkingen omtrent tweede-orde effecten van risico's?

E.3. Interview cost expert

Algemene Inleiding

1. Wat is uw functie en werkervaring in constructie- en infrastructuurprojecten?

Over Tweede-orde Effecten van Risico's (eventueel definitie uitleggen)

1. Bent u bekend met het fenomeen van 1e en 2e orde effecten van risico's?
2. In het geval van geen herkenning de volgende begrippen toelichten:
   - **Eerste-orde effecten van risico's** zijn de directe en voorzienbare impact van een risico in een bouw- of infrastructuurproject dat voortkomt uit een risicoanalyse-sessie. Vaak worden maatregelen genomen om de waarschijnlijkheid of impact van deze risico's te verminderen

preventief of corrigerend. Eerste-orde risico-effecten zijn directe gevolgen die kwantificeerbaar zijn en direct gekoppeld kunnen worden aan een oorzaak wat kan leiden tot een verhoging van de kosten of vertraging. Deze risico's worden geschat door de waarschijnlijkheid maal de impact in kostenramingen te berekenen. Bij het plannen van activiteiten worden deze effecten meegenomen door ze probabilistisch te berekenen en buffers op kritieke locaties toe te voegen.

- **Tweede-orde effecten van risico's** zijn de indirecte gevolgen die volgen op het initiële risico of die ontstaan uit een maatregel correctief of preventief. Deze effecten kunnen significant groter zijn mogelijk het initiële effect meerdere keren vermenigvuldigend. Ze kunnen projectactiviteiten beïnvloeden die niet direct getroffen waren waardoor deze activiteiten duurder worden en langer duren door verstoringen. Tweede-orde effecten omvatten randeffecten, rimpel-, domino-, cumulatieve, verstorende en cascaderende impact. Deze risico's worden gebudgetteerd in kostenramingen door deze zo goed mogelijk in de benoemde risico's en daarnaast een reserve voor onvoorziene uitgaven in de raming op te nemen. In de planning worden deze risico's meegenomen door de planning probabilistisch te berekenen waarbij risico's aan elkaar gekoppeld kunnen worden en door buffers op het kritieke pad toe te voegen.

3. Hoe definieert u eerste en tweede-orde effecten van risico's in de context van uw projecten?
4. Kunt u voorbeelden geven van eerste en tweede-orde effecten van risico's die u bent tegengekomen in uw projecten?

Identificatie

5. Welke methoden gebruikt u om tweede-orde effecten van risico's te identificeren tijdens de ontwerpfase?
6. Hoe complex vindt u het om second-order effects van risico's te identificeren?

Huidige Aanpak

7. Hoe zorgt u ervoor dat deze tweede-order effecten van risico's worden meegenomen in de projectraming?
8. Hoe complex vindt u het om second-order effects van risico's te ramen?

Oorzaken en Gevolgen

9. Wat zijn de meest voorkomende oorzaken van tweede-orde effecten in uw ervaring?
    - Denk hierbij aan trigger-events
10. Wat zijn de gevolgen van tweede-orde effecten van risico's? (in tijd en geld)
    - Denk hierbij aan het optreden van deze effecten
    - En het effect van het matig ramen ervan

Aanpassingen aan de Standaard Systematiek voor Kostenramingen 2018 (SSK-2018)

11. Zijn er wijzigingen die u zou aanbevelen in de SSK-2018 om beter om te gaan met tweede-orde effecten van risico's?
    - Denk hierbij aan het identificeren en ramen
12. Hoe denkt u over het ramen van risico's als kettingen in plaats van losstaande activiteiten?

Conclusie en Aanbevelingen

13. Heeft u verder nog aanbevelingen of opmerkingen omtrent tweede-orde effecten van risico's?

E.4. Interview project managers

Algemene Inleiding

1. Wat is uw functie en werkervaring in constructie- en infrastructuurprojecten?

Over Tweede-orde Effecten van Risico's (eventueel definitie uitleggen)

1. Bent u bekend met het fenomeen van 1e en 2e orde effecten van risico's?
2. In het geval van geen herkenning de volgende begrippen toelichten:
    - **Eerste-orde effecten van risico's** zijn de directe en voorzienbare impact van een risico in een bouw- of infrastructuurproject dat voortkomt uit een risicoanalyse-sessie. Vaak worden maatregelen genomen om de waarschijnlijkheid of impact van deze risico's te verminderen preventief of corrigerend. Eerste-orde risico-effecten zijn directe gevolgen die meestal kwantificeerbaar zijn en direct gekoppeld kunnen worden aan een oorzaak wat kan leiden tot een verhoging van de kosten of vertraging. Deze risico's worden geschat door de waarschijnlijkheid maal de impact in kostenramingen te berekenen. Bij het plannen van activiteiten worden deze effecten meegenomen door ze probabilistisch te berekenen en buffers op kritieke locaties toe te voegen.
    - **Tweede-orde effecten van risico's** zijn de indirecte gevolgen die volgen op het initiële risico of die ontstaan uit een maatregel correctief of preventief. Deze effecten kunnen significant groter zijn mogelijk het initiële effect meerdere keren vermenigvuldigend. Ze kunnen projectactiviteiten beïnvloeden die niet direct getroffen waren waardoor deze activiteiten duurder worden door verstoringen. Tweede-orde effecten omvatten randeffecten, rimpel-, domino-, cumulatieve, verstorende en cascaderende impact die de projectdynamiek, planningen en kostenramingen op een samengestelde manier kunnen beïnvloeden. Deze risico's worden gebudgetteerd in kostenramingen door een voorziening voor onvoorziene uitgaven in de raming op te nemen. In het plannen van activiteiten worden deze risico's meegenomen door de planning probabilistisch te berekenen waarbij risico's aan elkaar gekoppeld kunnen worden en door buffers op kritieke locaties toe te voegen.
3. Hoe definieert u eerste en tweede-orde effecten van risico's in de context van uw projecten?
4. Kunt u voorbeelden geven van eerste en tweede-orde effecten die u bent tegengekomen in uw projecten?
    - En wanneer is iets 2e order in plaats van 1e order volgens u?

Identificatie

5. Welke methoden gebruikt u om tweede-orde effecten van risico's te identificeren tijdens de ontwerpfase?
6. Waarom is het makkelijk of moeilijk om tweede-orde effecten van risico's te identificeren?

Huidige Aanpak

7. Hoe zorgt u ervoor dat deze tweede-orde effecten van risico's worden meegenomen in de projectplanning?
8. Waarom is het makkelijk of moeilijk om tweede-orde effecten van risico's te ramen of te schatten in de projectplanning?

Oorzaken en Gevolgen

9. Wat zijn de meest voorkomende oorzaken van tweede-orde effecten in uw ervaring?
    - Denk hierbij aan trigger-events
10. Wat zijn de gevolgen van tweede-orde effecten van risico's? (in tijd en geld)
    - Denk hierbij aan het optreden van deze effecten

- En het effect van het matig plannen ervan

Aanpassingen aan de huidige project planning methode

11. Zijn er wijzigingen die u zou aanbevelen aan de huidige project planning methode om beter om te gaan met tweede-orde effecten van risico's?
    - Denk hierbij aan het identificeren en het plannen ervan

Aanpassingen aan de Standaard Systematiek voor Kostenramingen 2018 (SSK-2018)

12. Zijn er wijzigingen die u zou aanbevelen in de SSK-2018 om beter om te gaan met tweede-orde effecten van risico's?
    - Denk hierbij aan het identificeren en ramen
13. Hoe denkt u over het ramen van risico's als kettingen in plaats van losstaande activiteiten?

Conclusie en Aanbevelingen

14. Heeft u verder nog aanbevelingen of opmerkingen omtrent tweede-orde effecten van risico's?