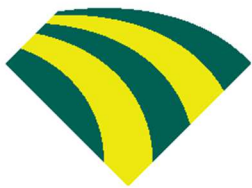


IMPROVED RISK MANAGEMENT IN INFRASTRUCTURAL CONSTRUCTION PROJECTS



P. van Veen

Student TU Delft | Construction Management & Engineering
Trainee Dura Vermeer Infra National projects



DURA VERMEER

Waarmaken van ambities



Source figures:

TU Delft: <http://www.kmeov.nl/biomedisch-ontwerpen-groep-7-8/>

Dura Vermeer: <http://aspari.nl/index.php?page=founders>



IMPROVED RISK MANAGEMENT IN INFRASTRUCTURAL CONSTRUCTION PROJECTS

*“IMPROVED ACCURACY AND PRECISION WITHIN THE RISK RESERVE, BASED ON THE PROJECT’S RISK PROFILE
DETERMINED THROUGH THE UNIQUE CHARACTER OF INFRASTRUCTURAL PROJECTS.”*

Master thesis

in order to obtain the degree of MSc

at the Technical University of Delft;

on the authority of the prof. ir. M.J.C.M. hertogh

Chairman of the Graduation Committee;

to be defended in public on Thursday, January 11th 2018 at 16:00

By

Pim van Veen, 4435265

January 6th, 2018

Version 2.3

Graduation committee

Prof.dr.ir. M.J.C.M. Hertogh (Chairman, TU Delft, Faculty of CiTG)

Prof.dr.ir. P.H.A.J.M. van Gelder (Supervisor, TU Delft, Faculty of TPM)

Ir. E. Hoseini (Supervisor, TU Delft, Faculty of CiTG)

Ir. M. van der Meer (Supervisor, Dura Vermeer)

Ir. J. van Bezooijen (Co-supervisor, Dura Vermeer)

I. Preface

The final phase of the Master Construction Management and Engineering is the graduation research. This graduation thesis is the document that is finally assessed to determine if the conducted research is of sufficient quality, so that I can be rewarded with the Msc title. The genesis of the current research topic lays within the internship period at Dura Vermeer that preceded this graduation period. During the internship is assisted in a large tender and is a research conducted towards costs, planning and risk management. Especially, the opportunities that statistics have to offer were interesting. Statistics, finance and risk management are the three fields of interest that have led to the current research.

The following quote is taken from the preface of the research proposal written in advance of the current graduation research:

“Despite the planning that is made for the graduation research, it is likely that things will turn out different than expected. Therefore, I try to hold my positive and ‘hands-on’ mentality.”

Looking back at this statement, the planning was in general terms sufficient. However, the difficulty is in the details. Towards the end of the research is found out that the planning was tight. A positive mindset is shown to be a crucial asset in successfully finalizing the research under this scheduling pressure. The planning tightness was especially caused by the challenging, two-folded goal that is set before the start of the research. Besides graduating with a good grade for the research, the research result is also used by Dura Vermeer. The research result should be of sufficient quality so that it is actually implemented in Dura Vermeer’s current practice. I see this graduation period as a personal victory in which both goals are accomplished.

I would like to thank all members of my graduation committee for their contributions towards the research. These contributions ensured that the quality of the research came first, even though this has led to additional effort and time. A special mentioning of M. van der Meer and E. Hoseini for their more repeating feedback on the research approach and content. Seven interviews are conducted in the different case studies, there help is much appreciated. Dura Vermeer is thanked for their openness in sharing confident information on a large number of projects. Without this cooperative attituded it was not possible to reach the current research results. Finally, a special thanks to Y. Nederpelt for her endless patience and reassuring words during some difficult periods.

What rests for me is to wish you a lot of reading pleasure.

A handwritten signature in blue ink, appearing to read 'Ryck', is written over a light blue horizontal line.

Konigsleiten, January 6th, 2018.



*“A point of view can be a dangerous luxury when substituted
for insight and understanding.”*

(Marshall McLuhan, Canadian Communications Professor)

II. Management summary

The construction sector faces projects that are unique, and thus comparability is difficult. Consequently, projects become increasingly complex and uncertain. These developments make projects risky and endanger the likelihood of their success. Research about construction projects showed that there were cost escalations in over 25% of the investigated projects (Flyvbjerg, Holm, & Buhl, 2002). Companies active in the construction sector typically budget a risk reserve to cope for these financial risks in projects. However, there is both scientific underexposure of and practical wish for a clear framework on the combination of (1) project characteristics, (2) uncertainty and complexity, (3) project's risk profile and (4) Risk reserve in budgets. This problem has resulted in the following main research question:

How can a project's risk profile be determined through its characteristics and the aspects of uncertainty and complexity for infrastructural projects so that accuracy and precision in the budgeted risk reserve can be improved?

The research result is thus twofold, and there is a need for predictive and descriptive elements in the research results. The descriptive element must explain all of the relations between the unique characteristics of projects, complexity and uncertainty, projects' risk profiles and their risk reserves. The predictive element aims to improve the accuracy and precision in budgeting the risk reserve. The research strategy is based on both inductive and deductive argumentation, but it also utilises the system engineering practices of validation and verification.

The research is divided into three phases. In the first phase, a theoretical framework is defined through a literature review. The second phase is based on four case studies and cross-case analyses, through which the theoretical framework is qualitatively validated. The final phase is the statistical research phase. Through two rounds of statistical analysis and a series of multiple regression analyses, the theoretical and practical framework is quantitatively verified. This verified model is the descriptive element of this research's results. The predictive element is a model that intends to forecast the risk reserve, with increased accuracy and precision, based on the unique project's risk profile.

The theoretical research phase is thus based on a literature review. The research topics included in this review are (1) risk reserve, (2) accuracy and precision, (3) risk profile, (4) complexity and uncertainty and (5) the unique character of infrastructural construction projects. These research topics are the core of the model displayed in figure 1. Project success is positively influenced by the quality of risk management, but also by an accurate and precise risk reserve. An accurate and precise risk reserve is a budgeted risk reserve that is equal to the required risk reserve. The required risk reserve is initially operationalised through the sum of actual incurred costs due to occurred risks. However, the case studies show that these costs are difficult to extract from the cost control documents.

For this reason, a different operationalisation is defined to calculate the required risk reserve. It is predominantly based on the result of the project's bare costs. Five cost categories are identified, namely the direct costs, indirect costs, risk reserve, company costs and profit margin. A sixth category can be included, the maintenance costs, but this notion falls outside of the scope of the current research. The combination of the five cost categories forms the project costs that the client pays to the contractor. The required risk reserve is calculated from the construction costs, which is a combination of the direct costs, indirect costs and risk reserve. The project's bare costs are the combination of the direct costs and indirect costs. The result included in the project's bare costs combined with the realised costs in the risk reserve form the required risk reserve. The formula of the required risk reserve is presented in equation 1. The company costs and profit margin are excluded from the calculation as these cost categories include different company strategies.

$$\text{EQUATION 1: } \text{Req. risk res.} = \frac{(\text{Actual bare costs} - \text{working budget bare costs}) + \text{actual costs risk reserve}}{\text{Working budget bare costs}} * 100\%$$

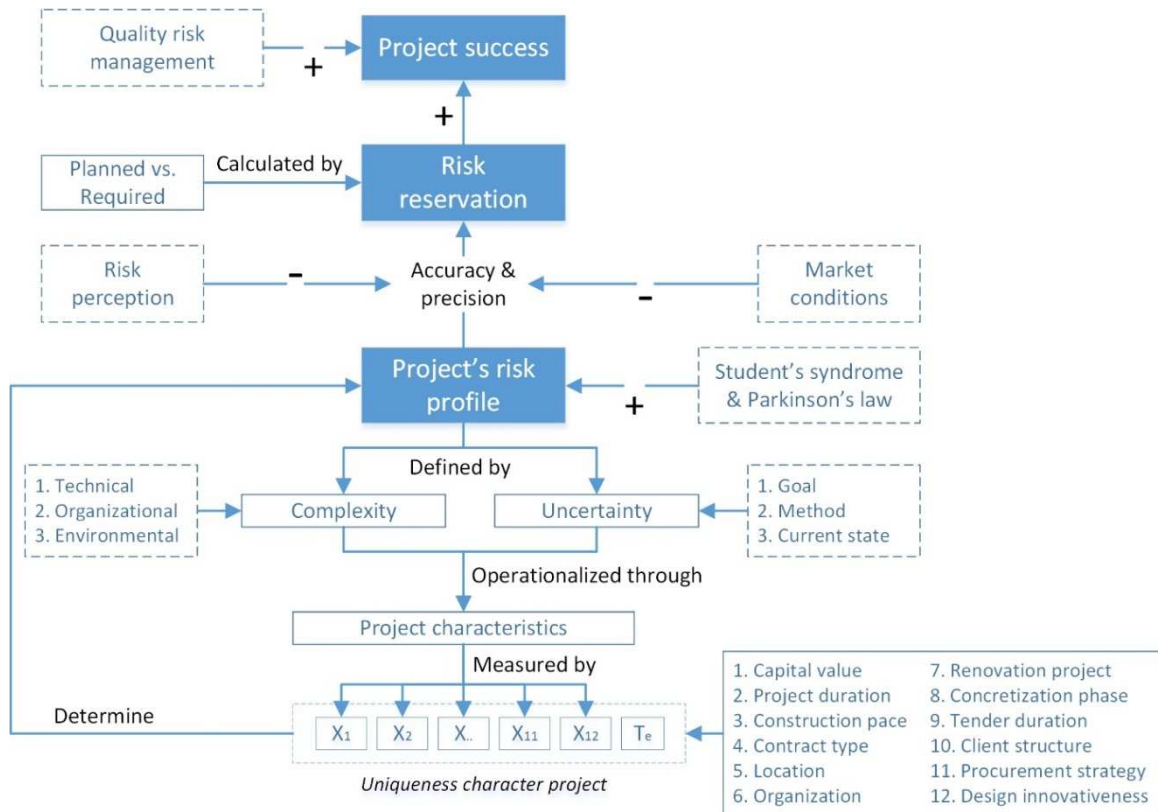


FIGURE 1: QUALITATIVELY VALIDATED MODEL BASED ON PRACTICAL AND THEORETICAL FINDINGS (SOURCE: OWN ILL.)

Figure 1 presents the validated model, which is the combination of the theoretical and practical findings. The accuracy and precision of the budgeted risk reserve is based on the difference between it and the required risk reserve. A perfect risk reserve has no difference and indicates perfect accuracy and precision. However, market conditions and risk perception are two external factors that affect the quality of the budgeted risk reserve. The current approach to budgeting is based on a probabilistic simulation of the risk register and expert judgement, also known as the 'inside view'. However, this approach is more sensitive to these two external factors. A different approach, proposed in the current research, is based on historical data of comparable projects, also known as the 'outside view'.

The difficulties of this proposed approach are the comparability of projects that are assumed unique and the need to determine the risk profile for each unique project. Figure 1 explains the operationalisation of a project's risk profile in relation to the unique character of the project. A project's risk profile is first defined by the two dimensions of complexity and uncertainty. Complexity within a project can be further defined by technical, organizational and environmental complexity. Uncertainty is based on the three sub-dimensions current state, goal and method uncertainty. These project aspects are further operationalised through independent project characteristics. The project characteristics are the 'fingerprint' of the project, and these characteristics allow unique projects to be comparable.

The focus of this research is on calculating the risk reserve based on a project's risk profile. It is important that the project characteristics still determine the project's risk profile, not merely explain the uniqueness character of projects. There are twelve identified project characteristics:

1. Capital value,
2. Construction duration,
3. Construction pace,
4. Contract type,
5. Location,
6. Project organization,
7. Renovation project,

8. Concretisation phase,
9. Tender duration,
10. Client structure,
11. Procurement strategy, and
12. Design innovativeness.

However, these are independent project characteristics and are not directly related to a project's risk profile. A project's risk profile is further operationalised through the required risk reserve. Each project characteristic is also further operationalised in quantifiable or classifiable parameters. The operationalisations of the characteristics are presented in table 13 in section 4.4.2. The cost control inconsistency with respect to costs due to risks makes it difficult to identify critical risks. However, the most critical risk in construction projects is the risk of not meeting the deadline. The phenomena of Student syndrome and Parkinson's law are assumed to cause this risk: "Parkinson's Law and the student syndrome law causes that the work will expands to fill the time available or that the job is delayed" (Khamooshi & Cioffi, 2013, p. 489).

These phenomena result in an increased risk profile, especially in the time-dependent indirect cost types. A project's risk profile is predominantly caused by these cost types. In this research, database is made based on financial and project data of 53 projects, of which 49 are actually used for statistical testing and verification of the model presented in figure 1. The project's risk profile is statistically tested and the indirect cost category consists of the largest risk profile. The indirect cost category is primarily based on time-dependent cost types. The difference in mean values between the direct cost category (on average 2.34%) and indirect cost category (on average -15.87%) is found to be significant at the 0.01 level and based on N = 49. The project's bare cost result of -2.4% is thus primarily caused by the time-dependent indirect cost types, like the project organization (-34.95%) and engineering (-18.9%) costs. This is also shown in figure 2, which presents the validated and verified model.

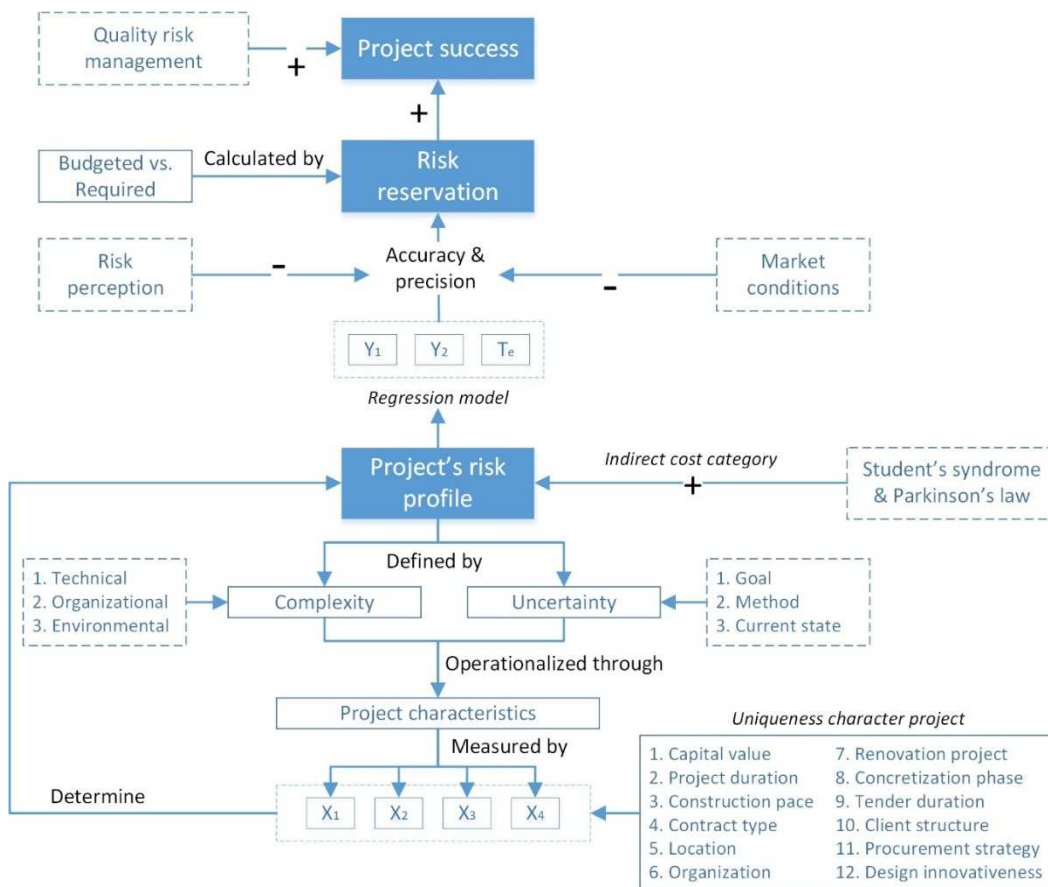


FIGURE 2: QUANTITATIVELY VERIFIED MODEL BASED ON THEORETICAL, PRACTICAL AND STATISTICAL FINDINGS (SOURCE: OWN ILL.)



The budgeted risk reserve is 2.53% of the project's bare costs on average, but the required risk reserve is 3.53% on average. The budgeted risk reserve is thus too optimistic, which is the main reason for an average realised profit margin of -0.54%. The average budgeted profit margin is 0.59%, which means that the risk reserve should be accurate and precise with such a small profit margin. A single percentage point too low can already result in a negative profit margin. If the budgeted risk reserve is 1% too low, then this indicates fierce market conditions and a risk perception that is too optimistic. The influence of market conditions is tested significantly through a correlation between the budgeted risk reserve and budgeted profit margin. A low budgeted profit margin correlates with a low budgeted risk reserve and vice versa.

Figure 2 explains the uniqueness characteristics of the 12 identified project characteristics, but only 4 are significantly correlated to or associated with the project's risk profile. In the model, X_1 to X_4 stand for the four project characteristics of construction pace, project organization, concretisation phase and design innovativeness. However, these four do not directly predict the required risk reserve. Through a series of multiple regression analyses based on the stepwise method, a regression model is found with the highest explanatory factor. The model is based on two predictors represented in figure 2 by Y_1 and Y_2 . The predictors are project organization and design innovativeness, of which the latter has the largest influence on the predicted variable, the required risk reserve. The stepwise regression method ensures a parsimonious model that is more easily generalizable. Equation 2 contains the formula that can predict the required risk reserve.

$$\text{EQUATION 2: } \textit{Required risk reserve} = 2.639 * \textit{innovative design score} - 8.924 * \textit{project organization dummy score}$$

The accuracy of the model is explained by the R^2 of the regression model, which is 41.9%. The standard error of the estimate is 6.53%, which is a measure of the precision of the proposed model. The accuracy of the proposed model, based on the 'outside view', is 41.9%, which is low. The precision of the model, however, is very small, with a standard error of 6.53%. The 95% prediction interval is calculated by multiplying the standard error with plus and minus 1.96. The predictions of the model fall within this interval around the regression line. The 95% prediction interval is plus and minus 13.06%. The average required risk reserve is 3.53%, so the 95% prediction interval is thus approximately seven times larger than the mean value. The accuracy and precision are too low to be used directly in future budgeting of risk reserves.

The quality of the current approach in budgeting the risk reserve is also tested. The accuracy of the regression model based solely on the budgeted risk reserve is 20.1%. The required risk reserve can only be predicted by the budgeted risk reserve with a 20% accuracy. The standard error of the estimate is 7.42%, which means that precision is even worse in the current approach. The 95% prediction interval is nine times larger than the average required risk reserve. "The proposed model thus improves the accuracy by more than 108% and the precision by 12%, which is a substantial improvement. Despite the large improvements in the accuracy and precision, it is still not enough for direct usage in future operations. However, the current approach performs much worse and requires improvements.

The validated and verified model presented in figure 2 is the second element of the research result, the descriptive element. It also partially answers the main research question. A project's risk profile can be determined by the unique character of the project, to which the construction pace, project organization, concretisation phase and design innovativeness are significantly related. The complexity and uncertainty aspects of a project are the dimensions of the project's risk profile. These dimensions are interrelated and cause higher risk in the project's profile, and therefore a higher risk reserve is required. A regression model based on the design innovativeness and project organization characteristics can predict the required risk reserve. The proposed model improves the accuracy with more than 108% and the precision with 12% compared to the current budgeting quality.

However, these improvements are not sufficient in order to be directly used in the predictive research result. It requires further improvements in the accuracy, but even more so in the precision.



Recommendations are made to improve on these parameters and ensure a valid and reliable predictive model. The short-term recommendations, or quick wins, are two-fold. Further research is recommended to reduce the inaccuracy of the model. More significant predictors result in higher accuracy and thus higher validity. Further research can investigate the project characteristics and their operationalisations, which can lead to more significant predictors. The same stands for the influence of market conditions and risk perception on the accuracy of the risk reserve. Experience within a project team is also factor that potentially influences the required risk reserve, and therefore may be interesting for further research. This is a task for science.

The second quick win is a recommendation for Dura Vermeer in order to improve precision in the model. Imprecision is caused by statistical variability, which can be reduced by a larger database. The database is currently based on 49 valid projects, but in two years, this number can be greatly increased. There is also a long-term recommendation for Dura Vermeer. The imprecision in the model is mainly caused by the large variance within the required risk reserve. This is a result of the chosen operationalisation. The original operationalisation based on costs incurred due to risks is found not to be useful. This is a result of the cost control inconsistency with respect to these costs. However, this operationalisation is less sensitive for 'noise' in the data and is likely to have a smaller spread in the variable. The recommendation is to adjust the cost control practice to be able to detect incurred costs due to risks. This is long-term recommendation as the cost control process has to be changed and the database has to start from 0, rather than 49. It is, however, highly recommended for creating a predictive model that is both accurate and precise, and thus also valid and reliable.



III. Managementsamenvatting

De constructiesector werkt aan unieke bouwprojecten, waardoor vergelijking moeilijk is. Daarbij groeit de complexiteit en onzekerheid van deze projecten. Deze ontwikkelingen maken de projecten risicovol en vergroten de kans op een financiële zeperd. Onderzoek toont ook aan dat bouwprojecten in meer dan 25% van de gevallen een kostenoverschrijding laten zien ten opzichte van de begroting (Flyvbjerg, Holm, & Buhl, 2002). Bedrijven die in de constructiesector actief zijn, zoals Dura Vermeer, budgetteren een risicoreservering ten tijde van de aanbesteding. Deze risicoreservering is bestemd voor financiële tegenvallers als gevolg van het optreden van risico's. Er is echter een wetenschappelijke onderbelichting van en een wens vanuit de praktijk voor een duidelijk framework op basis van de combinatie van de volgende factoren: (1) projectkarakteristieken, (2) complexiteit en onzekerheid, (3) projectrisicoprofiel en (4) risicoreservering in de begroting. Dit probleem is vertaald in de volgende hoofdonderzoeksvraag:

Hoe kan het risicoprofiel van een project bepaald worden op basis van de projectkarakteristieken en de aspecten complexiteit en onzekerheid voor infrastructurele bouwprojecten, zodat de nauwkeurigheid en precisie van de begrote risicoreservering verbetert?

Het onderzoeksresultaat moet dus tweeledig zijn. Er is gevraagd naar een 'voorspellend' en een 'verklarend' element in het onderzoeksresultaat. Het verklarende deel moet alle relaties tussen het unieke karakter van een project, de complexiteit en onzekerheid, het risicoprofiel van het project en de risicoreservering kunnen beschrijven. Het voorspellende deel is gefocust op het verbeteren van de nauwkeurigheid en precisie in de begrote risicoreservering. Dit onderzoeksresultaat is nagestreefd door een onderzoeksstrategie gebaseerd op zowel inductieve als deductieve argumentatie, maar ook volgens de systemengineeringpraktijken validatie en verificatie.

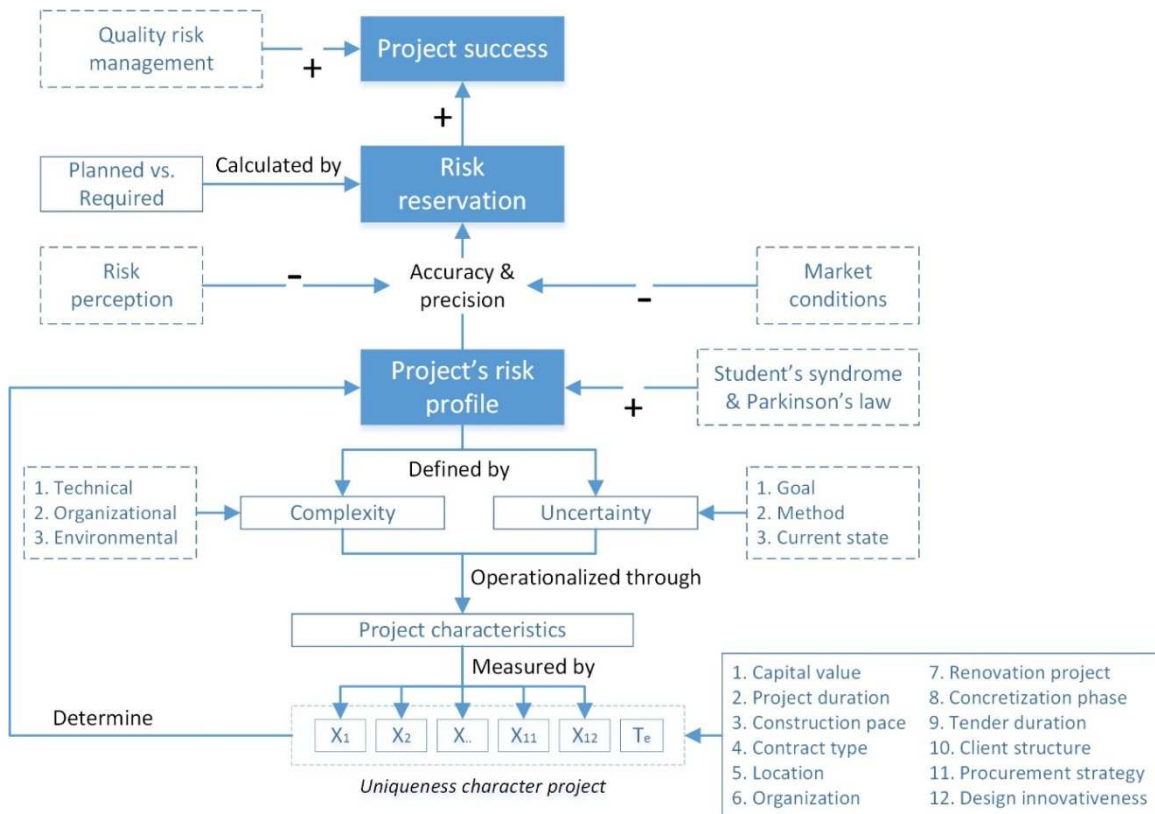
Het onderzoek is verdeeld in drie onderzoeksfasen. Het eerste deel is het theoretische onderzoek, gebaseerd op een literatuurstudie, waarin het theoretisch kader is bepaald. In het tweede onderzoeksgedeelte is het theoretisch kader kwalitatief gevalideerd op basis van vier casestudies en een cross-caseanalyse. De laatste onderzoeksfase bevat het statistische deel van het onderzoek. Door middel van twee rondes van statistische analyse en meerdere meervoudige regressieanalyses is het gevalideerde theoretisch kader kwantitatief geverifieerd. Het gevalideerde en geverifieerde model is het verklarende deel van het onderzoeksresultaat. Het voorspellende deel van het onderzoeksresultaat is een regressiemodel dat de risicoreservering voorspelt voor nieuw aan te besteden projecten, gericht op een verhoogde nauwkeurigheid en precisie. Dit is gebaseerd op het unieke karakter van het project en het risicoprofiel.

Het theoretische onderzoek is dus gebouwd op de literatuurstudie. De onderzoeksonderwerpen in deze studie zijn: (1) de risicoreservering, (2) nauwkeurigheid en precisie, (3) het projectrisicoprofiel, (4) complexiteit en onzekerheid en (5) het unieke karakter van infrastructurele bouwprojecten. Deze onderwerpen vormen ook de kern van het theoretische model dat is afgebeeld in figuur 3. Het succes van een project is positief beïnvloed door de kwaliteit van risicomangement, maar ook door een nauwkeurig en precies gebudgetteerde risicoreservering. De benodigde risicoreservering is in eerste instantie geoperationaliseerd door het totaal van gerealiseerde kosten als gevolg van opgetreden risico's. Echter, de casestudies toonden dat deze kosten moeilijk zijn af te leiden uit de kostencontroledocumenten. Deze kosten worden gedocumenteerd in andere begrotingsregels van het kostencontroledocument.

Om die reden is een nieuwe operationalisering bepaald, die de benodigde risicoreservering voornamelijk calculeert op basis van het geboekte resultaat in de kale kostprijs van het project. Vijf kostencategorieën zijn geïdentificeerd, namelijk de directe kosten, indirecte kosten, risicoreservering, algemene kosten en winstmarge. Een zesde categorie is onderhoudskosten, maar deze categorie valt buiten de scope van het huidige onderzoek. De vijf kostencategorieën gezamenlijk vormen de totale projectkosten, te betalen door de opdrachtgever aan de aannemer. De bouwkosten van het project zijn een combinatie van de directe kosten, indirecte kosten en risicoreservering. De kale kostprijs is gebaseerd

op de totale directe en indirecte kosten. Het resultaat geboekt in de kale kostprijs plus de werkelijke kosten in de risicoreservering, is de benodigde risicoreservering. De formule is weergegeven in vergelijking 3 berekent de benodigde risicoreservering. De algemene kosten en winstmarge zijn hierbij dus buiten beschouwing gelaten. Deze kostencategorieën bevatten een bedrijfsoverweging met betrekking tot de bedrijfsstrategie en zijn daarom niet opgenomen in de vergelijking.

$$\text{VERGELIJKING 3: Benodigde risicores.} = \frac{\text{Resultaat kale kostprijs} + \text{werkelijke kosten risicoreservering}}{\text{Werkbegroting kale kostprijs}} * 100\%$$



FIGUUR 3: KWALITATIEF GEVALIDEERD MODEL GEBASEERD OP PRAKTISCHE EN THEORETISCHE BEVINDINGEN (BRON: EIGEN ILLUSTRATIE)

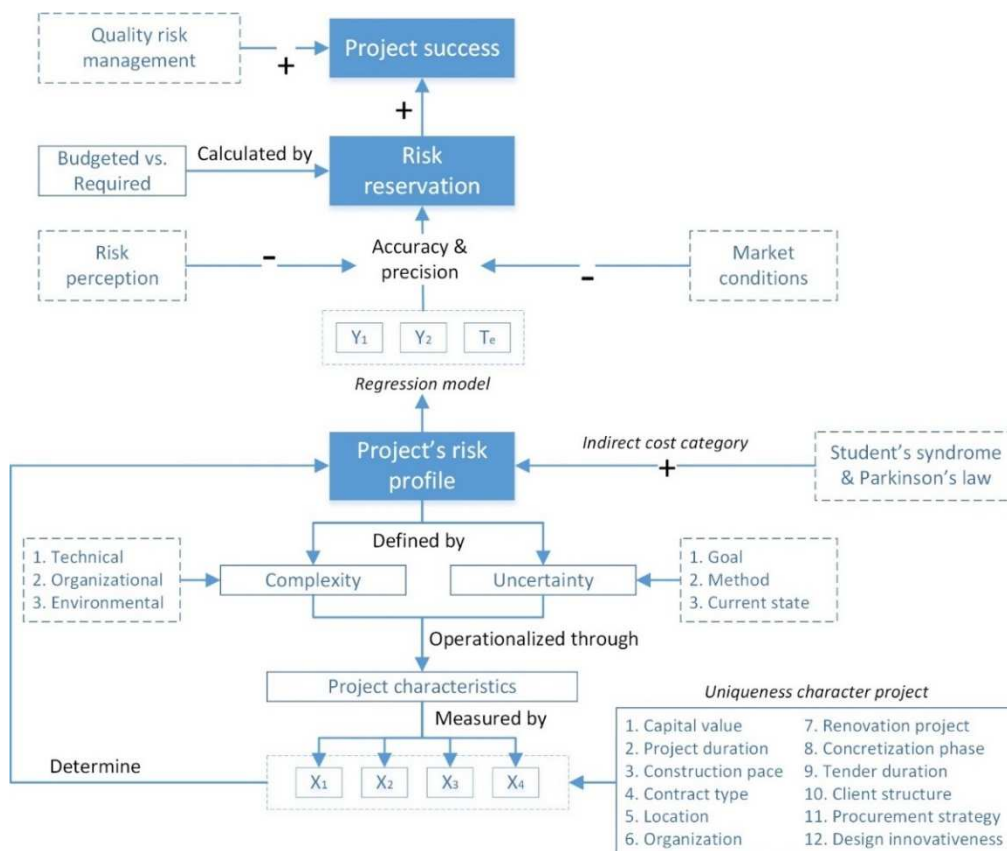
Figuur 3 geeft het gevalideerde model weer, in het Engels, gebaseerd op de theoretische en praktische bevindingen. De nauwkeurigheid en precisie in de gebudgetteerde risicoreservering is bepaald door het verschil met de benodigde risicoreservering. Een perfect gebudgetteerde risicoreservering betekent dat er geen verschil is en betekent een nauwkeurigheid en precisie van 100%. Echter, marktomstandigheden en risicoperceptie hebben als externe factoren een negatieve invloed op de kwaliteit van de begrote risicoreservering. De huidige aanpak in het begroten van de risicoreservering is gebaseerd op de probabilistische berekening van de risico's in het risicodossier en de expertbeoordeling. Deze aanpak staat bekend als de *inside view*. De *outside view* is een tweede aanpak die is voorgesteld in het huidige onderzoek. Deze aanpak is gebaseerd op historische gegevens van vergelijkbare projecten.

De moeilijkheidsgraad van de voorgestelde aanpak is de vergelijkbaarheid van een verondersteld uniek projectkarakter in relatie tot het bepalen van het bijbehorende projectrisicoprofiel. Figuur 3 licht de operationalisering van het risicoprofiel uit door middel van de dimensies complexiteit en onzekerheid. Complexiteit in een project is gedefinieerd als technische, organisatorische en omgevingscomplexiteit. Onzekerheid is gebaseerd op de drie subdimensies, namelijk huidige staat, doel en methodeonzekerheid. Deze dimensies, of projectaspecten, zijn verder geoperationaliseerd door middel van onafhankelijke projectkarakteristieken. Deze karakteristieken zorgen voor een 'vingerafdruk' van het unieke karakter van een project, wat vergelijking van projecten mogelijk maakt. De volgende twaalf karakteristieken zijn geïdentificeerd in de theoretische en praktische studies:



1. financiële grootte;
2. bouwtijd;
3. bouwsnelheid;
4. contracttype;
5. projectlocatie;
6. projectorganisatiestructuur;
7. renovatieproject;
8. concretiseringsfase;
9. aanbestedingsduur;
10. structuur opdrachtgever;
11. aanbestedingsstrategie;
12. ontwerpinnovativiteit.

Echter, dit zijn onafhankelijke projectkarakteristieken die niet direct gemeten kunnen worden voor een potentiële relatie met het risicoprofiel van het project. Het risicoprofiel is geoperationaliseerd door middel van de benodigde risicoreservering. De projectkarakteristieken zijn verder geoperationaliseerd door kwantitatieve of classificeerbare parameters. Deze operationalisering is in het Engels beschreven in tabel 13 in subparagraaf 4.4.2. Door de inconsistentie in het boeken van kosten veroorzaakt door risico's in de risicoreservering, is het moeilijk om directe relaties te leggen tussen kosten en risico's. Het is hierdoor moeilijk om de kritieke risico's te identificeren. Het risico dat het meest kritiek is gebleken in de bestudeerde projecten, is het niet behalen van de contractmijlpa(a)l(en). De fenomenen *student's syndrome* en *Parkinson's law* zijn de grootste veroorzakers van dit risico. Parkinson's law en student's syndrome zorgen ervoor dat het werk zich zal uitbreiden en de beschikbare tijd zal opvullen of zelfs het werk zal vertragen (Khamooshi & Cioffi, 2013).



FIGUUR 4: KWANTITATIEF GEVALIDEERD MODEL GEBASEERD OP THEORETISCHE, PRAKTISCHE EN STATISTISCHE BEVINDINGEN (BRON: EIGEN ILLUSTRATIE)

Deze fenomenen zorgen voor een verhoogd risicoprofiel, specifiek in de tijdsafhankelijke indirecte kostentypes. Deze kostentypes zijn dominant in relatie tot het projectrisicoprofiel. Een database is

aangelegd met zowel financiële als projectgegevens van 53 projecten, waarvan 49 bruikbaar zijn. Deze data zijn gebruikt voor het statistisch testen en verifiëren van het model weergegeven in figuur 4. Het risicoprofiel is statistisch getest en de categorie indirecte kosten bevat het grootste deel van het risicoprofiel. De categorie indirecte kosten is voornamelijk gebaseerd op tijdsafhankelijke kostentypes. Het verschil tussen het gemiddelde van de directe kosten (2,34%) en de indirecte kosten (-15,87%) is significant op het 1%-niveau op basis van $N = 49$. Het resultaat in de kale kostprijs van -2,40% is dus voornamelijk een gevolg van de tijdsafhankelijke kostentypes in de categorie indirecte kosten. Voorbeelden van zulke kostentypes zijn de projectorganisatiekosten (-34,95%) en ontwerpkosten (-18,90%). Dit is weergegeven in het gevalideerde en geverifieerde model in figuur 4.

De begrote risicoreservering is gemiddeld 2,53%, maar daar staat een gemiddelde benodigde risicoreservering van 3,53% tegenover. De begrote risicoreservering is dus te optimistisch, wat de voornaamste reden is dat de gemiddelde gerealiseerde winstmarge -0,54% is. De gemiddelde begrote winstmarge was 0,59%, wat betekent dat de nauwkeurigheid en precisie in de risicoreservering nog belangrijker is. De winstmarges zijn zo klein dat een risicoreservering die 1% te laag is, al het verschil tussen winst of verlies kan betekenen. Een 1% te laag begrote risicoreservering is een indicatie van een te optimistische risicoperceptie en/of felle marktomstandigheden. De invloed van marktomstandigheden is significant getest door middel van een correlatie tussen de begrote risicoreservering en de winstmarge. Een lagere winstmarge is gecorreleerd aan een lagere risicoreservering en vice versa.

Figuur 4 licht het unieke karakter van een project uit door middel van de twaalf geïdentificeerde projectkarakteristieken, echter, vier hiervan zijn significant gecorreleerd aan of geassocieerd met het risicoprofiel van het project. X_1 tot en met X_4 in figuur 4 staan voor de vier karakteristieken bouwsnelheid, projectorganisatie, concretiseringsfase en ontwerpinnovativiteit. Echter, deze vier karakteristieken voorspellen niet direct de benodigde risicoreservering. Door middel van een serie van meervoudige regressieanalyses is, volgens de stapsgewijze methode, een regressiemodel gevonden met de hoogste verklaarbare score. Het model is gebaseerd op de twee voorspellers ontwerpinnovativiteit en projectorganisatie, in figuur 4 afgebeeld door Y_1 en Y_2 . Ontwerpinnovativiteit heeft de grootste invloed op de voorspelde variabele, de benodigde risicoreservering. De stapsgewijze methode verzekert dat het een spaarzaam model is, dat gemakkelijk te generaliseren is en niet gevoelig is voor *database overfitting*. Vergelijking 4 bevat de formule die de benodigde risicoreservering kan calculeren.

VERGELIJKING 4: *Benodigde risicoreservering = 2.639 * score ontwerpinnovativiteit – 8.924 * project organization dummy score*

De nauwkeurigheid van het model is af te lezen aan de R^2 van het regressiemodel, die 41,9% is. Het model heeft een standaarderror van de schatting van 6,53%, wat een maatstaf voor precisie is. De nauwkeurigheid is laag bij een verklaarbaarheid van 41,9%, gebaseerd op de outside view. De precisie van het model is echter zeer laag. Het 95%-voorspellingsinterval is gebaseerd op de standaarderror vermenigvuldigd met plus en min 1,96. De werkelijk benodigde risicoreservering valt met 95% zekerheid binnen dit voorspellingsinterval, dat plus en min 13,06% is. De gemiddelde benodigde risicoreservering is 3,53%, dus het 95%-voorspellingsinterval is zeven keer zo groot als het gemiddelde. De nauwkeurigheid en precisie van het model zijn dus te laag voor direct gebruik in toekomstige aanbestedingen bij het begroten van de risicoreservering.

De kwaliteit van de huidige aanpak van het begroten van de risicoreservering is ook getest. De nauwkeurigheid van het regressiemodel, alleen gebaseerd op de gebudgetteerde risicoreservering, is 20,1%. De begrote risicoreservering kan de benodigde risicoreservering maar met een nauwkeurigheid van 20% verklaren. De standaarderror is 7,42%, de precisie is dus zelfs nog lager in de huidige aanpak gebaseerd op de inside view. Het 95%-voorspellingsinterval is negen keer zo groot als de gemiddelde benodigde risicoreservering. De voorgestelde aanpak resulteert in een model dat de nauwkeurigheid met 108% verbetert en de precisie met 12%. Dit is een substantiële verbetering, echter, het is alleen nog niet genoeg voor werkelijk gebruik door Dura Vermeer. Wat wel duidelijk is, is dat de huidige aanpak



ook niet presteert zoals het zou moeten, dus met een hoge nauwkeurigheid en precisie. De huidige aanpak verdient een grote verbetering, waarin de basis al is gelegd in de voorgestelde aanpak.

Het gevalideerde en geverifieerde model weergegeven in figuur 4, is het tweede deel van het onderzoeksresultaat, het beschrijvende of verklarende deel. Dit model beantwoordt ook deels de hoofdvraag bepaald in de start van het onderzoek. Het risicoprofiel van het project kan worden bepaald door het unieke karakter van het project, waarin de bouwsnelheid, projectorganisatie, concretiseringsfase en ontwerpinnovativiteit significant zijn gerelateerd aan dit risicoprofiel. De projectaspecten complexiteit en onzekerheid zijn de twee dimensies van het risicoprofiel. De dimensies zijn aan elkaar verbonden en zorgen voor een verhoogd risicoprofiel. Ze resulteren dus in een hogere benodigde risicoreservering. Een regressiemodel, gebaseerd op de karakteristieken ontwerpinnovativiteit en projectorganisatie, kan de benodigde risicoreservering voorspellen. De voorgestelde aanpak, volgens de outside view op basis van historische gegevens van vergelijkbare projecten, kan de nauwkeurigheid met 108% en precisie met 12% verbeteren ten opzichte van de huidige aanpak in het begroten van de risicoreservering.

Deze verbeteringen zijn voldoende, zodat het voorspellende deel van het onderzoeksresultaat direct gebruikt kan worden in de huidige bedrijfsvoering van Dura Vermeer. Dit vergt verdere verbetering in de nauwkeurigheds- en precisieparameters van het model. Aanbevelingen zijn gedaan om deze parameters te verbeteren, zodat het model valide en betrouwbaar is. De kortetermijnaanbevelingen, of *quick wins*, zijn tweeledig. Vervolgonderzoek kan resulteren in meer significante voorspellers in het regressiemodel en dus in een hogere nauwkeurigheid. Onderwerpen voor vervolgonderzoek zijn: (1) de projectkarakteristieken en bijbehorende operationalisering, (2) de externe factoren risicoperceptie en marktomstandigheden, (3) complexiteit en onzekerheid en (4) ervaring binnen het projectteam. Vervolgonderzoek is een taak voor de wetenschap, maar kan gestuurd worden door Dura Vermeer.

De tweede quick win is een aanbeveling aan Dura Vermeer om de precisie in het model te verbeteren. De afwezige precisie is veroorzaakt door statistische variabiliteit, wat gereduceerd kan worden door een grotere database. De huidige database is gebaseerd op 49 bruikbare projecten; na twee jaar kan dit aantal al sterk zijn toegenomen. Deze kortetermijnverbeteringen zullen voor een verhoogde nauwkeurigheid en precisie in het model zorgen. Het blijft de vraag of dit genoeg is, zeker gezien de lage precisie.

Een langetermijnaanbeveling is om het kostencontroleproces aan te passen, zodat kosten als gevolg van risico's wel herkend worden en ook gedocumenteerd worden. Deze verbetering zal ervoor zorgen dat de benodigde risicoreservering berekend kan worden met minder ruis in de data. Deze operationalisering is minder gevoelig voor dataruis en heeft daardoor een lagere variantie. Een lagere variantie betekent ook dat de precisie in het voorspellende model verbetert. Het is een langetermijnaanbeveling omdat de database vanaf 0 in plaats van 49 moet worden opgebouwd. Echter, dit is wel sterk aanbevolen voor het maken van een voorspellend model dat zowel nauwkeurig als precies is. Op deze manier kan een model worden gevonden dat valide en betrouwbaar is voor het begroten van risicoreserveringen in toekomstige projecten.

IV. Table of contents

I.	Preface.....	III
II.	Management summary.....	V
III.	Management samenvatting.....	Error! Bookmark not defined.
IV.	Table of contents	XV
V.	Table of figures	XVII
VI.	Table of tables	XIX
1.	Introduction.....	1
1.1	Problem definition	1
1.2	Research demarcation	3
1.3	Research relevance	4
1.4	Reading guide	5
2.	Research approach	7
2.1	Research strategy	7
2.2	Research method.....	8
3.	Theoretical framework	11
3.1	Risk reserve, accuracy and precision	12
3.2	Complexity, uncertainty and project's risk profile	16
3.2.1	Risk management and risk profile.....	16
3.2.2	Risk profile and complexity and uncertainty.....	18
3.3	Infrastructural projects and characteristics	21
3.3.1	Infrastructural projects	21
3.3.2	Infrastructural project characteristics.....	22
3.4	Theoretical model and propositions	25
4.	Practical study.....	27
4.1	Introduction case studies.....	28
4.2	Case study findings	29
4.2.1	Room for the Waal Nijmegen	29
4.2.2	Renovation Velsertunnel.....	32
4.2.3	Capacity expansion N279.....	36
4.2.4	Parking garage Tournooiveld	40
4.3	Cross-case analysis.....	44
4.3.1	Risk management and risks.....	44
4.3.2	Financial findings	45



4.3.3	Project characteristics.....	47
4.3.4	Other findings	49
4.4	Validated model and hypotheses.....	51
4.4.1	Practical adjustments to model	51
4.4.2	Operationalisation of project characteristics.....	52
4.4.3	Hypotheses	56
5.	Statistical analysis/research.....	57
5.1	Data collection	58
5.1.1	Database introduction	58
5.1.2	Statistical techniques	59
5.1.3	Database analysis.....	61
5.2	First round of statistical analysis.....	65
5.3	Second round of statistical analysis	73
5.3.1	Findings second round.....	76
5.4	Regression and statistical findings	78
5.4.1	Introduction regression analyses	78
5.4.2	regression analyses.....	79
5.4.3	Statistical findings	82
6.	Research result and discussion	85
6.1	Descriptive and predictive model	86
6.2	Discussion	89
6.2.1	Validity and reliability of research result.....	89
6.2.2	Scientific contribution.....	90
6.2.3	Research limitations.....	90
7.	Conclusion and recommendations	93
7.1	Conclusion	94
7.1.1	Answering sub-research questions	94
7.1.2	Overall conclusion.....	100
7.2	Recommendations – reliability and validity	101
7.2.1	Further research	101
7.2.2	Recommendations usage research results	101
VII.	Bibliography	103
VIII.	Appendix.....	107

V. Table of figures

Figure 1: Qualitatively validated model based on practical and theoretical findings (Source: own ill.).....	VI
Figure 2: Quantitatively verified model based on theoretical, practical and statistical findings (Source: own ill.)	VII
Figure 3: Kwalitatief gevalideerde model gebaseerd op praktische en theoretisch bevindingen (Source: own ill.)	Error! Bookmark not defined.
Figure 4: Quantitatively verified model based on theoretical, practical and statistical findings (Source: Own ill.)	Error! Bookmark not defined.
Figure 5: Proposed model explaining relation between the project and the required risk reserve through the project's characteristics, aspects and risk profile (Source: own ill.)	3
Figure 6: Scoping of project management to reserve (source: Own ill.)	3
Figure 7: Research questions linked to the proposed conceptual model (source: Own ill.)	4
Figure 8: Relations research phases and steps explained graphically (Source: Own ill.)	6
Figure 9: 'The wheel of science' (Wallace, 1971).....	7
Figure 10: Two Research steps in the Theory phase (Source: own ill.)	8
Figure 11: Four Research steps in the practice phase (Source: own ill.)	8
Figure 12: Four Research steps in the practice phase (Source: own ill.)	9
Figure 13: Relations research phases and steps explained graphically, theoretical phase (Source: Own ill.)	11
Figure 14: Context of risk reserve allocation in relation to project and project success (Source: Own ill.)	12
Figure 15: Division and definition of cost categories (Source: own ill.)	14
Figure 16: Example of a probability function of normal distribution (Source: Wikipedia).....	15
Figure 17: Model with relations between project's risk profile, project success, risk reserve and external factors (Source: own ill.)	16
Figure 18: Dimensions of a project's risk profile (Source: Own ill.)	20
Figure 19: Proposed model for the risk reserve allocation, external factors, project's risk profile, its dimensions and project characteristics, including different propositions of relations (source: Own ill.)	26
Figure 20: Relations research phases and steps explained graphically, Practical phase (Source: Own ill.)	27
Figure 21: Summary figure project's risk profile Room for the waal Nijmegen (source: Own ill.).....	32
Figure 22: Summary figure project's risk profile Renovation Velsertunnel (source: Own ill.)	36
Figure 23: Summary figure project's risk profile capacity expansion N279 (source: Own ill.)	40
Figure 24: Summary figure project's risk profile Parking garage Tournooiveld (source: Own ill.)	43
Figure 25: Relationship between the project result and the amount of additional work (Source: Own graph).....	46
Figure 26: Qualitatively validated model based on practical and theoretical findings (Source: own ill.).....	51
Figure 27: Relations research phases and steps explained graphically, Testing phase (Source: Own ill.)	57
Figure 28: Histogram of the required risk reservation (source: Own graph, extracted from SPSS)	64
Figure 29: Normal Q-Q plot of the required risk reservation (source: Own graph, extracted from SPSS).....	64
Figure 30: Scatterplot of manipulated construction pace 2 and required risk reservation (Source: own graph, extracted from SPSS)	66
Figure 31: Scatterplot of construction pace 1 and required risk reservation (Source: own graph, extracted from SPSS)	66
Figure 32: boxplots of project organization groups (Source: Own table, extracted from SPSS).....	67



Figure 33: Scatterplot of innovative design and required risk reservation (Source: own graph, extracted from SPSS)	70
Figure 34: Mean plot of project location groups (Source: Own table, extracted from SPSS)	71
Figure 35: Scatterplot of the budgeted risk reservation and required risk reservation (Source: own graph, extracted from SPSS)	73
Figure 36: Scatterplot of the budgeted profit margin and risk reservation (Source: own graph, extracted from SPSS)	74
Figure 37: Scatterplot of the year of procurement and difference risk reservation (Source: own graph, extracted from SPSS)	76
Figure 38: Relations rEsearch phases and steps explained graphically, Research result and discussion (Source: Own ill.)	85
Figure 39: Quantitatively verified model based on statistical findings (Source: own ill.)	86
Figure 40: Accuracy and precision in a stochastic variable (Source: Anthony Cutler, 10-02-2007)	87
Figure 41: Reliability and validity in observations (Source: Nevit Dilman, 2012, extracted from wikipedia)	89
Figure 42: Relations research phases and steps explained graphically, after conclusions and recommendations (Source: Own ill.)	93
Figure 43: Grapical answer to research sub-question one (Source: Own ill.)	94
Figure 44: Grapical answer to research sub-question two (Source: Own ill.)	95
Figure 45: Grapical answer to sub-research question three (Source: Own ill.)	96
Figure 46: Grapical answer to sub-research question four (Source: Own ill.)	97
Figure 47: Grapical answer to research sub-question five and the main research question, identical copy of figure 39 (Source: Own ill.)	99

VI. Table of tables

Table 1: Project’s risk profile for three projects, contingency reserve = Sum Residual risks	17
Table 2: Four lists of project characteristics developed in the literature	23
Table 3: Operationalisation of infrastructural construction projects characteristics (Source: Own table)	24
Table 4: Project characteristics of the Room for the Waal Nijmegen (i-Lent)	29
Table 5: Project characteristics of the renovation Velsertunnel.....	33
Table 6: Financial data of the profit margins per sub-project and partner.....	34
Table 7: PROJECT CHARACTERISTICS OF THE Capacity expansion N279 's-Hertogenbosch – Veghel’	37
Table 8: PROJECT CHARACTERISTICS OF THE parking garage Tournooiveld.	40
Table 9: financial data of the direct and indirect costs of the four studied projects (Source: Own table)	46
Table 10: Costs for UTA staff and Engineering compared to the project's bare costs (Source: Own table)	47
Table 11: Scoring of the influence of the project characteristics on project's risk profile (source: Own Table)	48
Table 12: Summary of the levels of measurements and their differences (Source: own table).....	53
Table 13: Operationalisation of the project characteristics (Source: Own Table)	55
Table 14: List of projects in the projects database (Source: Own table).....	59
Table 15: Correlation test of innovative design expert judgements scores (Source: Own table, Extracted from SPSS)	61
Table 16: Correlation test of innovative design average and Test score (Source: Own table, Extracted from SPSS)	62
Table 17: Descriptive statistic of the required risk reservation (Source: Own table, extracted from SPSS)	63
Table 18: Test of normality of the required risk reservation (Source: Own table, extracted from SPSS)	63
Table 19: Correlation analysis between construction pace 1 and required risk reservation (Source: Own table, extracted from SPSS)	65
Table 20: CORRELATION ANALYSIS BETWEEN manipulated CONSTRUCTION PACE 2 AND REQUIRED RISK RESERVATION (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)	66
Table 21: Descriptive statistics of project organization groups (source: own table, extracted from SPSS)	67
Table 22: Descriptive statistics of the manipulated project organization groups (source: own table, extracted from SPSS)	67
Table 23: Independent Samples t-Test of manipulated organization variable (Source: own table, extracted from SPSS)	68
Table 24: Descriptive statistics of concretization phase groups (source: own table, extracted from SPSS)	68
Table 25: Test of normality of concretization phase characteristic groups (Source: Own table, extracted from SPSS)	68
Table 26: Independent Samples t-Test of concretization phase (Source: own table, extracted from SPSS)	68
Table 27: Independent Samples t-Test of manipulated concretization phase (Source: own table, extracted from SPSS)	69
Table 28: CORRELATION ANALYSIS BETWEEN innovative design AND REQUIRED RISK RESERVATION (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)	69
Table 29: Descriptive statistics of location groups (source: own table, extracted from SPSS)	71
Table 30: ANOVA test results project location (Source: Own Table, extracted from SPSS)	71



Table 31: Independent Samples t-Test of manipulated location (Source: own table, extracted from SPSS)	72
Table 32: Descriptive statistics of manipulated location groups (source: own table, extracted from SPSS)	72
Table 33: Multiple comparisons Mean values location groups (Source: Own table, extracted from SPSS.....)	72
Table 34: Correlation analysis between budgeted risk reservation and required risk reservation (source: Own table, extracted from SPSS)	73
Table 35: Correlation analysis between budgeted risk reservation and profit margin (source: Own table, extracted from SPSS)	74
Table 36: Descriptive statistic of project's direct, indirect and bare costs (Source: Own table, extracted from SPSS)	75
Table 37: Paired samles test of direct and indirect cost variables (Source: Own table, extracted from SPSS).....	75
Table 38: Correlation analysis between difference risk reservation and required risk reservation (source: Own table, extracted from SPSS).....	76
Table 39: Model summary regression analysis without constant, based on construction pace manipulated database (source: own table, extracted from SPSS)	79
Table 40: Coefficient statistics of regression analysis without constant, based on construction pace manipulated database (source: Own table, extracted from SPSS)	80
Table 41: Model summary regression analysis without constant, based construction pace manipulated database (source: own table, extracted from SPSS)	81
Table 42: Model summary regression analysis without constant, based on construction pace manipulated database including the budgeted risk reservation variable (source: own table, extracted from SPSS)	81
Table 43: Coefficient statistics of regression analysis with constant, based on all projects (source: Own table, extracted from SPSS)	82

1. Introduction

The key question that motivates this research is how risk management can be improved. This research is thus aimed at understanding the practice of budgeting the risk reserve and determining the underlying factors which influence this risk reserve. The current chapter sketches the current situation of the construction sector and its associated problems. After a demarcation of the research problem, the corresponding research objective and research questions are elaborated. The introductory chapter closes with a guide of the report.

1.1 Problem definition

A project can be described as follows: *“A unique venture with a beginning and an end, conducted by people to meet established goals with parameters of cost, schedule and quality”* (Buchanan & Boddy, 1992). From Dubois & Gadde (2002, p. 621): *“Winch (1987) argued that construction projects are amongst the most complex of all undertakings. Gidado (1996) further emphasised this view by stating that there is a continuous increase in the complexity of construction projects.”* The construction sector is constantly challenged with the characteristic complexity of projects (Nicholas & Steyn, 2012, p. 351). Nicholas and Steyn have claimed that *“every project is risky, meaning there is a chance that things won’t turn out exactly as planned. Project outcomes result from many things, including some that are not predictable and over which project managers have little control.”* The chance that things turn out differently than expected means that there is uncertainty in projects. The focus of this research is infrastructural projects.

The performance and success of projects comprise the basis of this research. However, budget overruns and long delays are more the rule than the exception in most large and complex construction projects. Research on construction projects has shown that costs escalated beyond the original intention in over 25% of the investigated projects (Flyvbjerg, Holm, & Buhl, 2002). From (Bosch-Rekvelde, 2011, p. 1): *“Investigating about 600 projects in business, government and non-profit sectors, with budgets between \$40,000 and \$2.5 billion, Shenhar and Dvir reported a failure of even 85% when looking at meeting time and budget goals.”* Closer to home, ‘project failures’ in the Netherlands include the ‘Betuweroute’ between the harbour of Rotterdam and the border of Germany, the north-south metro line in Amsterdam and the high-speed railway line that connects Amsterdam and Belgium. A project can fail in terms of time and costs, but also from the perspective of quality.

Early works on complexity have explained the concept as a critical condition in projects. *“Certain project characteristics provide a basis for determining the appropriate managerial actions required to complete a project successfully. Complexity is one such critical project dimension”* (Baccarini, 1996, p. 201). The research of Baccarini described complexity in terms of technical and organisational complexity and suggested that it is measured through interdependencies and differentiation. More recent research has also claimed that complexity is an important characteristic of construction projects. *“The complexity of construction projects is highlighted from numerous case stories illustrating how seemingly insignificant factors and different understandings of situations can lead to unfortunate and undesirable consequences”* (Schultz, Jørgensen, Bonke, & Rasmussen, 2015, p. 424). Complexity can lead to unfortunate and undesirable consequences, which means that complexity can lead to threats and thus influence the project’s risk profile.

Since projects are unique ventures, it is inherent that they deal with uncertainties. This is the case for all kinds of projects, including infrastructural projects. The International Project Management Institute (PMI) described uncertainty in the Project Management Body of Knowledge (PMBOK) Guide as *“risk conditions—aspects of the project or organisation’s environment that increase project risk”* (McLain, 2009, p. 60). Uncertainty is also referred to as risk conditions, or aspects of a project that influence its risk profile. Risk conditions offer information about the likelihood of achieving a specific goal. In the construction sector, a goal is most often expressed with the iron triangle, which dictates the terms of



costs, time and quality. Akin to project complexity, project uncertainty is also assumed to affect a project's risk profile.

What becomes apparent is that uncertainty and complexity are two important conditions, aspects or characteristics of a project. It is important to note that recent research has defined uncertainty and complexity as **aspects of a project**, though it remains questionable whether these are the only two aspects. The research by McLain has related complexity to an indicator for the level of uncertainty in the project; however, the present research initially assumes project complexity and uncertainty as two different but interrelated aspects. Further research has explored whether there is indeed a dependency between uncertainty and complexity. Secondly, it is still unknown what project characteristics influence the levels of complexity and uncertainty, and there are limited suggestions for how should these be measured. It is thus useful to research if specific project characteristics are critical for determining the overall risk profile of the project.

A higher project risk profile is assumed to be related to higher levels of complexity and uncertainty, which, as described above, are related to project success. Project success is thus endangered by projects with larger risk profiles. The practice of project management is designed in such way that it should ensure project success. As project management encompass too extensive of a field of research, the focus of this graduation research is on risk management as a practice in project management. According to Maylor (2005, p.178): *"Risk management is a key element of ... ongoing management of projects, and the methods for this are well developed"*.

More recent research has explained that risk management is *"full of deficiencies that affect its effectiveness as a project management function and in the end, projects' performance"* (Serpellaa, Ximena, Howarda, & Rubio, 2014, p. 1). Risk management thus relates to projects' performance, so improvements in risk management can lead to improved project performance. Risk management is an important task in project management, such that risk management can be defined as follows: *"The identification of risks in the process, the assessment of these risks, categorising and prioritising risks, defining response actions, monitoring risks, and reporting about risks"* (Nicholas & Steyn, 2012, p. 352).

Risk management in projects is primarily focused on project risks, whereby a risk can be defined as *"the probability of an undesired event multiplied by the consequences"* (Jonkman, Morales-Nápoles, Steenberg, Vrijling, & Vrouwenvelder, 2015, p. 58). Here, the emphasis is on negative events; however, in risk management, there is a clear distinction between two types of risks. A risk can be a threat or an opportunity—an event with either positive or negative consequences. A more neutral definition of risk is from (Jonkman, Morales-Nápoles, Steenberg, Vrijling, & Vrouwenvelder, 2015, p. 58): *"Risk is a set of scenarios, each of which has a probability and a consequence."*

As previously elaborated, proper risk management can lead to increased likelihood of project success. Projects are unique ventures, and thus the risk profile of each project is also unique. This renders it difficult to develop a learning curve in risk management practices. One way of addressing the uniqueness of projects is through a universal method that can structure 'unique' projects to make them comparable. There is an extensive body of knowledge available about characteristics of project. One of these studies considered the construction factors that affect the duration of projects in Hong Kong, in which construction cost, type of construction, location, client priorities, productivity, type of contract and post-contractual developments were found to be influential (Chan & Kumaraswamy, 1995). However, this research aims to uncover the factors that influence durations, rather than the risk profile of an infrastructural project. Further research is required to determine which project characteristics are critical for the project's risk profile.

One way of managing risks is through allocating contingency budgets and reserved floats in the planning. In the current research, these are called the risk reserve. The risk reserve is an important measure in risk management to cope with risks. The actual required risk reserve is thus highly related to risk profile of the project and the characteristics of the specific project. A risk reserve that is perfectly attuned to the specific risk profile increases the probability of project success. However, there is a lack of ability in

science and practice to clearly frame the relations between project characteristics, complexity and uncertainty, project's risk profile and the required risk reserve. Figure 5 presents the framework through which all research topics are displayed and is the starting point of this research. Considering this introductory section, the following problem statement is drawn:

The construction sector is confronted with unique construction projects in which uncertainty and complexity are important aspects. These factors endanger the likelihood of success. The levels of uncertainty and complexity are tightly linked to the project and its properties, and they influence the project's risk profile. However, current practices in science and the construction sector lack the ability to clearly frame the relationship between (1) the project and its characteristics, (2) the project aspects of complexity and uncertainty (3) the project's risk profile and (4) the required risk reserve.

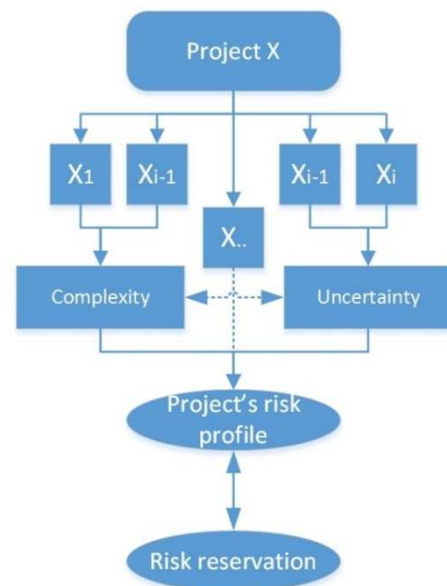


FIGURE 5: PROPOSED MODEL EXPLAINING RELATION BETWEEN THE PROJECT AND THE REQUIRED RISK RESERVE THROUGH THE PROJECT'S CHARACTERISTICS, ASPECTS AND RISK PROFILE (SOURCE: OWN ILL.)

1.2 Research demarcation

The starting points of this research are a problem that requires a solution and a research question that is answered by the results. The objective of this research is thus to overcome the problem that is faced by the problem holder, which in this case is the construction sector, through answering the main research question. Before the research objective and research questions are explained, the scope of the research is first narrowed down. The problem defined in the previous section is not fully confronted in the current research as the problem is too large for a single project. The most important research demarcation has been explained in the previous section. The reverse pyramid presented in figure 6 explains the relation between project management, risk management and risk reserves. Project success can be achieved through proper project management, but the current research focusses on the risk reserve allocation process as an important measure in risk management. Project success is attempted to achieved through improving the allocation of risk reserves.

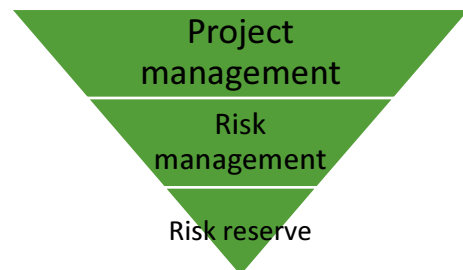


FIGURE 6: SCOPING OF PROJECT MANAGEMENT TO RESERVE (SOURCE: OWN ILL.)

The problem statement is as follows: *"The construction sector is confronted with unique construction projects..."*. The problem is further narrowed by focussing on the company Dura Vermeer Infra National Projects (DVILP), rather than the full construction sector. Rather than construction projects, DVILP is confronted with Dutch infrastructural projects. Such infrastructural projects are a smaller segment of the construction market. Typical infrastructural projects are, for example, dikes, roads and rail projects. The recommendations are therefore specifically aimed at DVILP.

Two other research demarcations are in regard to the project's risk profile and the risk reserve. Secondly, the research focusses on the project's risk profile, so risks are examined from that viewpoint, not from the perspective of a specific stakeholder within the project. Due to this approach, it is expected that the range of risks becomes extensive. Therefore, the scope is narrowed to project risks for the client (the project initiator) and Dura Vermeer (the general contractor). Other viewpoints remain beyond the scope of this graduation thesis. The risk reserve can refer both to the schedule and the budget. However, the focus of the research is on financial success, and thus the budgeted risk reserve is the research



subject. However, risks with consequences relating to time are not excluded from the research. These time-bounded risks also influence the risk reserve in the budget.

Finally, project success is pursued through an improved risk reserve allocation process. The model displayed in figure 5 proposes a risk reserve that is attuned the project's risk profile. However, improvements can be achieved in various ways. Improvement can be reached through a descriptive framework that generates more insight into the relations between the elements in the proposed model. A model that predicts the required risk reserve goes one step further than the descriptive framework. An improved risk reserve allocation, in the current research, is a predicted budgeted risk reserve that is more accurate and precise in relation to the required risk reserve. Following the problem statement and the explained research demarcation, the research objective of this graduation research is as follows:

To create a framework that can explain the relationship between the project, its complexity, uncertainty, risk profile and required risk reserve in order to predict this risk reserve based on these relations with improved accuracy and precision for DVDI.

The main research question is similar to the research objective, merely it is written in the form of a question. The research question in this graduation research is as follows:

How can an infrastructural project's risk profile be determined through its characteristics and aspects of uncertainty and complexity so that the accuracy and precision in the budgeted risk reserve can be improved?

To guide the research, the abovementioned main question is divided into five research sub-questions. These research sub-questions are based on the proposed model that is shown in figure 5. Figure 7 explains how the sub-questions are connected to this proposed model. Each sub-question answers a specific element of the model such that the sub-questions were formulated as follows:

- *SQ1: How do a project's aspects of uncertainty and complexity influence the project's risk profile, and are these the only two relevant aspects?*
- *SQ2: How can a project's aspects of uncertainty and complexity be measured through project characteristics?*
- *SQ3: What are the most critical risks for a project's risk profile and risk reserve?*
- *SQ4: What are the current practices in the budgeting of the risk reserve?*
- *SQ5: How can the determined risk profile lead to improved risk reserve accuracy and precision?*

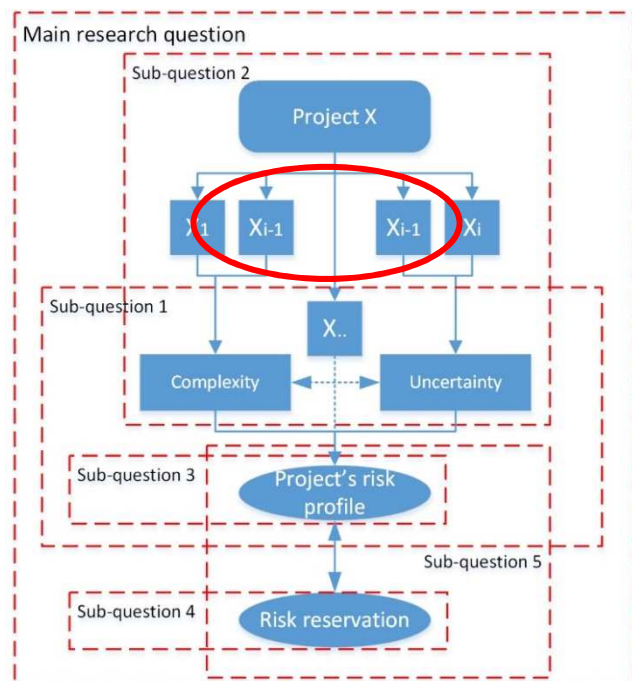


FIGURE 7: RESEARCH QUESTIONS LINKED TO THE PROPOSED CONCEPTUAL MODEL (SOURCE: OWN ILL.)

1.3 Research relevance

This research has both scientific and practical relevance. There is already an extensive body of knowledge on the topics of uniqueness, complexity and uncertainty, risk profiles and risk management in projects. However, there is extensive literature available only on the individual topics. The combination, as explained in the previous two sections, is underrepresented in the literature, especially with a combination of qualitative and quantitative research. A direct combination of a project's

characteristics, risk profile and risk reserve has not before been quantitatively tested on a large scale. There are multiple studies that are both theoretically and practically underpinned. However, the practical side ceases at the qualitative argumentation. The research that includes quantitative elements has typically been represented by limited sample sizes, limited generalisability or a focus on different measures in project and risk management.

The problem statement sketches a situation in which many projects are either over budget, not finished within schedule or even not fit for purpose. There is a difference between the client and contractor perspectives in terms of project failure; a financially successful project for the client can mean a loss for the contractor. This research is relevant to the construction sector in terms of the financial performance of projects. The research aims to close the gap between qualitative theory from a scientific standpoint and quantitative data from a practical standpoint. The research can provide practical guidelines for the construction sector on the one hand and a final quantitative testing step of current theory for science on the other hand. The main problem is the lack of large-scale data on executed projects. The collaboration with DVDI is therefore critical for the quality of the research. Many data are confidential company information and, for that reason, are excluded from the current research.

More specifically, DVDI is a division of the construction company Dura Vermeer Group. Dura Vermeer is a large Dutch building contractor. The strategy of Dura Vermeer is based on four priorities. One of these priorities is 'markt bewerking', which can be translated as an approach to broaden the market. For the year 2018, DVDI set the following ideal picture with respect to the second strategic priority: *"In 2018 DVDI has an embedded workflow to funnel the works present in the sector. We filter our work in such way that our distinctiveness can be materialised best in order to precisely aim which projects to tender and which not."* The current research can contribute to this strategic priority as project characteristics are examined to find relations between these characteristics and the project's risk profile and required risk reserve.

1.4 Reading guide

The thesis continues with the research approach in chapter two, which contains the research strategy and method. It explains the steps between the research question, defined in the current chapter, and the research's results. The research is divided in three phases, which are addressed in order of execution. Chapter three contains the findings of the first research phase, the theoretical phase. The theoretical framework is defined in three steps, and the fourth step graphically explains and elaborates on the framework. The second research phase is the practical study, and it is presented in chapter four. The four case studies and the findings are elaborated on in three different sections. The fifth chapter contains the testing phase, which is based on the findings of the statistical analyses. The sixth chapter consists of the description of the research result, as well as the discussion. The conclusion and recommendations are presented in the seventh and final chapter. The appendix is positioned after the bibliography.

On the first page of each new chapter is a figure that explains the research conducted so far and what is explained later in that particular chapter. The figure thus 'grows' as the research continues. The first figure is presented below as figure 8. The first steps are already presented, and the research strategy and method are the two steps that are taken in the following chapter.

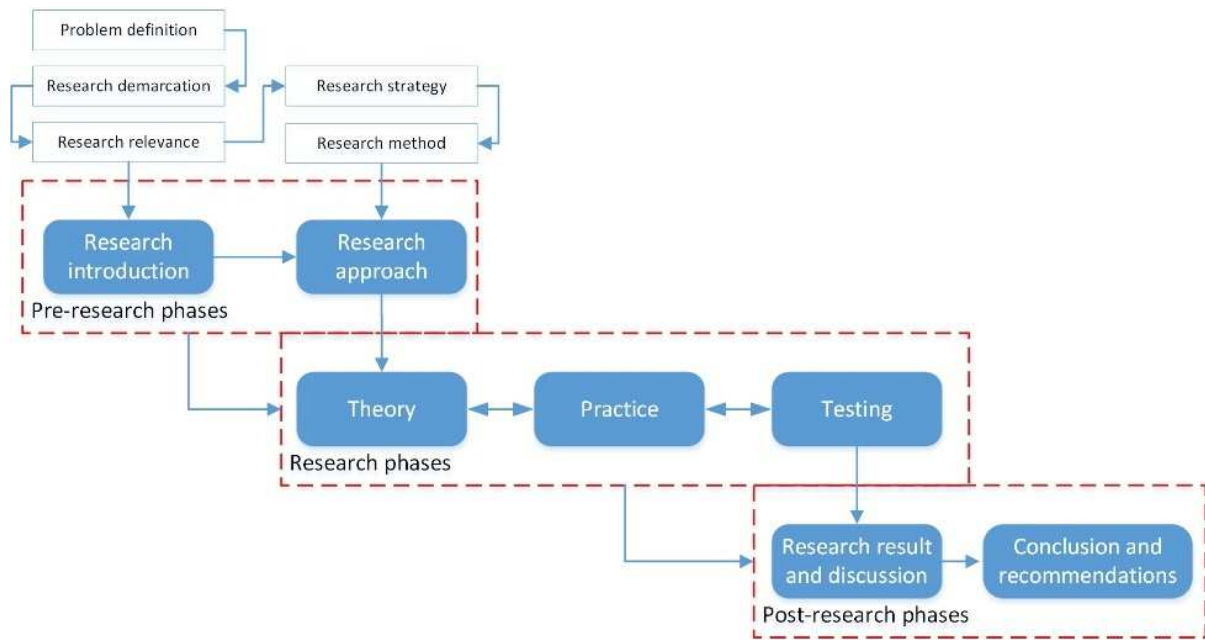


FIGURE 8: RELATIONS RESEARCH PHASES AND STEPS EXPLAINED GRAPHICALLY (SOURCE: OWN ILL.)

2. Research approach

The research objectives are to (1) describe the relation between a project, its risk profile and the required risk reserve and (2) predict the required risk reserve based on the unique character of the project. The research strategy and applied methods were designed and chosen to reach this goal. The research approach ensures the trustworthiness of the research result. This is addressed in the research strategy. Secondly, the research approach is explained more practically through the applied research method in combination with the different research steps.

2.1 Research strategy

To begin the section, two opposite lines of logic in scientific research are explained. These are the inductive and deductive methods of reasoning. After explaining both approaches, how these approaches return in the graduation research is explained. In this way, more understanding is created about how the research results in a reliable graduation thesis. However, first, the definitions of both induction and deduction are presented:

“induction is defined as reasoning from observed particulars to general statements or ‘laws’” (Lawson, 2005, p. 720).

“Making an inference from a generalisation to a particular case is typical case of deduction” (Evans, Newstead, & Byrne, 1993, p. 2)

The following example is widely used to explain the difference between both approaches (Evans, Newstead, & Byrne, 1993, p. 2):

- Inductive reasoning: *“All of the swans I have ever seen are white, therefore all swans are white.”*
- Deductive reasoning: *“All swans are white, so this swan is white.”*

The wheel of science is a well-known explanation of induction and deduction and is shown in figure 9. The difference between the approaches is that observations are translated into new theory through empirical generalisation in the inductive approach, from specifics to general statements, while deduction is the exact reverse: conclusions are drawn through decomposition. Consequently, general statements are translated in specific hypotheses and tested through observations. The

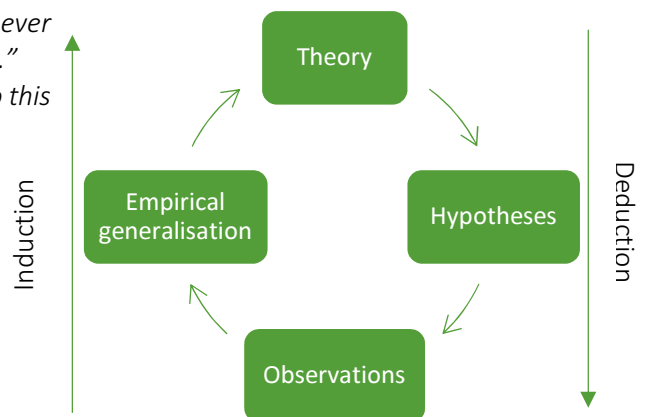


FIGURE 9: 'THE WHEEL OF SCIENCE' (WALLACE, 1971)

current research does not discuss the implications of both approaches, as this discussion lays outside of the scope of the current research. However, the current research follows both a deductive and inductive approach.

Theory is studied to design a theoretical model. The model is explained in a set of propositions. These propositions are validated qualitatively from a practical point of view. The observations from the practical study are generalised empirically to arrive at a theory that is practically validated. A set of hypotheses is derived from the newly developed theory. The theory is verified through quantitative testing in which the observations from the tests are generalised in the conclusions and recommendations of the research. What can be observed here is that the research strategy is based on two 'spins' of the wheel, and the research can thus be divided into three research phases. The first research phase is the theoretical phase, the second is the practical phase and the final phase is the testing phase.



The second phase is the practical phase, in which the theoretical model is validated qualitatively. The third phase is the testing phase, where the validated model is verified quantitatively. To indicate the difference between verification and validation, the following two questions are presented (Wasson, 2006, pp. 55-56):

- Validation: *“Did we acquire the correct product?”*
- Verification: *“Did we build the system correctly?”*

The third phase of the research is important primarily to close the gap in science, as elaborated on in section 1.3; the same remains true for the relevance to DVDI. The final phase improves the validity of the research results, but the predictive criterion in the research objective depends on the testing phase. The second round of the wheel of science improves the research quality but also increases the difficulty of it. An effective and efficient research design is thus important. The research method elaborates on how these criteria are secured in the research approach.

2.2 Research method

The research is divided into three phases and further explained in that order. This is done by means of the wheel of science. Before discussing the research steps and the methods applied, it should first be mentioned that this thesis is based on desk research, rather than field tests or laboratory research. The problem statement and research objective do not leave room for such types of research, especially in light of the effectiveness and efficiency criteria. It has already been mentioned that the research is both theoretical and practical and uses a combination of qualitative and quantitative methods. The research steps and methods have been tuned to the aforementioned strategy and criteria.

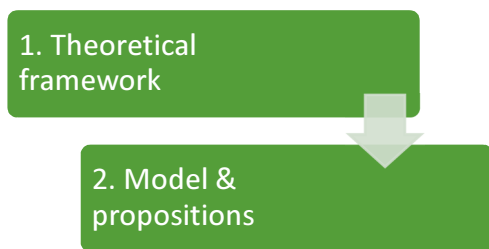


FIGURE 10: TWO RESEARCH STEPS IN THE THEORY PHASE (SOURCE: OWN ILL.)

The first research phase is the theoretical phase, which includes the first two steps of the research. These are graphically explained in figure 10. Existing theory is examined and studied through a literature review to create a theoretical framework, which is the first step in the wheel of science. The subjects that are to be reviewed are as follows: (1) project characteristics, (2) complexity and uncertainty, (3) risk profiles and (4) risk reserves. The second step is to design a model based on the theoretical framework, including a series of propositions. The propositions are the starting point of the next research phase, presented graphically in figure 11.

The second phase is based on four research steps. The theoretical model and propositions are qualitatively validated. The practical study is primarily based on four case studies executed independently from each other. The choice of four case studies is based on the principle of theoretical saturation. Theoretical saturation is reached when a new case study does not result in new findings, and it is expected to occur after four case studies. The research methods applied in the case studies are project documentation review and interviews. An important condition under which the cases should to be studied is that the documentation is open. The collaboration with Dura Vermeer ensured that these documents can be studied. There are different methods of conducting interviews, which can range from fully structured to unstructured (Tashakkori & Teddlie, 1998). The current

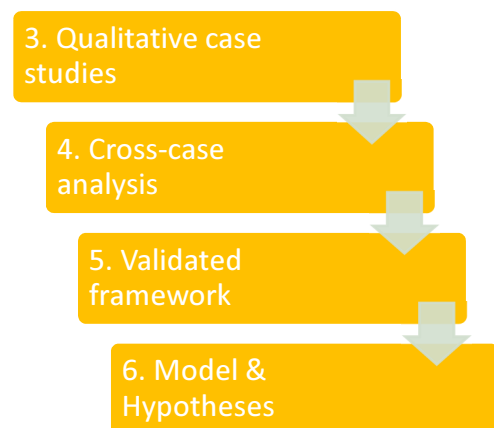
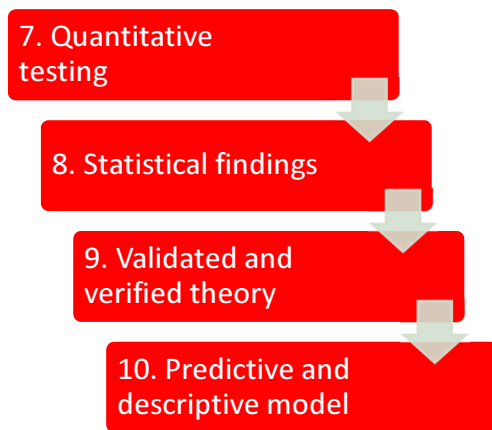


FIGURE 11: FOUR RESEARCH STEPS IN THE PRACTICE PHASE (SOURCE: OWN ILL.)

research chose to incorporate interviews performed with a semi-structured format.

In a fully structured interview, which comes closest to a questionnaire, it is easier to get a larger sample of data. However, it is more difficult to extract opposing views, for example, on the current set of project characteristics. This approach is more aimed at obtaining quantitative data rather than qualitative information. For this reason, it was chosen to conduct semi-structured interviews with key members of the studied projects, and semi-structured interviews ensure that it still possible to compare the results of the different performed interviews. These expert opinions are used to validate the project characteristics and their relationship to the project’s risk profile and corresponding risk reserve. This comparability condition in the interviews is important for the fourth research step, the cross-case analysis. The findings of each individual case are empirically generalised in the cross-case analysis. This is step is executed to compare the theoretical framework and the designed model with the findings from the practical research, which results in a validated theoretical framework. Finally, the combined theoretical and qualitative practical findings are translated into a validated model and a set of hypotheses. As with the propositions in the theory phase, the hypotheses are the starting point for the subsequent research phase.



The testing phase is the final research phase, and the four research steps are presented graphically in figure 12. The individual hypotheses are quantitatively tested in research step seven. However, this seventh step requires a large sample of data. Data collection was aimed at projects executed by DVDI. Further research should lead to a set of criteria to which the projects must comply to be used for the database. The same applied to the appropriate statistical technique to be used in the quantitative tests and the size of the database such that these are primarily dependent on the characteristics that are found in the first two phases. The findings of the individual statistical tests are considered and merged in the eighth step, the empirical generalisation step. This is done through statistical

FIGURE 12: FOUR RESEARCH STEPS IN THE PRACTICE PHASE (SOURCE: OWN ILL.)

technique regression analysis, which makes it possible to combine multiple significant relations in a single statistical test. The statistical findings are used to verify the theoretical and qualitatively validated theory. The last step is the design of the descriptive and predictive model which can improve the accuracy and precision of risk reserve allocation in future infrastructural projects. Step 10 is the final research result to ensure the research objective has been reached.



3. Theoretical framework

The first research phase is the theoretical phase, which is presented in the current chapter. Figure 13 displays the steps that were taken in this research phase. The theoretical framework presented in this chapter is based on a literature review of the six research elements, as graphically represented in figure 13. The literature review is added to the appendix as appendix A. This thesis presents only the main findings of the literature review, divided in three sections. The topics of these sections are as follows: (1) Risk reserve and the accuracy of the budgeted risk reserve with respect to the required risk reserve; (2) The risk profile of the project and the project aspects complexity and uncertainty; and (3) The unique character of infrastructural construction projects and their project characteristics. The findings are combined in the final section, in which the designed theoretical model is elaborated and the propositions that explain the assumed relations in the model are expressed.

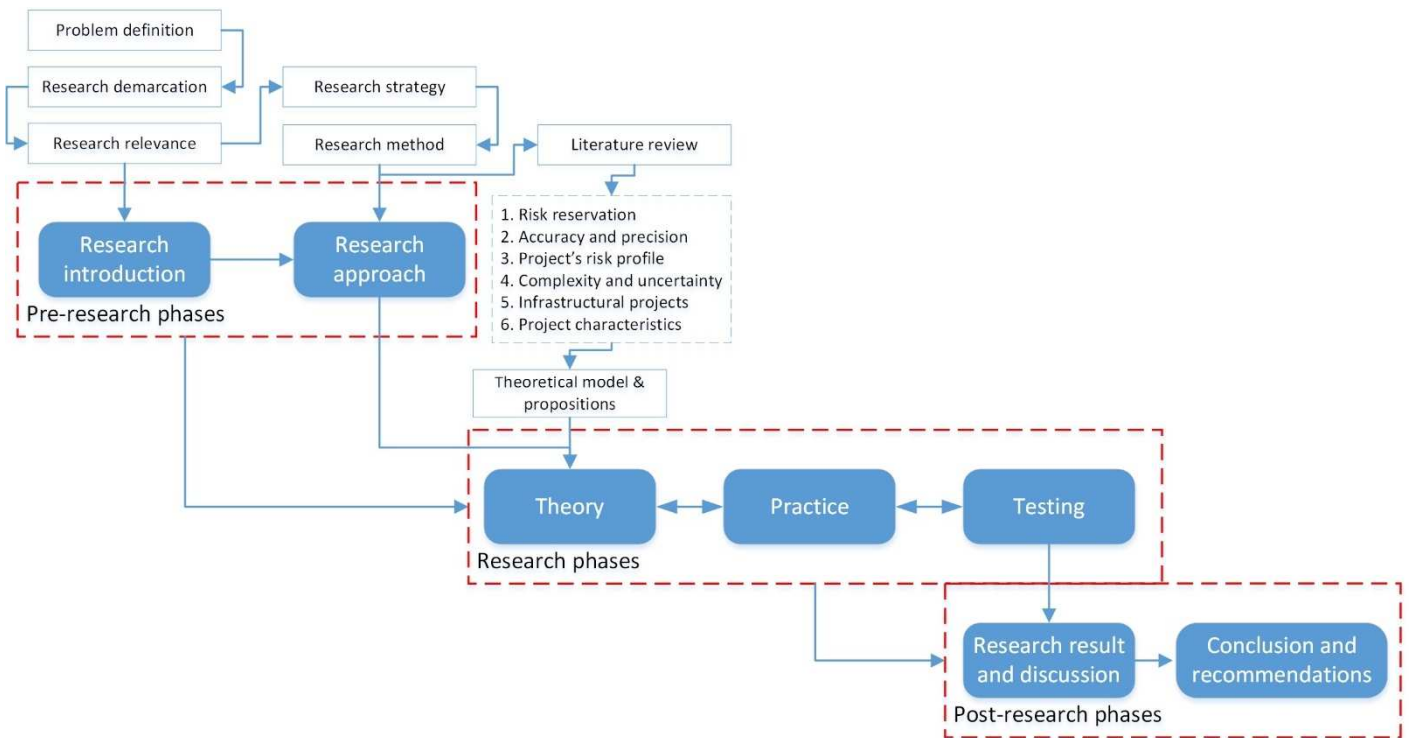


FIGURE 13: RELATIONS RESEARCH PHASES AND STEPS EXPLAINED GRAPHICALLY, THEORETICAL PHASE (SOURCE: OWN ILL.)



3.1 Risk reserve, accuracy and precision

The first element in the theoretical framework is the risk reserve in combination with accuracy and precision. The aim of this graduation thesis is to improve the accuracy and precision in future risk reserve allocations of infrastructural projects. In order to do so, a more in-depth examination of the context of risk reserves is carried out. This is followed by a study on risks, in which different aspects of risks are discussed. The section continues with a closer look at risk reserve methods and calculation approaches. The section closes with a short summary of the findings.

The context of the risk reserve is briefly mentioned in the introductory chapter. According to Nicholas & Steyn (2012, p. 9): “A project is a system of interrelated components—work tasks, resources, stakeholders, as well as schedules, budgets, and plans. The purpose of project management is to integrate the components to accomplish the project goal.” Project success or project performance can be reached in terms of costs, time and quality, which is thus the responsibility of project management. Risk reserve allocation is a measure in risk management to cope with risks that threaten project success. The risk reserve is an important practice in project management. The current research focusses on a risk reserve determined based on the project’s risk profile in order to improve the accuracy and precision of the budgeted risk reserve. This context of the relation between risk reserve, a project’s success and its risk profile is graphically explained in figure 14 (Bosch-Rekveltdt, 2011). A project’s risk profile can negatively influence the project’s success, but an accurately and precisely budgeted risk reserve based the project’s risk profile can increase the chance of the project’s success (Baccarini, 2004).

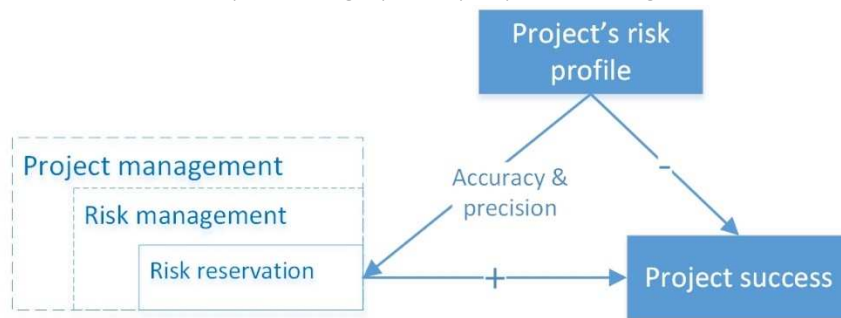


FIGURE 14: CONTEXT OF RISK RESERVE ALLOCATION IN RELATION TO PROJECT AND PROJECT SUCCESS (SOURCE: OWN ILL.)

“The identification of risks in the process, the assessment of these risks, categorising and prioritising risks, defining response actions, monitoring risks, and reporting about risks” (Nicholas & Steyn, 2012, p. 352). Numerous studies are available on this subject, and there is also a standard from the International Organisation for Standardisation on risk management: ISO31000;2009. However, all considerations of risk management view it as a process with multiple steps aimed at risk identification, assessment, monitoring, etc. The main theme of risk management is risks. The definition given in section 1.1 is from (Jonkman, Morales-Nápoles, Steenbergen, Vrijling, & Vrouwenvelder, 2015, p. 58): “Risk is a set of scenarios, each of which has a probability and a consequence.”

“The risk is the uncertainty measured, and uncertainty is a risk that cannot be measured” (Serpella, Ferrada, Howard, & Rudio, 2014, p. 655). This quote means that there is measurable uncertainty (risks) and unmeasurable uncertainty, or foreseeable and unforeseeable uncertainty. There is a clear understanding in risk management studies that there is a difference between “known unknowns” and “unknown unknowns”. “The challenge of effective risk management is to turn as many of knowable unknowns into known unknowns as is practical through creative risk identification. On the other hand, unknown unknowns (emergent risks) ... cannot possibly be predicted until they occur. Non-specific risk provision is the budget set aside in excess of the specific risk provision ... in the face of as yet unidentified risks” (Eldosouky, Ibrahim, & Mohammed, 2014, p. 864). Following this statement, the two types of risks result in two different categories of risk reserves: (1) The contingency reserve (CR) for the known-unknowns (specific risks) and (2) the management reserve (MR) for the unknown-unknowns (emergent risks) (Lee, Lee, Park, Kim, & Jung, 2017).

The definition of a risk, as stated in sub-section 1.2.1, holds three elements. The set of scenarios (S_i), also called the events, the probability of the events and the consequences of those events. Such scenarios can either compose a positive set, a negative set or a combination of both. The risk is the multiplication of the probability and the consequence of the S_i . The consequence of a set of scenarios is also called the effect or impact of the risk. *“This impact is mostly described in terms of money”* (Kremers, 2013, p. 26); however, it can also be in terms of time, quality, safety, environment and so on. The current research focusses on the risks with time and types of impacts costs. The probability that such impact actually materialises is the second element of the risk quantification step. The probability can be expressed in multiple ways, including as a probabilistic function or as a deterministic value. The probability that the scenarios or events do happen, with a range from 0% to 100%, is the quantification of the chance. The severity of the risk is described as the risk criticality in most studies.

Past research has explained that effective risk management should prioritise the most critical risks and focus quantification and response actions only on these risks. Risk responses are then allocated to the critical risks, rather than all identified risks. Risk prioritising is linked to the ‘Pareto principle’, also known as the ‘80/20 rule’ (Creemers, Demeulemeester, & Van de Vonder, 2014). *“It is a shorthand name for the phenomenon that in any population which contributes to a common effect, a relative few of the contributors account for the bulk of the effect”* (Craft & Leake, 2002, p. 729). In other words, only a limited set of risks is responsible for the project’s risk profile. Risk criticality is also dependent on the risk owner. For example, the risk of a two-week delay has a probability of 50%, which means that the risk is one week. By dividing the delay by the total project duration, it is possible to put the risk in a more useful context. In this example, the risk of one week delay means a risk of 5% delay. However, contractor A sees this as a minor risk, whereas contractor B thinks this is a major risk.

This phenomenon is called ‘risk perception’ or ‘risk attitude’.

There are three widely known types of risk attitudes, namely: risk-averse, risk-neutral and risk-seeking. Whereas a risk-averse attitude is aimed at avoiding negative risks, the risk-seeking attitude is aimed at large incomes and is less interested in the possible downside effects. Construction companies typically have a risk averse attitude (Jonkman, Morales-Nápoles, Steenbergen, Vrijling, & Vrouwenvelder, 2015). This is an important detail in deciding a project’s risk profile. Quantification of the risks is not the only factor in the decision regarding the risk profile; the risk attitude is important as well. Finally, there exists a difference between the initial risk and the residual risk. Another important step in the risk management process is the risk responding step. *“If the risks are considered unacceptable, several forms of risk reduction can be implemented”* (Jonkman, Morales-Nápoles, Steenbergen, Vrijling, & Vrouwenvelder, 2015, p. 65). Multiple risk reduction actions can be used to either reduce the probability and impact of the threat or to increase the probability and impact of the opportunity. The types of risk responses and their usefulness are neglected in the current research, but it is important to know that there is initial risk, risk action and residual risk. These are also known as pre-mitigated risk, mitigating action and post-mitigated risk.

The risk reserve is based on a contingency and management reserve. These two cost categories are not the only two as multiple categories are known. Project costs can be classified further into direct and indirect costs, contingency, general overhead and profit (Wong, 2015). General overheads are the costs that the contractor incurs outside of the projects. The company costs combined with the profit margin are budgeted to keep the company profitable. Company cost examples are marketing, non-declarable staff or company housing. The direct and indirect costs are the foreseen costs, or the project’s bare costs. Figure 15 presents the structure of the different cost categories and the grouping terms used in the remainder of the thesis. “Project costs” is the overall group name, which can be specified in project construction costs, company costs and profit margin and so on. The research focusses on the accuracy and precision in the risk reserve and thus the combination of the contingency and management reserve. These two reserves and the approaches to determining their required volume is explained in more detail before it is related to the project’s risk profile.

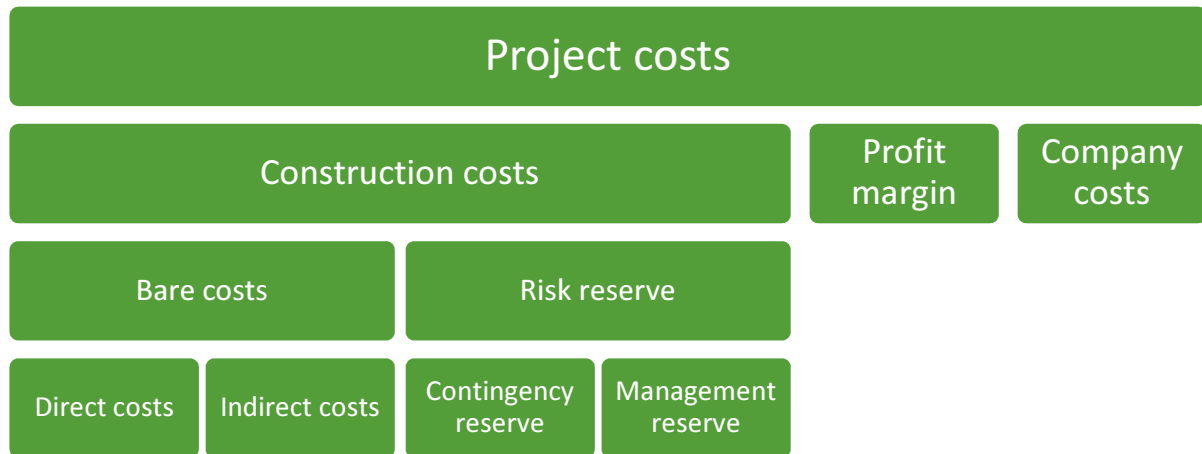


FIGURE 15: DIVISION AND DEFINITION OF COST CATEGORIES (SOURCE: OWN ILL.)

"Contingency is probably the most misunderstood, misinterpreted and misapplied word in project execution. Contingency can and does mean different things to different people" (Baccarini, 2004, p. 1). To clarify, the following definition of contingency is used in the remainder of this thesis (PMI, 2008):

"The amount of money or time needed above the estimate to reduce the risk of overruns of project objectives to a level acceptable to the organisation."

The contingency reserve is reserved for the known unknowns, or the identified risks. The management reservation is a buffer for the unknown unknowns, or the hidden risks. The known unknowns are the risks, positive or negative, that are identified. The contingency reserve is a result of this identification step; however, it is also the product of the quantification and risk response steps. This also means that there are three moments of estimation and misinterpretation. The management reserve is intended to account for this misinterpretation and thus ensure the accuracy of the risk reserve. Closely related to the term accuracy is precision, though the relation between the two terms exists without dependency. Accuracy offers information about the difference between an estimate and the true value. It can be described through statistical bias and is caused by systematic errors. Precision offers information about the bandwidth of the estimate and can be described through statistical variability caused by random errors. For example, an estimate based on a large sample size, or dataset, is likely to have small statistical variability. However, if the real world is dissimilar to the dataset, then there is a statistical bias.

Precision in risk reserves can be generated through a large dataset, but accuracy is more difficult to obtain. A previous study based on 258 infrastructural projects showed that there are four aspects that cause estimating inaccuracies, namely technical, economic, political and psychological (Flyvbjerg, Holm, & Buhl, Underestimating Costs in Public Works Projects: Error or Lie?, 2002). The study concluded that the systematic error was not the reason for this inaccuracy, but rather it was lying in order to receive approval for the project. This phenomenon is also called optimism bias. Optimism bias can best be explained as strategic misrepresentation in estimates, such as in management reserves. Inaccuracies in estimations through optimism bias are most often a result of the 'inside view', whereas an 'outside view' would be more appropriate (Kahneman & Tversky, 1977).

The inside view looks to the 'inside' of the project, thus a project specific view. The outside view means that estimates are based on reference projects or other types of historical data, thus a non-project specific view. The current research on accurate risk reserves is focussed on this 'outside view' in order to provide a framework and method to determine the project's risk profile based on the results of previous projects. Project characteristics are the measurements that should determine this risk profile. Secondly, underestimation is a serious difficulty because of a second set of phenomena called Parkinson's law and student syndrome law. According to Khamooshi & Cioffi (2013, p. 489): "*Parkinson's Law and the student syndrome law causes that the work will expands to fill the time available or that the job is delayed*". This phenomenon has been researched extensively (Parkinson, 1957). Here, it is stated

that work expands to fill the available time, but the same counts for expenses and thus also expenses of risk reserves. Time-bounded risks are likely to become critical to the project’s risk profile due to this phenomenon.

Parkinson’s law and student syndrome law influence the project’s risk profile through time-bounded risks.

Optimism bias can be overcome by applying an estimation process based on a reference project and a valid database of project information. Parkinson’s law is more difficult to cope with in an estimation process. Contingency reserve is thus dependent on the number of identified risks, with a specific consideration of the post-mitigated risks rather than the pre-mitigated risks. However, how the management reserve is calculated is unknown. *“Despite its role and importance, the management reserve is often estimated just as a percentage of the estimated project cost baseline (i.e., deterministic point estimation), which is typically derived from intuition and experience”* (Lee, Lee, Park, Kim, & Jung, 2017, p. 1). This is the previously explained project-specific view. Critics of this method have explained the method as unscientific and arbitrary. The traditional percentage method is supposed to be based on historical data (Baccarini, 2005). Recent case studies, however, have not shown such a background. The estimation process of a project reserve is seen as a ‘black box’ with project information as input and a percentage as output (Kremers, 2013, p. 29). Therefore, an alternative approach is proposed in the current research based on a project’s risk profile measured through a set of characteristics of a project.

Risk management has two main approaches: the deterministic and probabilistic approach. There can, however, be a third contingency calculation method, the modern mathematical method (Bakhshi & Touran, 2014). Fuzzy techniques belong to this third method, but this is not further discussed in the current literature review. The deterministic and probabilistic approaches are applicable to the costs (Purnusa & Bodea, 2013), (Eldosouky, Ibrahim, & Mohammed, 2014), (Xenidis & Stavarakas, 2013), (Bakhshi & Touran, 2014) and time (Pawan & Lorterapong, 2016) contingencies, as well to the combination of time and cost (Purnus & Bodea, 2014). The greatest difference between the two approaches is that the deterministic approach is based on deterministic and point-estimate values, and the probabilistic approach is based on stochastic values. Point-estimate values cannot mathematically incorporate uncertainty, whereas the probabilistic approach can (Xenidis & Stavarakas, 2013). Appendix A, section 1.2.4 gives an extensive review of both approaches.

Highlights of the review are that the deterministic approach cannot act as the backbone of the calculation of the management reserve. Secondly, the probabilistic approach can better incorporate uncertainty in estimates (Bakhshi & Touran, 2014, p. 54). In the probabilistic approach, stochastic variables are used to describe a duration, cost estimate or risk probabilities and effects. What is important is that probability calculus is designed to calculate randomness or uncertainty in variables.

“The random variables can be described by its mean (μ) and variance (σ). The mean stands for the mathematical expectation as an important measure of central tendency for random variables. The variance is a measure of dispersion around the mean.” (Jonkman, Morales-Nápoles, Steenberg, Vrijling, & Vrouwenvelder, 2015, p. 21). With these two characteristics of a random variable, it is possible to make a probability distribution function (pdf), an example of which is shown in figure 16.

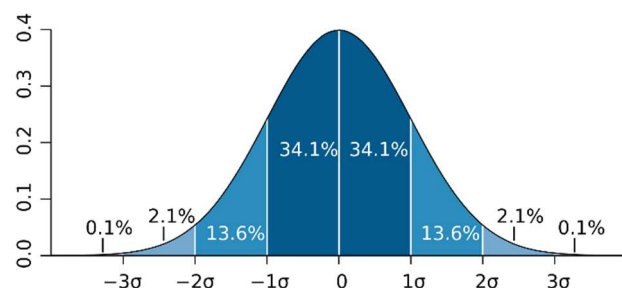


FIGURE 16: EXAMPLE OF A PROBABILITY FUNCTION OF NORMAL DISTRIBUTION (SOURCE: WIKIPEDIA)

Re-evaluating the research objective, the final model should be descriptive and predictive. This model can be in the form of a probability distribution, as in figure 16 in which precision is determined by the variance and accuracy by the difference between the mean value of the budgeted and required risk



reserves. Risk reserve accuracy and precision is thus split into the contingency and management reserve. Optimism bias and risk perception influence the budgeted risk reserve, in addition to the assumed influence of the project's risk profile. Current practices in determining the risk reserve are mainly project specific and based on the 'inside view'.

An 'outside view' can overcome such external influence in an accurate and precise budgeted risk reserve. However, this requires a large database with data on similar, or comparable, realised projects. The 'inside view' can be based on a deterministic or probabilistic approach. Confidence levels in probabilistic distributions can be used for determining the management reserve, but again, this is done based on the 'inside view'. A combination of both approaches can be a solution for improving the accuracy and precision in the risk reserve. A consideration in the contingency reserve can be that, for example, instead of an 80% confidence level, a 90% confidence level is chosen for the risk register. The additional 10% in this example is then reserved for the unknown unknowns and used as management reserve. The contingency reserve can benefit from the probabilistic approach, but the management reserve is still calculated or determined 'unsubstantiated'.

3.2 Complexity, uncertainty and project's risk profile

3.2.1 Risk management and risk profile

Previous section further elaborated on the risk reserve, approaches to calculate the contingency and management reserve and the criteria accuracy and precision in estimates like the risk reserve. Figure 17 shows the findings of the first part of the literature review. The triangle between project success, risk reserve and project's risk profile has been explained in a previous section, but the four new blocks have not. The risk reserve can be divided in the contingency reserve (CR) and management reserve (MR), each budgeted for a different type of risk. The risk perception influences the perceived risk profile of the project and therefore also the accuracy and precision in the risk reserve. A higher risk perception results in a higher budgeted risk reserve, but it endangers the accuracy and precision. The other external factor of student's syndrome and Parkinson's law have an increasing effect on the risk profile, and especially the time-bounded risks are critical due to these phenomena.

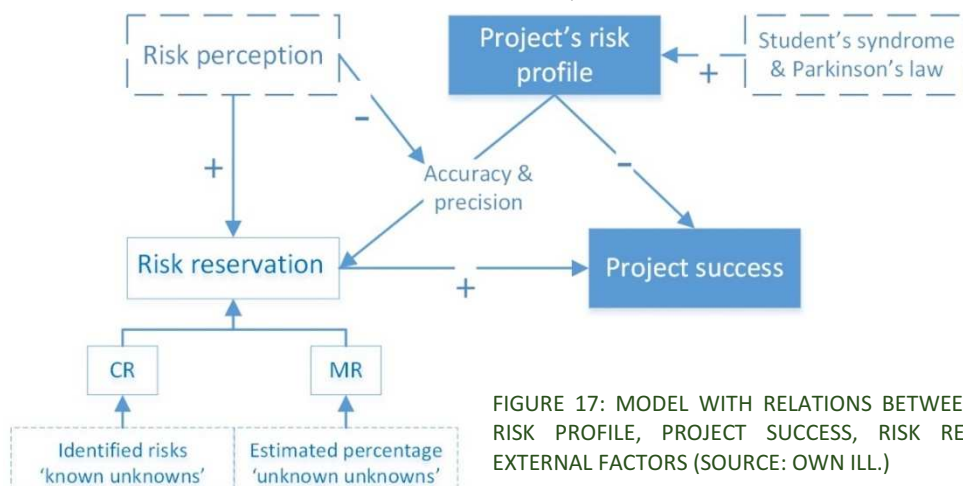


FIGURE 17: MODEL WITH RELATIONS BETWEEN PROJECT'S RISK PROFILE, PROJECT SUCCESS, RISK RESERVE AND EXTERNAL FACTORS (SOURCE: OWN ILL.)

The current section focusses on the next block in the model: the project's risk profile and its assumed relation with project complexity and uncertainty. However, first, the focus is on the relation between the risk reserve and the project's risk profile.

The risk reserve is the quantified 'expectation' of the risk profile of a project. This is thus the sum of the estimated contingency reserve and management reserve. The contingency reserve is the sum of the residual risks (RR) that are identified. The residual risk is only taken into account when the costs of the initial risk (IR) are higher than the combination of the costs of the residual risk and the risk reducing measure (RRM). When this is indeed the case, then the RR is taken into account, and otherwise the IR

is considered. The management reserve closes the gap between the project's risk profile and the contingency reserve. The following equation explains this relation between risk profile and risk reserve.

EQUATION 5: $Project's\ risk\ profile = \sum_{i=1}^n RR_i + MR ; RR + RRM \leq IR$

This equation is very much dependent on the approach of determining the project's risk profile. The 'outside view' is a solution for this problem. However, a second problem arises in the definition of the RRs and IRs in relation to the contingency reserve. The risk identification process or the risk management process as a whole is also an important and influential factor in two different ways; first, as influencing factor on the overall level of the risk profile, and second, as an influencing factor of the management and contingency reserve ratio. First, the ratio between the two types of risk reserves. The quality of the risk identification process can influence the number of risks identified and therefore influences the amount of contingency reserve in the budget. Following the line of reasoning in equation 5, the risk identification process does not influence the project's risk profile, only the sum of risks. As this sum of risks becomes larger, the management reserve becomes smaller. The risk identification process does not affect the logic of the construct in equation 5.

However, the risk response step in the management process does affect the construct presented in equation 5. This is the step in which risks are assessed and risk responses are defined to lower the overall risk. The project's overall risk profile, according to equations 5, is the management reserve combined with the sum of the RRs, if and only if the IRs are higher than the RR combined with the RRM. A direct result of this proposition is that the quality of the risk management process can influence the project's risk profile. A proper risk management process can find measures that reduce the risk by half, whereas different projects have RRM that only reduce the risk by 25%. Assuming that both projects are the same, then the risk profile of the project with the 'good' risk management process is smaller than risk profile of the project with the 'bad' risk management process. However, this is not recognised in the equation. The management reserve 'compensates' for this increased project management quality. This is explained by three examples presented in table 1.

Table 1 shows an example with quality implications of RRM quality and risk identification quality in the propositions in equation 5. The projects are assumed to be alike with construction costs of €10,000 and the project's risk profile of €1,500. The total construction costs are calculated by the sum of construction costs, RRM, contingency reserve and management reserve. The contingency reserve is the sum of the RRs, as proposed in equations 5.

TABLE 1: PROJECT'S RISK PROFILE FOR THREE PROJECTS, CONTINGENCY RESERVE = SUM RESIDUAL RISKS

	Project X	Project Y	Project Z
Project bare costs	€10,000	€10,000	€10,000
Sum initial risks	€1,200	€1,200	€1,300
Risk reducing measures	€100	€200	€200
Sum residual risks	€800	€600	€700
Contingency reserve	€800	€600	€700
Management reserve	€700	€900	€800
Total construction costs	€11,600	€11,700	€11,700

The effect of the risk identification step is explained by the difference between Projects Y and Z. With the quality of RRM kept equal, the difference in sum of IRs and RRs is 'compensated' for by the management reserve. However, the RRM in project Y and Z are twice that of project X. By investing an additional €100, the sum of the RRs can be lowered by an additional €200. However, the management reserve again compensates for this increased risk management quality. This example illustrates the problem that exists in determining a project's risk profile based on the 'inside view'. Success in tenders is based on the overall project costs, so a reduction of this overall costs can mean the difference between tender success or failure. A sharp bidding price and an accurate and precise risk reserve is therefore optimal. The 'outside view' can potentially overcome this budgeting difficulty. An



important finding in the presented example is that of the quality of risk management as a second external factor in the budgeted risk reserve.

The project's risk profile declines over the course of the project, and thus it also lessens between the tender and construction phase (Kremers, 2014). This trend manifests in a planned and realised risk reserve. It is the aim of the current research to determine the risk reserve based on a project's risk profile and based on realised values of similar realised projects. However, the risk control step in the management process does influence the realised risk reserve. Through the assumption of planned and realised risk reserve, the risk control quality can be measured through the difference between both. This is an additional opportunity for the approach in current research. Equation 6 proposes an operationalisation method to calculate the risk management quality ratio.

EQUATION 6:
$$\text{Quality risk control} = \frac{\text{Planned risk reserve}}{\text{Planned risk reserve} - \text{Realised risk reserve}}$$

The second method follows an entirely different approach, which is a more in-depth approach in the project's risk profile. The risk profile is estimated based on the project's characteristics. However, it is possible to divide the risk profile into different types of risk categories, such as the exogenous and endogenous types of risks or the RISMAN categories identified in appendix A sub-section 1.2.2. Not only the sum of management reserve and contingency is calculated, but the risk profile is also divided between different types of risks. This method is more detailed than the previous method and provides additional information for determining the project's risk profile. However, this is also the more difficult method to accomplish. Far more data are needed to define such relationships between a project's characteristics and its risk profile. The trade-off is between a less detailed but practical approach and the more detailed but theoretical approach.

The project's risk profile is the quantified sum of the identified and unidentified risks, or the sum of the contingency and management reserve. The quality of risk management, both during the tender phase and the construction phase, influences the depth of the risk reserve. The quality of risk management in the tender phase influences the budgeted risk reserve, and the quality in the realisation phase influences the required risk reserve. Closing the gap between the budgeted and required reserve is the objective of the research.

3.2.2 Risk profile and complexity and uncertainty

There is an extensive body of knowledge on the topics of complexity and uncertainty, also in relation to the risk profile of a project. The current sub-section takes a closer look at the different methods of defining the project's risk profile. Uncertainty can, for instance, be such a risk profile dimension. Two Dutch studies, Kremers (2014) and de Meyer et al. (2012), have mentioned uncertainty as a dimension that influences the project's risk profile:

"Sommige projecten hebben weinig onzekerheden – alleen de complexiteit van de taken en de relaties is belangrijk. Maar de meeste projecten worden gekenmerkt door verschillende soorten onzekerheid" (de Meyer, Loch, & Pich, 2012, pp. 55-56). *"Een onzekerheidsprofiel ... geeft aan welke soorten onzekerheid in potentie het belangrijkste zijn"* (de Meyer, Loch, & Pich, 2012, p. 61). Translated: "Some projects have few uncertainties, so the complexities of the tasks in then important. However, most projects are characterised by different types of uncertainty. An uncertainty profile determines what types of uncertainty are present." The research highlight complexity as a project's risk profile dimensions, but it emphasises the uncertainty dimension.

Different approaches for determining the required risk reserve can also be found, like the research on management reserves calculated through past performance in terms of costs and time (Lee, Lee, Park, Kim, & Jung, 2017). The research results of the management reserve based on risk and past performance showed great improvements in the accuracy of the management reserve compared to the traditional percentage estimate. The accuracy improvement was tested by applying the new calculation method to three randomly selected realised projects. The original management reserve was compared to the

management reserve that would have been calculated following the newly defined method. An interesting element of the research is that project complexity was a type of risk that influenced the risk reserve.

Another study tried to determine relationships between a set of project characteristics and accuracy in the contingency (Baccarini, 2004). Contingency accuracy was calculated through a comparison of budgeted construction contingency and final variation of the contract value. Based on a dataset of 48 projects, the mean value of construction contingency was 5.24%, whereas the mean of the contract value variation was 9.92%. This means that there was a difference of 4.68%, but a smaller difference would mean higher accuracy. The independent variables examined were project size, bid variability, bids received, project duration, project location and year of the bid. Pearson correlation analysis did not result in significant correlations. (Baccarini, 2004). However, the research was aimed at the accuracy of the contingency budget and not at the size of the contingency budget, like the current research.

Early work already put effort into explaining complexity in a variety of systems, from (Bosch-Rekvelde, 2011, p. 34): *“complex systems were already defined as systems that consist of a large number of components that heavily interact with each other”* (Simon, 1962). The interaction of components can thus be an indication of complexity. This idea is in line with the following definition of project complexity: *“It is proposed that project complexity be interpreted and measured in terms of differentiation and interdependencies”* (Baccarini, 1996, p. 203). The research of Baccarini explained complexity in terms of technical and organisational complexity and measures it through the sum of interdependencies and differentiation. A different approach for determining project complexity is defined by the PMI. The PMI grouped causes of complexity into the following three categories: human behaviour, system behaviour and ambiguity (Nguyen, Nguyen, Le-Hoai, & Dang, 2015, p. 1364).

Another approach in project complexity is based on the distinction between structural uncertainty and uncertainty (Williams, 1999). Structural uncertainty was explained through the number of elements and the interdependencies between the elements. The principle behind this explanation is as follows: *“Complexity is more than the sum of individual elements”* (Kauffman, 1995). Uncertainty is divided into goal uncertainty and method uncertainty. The explanation of structural uncertainty has much in common with the definitions from Simon (1962) and Baccarini (1996). A combination of both studies is proposed as well, which leads to a division of project complexity into structural complexity and uncertainty (Hagan, Bower, & Smith, 2011). The current research clearly divides uncertainty from complexity. Complexity is seen as structural complexity (Hagan, Bower, & Smith, 2011), structural uncertainty (Williams, 1999) or technical and organisational complexity (Baccarini, 1996) as part of ‘project complexity’. The direct result of this assumption is that uncertainty is assumed to be an independent dimension, rather than a sub-dimension of complexity. Uncertainty is explained later in this section in more detail.

Besides the technical and organisational aspects of complexity, other aspects have been assumed in different studies. Among others, Bosch-Rekvelde (2011) defined a third aspect of complexity, namely environmental complexity, and he argued that the environment can include ‘softer’ elements in the complexity definition. Environmental complexity encompasses both the physical and relational environment of the project, such as location and stakeholders (Bosch-Rekvelde, 2011, p. 37). All of the previously mentioned studies are theoretical perspectives on complexity, though a more practical view can be presented as well. The ‘practitioners view’ is based on opinions of project managers and has resulted in six aspects of complexity, namely: (1) technical, (2) social, (3) financial, (4) legal, (5) organisational and (6) temporal (Hertogh & Westerveld, 2010).

Three dimensions, technical, organisational and environmental, are defined in almost all research on complexity. These three include both ‘soft and hard’ aspects of complexity, so they still represent a comprehensive viewpoint. The practicality of the complexity definition is important, and for this reason, complexity is bounded by these three aspects. To conclude, complexity can be defined as follows:



Complexity is the sum of the individual elements and the interdependencies between those elements within a project, measured in terms of technical, organisational and environmental aspects of the project.

Uncertainty has already been briefly mentioned in the description of complexity. It was defined as a dimension of project complexity and was divided further into goal and method uncertainty (Williams, 1999). The PMI has described uncertainty in the PMBOK Guide as “*risk conditions— aspects of the project or organisation’s environment that increase project risk*” (McLain, 2009, p. 60). Uncertainty is called risk conditions, or aspects of the project that influence the project’s risk profile. “*Uncertainty is measured roughly by the difficulty in predicting the final outcome in terms of the dimensions of time, cost, and technical performance*” (Nicholas & Steyn, 2012, p. 5). Uncertainty decreases when projects are similar to previous projects and abundant knowledge is already known. This is explained by the “learning curve” concept. The newness of a project is therefore an indication of the related level of uncertainty. “*Generally, the more often something is done, the less the uncertainty in doing it. This is simply because people learn by doing and so improve their efforts*” (Nicholas & Steyn, 2012, p. 5).

The ‘newness’ of a particular project is found to be important for the level of uncertainty. This is very dependent on the availability of information. McLain (2009, p. 60) explained uncertainty as: “*Uncertainty implies a lack of information, making it difficult to understand, let alone measure.*” Therefore, information or the absence of it is an important element of uncertainty. Uncertainty can also be defined as follows: “*Any deviation from the unachievable ideal of completely deterministic knowledge of the relevant system*” (Fijnvandraat & Bouwman, 2010, p. 5). This definition makes it possible to distinguish uncertainty that can be reduced (epistemic uncertainty) and that which cannot be reduced (variability uncertainty) through increased knowledge. Uncertainty can thus be divided in epistemic and variability uncertainty and measured qualitatively by means of certainty about the future.

This classification can be found in different studies as well. Uncertainty is classified into two main categories: “*(1) natural variability due to randomness; and (2) knowledge uncertainty due to lack of knowledge*” (Duzkale & Lucko, 2016a, p. 3). A final approach to categorising uncertainty suggests to divide it in the following four types: (1) ambiguous uncertainty; (2) inherent variability; (3) event uncertainty; and (4) systematic uncertainty (Wong, 2015). To conclude, there are multiple methods for defining and categorising uncertainty: through the division of goal and method uncertainty, by distinction of epistemic or variability uncertainty or by internal and external uncertainty. The definition of uncertainty used herein is mainly based on (Williams, 1999) and (Fijnvandraat & Bouwman, 2010). It includes the epistemic and variability types of uncertainty and the method and goal division to which uncertainty has an effect. The remainder of this research uses the following definition of uncertainty:

Uncertainty is based on either lacking knowledge (epistemic) or randomness (variability) and can be divided in uncertainty of the goal of the project (goal uncertainty) and uncertainty in the method to reach the goal of the project (method uncertainty).

Complexity was measured by means of differentiation and interdependencies by Baccarini (1996) and in terms of technical, organisational and environmental complexity by Bosch-Rekvelde (2011). Uncertainty is defined by goal and method uncertainty and is the sum of epistemic uncertainty and variability. These ideas are linked to each other by project complexity by Williams (1999). These project aspects are seen as the two dimensions of the project’s risk profile, but their independence cannot be concluded. The risk profile is therefore explained graphically by the two circles presented in figure 18. The project is either complex and certain (1), straightforward and uncertain (2) or complex

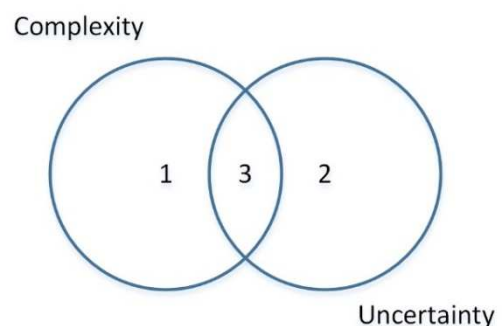


FIGURE 18: DIMENSIONS OF A PROJECT'S RISK PROFILE (SOURCE: OWN ILL.)

and uncertain (3), and whichever qualities it has influences its risk profile. Complexity and uncertainty can explain the project's risk profile, but the current research focusses on the independent project characteristic that causes these levels of complexity and uncertainty.

“De optimale hoogte van Onvoorzien ... De mate (van de pot Onvoorzien) is afhankelijk van de kenmerken van het project. Bij een project met veel onzekerheden, zoals m.b.t. ondergrond en inpassing, zal dit anders zijn dan een standaard project in de groene wei” (Kremers, 2014). Translated: The optimal height of the risk reserve is dependent on project characteristics. A project with much uncertainty, for example in the soil or integration, has a different required risk reserve than a standardised project in the green fields. On the basis of a regression analysis on 17 projects, the following five factors were found significant in relation with the realised project reservation: (1) project size, (2) knowledge of the initial assets, (3) project preparation, (4) stability of the initial project scope and (5) project duration (Kremers, 2013, p. 80). The project size and project duration were found to be correlated, and they are not incorporated further in this analysis. The three other factors explain 68% of the spent project reserve based on the utilised dataset.

An interesting fact regarding these three factors is that all can be traced back to the level of certainty or uncertainty. Secondly, all three are not project characteristics, but rather external factors. Besides, all three are 'subjective' in the sense that they determine the level of that particular factor. Knowledge of the initial assets, for example, is difficult to measure compared to project duration or capital value. The present research is particularly interested in those characteristics that are objective in terms of measurability, and this idea is examined in the next section of the theoretical framework.

3.3 Infrastructural projects and characteristics

3.3.1 Infrastructural projects

First, it is explained what a 'regular' project is, then the infrastructural element of projects is introduced to derive in a single definition for infrastructural projects. Three definitions are presented as a starting point:

- *“A project is a temporary endeavour undertaken to create a unique product, service, or result. The temporary nature of projects indicates a definite beginning and end. The end is reached when the project's objectives have been achieved or when the project is terminated because its objectives will not or cannot be met, or when the need for the project no longer exists”* (PMI, 2008, p. 5).
- *“A unique venture with a beginning and an end, conducted by people to meet established goals with parameters of cost, schedule and quality”* (Buchanan & Boddy, 1992);
- *“A unique set of co-ordinated activities, with definite starting and finishing points, undertaken by an individual or organisation to meet specific performance objectives within defined schedule, cost and performance parameters”* (Maylor, 2005, p. 4).

These three definitions are much alike and already provide for a clear understanding of a project. It is unique, has a begin and an end (temporary), has people who are involved and it should meet an objective or goal with time, cost and quality parameters. However, for an additional understanding of all the different elements of the definition of a 'project', the following elements are listed (Nicholas & Steyn, 2012, p. 22):

1. *“Having a single, definable goal or purpose and well-defined end-items or deliverables;*
2. *Being unique;*
3. *Being somewhat or largely unfamiliar and risky;*
4. *Utilising skills and talents from different professions and organisations;*
5. *Being a temporary activity;*
6. *Having something at stake; and*
7. *Being the process of working toward a goal.”*



The uniqueness characteristic is explained, as well as the relation with uncertainty and risks. However, the influence of the infrastructure element on a project must be determined. What becomes apparent is that it is just an addition of two adjectives to the term 'project'. By restating 'infrastructural construction project' as, 'A project in which infrastructure is constructed', it is already clearer what is meant by such type of project. By defining the terms 'construction' and 'infrastructure' and by combining these with the definition of a project, it is possible to obtain a final definition that is used in the following chapters of this research. After a first examination of the term infrastructure, some features of typical infrastructures become apparent. Infrastructures refer to the following ideas:

- Physical network industries,
- Specific and large-scale technologies and
- Developments that perform fundamental socio-economic functions (Kasper, 2015).

Typical infrastructures are energy, communication, transport, or water management networks, and thus they construct, for example, dike systems, electricity grids, roads and railway networks. Other features with respect to infrastructures are *"high initial costs, a long period before recapturing return on investment, irreversibility and indivisibility of investments, high entry and exit thresholds, and inelastic demand"* (Fijnvandraat & Bouwman, 2010, p. 3). These features make infrastructural projects different from regular projects in the sense that the client, in most cases, is not a private investor, but a public institution like the government. The definition of an infrastructural project does not differ much from a 'general' project, with the only difference being the 'system' part of the definition. The project is still a system, but with the adjective 'infrastructural', it becomes an infrastructural system. This 'infrastructural' adjective refers back to the features that are listed and defined by (Fijnvandraat & Bouwman, 2010).

Finally, an infrastructural project is a venture with a beginning and ending. The time between beginning and end is called the project's life cycle. The beginning is mostly defined as the project initiation, and the end is the project delivery. Looking at the life cycle of the infrastructural system, the ending can be defined as the moment the infrastructure is demolished. The typical system life cycle is composed of a series of phases, which can be defined as the (1) definition, (2) procurement, (3) development, (4) operations and support and (5) disposal phase (Wasson, 2006). In the procurement phase, the project is offered to the market. The contractors make a price for the project based on a detailed design, and the lowest bid wins the contract. This is the traditional method; other methods are explained in the next sub-section. However, the current project focusses on the procurement and development phase in which the risk reserve is budgeted and spent.

3.3.2 Infrastructural project characteristics

Infrastructural projects have been defined in the previous sub-section, and the current sub-section examines which project characteristics explain the uniqueness of projects. Whereas features represent the general elements of infrastructures and construction, characteristics are the **measurable elements** of projects that distinguish one infrastructural project from another. The word 'characteristic'

"comes from the Greek, word for a property, attribute or trait of an entity."

'Project characteristics' thus means those properties of a project that distinguish different types of projects, which are applicable to all projects, and the values that are obtainable. Different studies have explored the collection of the different objectives and independent project characteristics, all with different objectives for defining the characteristics. These studies are aimed at project characteristics that influence project duration (Chan & Kumaraswamy, 1995), project success (Belassi & Tukel, 1996), project complexity (Hertogh & Westerveld, 2010) and cost and time performance from a client's perspective (Manley & Chen, 2016). These characteristics were collected based on the definition made in the current research; however, there is not an unanimously chosen term for 'characteristic' used in the various studies. Terms like 'factors', 'elements', 'properties', 'traits' or 'aspects' are used. It is

therefore important that the used definitions are critically examined, in addition to the found characteristics. Table 2 displays the found project characteristics.

Chan & Kumaraswamy, 1995	Belassi & Tukel, 1996	Hertogh & Westerveld, 2010	Manley & Chen, 2016
Construction cost/value	Size and value	Size in terms of costs and duration	Project value
Type of construction	Uniqueness of project activities	Project context	Site conditions
Location	Density of the project network (independencies between activities)	Uniqueness of project	Regulation
Client's priorities	Urgency	Stakeholder constellation	Client characteristics
Post contractual developments	Life cycle	Project organisation	Supply-chain relationships
Type of contract	Project organisation	Contracting structure	Type of contract
Productivity			Project organisation

TABLE 2: FOUR LISTS OF PROJECT CHARACTERISTICS DEVELOPED IN THE LITERATURE

The considerations for determining the final set of project characteristics are elaborated on in greater detail in appendix A in sub-section 1.1.3. The literature review resulted in six project characteristics that are assumed to be independent and objective and are listed below:

- Capital value,
- Construction duration,
- Actor participation,
- Type of contract,
- Location construction site and
- Construction pace.

These six are only the independent infrastructural project characteristics, but not yet the parameters that are easily measured in order to determine the project's risk profile. The risk profile of the projects is defined by the dimensions of complexity and uncertainty, as explained in section 3.2.2. However, the project's risk profile is determined based on the unique character of each project, or in other words, based on the project's characteristics. The six project characteristics are therefore further operationalised in classifiable or quantifiable parameters. In table 3, the final operationalisation of the characteristics is presented.

Characteristic	Parameter	Quantity	Classification
Capital value	Project's bare costs	Euros	<ul style="list-style-type: none"> • < €10,000,001 • €10,000,001 – €50,000,000 • > €50,000,000
Project duration	Construction time	Days	<ul style="list-style-type: none"> • < 61 days • 61 – 180 days • > 180 days
Construction pace	Task density in planning	Ratio	None
Type of contract	Number of contractual responsibilities	Option	<ul style="list-style-type: none"> • Single responsibility (Build) • Early project involvement (D&B) • Full project involvement DBM(FO)
Location construction site	Spatial environment	Option	<ul style="list-style-type: none"> • Urban area • Rural area • Natural area



Project organisation	Number of disciplines	Option	<ul style="list-style-type: none"> • Mono-disciplinary organisation • Multi-disciplinary organisation
----------------------	-----------------------	--------	---

TABLE 3: OPERATIONALISATION OF INFRASTRUCTURAL CONSTRUCTION PROJECTS CHARACTERISTICS (SOURCE: OWN TABLE)

The first characteristic to be operationalised is capital value as an indication of the project size. It is straightforward in terms of the description of the characteristic, as well as the parameter to measure the capital value. Capital value stands for the project size in terms of costs, but the type of cost used is more difficult, as explained by figure 15. It was chosen to use the project's bare costs and thus exclude the risk reserve, company costs and profit margin. The company costs and profit margin are budgeted to maintain company continuation, not the costs to realise the project, and they do not explain the project size. The current research aims to improve contingency accuracy, so it would be counterproductive to include the risk reserve for determining the capital value. Otherwise, the construct becomes that contingency is estimated based on a variable which already included a presumed contingency budget. Capital value is thus operationalised through the infrastructural project's bare costs, which means only the direct and indirect costs.

The second project characteristic to operationalise is the project duration. It is a straightforward characteristic in terms of the parameter, just as with capital value. The difference here is that the parameter is time instead of costs. More specifically, the consideration is time that is needed to finish the construction of the infrastructure. Construction time is counted from possession of the construction site to practical completion of the infrastructure measured in days (Chan & Kumaraswamy, 1995). Again, it was chosen only to incorporate the construction phase of the project and thus not the design or maintenance periods. This was chosen in order to avoid a correlation with the type of contract characteristic. Calendar days were chosen as the unit of measure as they are a simple quantification to manage. The classification of the capital value and project duration defined in the table are based on the simple categorisation of 'small', 'medium' and 'large'.

The third construction pace characteristic concerns the project schedule, just as the previous characteristic. However, this characteristic concerns the amount of work per time unit. Rather than the total project duration, the objective is to determine the execution intensity of the project. What actually is examined within this characteristic is the total number of tasks executed simultaneously. One calculation method to operationalise this characteristic is by dividing the total duration by the sum of all tasks. It seems a suitable method to define the construction pace, but differences between schedule details are neglected here. Different projects have different schedules and levels of details within these schedules. It is difficult to determine if project schedules have the same level of detail and therefore do not represent a suitable operationalisation. A different approach to identify the construction pace is by taking the single task durations as starting point. The problem of the level of detail in the schedule can be overcome if the sum of the individual tasks' duration is used, not the number of tasks. In this way, a project with four tasks executed in parallel can have a higher construction pace than a project with one hundred tasks performed in a series. Equation 7 shows the operationalisation of the construction pace.

EQUATION 7:
$$\text{Construction pace} = \frac{\sum \text{individual task durations}}{\text{Overall project duration}}$$

The fourth operationalisation is that of the type of contract characteristic. The characteristic is aimed at contractual responsibilities in particular. The life cycle characteristic is also covered within the current characteristic, and therefore the operationalisation should be defined in such way that the life cycle is indeed included. The number of contractual responsibilities is the parameter to classify the type of contract characteristics. The question of how to define the different classes in this characteristic remains. The traditional method only includes the construction phase of the project's life cycle. This contracting model can be seen as the starting point or benchmark of the operationalisation. Deviations from the starting point indicate a different class of contract type, which raises the question of whether the number of contractual responsibilities are decisive in this parameter or if it is the specific

responsibility, such as the design element in the contract or the finance element. It is possible to categorise the contractual responsibilities with respect to the benchmark.

The design element, also called the engineering element, is a contractual responsibility that indicates early involvement in the project. The building phase is preceded by the design phase. This could also be done for late project involvement, and thus would include construction and maintenance and possibly even operations and responsibilities. However, it is very unlikely that late project involvement is not preceded by early project involvement. It was therefore chosen to combine early and late project involvement in the third and final class of this project characteristic parameter, namely the full project involvement. This is considered from the general contractor's perspective.

The fifth project characteristic to discuss is the location of the construction site. It is a clustering of the characteristics of location, project density network, construction site and the environment element of the project context. Because the characteristic needs to include multiple elements, it is more difficult to find a parameter that includes all elements, is measurable and distinguishes different classes of construction site locations. The final classification is based on three different areal features, namely urban, rural and natural.

The supply chain, stakeholders, contractor's project organisation and client are the actors that were identified in the previous sub-section. The actor participation characteristic is excluded due to the chosen operationalisation of the project location. The stakeholder element of a project is already included in the location characteristic. A project organisation can be defined as follows: *"The individuals or departments, subcontractors, and managers that will perform and manage the work, and specifies their responsibilities"* (Nicholas & Steyn, 2012, p. 164). The number of individuals or departments is mentioned as a possible parameter of this characteristic. Specifically looking at the contractor's perspective of the project organisation, the total number of individuals indicates the project size. However, the number of departments does not necessarily mean that the project size is small or large. A contractor's project organisation with multiple departments can also mean that the project has a wide array of specific tasks that cannot be executed by a single department. The parameter for the project organisation is thus the number of disciplines. Classification of this parameter is based on the example of mono- and multi-disciplinary projects, so a project is either mono-disciplinary or multi-disciplinary.

To conclude this section, the risk profile is thus defined by the dimensions of complexity and uncertainty. These project aspects are the result of each specific unique project. The unique character of projects is translated into six project characteristics that are independent. The project characteristics are further operationalised in a parameter that is quantifiable and classifiable.

3.4 Theoretical model and propositions

Project success in combination with an improved risk reserve is the goal of this research. The improved risk reserve can be achieved through higher accuracy and precision in the budgeted risk reserve. The risk reserve is divided into contingency and management reserve, and it is linked to the project's risk profile in the current research. Figure 19 presents the theoretical model with all of the relations which have been elaborated in the previous three sections. The project's risk profile is defined by the project aspects of complexity and uncertainty. However, student's syndrome and Parkinson's law can have an influence on the time-bounded risks, and thus can have an increasing effect on the project's risk profile. An increased risk perception is assumed to lead to an increased risk reserve, but also to reduced accuracy and precision. A third external factor is the quality of risk management. Increased quality of risk management leads to a lower required risk reserve as fewer risks occur due to proper management.

The improved risk reserve is based on the determined risk profile, which is defined by the complexity and uncertainty of the project aspects. Complexity is based on technical, organisational and environmental complexity, while uncertainty is divided into the sub-dimensions of goal and method uncertainty. The unique character of each project causes the project's risk profile and thus is further operationalised through independent and measurable project characteristics. These six characteristics



are capital value, construction duration, construction pace, contract type, location and organisation. The X_1, \dots, X_6 represent the characteristics in the theoretical model. However, there is also systematic error (T_e) included in the set of characteristics. This error explains the bias of the model in explaining the project's risk profile. The larger the error, the higher the inaccuracy of the model and thus the lower the accuracy in the budgeted risk reserve.

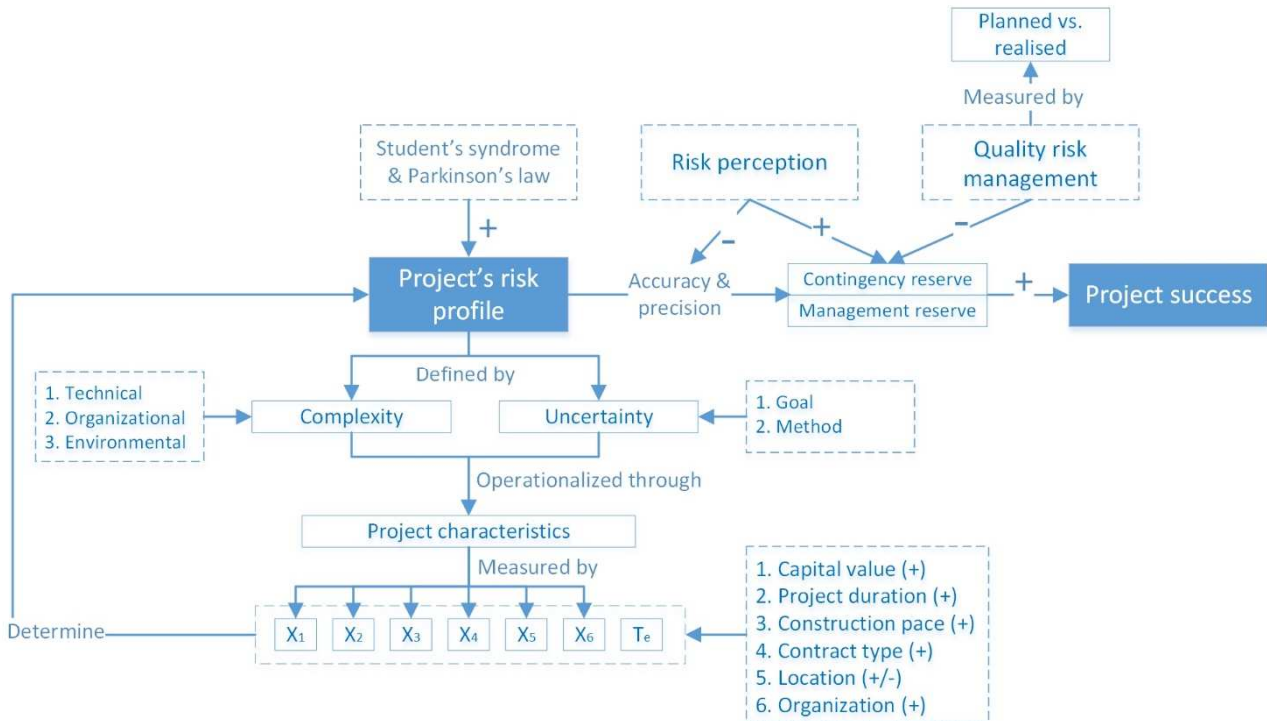


FIGURE 19: PROPOSED MODEL FOR THE RISK RESERVE ALLOCATION, EXTERNAL FACTORS, PROJECT'S RISK PROFILE, ITS DIMENSIONS AND PROJECT CHARACTERISTICS, INCLUDING DIFFERENT PROPOSITIONS OF RELATIONS (SOURCE: OWN ILL.)

Figure 19 shows the theoretical model, with all of the arrows explaining the assumed relations. However, there are also plus and minus signs included in the model. These signs indicate an assumed positive or negative relation. The external factors and their influence are explained, but the expected relations of the individual characteristics are not. The following list of propositions explain these assumptions in the theoretical model, which are tested in the following research phase:

- *Proposition 1: Capital value is positively correlated with the project's risk profile.*
- *Proposition 2: Project duration is positively correlated with the project's risk profile.*
- *Proposition 3: Construction pace is positively correlated with the project's risk profile.*
- *Proposition 4: The contract type is associated with the project's risk profile.*
- *Proposition 5: The project location is associated with the project's risk profile.*
- *Proposition 6: The project organisation is associated with the project's risk profile.*
- *Proposition 7: Student's syndrome and Parkinson's law influence the time-bounded risks and the project's risk profile.*
- *Proposition 8: Risk perceptions are positively correlated with the budgeted risk reserve and negatively with the accuracy and precision of the risk reserve.*
- *Proposition 9: The quality of the risk management process is negatively correlated with the required risk reserve.*
- *Proposition 10: An accurate and precise risk reserve is associated with project success.*

4. Practical study

The relation between the project's risk reserve, risk profile, complexity and uncertainty, characteristics and the external factors of the quality risk management and risk perception are elaborated on and explained graphically in figure 20. The second phase of this graduation research is designed to validate the theoretical model from a practical point of view. Four projects completed by Dura Vermeer are used as case studies. The individual case findings are compared to each other in a cross-case analysis. This empirical generalisation is executed so these practical findings can be used to validate the theoretical model that has been obtained in the previous research phase. The result of the current research phase is a practically validated model that graphically explains the relations between the risk reserve and its assumed influential factors. The second result is a set of hypotheses that can be tested in the following research phase. Figure 20 graphically explains the research steps that are taken in this research phase. Appendix B contains the full case studies, the interviews are added to the appendix as appendix D. Appendix C includes the financial data of the studied projects, but these are confidential.

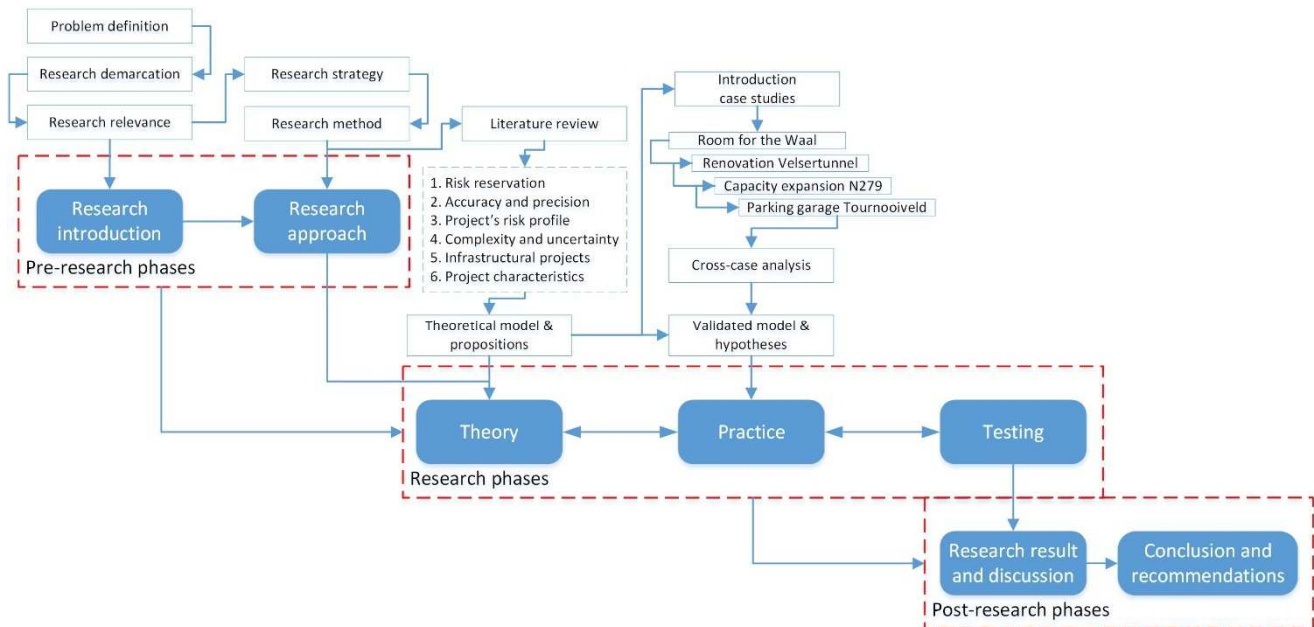


FIGURE 20: RELATIONS RESEARCH PHASES AND STEPS EXPLAINED GRAPHICALLY, PRACTICAL PHASE (SOURCE: OWN ILL.)



4.1 Introduction case studies

This research is conducted in collaboration with Dura Vermeer, with the research result intended for future use in the business management of Dura Vermeer, which is in return for transparency of information on projects executed by Dura Vermeer. It is important to note that DVILP is a department within the Dura Vermeer Division Infra (DVDI), which is one of the five divisions in the Dura Vermeer Group. The ambition of Dura Vermeer is threefold: (1) occupy one of the top three spots among innovators in construction, (2) ensure a financially healthy return and (3) operate as one of the most successful companies in the industry. In order to reach these goals, four strategic priorities have been defined by Dura Vermeer. These four priorities are improving operating profit, broadening market operation, strengthening organisation and cultivating innovation. The current research can potentially contribute to this first priority, with the objective of this research aimed at improved project success through more accurate risk reserves.

Infrastructural types of projects are executed by DVDI. The decision to undertake a project is realised by the national or regional department of the DVDI, and it is based on the size and impact of the project. The projects that are accepted or tendered range from small road constructions to large highway or dike projects. The clients of these projects range from small private parties to large public organisations, like the national government. The yearly turnover of DVDI is approximately €500 million (Dura Vermeer, 2017), thus there is room for only a few large infrastructural projects. An example of such a project that is currently tendered, namely, the new A16 highway at Rotterdam. It is 11 km of highway connecting the A13 with the current A16/A20. The tender phase takes approximately one year and the expected value of the project is in the range of €500 million. There is, of course, a change in each tender that is not rewarded with the contract. The effect can be that costs are incurred in the procurement phase, which are not covered by project. However, for such large projects, it is more critical as the investment is also larger.

The focus herein is rather on those medium-sized projects and not the largest projects. An example of such project is the 'zuidelijke omlegging Oudenbosch', which is new multi-disciplinary road project for the province of North Brabant. The project value is approximately €21 million and can be classified as a medium-large project. The focus is on these multi-disciplinary projects whose financial range is between €10 million to €50 million. To function as the background for the case studies, an introduction is first given about risk management and risk profiles within DVDI projects. The following citation is translated from the year report of the Dura Vermeer Group NV from the year 2016:

*“Dura Vermeer chooses to focus on projects that fit the company, with respect to size, experience, expertise, **general risk profile** and financial capacity, whereby we can make a difference compared to our competitors. These include ideas such as innovative character, complexity, desired integral approach and any necessary financial contribution. The manner of project acquisition also plays a role, such as the tender process, building combination, own development or public-private partnership. The mutual composition of these elements in the projects eventually **determines the risk profile of the project**”* (Dura Vermeer, 2017, p. 15).

The translated citation clearly describes projects' risk profile as key criteria in project acquisition. The project's risk profile is here linked to, but not limited by, the project aspects of innovative character, complexity, integral approach and financial contribution. The current research clearly corresponds to this company strategy on project risks. As proposed in this research, complexity is also linked to the project's risk profile in the strategy of Dura Vermeer.

In total, 19 projects were potential candidates for the case studies. However, these were funnelled to four projects. The shortlist of 19 projects all include an estimated project value of €10 million or higher. The second criterion for the making of this shortlist is the type of project. Four case studies with identical findings cannot validate the theoretical findings, so the shortlist consists of all types of projects. Other important criteria are data availability, stage of project completion (should be at least 95%) and differing project characteristics. The data availability and completion criteria are 'hard criteria', and thus

mandatory in the decision. The final decision was made based on the differences between the project characteristics. These three criteria together resulted in the decision of the following four projects:

1. Room for the Waal Nijmegen,
2. Renovation velsertunnel,
3. Capacity expansion N279 and
4. Parking garage Tournooiveld.

The above-mentioned projects are studied in the upcoming section. The studies are based on general non-confidential documentation, but also on project documents with confidential information from Dura Vermeer to the 'outside world'. Planning, for example, is not confidential. However, financial reports and forecasts are confidential. The case studies include such confidential information and are therefore not publicly available. A different version of this thesis without confidential information is therefore crafter to be made available to the public. The documentation review is validated through interviews with key project members. Documentation used for the case studies includes the following:

- Project plans and drawings,
- Project schedule(s),
- Project budget (and realised cost),
- Risk register and
- Financial reports and forecasts.

4.2 Case study findings

The full case studies can be found in appendix A, as well as the interviews that were conducted with two key project members for each case study. The general interview protocol and project-specific interview protocols are also found in appendix D. The project manager or project director was interviewed in addition to the risk or process manager. The interviews were conducted to check and improve the initial case findings based on the project documentation review. The thesis only includes the summary and findings of the case studies. Citations are used during the case study for additional clarification of a particular case finding. The projects are individually studied, but findings from earlier cases are included in the approach of the subsequent case studies. Each sub-section contains a single case study, with the general project information, project characteristics, financial aspects, critical risks and case findings.

4.2.1 Room for the Waal Nijmegen

The first project of study is the Room for the Waal Nijmegen. This is a project in the Dutch national program 'Room for the river'. Within this program, there are over 30 projects that (1) creates more room for the Dutch rivers to secure the water safety in the river delta and (2) improve the attractiveness of the living environment.¹ The River Waal makes a sharp turn between Nijmegen and Lent and, combined with high water levels, can become a funnel that is unable to process the amount of water present. The project Room for the Waal Nijmegen is a combined project for a new secondary channel, new bridges, dikes and inland spatial activities. The project characteristics are explained in table 4.

Type of project	Water project
Year of procurement	2012
Project's bare costs	€125 million
Construction duration	1,200 days
Construction pace	Parallel
Contract type	ECM
Project location	Urban/Natural
Organisation	Partnership between Dura Vermeer (70%) & Ploegam (30%)

TABLE 4: PROJECT CHARACTERISTICS OF THE ROOM FOR THE WAAL NIJMEGEN (I-LENT)

¹ <https://www.ruimtevoorderivier.nl/>



In addition to the six identified characteristics that explain the project's uniqueness, the table also includes the type of project and the year in which it was procured. Two matters can be noticed: first, the construction pace is explained as parallel, rather than as a ratio. The operationalisation defined in the theoretical research phase is not useful in practice. A new operationalisation is required for further research. The same counts for the organisation characteristic; the project is multi-disciplinary, but it was also executed in a partnership with a fellow competitor. The classification defined in the operationalisation of project organisation should be updated. Dura Vermeer had a majority interest in the combination with 70% over the 30% of Ploegam. The case study is based on a documentation review, including the financial documents. Appendix C shows table 6 with all of the financial data of the project.

The table with financial data is divided into six cost categories of which the maintenance costs is a new category not yet identified. However, it is not a cost type that is needed to construct the project and therefore not within the scope of the current research; for this reason, it is not further addressed. The direct and indirect cost categories are broken down per project object or cost type. This is done to examine what causes the financial success or failure of the project. Before this step, it should first be noticed that there is a difference between the initial budget, working budget and realised costs. The budget made in the tender phase used for the tender bid is defined as the 'initial budget'. However, during the course of the project, the budget changed, as funds from one cost line are budgeted in a different cost line. These changes are the 'adjustments to budget' column, but they do not result in an additional budget for the project as a whole. Additional budget is caused by contract changes accepted by the client, which result in additional work.

The working budget is the initial budget plus the additional work and adjustments to budget. The realised cost per budget line is the sum of actual costs and future costs. The final project result is a loss of €4.75 million or -3.79% with respect to the working budget of the project's bare costs. The ongoing indirect costs and extended Waal bridge are the main drivers of the project loss. The ongoing indirect costs are the costs of the Executive Technical Administrative (UTA)-staff, engineering and construction site equipment. These are the time-bounded indirect cost elements of the project. However, considering the cost item results without the budget adjustments, the new secondary channel is also a cause of the project loss. The extended Waal Bridge and ongoing indirect costs remain to be heavy-loss cost elements.

Project leader (Appendix D, 4.2.2): *"The time pressure within the project was a great influence the project's risk profile and especially on project expenditures in UTA staff and the extended Waalbrug."*

The indirect cost category shows the largest cost overrun, compared to the direct costs, which is both before and after the budget adjustments. The direct costs have a positive cost result based on the initial budget and working budget. The result in the direct costs became negative only after the budget was adjusted to the indirect cost budget. The negative result in the project's bare costs is higher than the project loss: it is a loss of €8.93 million. The project result is less negative, mainly due to the contingency reserve. The budgeted risk reserve is only based on the contingency reserve; the management reserve is not budgeted. The risk reserve is 6.25% of the project's bare costs and the sum of the contingency reserve and the archaeological and the NGE's budget. Only 3.92% of the 6.25% is actually spend. These expenditures are only booked in the archaeology and NGE's budget lines, not the contingency reserve. The €2.92 million remains to cover the budget overrun in the project's bare costs.

No costs are booked in the contingency reserve, and the management reserve is not budgeted at all. The required risk reserve is therefore difficult to determine based solely on the risk reserve. This because risks have occurred and costs are incurred due to these risks. The only problem is that these costs cannot be traced back to these risks, as the costs are booked into the project's bare costs. The risk reserve is meant to account for the financial setbacks caused by projects risks that endanger the financial success, or put differently, those that endanger the budgeted profit margin. The required risk reserve is therefore

calculated based on the realised costs in the risk reserve plus the result booked in the project's bare costs. The required risk reserve calculated following this line of reasoning is 11.04%, which is 4.8% more than actually budgeted. The budgeted profit margin was initially zero, thus no profit was budgeted. The realised profit turned out to be far lower than the budgeted profit margin. The required risk reserve is thus that value that the profit margin is as budgeted.

Project leader (Appendix D, 4.2.2): *“Dura Vermeer really wanted to retrieve the project, the commercial interest resulted in the fact that no profit margin was budgeted. ... The opportunity for additional work could have played a role within this decision. Budgeting a management reserve was not standard within the company's vision; now this a normal budget item in new tenders such as, for example, the project Ooijen-Wanssum.”*

The management reserve was not budgeted, but the contingency reserve was. This is based on a probabilistic simulation on the risk register with stochastic values for the probability and impact. These calculations are continuously executed during the realisation phase and based on an updated risk register. This is done in order to determine if the budget for the risk reserve is still sufficient in size in relation to the calculated risk profile. However, these calculations were influenced greatly by political considerations by Dura Vermeer.

Project leader (Appendix D, 4.2.2): *“The difference between the risk reserve budget and the calculated P85 value is a good example of political considerations. The project result was under pressure, therefore money from the risk reserve was released. This is justified by a political lowering of the risk profile calculated in @risk. This makes the value of @risk calculations doubtful. Transparency is key in such calculations, which is currently not the case.”*

There is thus budget released from the risk reserve to cope for cost overruns in the project's bare costs. However, this does not necessary mean that the risk profile of the project is actually reduced. There is a software program called @risk in which probabilistic calculations can be executed. The most critical risk during the project was not meeting the deadline, as indicated by J. Janssen. This risk primarily affected the time-bounded cost elements, like the project organisation and the construction site costs. However, this was not the only risks, other risks during the realisation were soil contamination, acquiring permits, water level of the Waal and archaeology.

Process manager (Appendix D, 4.2.3): *“Soil contamination, water level of the Waal, permits, archaeology and tight schedule deadlines were the most critical risks, of which only the water level and archaeology risks were identified in the tender phase.”*

The inconsistencies in the cost documentation, with respect to costs due to the occurred risks, make it too difficult to relate risks to the financial result of the project. The relation between the project's risk profile and risk reserve is therefore more difficult to prove. However, the fact remains that risks have occurred and that these resulted in additional costs. Only the costs are difficult to track down, thus exact numbers cannot be shown. The focus of the case study therefore shifts to the unique character of the project and its potential effect on the project's risk profile. The six project characteristics are the starting point of the uniqueness characteristics, but additional characteristics are examined as well.

The six identified characteristics are examined for a potential relation with the cost overrun in one of the cost types or, more general, in a cost category. The project characteristics of capital value, project location and organisation did not seem related to the different cost overruns or the project's risk profile. The construction pace highly affected the different cost overruns, mainly in the time-bounded cost elements like the UTA staff and the construction site materials. Not meeting the deadline is a risk assumed to be related with the external factors of Student's syndrome and Parkinson's law and thus may affect the project's risk profile. The large construction duration can be the root cause of these phenomena. A high construction pace, or perceived high construction pace, can influence this process. The extended Waal bridge faced large overrun. Many of the design decisions were already taken and therefore not changeable or optimisable for Dura Vermeer. This was the result of the engineering, construct and maintenance (ECM) contract type. The contract includes engineering responsibilities, but



not the design flexibility of the design, construct and maintenance (DCM) type of contract. This is found to be a risk-increasing project characteristic.

Project leader (Appendix D, 4.2.2): *“In both companies, there was a lack of experience with this type of project and especially the size of the project. This project entails more risks, which were not covered financially. There was no ‘learning money’ budgeted.”*

Process manager (Appendix D, 4.2.3): *“The largest financial setbacks are a result of mistakes in the tender phase. Underestimation here is a critical external factor. The tender phase was only nine weeks, which led to large uncertainty and was an important cause of this underestimation.”*

The two presented citations present two different characteristics that influenced the project’s risk profile, namely, the amount of experience the project team had with this particular kind of project. The second citation regards mistakes made in the tender phase. The tender phase of the current project was only nine weeks long, which is considered short. The short duration of the tender phase led to increased uncertainty and thus to an increased risk profile. The case findings are summarised in figure 21, in which the coloured boxes stand for the criticality of the characteristic in relation to the project’s risk profile. Red is critical, yellow means no influential and orange is in between. The lowest bullet lists are the negative and positive project outcomes and aspects. The red bullet list stands for the negative points and the green list for the positive aspects and outcomes. Project success was not reached financially, but it is seen as an excellent project in terms of quality as well as stakeholder acceptance.

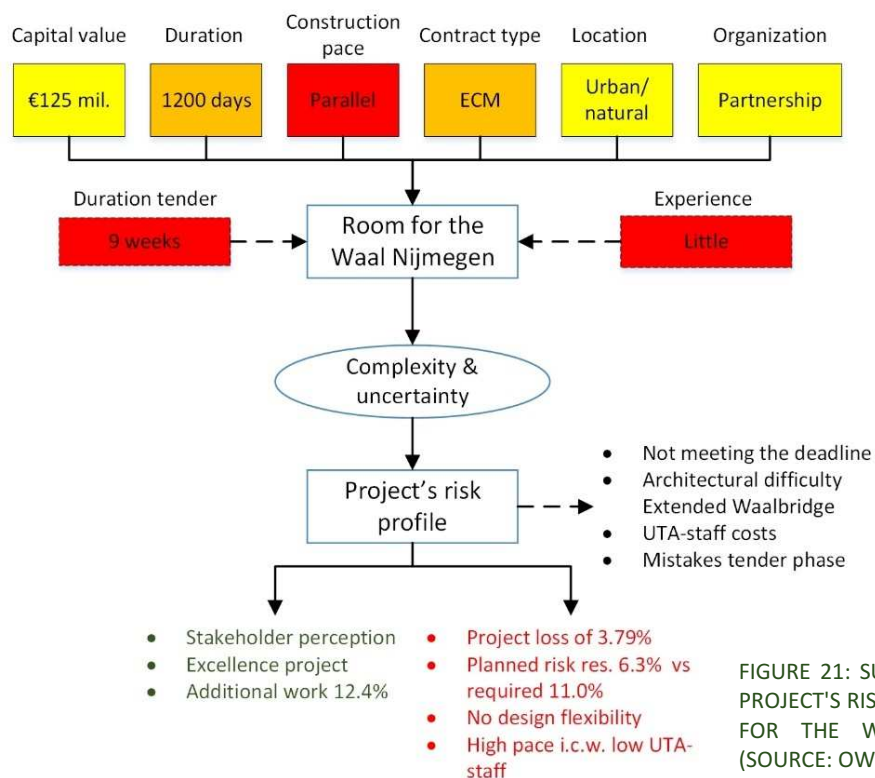


FIGURE 21: SUMMARY FIGURE PROJECT'S RISK PROFILE ROOM FOR THE WAAL NIJMEGEN (SOURCE: OWN ILL.)

4.2.2 Renovation Velsertunnel

The second case to be studied is the Renovation Velsertunnel project. The project is a renovation project of the Velsertunnel that was constructed in 1952 and put into service in 1957. It is for this reason that multiple elements of the tunnel are outdated, which concerns both the tunnel installations and some constructive elements. However, the major part of the renovation was based on the installations and obtaining the right safety level. The constructive renovation concerned increasing the crossing height of the tunnel by 12 cm, inputting new tarmac, removing asbestos, constructing five new safe rooms and implementing new tunnel entrance protection portals. This last measure ensures that the lowest part of the tunnel is at the opening of the tunnel tubes, rather than in the middle. Finally, the water reservoir

in the tunnel doubled in size so that water can be retrieved by the fire brigade for a longer period for firefighting. The installation part of the tunnel renovation mainly concerns the traffic control system, lighting, ventilation, fire escape installation and all of the required cabling for the new installations.

Type of project	Tunnel project
Year of procurement	2013
Project's bare costs	€67 million
Construction duration	446 days
Construction pace	Parallel, temporary closure
Contract type	DBM
Project location	Rural
Organisation	Partnership of SPIE (34%), Dura Vermeer (22%), Besix (22%) & Croon (22%)
Tender duration	9 months, including concretisation phase

TABLE 5: PROJECT CHARACTERISTICS OF THE RENOVATION VELSERTUNNEL.

The first eight rows of table 5 are similar to those of table 4 in sub-section 4.2.1. These explain the project type and year of procurement, as well as the six identified project characteristics. However, the ninth row explains the tender duration, which was found to be critical to the project's risk profile in the project 'Room for the Waal Nijmegen'. For this reason, the tender duration is included in the set of project characteristics that is examined in the study of the unique character of the project. The tender duration was nine months and included a concretisation phase between the contract award and the start of the contract. The period was aimed at cementing mutual understanding of the contractual responsibilities and project risks between the client and the contractor. The tender duration is long in comparison with the tender duration of the Room for the Waal Nijmegen project.

The construction duration is 14 months, or 446 calendar days, and the contractual duration is longer, with almost two and a half years. This discrepancy is due to the design phase that precedes the construction phase. However, the tunnel was renovated and therefore fully closed off from traffic. This resulted in a stringent time period in which all of the activities needed to be executed. The tunnel was only closed for nine months, meaning that all of the work had to be done within this period. The construction pace was high due to this scheduling challenge in which the work week was based on 16 or 24 hours per day, 7 days per week. The project was executed by the combination organisation 'Hyacinth'. Dura Vermeer had only a minority interest in the partnership, with 22%; SPIE had the largest interest with 34%, and Besix and Croon both also had an interest of 22% in the project. However, the civil and infrastructural part was 'subcontracted' by Hyacinth to 'Hyacinth civil and infrastructure', which is a combination of Dura Vermeer (50%) and Besix (50%). Hyacinth was mainly responsible for the installations and overarching costs, such the costs for engineering and project organisation.

The financial aspect of the project is analysed and documented in tables 7 and 8, presented in appendix C. There are two tables because of the two sub-projects: the civil and infrastructural sub-project and the overall sub-project. Again, a difference is found between the initial budget and the working budget. However, this is only as a result of additional work, not due to adjustments between budget lines, like in the project 'Room for the Waal Nijmegen'. There are two different tables with the financial results. The first is that of the overall project, Hyacinth large, the second is the Hyacinth civil and infra. The Hyacinth civil and infrastructural is also included in the Hyacinth large table, but the working budget is equal to the realised costs. There is thus no cost result booked into the Hyacinth large project because otherwise the profit is counted twice.

There is a difference between the two sub-projects, which resulted in two different profit margins. The final project result in the hyacinth large project is €920,000, which is 1.31% of the working budget of the project's bare costs. The profit can indicate financial success in this sub-project. However, the budgeted profit was €1.94 million, which is 3.68% of the initial budget of the project's bare costs. The profit margin is also reduced in the working budget with respect to the initial budget. This is mainly due



to the costs of additional work. Additional work means higher construction costs, but not higher project turnover or total project costs.

Project director (Appendix D, 4.3.2): *“Additional work, unforeseen, leads to additional costs. The direct costs are likely to be covered, but indirect costs are, in most cases, not paid for by the client. This largely influences the project result, mainly in staff costs or construction site costs.”*

The additional work resulted in higher company costs that were not honoured by the client. A portion of the budgeted profit margin was therefore released to the budget for the company costs. The amount of additional work has thus not led to a higher profit in the Hyacinth large. The opposite is true for the sub-project Hyacinth civil and infrastructure. The additional work positively affected the project result in this part of the project.

Process manager (Appendix D, 4.3.3): *“The small Hyacinth made more profit than the large Hyacinth. The civil and infrastructural work is a far more profitable sub-project.”*

The profit margin in the small Hyacinth was initially budgeted for €920,000, which is 6.5% of the project’s bare costs. The profit margin increased to €1.35 million in the working budget. This is a drop to 6.26% with respect to the working budget of the project’s bare costs. The amount of additional work within the small Hyacinth was 51% with respect to the initial budget of the bare costs of the project. Additional work led to an absolute increased profit margin, but not in terms of percentages. However, the small Hyacinth was far more profitable than the large Hyacinth. The sub-project result was €5.13 million, which is 23.86% of the working budget of the project’s bare costs. The combined project result was €6.05 million or 8.98%, but the profit was not split evenly between the partners in the combined project organisation. The profits made by the four project partners are explained in table 6.

	Bare costs (€)	Profit (€)	Profit (%)
Large Hyacinth	€ 45,880,232.00	€ 923,488.00	2.01%
Small Hyacinth	€ 21,476,680.00	€ 5,125,295.00	23.86%
SPIE	€ 15,599,278.88	€ 313,985.92	2.01%
Dura Vermeer	€ 20,831,991.04	€ 2,765,814.86	13.28%
Besix	€ 20,831,991.04	€ 2,765,814.86	13.28%
Croon	€ 10,093,651.04	€ 203,167.36	2.01%
Total	€ 67,356,912.00	€ 6,048,783.00	8.98%

TABLE 6: FINANCIAL DATA OF THE PROFIT MARGINS PER SUB-PROJECT AND PARTNER.

The project result for all four partners in the combination organisation is positive, but the percentages show that Dura Vermeer and Besix had far better results than SPIE and Croon. The subcontracting costs in Hyacinth small are the main driver of this large profit. The largest drivers of the reduced profit in the Hyacinth large are the project organisation and ongoing indirect costs. These two cost types are typical time-bounded costs in the indirect cost category. The project’s risk profile is mainly visible within these time-bounded cost items. The direct cost category, however, is sufficiently positive to ensure financial success for Dura Vermeer. The influence of the risk reserve is not marginal, with a combined budgeted contingency reserve of €2.05 million. There was no management reserve budgeted in the project.

Process manager (Appendix D, 4.3.3): *“When a budget is made without hidden reserves, then it is possible to use different types of risk reserves. However, this is not the case as many reserves are already made in the different budget lines. An additional management reserve only results in extrapolation and in a bidding price which is too high to win the contract.”*

The management reserve was not budgeted, as it was expected to only add additional buffer to the project which could have resulted in a bidding price that was too high to be competitive. The budget for the different project objects already includes such buffers. More interesting is that the contingency reserve does not show any booked cost in its budget line. However, there are indeed incurred risks and RRM taken to control the project, but the costs of these risks and measures are just not consistently

documented in the risk reserve budget line. These are booked in the direct and indirect costs, like as was done in the project 'Room for the Waal Nijmegen'.

Process manager (Appendix D, 4.3.3): *"The budget made in the tender is a summation of faults; a project always develops differently than expected. A distinction has to be made between what is budgeted and what has to come from the risk reserve."*

Process manager (Appendix D, 4.3.3): *"Risk management is still an undervalued activity within the project. It is merely a side activity because it is obligatory to do. Risk controlled project management happens, but it is not documented properly."*

The risks cannot be related one-on-one to the project's risk profile and contingency reserve due to this documentation inconsistency in risk management. This does not mean that the risks are managed improperly, but the financial consequences of these occurred and controlled risks are unknown. The most critical risks within the project are the strict deadline because of the nine-month tunnel closure, uncertainty of the current state of the tunnel and asbestos. All three are interrelated because asbestos is an example of uncertainty of the current state of the tunnel. The exact amount of asbestos, but also the amount of reinforcement steel used in the concrete, was not fully known, which can lead to additional costs, but also additional time, affecting the planning. The deadline resulted in a high construction pace, but also in a budget overrun in the project organisation.

Project director (Appendix D, 4.3.2): *"A good tender is crucial for the project result. The whole scope of the project has to be investigated and known."*

The six identified project characteristics, combined with the tender duration, explain the unique character of the project and can determine the project's risk profile. The tender duration is nine months, excluding the concretisation phase. This is a long period in which the project scope could be examined thoroughly. The location and stakeholders can influence the project's risk profile, but this is related to the contract. The division of responsibilities between the contractor and client plays an important role.

Project director (Appendix D, 4.3.2): *"For the location, the environment and its stakeholders can increase uncertainty. The location and contract type combined is decisive. When 'we' can directly communicate with the stakeholders, it does not need to be more difficult. However, if it goes through the client, then it makes things more complicated."*

The size of the project, both in terms of duration and costs, did not influence the project's risk profile. No project risks are related to these project characteristics. The construction pace on the other hand, is related to the project's risk profile. The tight schedule resulted in a high construction pace, which required more effort from the UTA staff and thus more costs within this budget line. The UTA staff fell under the responsibility of the large Hyacinth, meaning that the construction pace mainly influenced the risk profile of this sub-project. The vertical split in the project organisation resulted in different interests between the project partners, which did not contribute to positive collaboration between the project partners. The overrun in the engineering budget is linked to the type of contract in which the design was the responsibility of the Hyacinth organisation.

Project director (Appendix D, 4.3.2): *"The vertical split in the organisation was a first-class mistake; it was the company strategy of SPIE. However, afterwards, there was regret about this decision, especially by SPIE."*

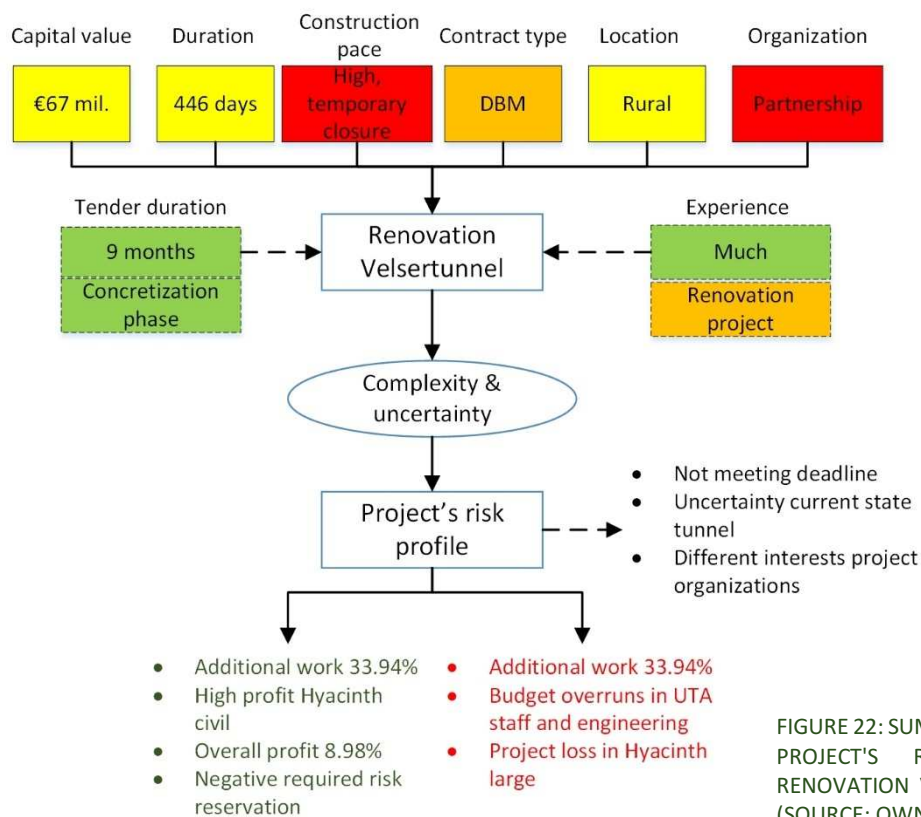
The tender duration thus positively influenced the risk profile of the project, such that it led to increased understanding of the project scope and thus a reduced level of uncertainty. The concretisation phase was planned after the contract award and before the start of the actual contractual responsibilities. Time was used to create mutual understanding of the contractual responsibilities of both the general contractor and client. The level of goal uncertainty was further reduced within this period. This period likely positively contributed to the level of trust between the two project partners. Additional work is accepted more easily knowing that the contractor is working in the best interests of the project and the client's wishes. An additional project characteristic is the renovation aspect of the project. Renovation



projects include more uncertainty in the current state of the object to be renovated and therefore lead to an increased risk profile. This can be related directly to, for example, the risk of asbestos and the amount of steel in the reinforced concrete floor.

Process manager (Appendix D, 4.3.3): *“The fact that the project is a renovation project makes it riskier. Uncertainties in the current situation are an unavoidable element in such projects.”*

Finally, figure 22 presents a graphical summary of the case study findings. The project characteristics and colours explain their effect on the project’s risk profile. The amount of additional work was found to be both positive and negative for the project. In the large Hyacinth, it was not positive, while in the small Hyacinth, it was positive. The amount of experience by the project team, tender duration and concretisation phase positively influenced the project’s risk profile. The construction pace, split project organisation and renovation character of the project, in particular, resulted in project risks. The overall project profit was 8.98%, which is high. However, only Dura Vermeer and Besix profited from this high figure. Hyacinth civil and infrastructural had the largest realised profit. The large Hyacinth consisted of the largest budget overruns, with the project organisation and ongoing indirect cost types as main drivers. These time-bounded indirect cost types had the largest budget overruns and were likely influenced by student’s syndrome and Parkinson’s law.



4.2.3 Capacity expansion N279

The third case study is in regard to the project ‘Capacity expansion N279 's-Hertogenbosch – Veghel’. The project is primarily a road widening in the province of North Brabant. The 13.5 kilometre widening of the N279 from 2x1 lanes to 2x2 lanes is the largest part of the project. Furthermore, its connections to the two national highways were reconstructed, and four crossings that were designed as single-level crossings were changed to uneven crossings. The N279 underpasses the intersecting roads. One whole new crossing was constructed, which was designed as an uneven crossing as well. Along the N279 is also a new cycling route, including a new bridge over the N279. A very different element in the project is the natural redevelopment project ‘Dynamische Beekdal’. The natural area of the project is Hersend-Aveld. The river Aa runs through the area for which additional space is realised. This way, the Aa can more freely meander. The sub-project Dynamische Beekdal is only a small element in the project as a whole.

Type of project	Infrastructural projects
Year of procurement	2014
Project's bare costs	€61 million
Construction duration	607 days
Construction pace	Semi-parallel
Contract type	DBM
Project location	Rural/natural
Organisation	Partnership of Dura Vermeer (75%), Ploegam (12.5%) & Biggelaar (12.5%)
Tender duration	3 months, including concretisation phase
Renovation	No

TABLE 7: PROJECT CHARACTERISTICS OF THE CAPACITY EXPANSION N279 'S-HERTOGENBOSCH – VEGHEL'.

The project is an infrastructural project procured in 2014 and completed in April 2017. The project size in terms of capital value is €61 million, and thus it is in the range of the capital value of the project 'Renovation Velsertunnel'. The contractual duration was three years, but the construction duration was only 607 days. The project included a design responsibility in the contract. The project location is natural and rural, as the project contains a natural sub-project. However, the main project was located in a rural location. The construction pace was semi-parallel, which was a result of the promise made by combination of 'the Vaart'. The project was realised by the Vaart, which is a combination of the three partners Dura Vermeer (75%), Ploegam (12.5%) and van de Biggelaar (12.5%). The tender duration was three months, excluding a two months' concretisation phase.

Project director (Appendix D, 4.4.2): *"The project is based on the principle Best Value, meaning that 'the Vaart' is the expert and the client only controls the project risks from a distance."*

The project was procured based on the Best Value Principle (BVP), so the notion of 'the best for the project' played a central role in the procurement and execution phases. Not only a bidding price was made by the combination the Vaart during the tender phase, but also a (1) performance substantiation, (2) risk register including both threats and opportunities and (3) interviews with key functionaries. These qualitative aspects were judged by the client and resulted in a fictional reduction on the tender bid. The offers of all contenders in the procurement phase are compared both on quality and price. The performance substantiation stands for a series of project claims made by the Vaart. Project claims are, for example, that the N279 can be completed 10 months before the contractual deadline. The claim resulted in a higher fictional reduction on the tender bid, but also in a relatively fast construction pace. This type of project is not new for Dura Vermeer, as multiple road-widening projects have been executed by the group. However, the BVP is a new project characteristic, especially in combination with the design responsibility.

The project costs are presented in table 9, and also in appendix C. The budget line N279 A2-Nijvelaar is the first observable element of the table. This sub-project originally was not in the scope of the project, but it was seen by the contractor as an opportunity. The Vaart offered to overtake the 'Nijvelaar' crossing as an uneven crossing, rather than as an even crossing with traffic lights. The client saw the added value of this 'project opportunity' and accepted the scope change. The Vaart designed and constructed this sub-project. However, this opportunity was accepted after signing the contract, and the execution of this sub-project required additional planning and was therefore executed following a different deadline. This sub-project has not been completed at the time of this case study. It is therefore excluded from the current financial analysis. This way, the 95% realised project criterion is not violated.

Project director (Appendix D, 4.4.2): *"The project is going well, seen from a financial perspective."*

The project shows a positive result in financial terms. The project profit was €4.48 million, which is 7.33% with respect to the working budget of the project's bare costs. This is a suitable result, especially compared to the 3.44% profit margin initially budgeted and the 3.67% profit margin in the working budget. The realised profit is twice as high as the budgeted profit margin. However, there is a large



difference between the direct and indirect cost categories. The positive result in the direct cost category is not assignable to a single budget line. Strong performance was achieved across the board. The same counts for the indirect cost category, but the other way around. Engineering, UTA staff and various costs, such as construction site materials, all show a budget overrun of more than 10%. The largest absolute loss is found in the UTA staff, with a loss of €1.46 million. This loss is, however, assumed to be a reason for why the project proceeded above expectations.

Project director (Appendix D, 4.4.2): *“There was financial space to deploy additional staff, which helps the project to proceed positively. Projects with financial cuts in staffing tends to end up in a negative spiral.”*

There is a pattern in the indirect cost types that are influenced by time. Again, the UTA staff is a large negative cost driver, whereas the Student’s syndrome and Parkinson’s law are assumed to influence this budget overrun. The risk reserve is based on a contingency and a management reserve. However, there are also RRM’s included in the direct costs, namely archaeology, flora and fauna and NGEs. The risk register was one of the three criteria on which the Vaart was judged in the BVP, so risk management is taken seriously in an early stage. The risk register was probabilistically simulated, which resulted in a contingency reserve of €900,000 based on 92 threats and 73 opportunities. The current project included a €250,000 management reserve, making the total risk reserve €1.15 million. The budgeted risk reserve is 2.91% of the budgeted bare costs, but it decreased to 2.31% compared to bare costs in the working budget. There are no costs documented in the contingency and management reserve, only due to RRM’s in archaeology, flora and fauna and NGEs.

Project director (Appendix D, 4.4.2): *“Costs have been made due to occurred risks for sure. An example is additional costs for placing sheet piles. These costs are probably booked at the object post in the budget to which these costs relate.”*

Process manager (Appendix D, 4.4.3): *“There are definitely occurred risks with financial consequences.”*

As in the previous two case studies, the fact that no costs were booked in the risk reserve does not mean that no costs were made due to incurred risks. Different from the previous two studied projects, the risk management practices were applied in the realisation phase. The risk profile of the project was quantified every four weeks in a progress report. The risks were reduced through RRM’s or controlled for based on this quantified risk profile. The full quantification method was based on the ‘fine and kinney’ method and is elaborated on in greater detail in appendix B, section 2.3.4. Figures 23, 24 and 25 show the project’s risk profile throughout the project as used in the progress reports every four weeks. The number of risks and the risk profile decreased as the project progressed, both absolute and relative. A sharp drop can be noticed after the finish of the design, where after much uncertainty is reduced. The risk profile is thus actually added as a key performance indicator (KPI) to the management tool set.

The largest risks were design and scope difficulties, flora and fauna, archaeology, uncertainty of the current situation, damage due to construction, soil conditions, cabling and piping and risks with time effects. The uncertainty of the current situation is again a difficulty, especially in combination with the design and scope difficulties. These risks are related to the design responsibility in the contract. The capital value and construction duration of the project did not lead to additional risks or budget overruns. The same counts for the fact that the project was executed in a partnership, rather than Dura Vermeer alone. However, the type of client did influence the project’s risk profile. Communication with the province is assumed different than, for example, with Rijkswaterstaat (executing organisation of the national government), which is assumed to be stricter.

Process manager (Appendix D, 4.4.3): *“The six defined project characteristics give a good representation of the project’s risk profile. However, the type of client is also influential in this matter. There is a difference between RWS or the province as client.”*

Besides the type of client, the client structure is also assumed to increase risks. Parts of the project, the connections with the A2 and A50, are not delivered to the province, but to Rijkswaterstaat. This is, according to H. Wijnstra and P. van der Zande, always a risk. The Dynamic Beekdal part of the project was a project of the Waterschap. However, the province was the client, not the Waterschap. The fact that there was multi-layered client structure makes the project more complicated. The size of the organisation thereby also influences the project's risk profile. The budget overrun in the engineering cost post was an effect of the risk of not meeting the deadline. The design phase was delayed, which was corrected through additional effort and thus further costs. The combination of the design responsibility in the contract and experience is the reason for this overrun. There was sufficient experience with the current type of project in the project team, only the BVP and design responsibility were new. This new contract responsibility only had a short history within general contractors. The tender duration was limited in time and therefore choices had to be made with respect to the level of detail in evaluating the scope of the project elements, which always causes risks as uncertainty can arise.

Project director (Appendix D, 4.4.2): *“Within this project, the specific situation and environment make the project complex. The work itself is not rocket science. Experience has an important role in the project success. Finally, the tender phase is limited in time and much work has to be done within this period. This always causes risks, as not all project elements can be evaluated, that the execution phase has to address.”*

The tender duration of current project was three months, which is six months less than for the project Renovation Velsertunnel, which is alike in terms of capital value. However, it was also more than the nine weeks' tender duration of the project Room for the Waal Nijmegen. Just with the Velsertunnel renovation, the project 'N279' also included a concretisation phase before the start of the contract. This final phase before the start of the project resulted in fewer scope uncertainties and better task division between the client and the contractor. This is assumed to be a factor that lowered the project's risk profile. The largest cost overrun occurred in the UTA staff, the same as with the two previous projects. The largest drivers of this overrun were the construction pace, but even more so was the BVP. The project opportunity of the uneven crossing 'Nijvelaar' was adopted by the client. This has resulted in many additional questions that had to be answered by the contractor.

Project director (Appendix D, 4.4.2): *“When an opportunity is offered by Dura Vermeer, many risks are taken over from the client. Risks that were not fully known initially. In the project N279, the opportunity meant that the crossing had to be designed from zero, including a change in the provincial integration plan (PIP). Due to this offered opportunity, the cabling and piping under the surface are also the responsibility of the Vaart, what turned out to be a large risk, a risk that was controlled sufficiently so that it did not occur. This had a large influence on the costs for the UTA staff.”*

The BVP resulted in an opportunity offered to the client to be executed by the Vaart in the same project. However, additional responsibilities came with such promises. Activities that are normally executed by the client were executed by the Vaart, so therefore the risks that accompany such activities were also adopted by the Vaart. In this case, the PIP had to be changed, which required political support of the province and support by the other stakeholders in the project. In this way, the cabling and piping risks become a contractor risk, rather than a client risk. This is a risk-increasing project characteristic, but both in terms of a project threat and opportunity. The BVP is thus assumed to be one of the causes of the cost overrun for the UTA staff, but it also resulted in much more project management freedom.

Figure 23 presents a graphical summary of the case study on the project Capacity expansion N279. The main findings are that the project shows a positive project profit and the BVP was both an opportunity and a threat to the project. The construction pace and the client structure caused an increased risk profile. The combination of experience and contract type is also a reason for an increased risk profile. The completion deadline was the largest risk during the design phase. In the construction phase, the cabling and piping, permits and soil conditions were the most critical risks.

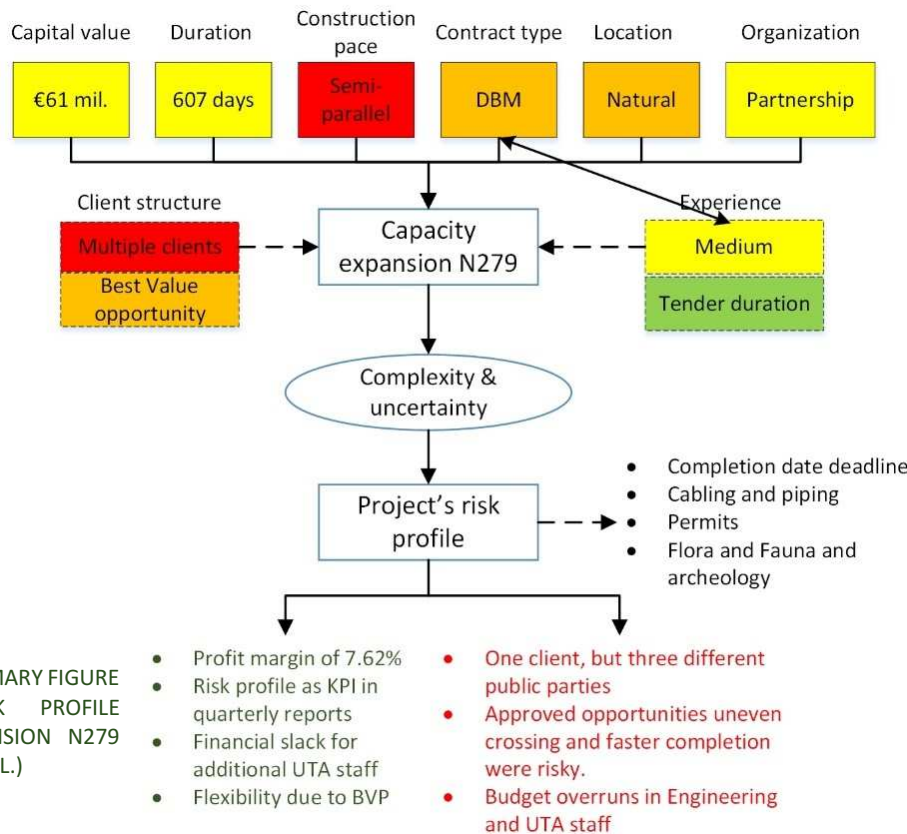


FIGURE 23: SUMMARY FIGURE PROJECT'S RISK PROFILE CAPACITY EXPANSION N279 (SOURCE: OWN ILL.)

4.2.4 Parking garage Tournooiveld

The final case study is on the underground parking garage Tournooiveld project. The full case study is presented in appendix B, and this sub-section is a brief summary of the case study and main findings. The initiative is not a public initiative, like the three other projects, but a private initiative. Local residents, cultural organisations and entrepreneurs already developed plans for the parking garage in 2010. The PTV group is a combination of Dura Vermeer (50%) and SENS real estate (50%) and further addressed the planning of the new garage. The project is therefore, besides a private project, also a project of its own assignment. The garage was sold after the completion of Interparking. The parking garage is 97.5 meters long and 34 meters wide, with all three stories below ground level. The garage was constructed in the centre of The Hague surrounded by monumental buildings. To reduce the amount of vibrations, the garage was constructed with Cutter Soil Mix (CSM) walls and an underwater poured concrete floor. The underwater poured concrete floor is part of the construction. However, new 10-meter high concrete walls have been poured on top of the floor next to the CSM walls. The concrete's inner structure was made afterwards, followed by the other construction activities and installation work.

Type of project	Civil project
Year of procurement	2014
Project's bare costs	€14.9 million
Construction duration	702 days
Construction pace	Serial scheduled
Contract type	D&B
Project location	Urban
Organisation	Multi-disciplinary
Tender duration	3 months
Renovation	No
Client structure	Dura Vermeer development
Best value principle	No

TABLE 8: PROJECT CHARACTERISTICS OF THE PARKING GARAGE TOURNOOIVELD.

With Dura Vermeer as the client, it makes sense that Dura Vermeer is also the general contractor for the realisation of the garage. On the other side, the contractor is also a combination organisation. The PTV company has an agreement with IPTOUR, which is a partnership between Dura Vermeer Beton- en Waterbouw (DVBW) and Dura Vermeer Infra (DVI). Both companies are working companies within DVDI, therefore it can be stated that Dura Vermeer was both the client and the contractor. The contractor remained IPTOUR, but due to a reorganisation within DVDI, the combination DVBW and DVI changed to a single organisation DVILP. However, the lack of market competition to win the contract did not mean that IPTOUR was able to ask a higher price. In addition, PTV also have to sell the parking garage, thus a low construction price means a higher probability of selling the garage.

The first tender budget of IPTOUR was €15.66 million, but this price was not the final price agreed upon in the contract with PTV. First, PTV hired IGG Boiton de Groot, a cost consultancy company, to make a cost estimate for the project plan as well as give a second opinion. The cost estimate of IGG Boiton de Groot was €12.54 million. The first tender price of IPTOUR was thus substantially higher. The difference was more than €3 million between both cost estimates. After different rounds of budget corrections, IPTOUR and PTV agreed upon the price of €14.58 million. The procurement strategy was thus not based on the best value principle or Most Economically Advantageous Tender (MEAT) and without a concretisation phase. The contract includes both the design and construction responsibility, with planning that is mainly serial scheduled.

Appendix C contains table 10 with the financial results documented. The large overall cost overrun and negative project result are the first aspects to be noticed. The budgeted profit margin was €380,000, which is 2.59% of the working budget of the project's bare costs. The profit margin turned in a project loss of €-3.03 million, which is a loss of -20.39%. Like the project Room for the Waal Nijmegen, there were adjustments made to the different budget lines through reallocation of these budgets. The research therefore mainly considers the cost type results without these adjustments. The direct and indirect cost categories both had a negative project result, but the indirect cost category performed very poorly. The budget overrun in the indirect cost category was €2.01 million, which is almost 50%. The direct cost category shows a cost overrun of €1.68 million, which is also large, with the costs at 16% above budget.

Process manager (Appendix D, 4.5.2): *“During the making of the budget, the UTA is thought about too lightly. This can be due to two reasons; first, to reduce the price to make the garage more sellable. Secondly, because of scope uncertainties as in the relationship between client and contractor.”*

The concrete tube and the concrete inner structure are the two main drivers of the overrun in the direct costs. The costs for engineering and UTA staff showed the largest budget overrun with respect to the indirect costs. This is in line with the three other projects, where budget overruns were also located in the UTA staff and engineering cost types. What is different here from the three previous projects is the amount of additional work, or better, the lack of it. The project was a Dura Vermeer project in the sense that Dura Vermeer was the client of the project. Additional work claimed by IPTOUR, the contractor, meant additional costs for PTV, the client. Additional work thus led only to increased costs for either Dura Vermeer the client or Dura Vermeer the contractor. This can be the reason that only 0.84% additional work was approved by PTV to IPTOUR.

A different scenario could be that IPTOUR was facing a project loss in the realisation of the parking garage, but PTV made a profit by selling the garage to the highest bidder. In this project, the highest bidder was Interparking, who bought the garage for €21.75 million. There is an expected project result of €990,000, which is €460,000 more than initially budgeted. There is thus a profit on the client side of the project, but this does not cover the loss of €3.03 million on the contractor side. The client partner, SENS real estate, received a profit due to the realisation of the garage, though PTV does not have additional work approved by Interparking, which may influence the relation between IPTOUR and PTV.



The risk management process started in the tender phase with the identification of risks, both negative and positive events. The same strategy in the other projects was followed, meaning that the risks were analysed, quantified and documented in a risk register. The level of the risk reserve was solely based on the contingency reserve, which was calculated based on the probabilistic simulation of the risk register. Different from the other three projects is that there was a division made between the contractor and the client risks, so these were separately calculated. The combination of contractor threats and opportunities result in a contingency reserve of €230,000 million. The financial risk profile, as identified in the tender phase, is larger for the client. There were 28 client risks identified with potential cost consequences. The deterministic value of PTV's risks was €1.23 million, and the probabilistic value was even €1.39 million. This makes the combined financial project's risk profile €1.62 million, of which only 14% falls under IPTOUR's responsibility. However, during the project, it turned out that most of the risks fell under the responsibility of IPTOUR.

Process manager (Appendix D, 4.5.2): *"The distribution of risks is complex, primarily due to the triangle Dura Vermeer, SENS and Interparking. A clear client and contractor relationship would have made the allocation of risks much easier. ... When a risk occurred, then it was in most cases taken by IPTOUR, also because SENS was unable to bear any risks."*

As stated in the quote by B. Rademaker, the difficult client structure with the three partners resulted in a risk distribution that actually rested fully on IPTOUR. The combined financial project's risk profile of €1.62 million, which was initially determined, was thus more than 14% the responsibility of IPTOUR. The risk reserve of €230,000 million was too low, but again no costs were documented in the contingency reserve budget line. The high project loss, however, does indicate that multiple large risks occurred, which is confirmed by the interviews and project documents. The risk reserve was only 1.58% of the project's bare costs. The required risk reserve, to cover for the loss in the project's bare costs, should have been more than 24%.

Process manager (Appendix D, 4.5.2): *"The duration of the construction phase was short and the pace high, which makes it difficult to cope with any setbacks. Acceleration measures are therefore necessary, which, in most cases, lead to increase project costs."*

The most critical risk of the project is that of not meeting the deadline, just as in the three other projects. The phenomenon of student's syndrome is expected to play a role within this time-bounded risk. The construction pace is explained as high and the duration short, but this is not observed in the project characteristics. The construction pace operationalisation was not found usable in practice and needed to be re-evaluated. The fact that the project was serially scheduled does not mean that the construction pace was low. An explanation can be that the activities could not be scheduled in parallel due to the chosen construction pace, but therefore the activities are more sensitive to delays and thus the deadline was more endangered. Other projects risks were the sensitivity of the monumental buildings surrounding the construction site.

Process manager (Appendix D, 4.5.2): *"The project Tournooiveld applied CSM walls, which is a construction method that is not yet fully known at Dura Vermeer. This definitely increased the project's risk profile and required additional effort of the project organisation."*

This sensitivity has led to a construction method with as few vibrations as possible. However, the downside is that the construction method was innovative, and Dura Vermeer had little experience with it. This resulted in multiple risks with respect to the construction method. Other risks were a result of the 'grey area' between the contractor and client responsibilities. Political sensitivity and cabling and piping are risks normally borne by the client, unless differently demarcated in the contract. However, due to the non-traditional client-contractor relation, these risks fell under the responsibility of IPTOUR. The same happened in the project Capacity expansion N279, in which the Vaart was responsible for changing the PIP and the cabling and piping for the offered 'project opportunity'.

The initial budget made by IPTOUR, which was revised after the second opinion of IGG Boiton de Groot, came closer to the realised costs than the final budget. However, it was still too optimistic based on the

present knowledge. The combination of the first project price calculated by IPTOUR and the combined risk reserve of the contractor and client risks approaches the actual project costs even further. The difference in this described situation was only €330,000. Besides the project’s risk profile, the market conditions played a role in the current approach of calculating the required risk reserve. The required risk reserve was thus calculated differently than initially expected. The financial consequences of risks were documented in the direct and indirect cost categories. The required risk reserve was therefore calculated based on the result of the project’s bare costs. The risk profile of the current project was found to be large, as based on the required risk reserve, but the saleability of the garage influenced the required risk reserve as well. The primary project characteristic that influenced the risk profile of this project was the client structure.

Process manager (Appendix D, 4.5.2): *“There is no clear client plus Dura Vermeer has a 50% interest in PTV. There was no possibility for IPTOUR to directly communicate contract changes with Interparking, which makes it much more complicated.”*

In the project Capacity expansion N279, the project had multiple clients, which is a risk-increasing project characteristic. The client structure of the current project was also a difficulty, but in a different way. The client was PTV, which is partly owned by Dura Vermeer. There is a single client in IPTOUR, but the final client, Interparking, could not be spoken to. Additional work necessary to construct the garage was not negotiated with Interparking due to the difficult contractual relations in the project. The fact that the project was sub-surface in combination with this client structure was also a risk. The cabling and piping risks were due to the client structure, a responsibility of the contractor instead of the client.

The innovative character of the design is a result of the construction location, and it influences the level of experience that the project team had with the construction method. The innovative design has led to method uncertainty in the project. Finally, the construction pace was found to be critical to the risk profile of the project as well, despite the serial planning. The findings of this fourth case study about the project parking garage Tournooiveld are graphically summarised in figure 24. A positive project result is the profit in the client organisation, but this does not cover the large project loss in the executing organisation IPTOUR. Dura Vermeer gained a lot of experience in constructing this sub-surface parking garage, which can be exploited in future projects that are similar to parking garage Tournooiveld.

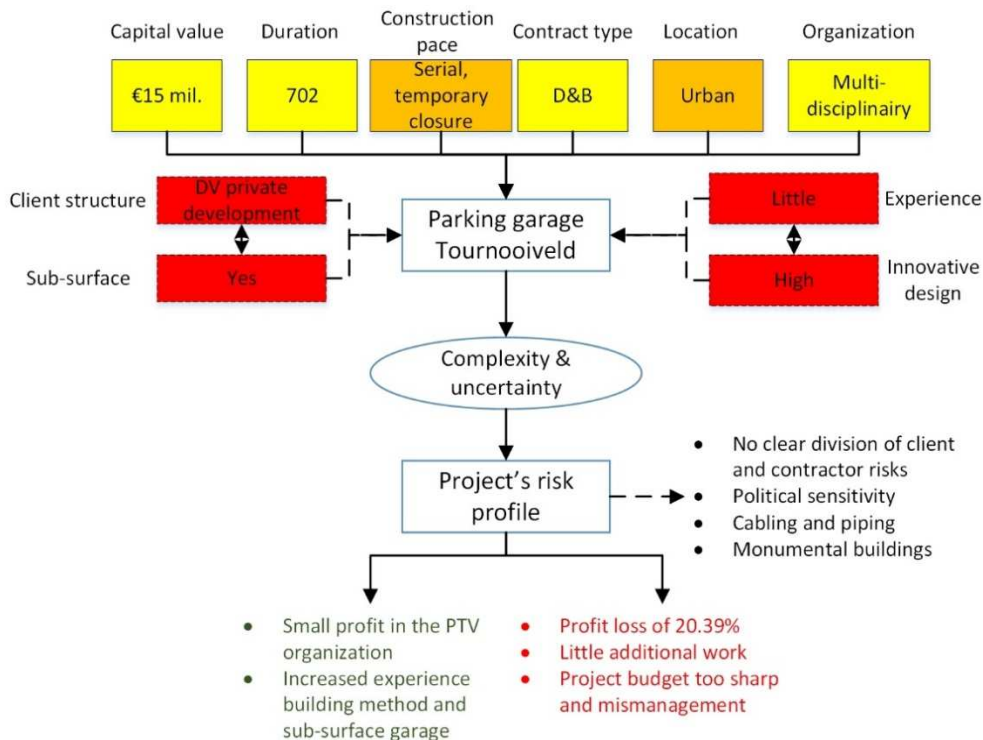


FIGURE 24: SUMMARY FIGURE PROJECT'S RISK PROFILE PARKING GARAGE TOURNOOIVELD (SOURCE: OWN ILL.)



4.3 Cross-case analysis

A single case study conclusion can be derived from the four case studies. The current section compares all four findings to arrive at a single set of findings that is a proper reflection of the practices with regard to the infrastructural projects of Dura Vermeer. Empirical generalisations are necessary to combine all findings so that they can be compared to the theoretical model. First, risk management practices are compared, then the different risks that occurred are examined, followed by a comparison to the financial findings and finally the projects' characteristics with respect to their risk profiles are evaluated.

4.3.1 Risk management and risks

The risk management approach in the tender phase is equal in all four of the studied projects. However, this is the exactly the opposite in the realisation phase. In section 4.1, the following citation is presented:

“Dura Vermeer chooses to focus on projects that fit the company, with respect to size, experience, expertise, general risk profile and financial capacity, whereby we can make a difference compared to our competitors. These includes ideas as innovative character, complexity, desired integral approach and any necessary financial contribution. The manner of project acquisition also plays a role, such as tender process, building combination, own development or public-private partnership. The mutual composition of these elements in the projects eventually determines the risk profile of the project” (Dura Vermeer, 2017, p. 15).

The risk register is made in the tender phase to eventually determine the required risk reserve that is included in the budget. Only one of the studied projects included both a management reserve and a contingency reserve in the budget of the risk reserve. The three other projects solely budgeted for a contingency reserve to cope with the project's unknown unknowns. Risks are identified, analysed and finally quantified in terms of likelihood and effect. The risk register was probabilistically simulated in all four projects, which means that the deterministic values were translated into stochastic variables. The contingency reserve was determined based on the P85 value calculated in the @risk software. However, there is no such calculation link between the risk profile of the project and the budgeted risk reserve. The abovementioned citation therefore does not influence the risk reserve. There was no indication found that such a **general risk profile**, besides the risk register, was determined in the tender phase.

This is not true for the design and construction phase in the 'capacity expansion N279' project. The project is the only one in which an attempt was made to determine the project's risk profile. The risk profile of the project was determined every four weeks based on the risk register. The risk profile was quantified, analysed and controlled. Every three months, the project's risk profile was judged for each consequence type (costs, time, quality, safety and environment). It was added to the quarterly reports as KPIs, which could be judged by top management. Consequently, the N279 project is also the only project with a budgeted management reserve. It can be said that the followed approach in the N279 project, with respect to risk management, was suitable. The financial result can be used as proof, among other uses, and can underpin the made statement.

The present research focusses on a different approach to calculating a project's risk profile, but this approach is aimed at the tender phase, rather than the realisation phase. The three other projects did not determine such project risk profiles. The risk register is kept current in all four projects, but all for different reasons and with methods of doing so. The parking garage Tournooiveld only updated the risk register deterministically to monitor the risks and define risk control measures. The project Renovation Velsertunnel went one step further with respect to risk management. The risk register was calculated deterministically to evaluate if the budgeted risk reserve was still sufficient for the project risks. Portions of the risk reserve fell free to the project when the risk reserve was sufficiently high to cope for the RRs. The risk register was thus key in this decision, as no actual costs were booked in the risk reserve.

In the Room for the Waal Nijmegen and capacity expansion N279 projects, the risk registers were also kept current through their continuous evaluation. However, the total volume of the project risks was calculated probabilistically instead of deterministically. The values calculated were also used to evaluate

if the budgeted risk reserve was still sufficient or if a portion could fall free to the project. However, the calculations in Room for the Waal Nijmegen were doubtful, as certain values were changed to rectify the current budget for the risk reserve. This is the opposite of the intention of these calculations; the preferred outcome is actually the starting point, and the risk values are adjusted to arrive at this outcome. Such evidence was not found for the projects Velsertunnel or N279.

The project's risk profile is crafted in the realisation phase, which is during the design and construction of the project, and it is based on the risks in the risk register. Each project is risky in its own way, some more than others. The risks that make the project riskier are different for each project. The cost documentation inconsistency in relation to the risk reserve makes it difficult to draw direct relations between the budget and the costs due to risks. The risks that occur have financial consequences, but these incurred costs are booked in different cost posts. A different approach in cost control is required to determine this one-to-one relationship between project risks and the required risk reserve. A differentiation in risk categories would make such relationships easier to determine.

The costs due to risks are difficult to analyse. For this reason, the most critical risks to a project's risk profile are qualitatively judged. The threat of exceeding the deadline was a critical risk in each of the four projects. Other risks that were critical for the projects were obtaining permits, flora and fauna, archaeology, cabling and piping, soil conditions and uncertainty of the current state of the project object. However, these risks are not universal for all projects, only for particular projects. The risks are therefore directly related to project characteristics and budget overruns in specific project cost items. First, the financial aspects of the four projects are discussed.

4.3.2 Financial findings

Table 11 in appendix C presents the summarised financial data of all four projects. For all four projects, the bare costs, risk reserve, company costs and profit margin are displayed in terms of the initial budget, working budget, actual costs and the result. The result is the working budget minus the actual costs. The last column at the end of the project row is the final project result. The lower table represents the percentages for the contingency reserve, management reserve, risk reserve and the required risk reserve. The final three columns show the budgeted profit margin, the project result and the amount of additional work.

The result for the project's bare costs and any costs incurred due to risks are leading in the calculation of the required risk reserve. The required risk reserve can thus be both positive or negative. A negative required risk reserve means that amount of costs booked on risk reserve is smaller than the positive resulted booked in the project's bare cost. The profit margin is excluded from the calculations because some projects have a negative profit margin and some a positive. This is dependent on **market conditions** and the company's current strategy. This would be a disturbing effect on the goal of these calculations. The required risk reserve is budgeted for project risks within the project costs. The total value of these financial setbacks is the target of the calculations, not the company's strategy or **market conditions**.

These market conditions influence the profit margin, as is seen in the example of the project Room for the Waal Nijmegen. The profit margin is the cost type, in which external factors can play a role, combined with the company's strategy. It should not influence the budgeted risk reserve. A project procured in a market with fierce competition can result in the decision to lower the construction costs in order to obtain the contract. However, this would also influence the project's bare costs, and thus the required risk reserve and the budgeted risk reserve. A relation between a low profit margin and budgeted risk reserve can be an indication of the **market condition** as an external factor. In addition to the required risk reserve and the external factor of the market condition, this cross-case analysis also explains financial aspects: (1) additional work, (2) direct and indirect cost categories and (3) UTA staff and engineering cost types.



The relation between additional work and the project result is explained in a graph presented in figure 25. The project with the highest profit margin also had the highest amount of additional work. The project with the largest financial loss also had the lowest amount of additional work. The trend line drawn between the four dots indicates a slightly positive correlation between the amount of additional work and the project result. Further testing is required to obtain better insight into this relationship, and this idea is worthy of being adopted as a hypothesis that can be tested in the subsequent research phase. It is important to mention that the amount of additional work is not a project characteristic that can explain the expected project's risk profile in advance. It is only interesting to observe because it offers better insight into the drivers of the project result and the required risk reserve. The amount of additional work can possibly be traced back to other project characteristics.

Relationship add. work and project result

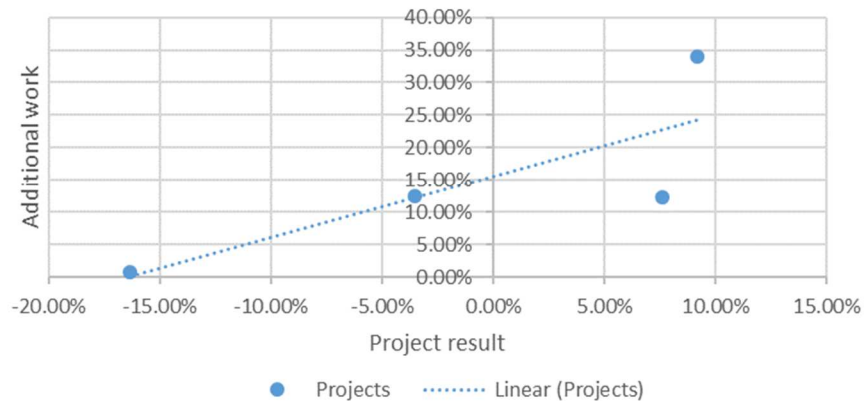


FIGURE 25: RELATIONSHIP BETWEEN THE PROJECT RESULT AND THE AMOUNT OF ADDITIONAL WORK (SOURCE: OWN GRAPH)

The case study showed differences in the results of the direct and indirect cost categories. The direct costs show far better results than the indirect costs. Table 9 displays the financial figures of the initial budget, working budget, actual costs and results for the direct and indirect costs of all four projects. Two ideas can be observed from these values. First, all projects had a budget overrun in the indirect cost category, even the projects with positive project results. Second, the percentage of indirect costs becomes larger in comparison to the direct costs in each project. The Room for the Waal Nijmegen project started with 20.5% of indirect costs, with respect to the bare costs. This only grew to 28.7% in the working budget and within the actual costs, it became even 32.1%. Consequently, 78.9% of the negative result was caused by the overrun in the indirect costs, and thus the largest part of the overrun was caused by the smallest type of cost.

TABLE 9: FINANCIAL DATA OF THE DIRECT AND INDIRECT COSTS OF THE FOUR STUDIED PROJECTS (SOURCE: OWN TABLE)

Project name		Direct costs	Indirect costs	Bare costs	Direct	Indirect
		A	B	A + B = C		
Room for the Waal Nijmegen	Initial budget	€ 88,594,581.00	€ 22,899,093.00	€ 111,493,674.00	79.5%	20.5%
	Working budget	€ 89,285,988.00	€ 36,006,159.00	€ 125,292,147.00	71.3%	28.7%
	Actual costs	€ 91,165,101.00	€ 43,052,232.00	€ 134,217,333.00	67.9%	32.1%
	Result	-€ 1,879,113.00	-€ 7,046,073.00	-€ 8,925,186.00	21.1%	78.9%
Renovation Velsertunnel	Initial budget	€ 27,203,864.00	€ 23,086,525.00	€ 50,290,389.00	54.1%	45.9%
	Working budget	€ 35,416,737.00	€ 31,940,175.00	€ 67,356,912.00	52.6%	47.4%
	Actual costs	€ 33,590,023.00	€ 32,300,747.00	€ 65,890,770.00	51.0%	49.0%
	Result	€ 1,826,714.00	-€ 360,572.00	€ 1,466,142.00	124.6%	-24.6%
Road widening N279	Initial budget	€ 42,485,884.00	€ 11,972,520.00	€ 54,458,404.00	78.0%	22.0%
	Working budget	€ 45,542,689.00	€ 15,562,743.00	€ 61,105,432.00	74.5%	25.5%
	Actual costs	€ 40,578,737.00	€ 18,173,382.00	€ 58,752,119.00	69.1%	30.9%
	Result	€ 4,963,952.00	-€ 2,610,639.00	€ 2,353,313.00	210.9%	-110.9%
Tounooiveld parking garage	Initial budget	€ 10,798,824.00	€ 3,945,720.00	€ 14,744,544.00	73.2%	26.8%
	Working budget	€ 10,747,190.00	€ 4,105,666.00	€ 14,852,856.00	72.4%	27.6%
	Actual costs	€ 12,475,326.00	€ 6,062,297.00	€ 18,537,623.00	67.3%	32.7%
	Result	-€ 1,728,136.00	-€ 1,956,631.00	-€ 3,684,767.00	46.9%	53.1%

Another financial finding in the case studies is that the cost types engineering and UTA staff showed large budget overruns. For all four projects, the results of these cost types are compared to the results of the project's bare costs. Table 10 displays the results for both the engineering and the UTA staff. The presented percentages in the final column display the combined costs for UTA and engineering as a portion of the project's bare costs. Beside that all projects showed negative results, it can be stated that only a small portion of the projects caused these budget overruns (63.8% and 53.6%) or drastically reduced profit margin (-214.8% or -82.2%).

TABLE 10: COSTS FOR UTA STAFF AND ENGINEERING COMPARED TO THE PROJECT'S BARE COSTS (SOURCE: OWN TABLE)

Project name		UTA-staff	Engineering	Bare costs	Result	
		A	B		A + B = C	
Room for the Waal Nijmegen	Initial budget	€ 10,875,857.00	€ 6,891,633.00	€ 111,493,674.00		15.9%
	Working budget	€ 13,892,146.00	€ 5,386,613.00	€ 125,292,147.00		15.4%
	Actual costs	€ 17,775,598.00	€ 7,197,844.00	€ 134,217,333.00	-€ 5,694,683.00	18.6%
	Result	-€ 3,883,452.00	-€ 1,811,231.00	-€ 8,925,186.00		63.8%
Renovation Velsertunnel	Initial budget	€ 5,219,099.00	€ 9,595,316.00	€ 50,290,389.00		29.5%
	Working budget	€ 7,673,366.00	€ 11,332,497.00	€ 67,356,912.00		28.2%
	Actual costs	€ 8,987,205.00	€ 13,168,241.00	€ 65,890,770.00	-€ 3,149,583.00	33.6%
	Result	-€ 1,313,839.00	-€ 1,835,744.00	€ 1,466,142.00		-214.8%
Road widening N279	Initial budget	€ 6,246,478.00	€ 2,878,216.00	€ 54,458,404.00		16.8%
	Working budget	€ 8,221,142.00	€ 4,202,484.00	€ 61,105,432.00		20.3%
	Actual costs	€ 9,680,265.00	€ 4,677,071.00	€ 58,752,119.00	-€ 1,933,710.00	24.4%
	Result	-€ 1,459,123.00	-€ 474,587.00	€ 2,353,313.00		-82.2%
Touwoiveld parking garage	Initial budget	€ 1,462,980.00	€ 749,595.00	€ 14,744,544.00		15.0%
	Working budget	€ 1,525,169.00	€ 774,006.00	€ 14,852,856.00		15.5%
	Actual costs	€ 2,922,247.00	€ 1,353,075.00	€ 18,537,623.00	-€ 1,976,147.00	23.1%
	Result	-€ 1,397,078.00	-€ 579,069.00	-€ 3,684,767.00		53.6%

The first conclusion that can be drawn from these financial values is that the risk profile is larger in the indirect cost category than in the direct cost category. More precisely, the time-dependent indirect costs show large financial budget overruns and indicate an increased risk profile. Recalling student's syndrome law and Parkinson's law, these phenomena cause work to expand to fill the available time. These phenomena thus have a large influence on the time-dependent cost types, which are mainly indirect cost types. Examples of such cost types are the UTA staff, engineering and construction site equipment. To conclude, the working budget and realised costs are used in the calculations in the subsequent phase to explain the result of each cost type and category. The initial budget is therefore neglected in these calculations. The initial budget is solely used to determine the amount of additional work.

4.3.3 Project characteristics

Third topic of this empirical generalisation of the practical findings is the project characteristics, and more precisely, their potential influence on the project's risk profile. Six project characteristics have already been identified in the theoretical research phase. The current phase has also examined the unique character of projects and explored potential different project characteristics that can explain this unique character. Table 11 presents the six 'theoretical' project characteristics and seven new 'practical' characteristics found in the case studies. The colours used in the summary figures at the end of each case study are processed in this table. The used colour corresponds to a score, and the scoring method is in the form of pluses and minuses, which stand for each characteristic's effect. A green colour means a positive effect and thus a reduction in the project's risk profile. The green colour is expressed as a plus. The colours orange and red are scored with a minus or double minus, which stand for negative or critical to the project's risk profile. The yellow colour is expressed as a +/-, which stands for a non-effect on the risk profile.



Project	Capital value	duration	Construction pace	Contract type	Location	Organization	Tender duration	Concretization phase	Renovation	Client structure	Best Value Principle	Innovative design	Experience*
Room for the Waal Nijmegen	+/-	-	-	-	+/-	+/-	-	+/-	+/-	-	+/-	-	-
Renovation Velsertunnel	+/-	+/-	-	-	+/-	-	+	+	-	+/-	+/-	-	+
Capacity expansion N279	+/-	+/-	-	-	-	+/-	+	+/-	+/-	-	-	+/-	+/-
Parking garage Tournooiveld	+/-	+/-	-	+/-	-	+/-	+/-	+/-	+/-	-	+/-	-	-

TABLE 11: SCORING OF THE INFLUENCE OF THE PROJECT CHARACTERISTICS ON PROJECT'S RISK PROFILE (SOURCE: OWN TABLE)

Importantly, the objective of the scoring is not to be scientifically bulletproof, but merely as a method of comparison. The scoring is used as indication of the effect of the characteristic on the risk profile of the project. This scoring method is used as starting point for the formation of the set of hypotheses in the following section. The same stands for the operationalisation of the final set of project characteristics. The current sub-section focusses on the composition of the final set of characteristics that is assumed to explain the unique character of a project and determine its risk profile. First, the six already identified project characteristics are capital value, construction duration, construction pace, contract type, location and organisation.

The capital value was not found to be influential for the project's risk profile and the construction duration in all projects except for the Waal Nijmegen project. This is because it was an extremely long duration of almost four years. The construction pace had a negative effect on the project's risk profile in all projects; however, the operationalisation defined upfront was not applicable. The contract type is a characteristic that can boost the level of flexibility. A DB(M) contract provides for design freedom, but also greater responsibility. For this reason, in all four projects, there was a budget overrun in the engineering cost post. It is therefore potentially a characteristic that may increase the risk profile of a project. The locations of urban and natural seem to be associated with a higher risk profile compared to a rural project location. The organisation was influential for only one project, but this was due to a different reason than initially expected in the defined characteristic operationalisation. The 'split organisation' caused an increased project risk profile in the project Renovation Velsertunnel.

The seven 'practical' project characteristics identified are tender duration, concretisation phase, renovation, client structure, BVP, design innovativeness and experience. First, the experience project characteristic was influential to the project's risk profile in three of the four projects. Experience can have both an increasing and decreasing effect on the risk profile. However, the precondition for the set of project characteristics is that it is an objective project characteristic. Experience is, however, not a project characteristic, and rather it is a result of the composition of the members in the project team. Experience is therefore excluded from the set of project characteristics. This factor is thereby closely linked to the project characteristic of design innovativeness. The more innovative the design is, the lower the level of experience is present within the project team.

The design innovativeness, together with the construction pace and client structure, is the most critical characteristic in relation to the project's risk profile. The difficulty of the measurability criterion in this characteristic is tackled in the following section. The tender duration and renovation character of the project are two other characteristics that influenced the risk profile as well. A short tender duration increases uncertainty because an in-depth investigation is not possible due to the limited available time. Longer tender durations make it possible to understand all aspects and the scope of the project. A renovation project causes difficulties in determining the current state and situation of the object to be renovated. The situation 'behind the wallpaper' causes uncertainty, as it is not fully known in advance.

The BVP strategy obtained by the client was applied in one project, the Capacity expansion N279 project, but it was found influential to the risk profile of the project. However, the other projects also had non-traditional procurement strategy, meaning that the contract was awarded not just based on the bidding price. The projects Renovation Velsertunnel and Room for the Waal Nijmegen were procured following a MEAT strategy, and Tournooiveld was a non-public procurement. The BVP strategy is thus not a project characteristic but only a classification in the project characteristic of 'procurement strategy'. The two projects with positive project results both included a concretisation phase after the procurement phase. The presence of a concretisation phase potentially reduces the uncertainty aspect within these projects. For this reason, the concretisation phase is included as a project characteristic.

The final project characteristic to be quantitatively tested in the next research step is the client structure. For three of the four projects, it is concluded that it increased the project's risk profile. Those projects all had a 'complicated' client structure, and Renovation Velsertunnel is the only project that had a 'traditional' client structure. Traditional means that there is a single client, who also finances the project. The set of project characteristics is doubled to twelve with the client structure. Decisive characteristics for the financial project success and failure were based on the four case studies: construction pace, contract type, client structure and design innovativeness.

4.3.4 Other findings

This final sub-section focusses on the other findings that arose from the case studies. Complexity and uncertainty as project aspects are discussed, as well as the external factor identified in the theoretical phase. This sub-section closes with thoughts on the 'outside view' in budgeting the risk reserve. First, complexity and uncertainty are addressed, the definitions of which have been presented in section 3.2.2. The financial consequences of the occurred risks are difficult to trace back to the project's risk profile, but the same counts for the project aspects of complexity and uncertainty. The meanings of these project aspects are not unanimously known by the interviewed project members. The term complexity was used 21 times in the interviews, and uncertainty was used 7 times. However, the underlying meaning in the use of these terms is not alike. The relations of complexity and uncertainty are therefore more difficult to link to a project's risk profile. However, what can be noticed from the different interviews is that both project aspects are definitely related to a project's risk profile.

Primarily, uncertainty is clearly presented as risk-increasing project aspect. The defined goal and method for uncertainty can be traced back to the project, but also a third dimension of uncertainty. Uncertainty about the current state of the 'system' to be renovated or current state of the project site can also be observed as a sub-dimension of the project's risk profile. The external factors of student's syndrome and Parkinson's law and the market conditions are elaborated on in this cross-case analysis. The quality of risk management is also addressed. There are differences in risk management approaches in the realisation phase. The approaches in the tender phase are alike and therefore do not cause differences in the budgeted risk reserve. However, this is not completely true. The contingency reserve is based on the probabilistic simulation of the risk register. The height of the risk reserve is thus highly influenced by the quality of the identification, quantification and risk control steps in the risk management practice.

The quality of risk management, with respect to the risk reserve, is difficult to calculate. The initial operationalisation determined the quality of risk management based on the budgeted and realised values for the risk reserves. However, the realised costs were documented differently. The quality of the risk management process can therefore be calculated based on the difference between the budgeted and required risk reserve. The risk perception is related in the theoretical framework to optimism bias. There are no direct signs of risk perception, but optimism bias can be spotted in the UTA staff. The budgets for the UTA staff were too low in all of the projects, partially due to the project's risk profile, but also because of optimism bias. The decision in P-value in the probabilistic simulations on the risk register to determine the risk reserve is an indication of risk perception.



This section concludes with an overview of the standpoint of personnel within Dura Vermeer on the 'outside view' that is examined and proposed in the current research. The interviews all ended with the same question on how the 'interviewee' thought about a risk reserve budgeted based on historical data of projects with the same unique character. The question was aimed at examining the preference between the 'inside view' and the 'outside view'. Again, the transcripts from the interviews can be viewed in appendix D. The following quotations are taken from these seven interviews.

Project leader (Appendix D, 4.2.2): *"This should be done based on all three methods, thus it is project specific on the risk register. The level of the risk reserve should be substantiated by expert judgement, so that it then can be compared to historical data of alike projects."*

Process manager (Appendix D, 4.2.3): *"A budgeted risk reserve on the basis of historical data on completed projects and project characteristics, combined with the risk register and expert judgement would be the most appropriate and accurate method. Each project is unique, so deepening in the project is therefore important for understanding the project's risk profile. Results in the past are risky but can function as a good starting point and controlling measure."*

Project director (Appendix D, 4.3.2): *"This should be done on the basis of expert judgement and the risk register. Historical data are basis on post calculations, which should be done, but it is not customisation and therefore it is risky."*

Process manager (Appendix D, 4.3.3): *"A 'pure' cost price is important, whereas a closer look at the risks should be taken afterwards. This is a combination of expert judgement and historical data of previous projects. ... However, it is also important that the project's bare costs are not too high. Adding up additional buffers actually means that there is no trust in the project's bare costs. All of the experience of previous projects can result in a risk reserve that is too pessimistic."*

Project director (Appendix D, 4.4.2): *"This should be done based on both approaches. However, it is important that the project-specific risk profile is examined because no project is equal. The combination with historical data can then result in a more accurate risk reserve."*

Process manager (Appendix D, 4.4.3): *"A combination; the best is to compare both approaches. The calculated risk reserve based on historical data still has be worked out and proven itself, therefore expert judgement and the risk register should function as the starting point."*

Process manager (Appendix D, 4.5.2): *"A risk register in the tender phase is never conclusive. Knowledge of previous and comparable projects should therefore be added to the budgeting approach. However, it remains important to look at the project specific to the risk profile."*

What becomes apparent in these ideas is that there is a preference for a budgeting approach that combines both historical data with expert judgement and a project-specific risk register. The 'outside view' first has to be developed in greater detail and then prove its usefulness in improved accuracy and precision for budgeting the risk reserve. It can be stated that the idea of historical data is accepted. However, the effect of this approach is unknown in this phase and may result in some reluctance among the interviewees.

4.4 Validated model and hypotheses

The case studies have been executed and the empirical generalisation of these findings has been defined in the cross-case analysis. Current section continues by comparing these practical findings to the theoretical model derived in the theoretical research phase. The model is translated to a set of hypotheses that are quantitatively tested in the subsequent research phase. In order to do so, first, multiple model elements have to be operationalised, such as the twelve project characteristics.

4.4.1 Practical adjustments to model

In this sub-section, the theoretical model, displayed in figure 19, is validated and adjusted based on the empirically generalised practical findings of the case studies. The validation of the model is done qualitatively from a practical viewpoint. Figure 26 presents the model that combines both the theoretical and practical findings.

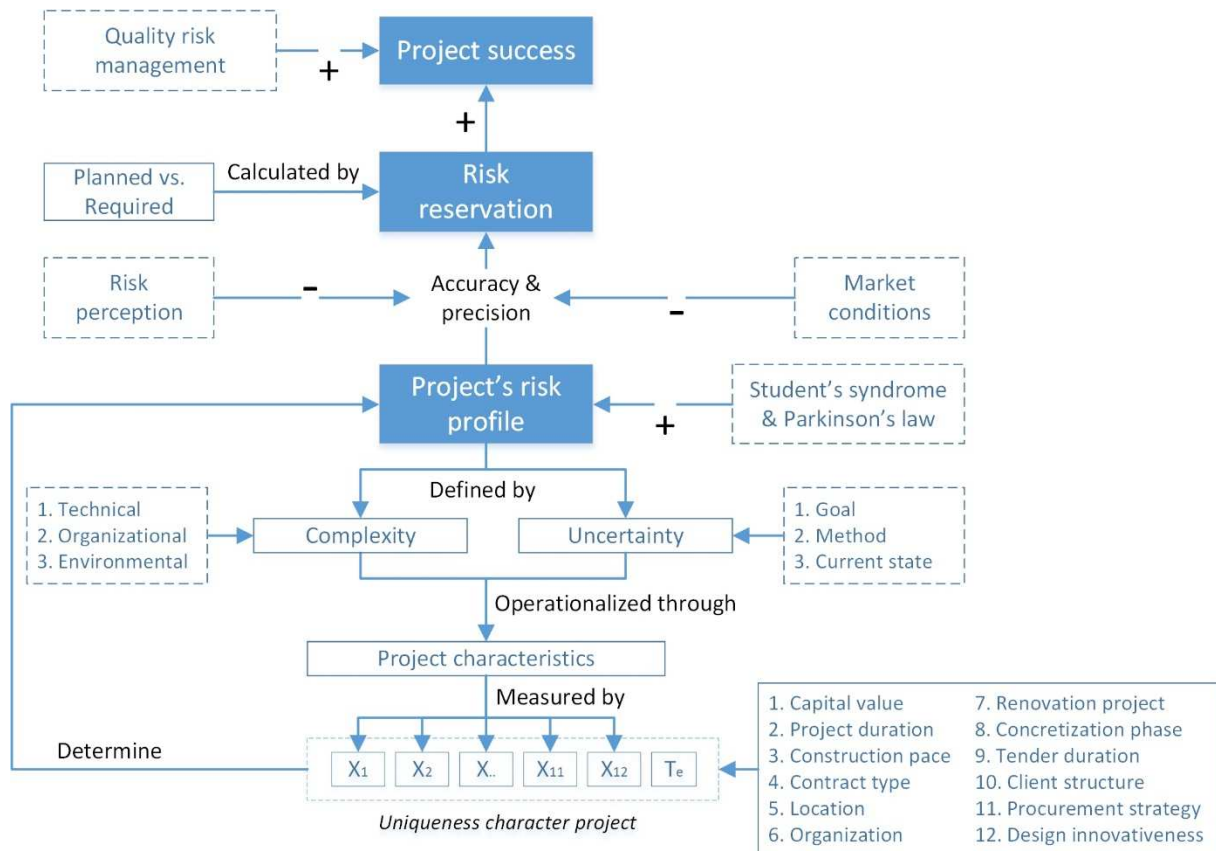


FIGURE 26: QUALITATIVELY VALIDATED MODEL BASED ON PRACTICAL AND THEORETICAL FINDINGS (SOURCE: OWN ILL.)

The main elements in the validated model are equal to the theoretical model. An important difference is the risk reserve element, which replaces the contingency and management reserve elements. The research objective is to improve financial project success through an accurate and precise risk reserve based on the project's risk profile. These three elements are the core of the model and are highlighted by an entirely blue model element. The risk management quality still influences the construct between financial project success and the risk reserve. However, the quality of the risk management during the realisation phase does not influence the risk reserve budgeted in the tender phase. The effect of the management practices used in advance of the project are not known, but these can affect the financial success of the project. This is explained in the model with a plus sign between the model elements.

$$\text{EQUATION 8: } \text{Req. risk res.} = \frac{(\text{Actual bare costs} - \text{working budget bare costs}) + \text{actual costs risk reserve}}{\text{Working budget bare costs}} * 100\%$$

The risk reserve is not solely based on the actual costs due to real risks, but also on the result in the project's bare costs. Equation 8 presents the formula of the required risk reserve as a percentage of the



working budget of the project's bare costs. This approach means that there is a budgeted and required risk reserve. The difference between the two risk reserves explains the accuracy of the budgeted risk reserve. A small difference means higher accuracy in the budget. However, the external factors of risk perception and market conditions can influence this accuracy and precision in the risk reserve. These factors should not affect the volume of the risk reserve, but the research showed that it does happen. High levels of risk perception result in a risk reserve that is too pessimistic, and a low level of risk perception results in a risk reserve that is too optimistic. Market conditions should not influence the risk reserve, only the profit margin. However, strong competition in the market potentially results in a reduction of construction costs, which is done to win the contract. These relations are explained graphically with a minus sign aimed at accuracy and precision in the risk reserve.

The external factors of student's syndrome law and Parkinson's law have a risk-increasing effect on the project's risk profile, as has been concluded from the case studies. These phenomena primarily affect the time-dependent indirect costs, for example engineering and UTA staff. This is explained with a plus sign, thus an increasing effect, in the validated model. The risk profile of the project is still defined by the project aspects of complexity and uncertainty, The only difference is the current state uncertainty, which is added as sub-dimension of project uncertainty. The project aspects are still operationalised through the project characteristics. However, the difference is that the unique character of the project is based on twelve characteristics, rather than six. The characteristics of renovation project, concretisation phase, tender duration, client structure, procurement strategy and design innovativeness are added to the model. The operationalisation of these characteristics is explained in the following sub-section.

4.4.2 Operationalisation of project characteristics

Six new project characteristics are defined in this practical research phase, and they require operationalisation. However, the operationalisation of the original characteristics requires adjustments as well. Before the new operationalisations are elaborated on, the methods of testing are first explained. The methods of testing are the statistical techniques that were used in testing for relations between the project's risk profile and the project characteristics. The operationalisation forms the basis of the hypotheses to be tested. It is therefore important that the preconditions of these statistical techniques are taken into account when defining the operationalisations of the twelve project characteristics. The operationalisation of the project's risk profile is already known, namely the required risk reserve.

The level of measurement is elaborated on before the statistical techniques are discussed. The level of measurement actually determines what types of statistical analysis techniques can be used. The hypotheses all include two variables; the variable construction duration, for example. The operationalisation of the construction duration in the theoretical framework is measured in calendar days and classified in three different classes. This instantly explains the difference in the level of measurements. The classified construction duration is a different level of measurement compared to the raw data in terms of calendar days. The classified duration is a so-called ordinal level of measurement, and the calendar days type of operationalisation is of the so-called ratio level of measurement. A rule within statistics can be expressed as follows:

“The higher the level of measurement is, the more analysis techniques can be used and the more powerful the results are.” (T. Arentze, November 25th 2014)

This quotation means that within statistics, it best to strive for the highest possible level of measurement in the data set. The classifications defined in the theoretical framework for the project characteristics of capital value and construction duration are therefore counter-desirable; the unclassified parameters are more usable for the current research goal. Four different levels of measurement are known, namely: (1) nominal, (2) ordinal, (3) interval and (4) ratio.

The nominal level is based on categories without order, for example location, which is divided into three categories. There is no hierarchical level between the categories. There is a difference between

dichotomous variables and nominal variables. A dichotomous variable is similar to the nominal variable, only with two categories instead of three or more. An ordinal level is based on categories as well, but with an order between the categories, which means that there is a hierarchical difference between the categories. An example can be a person’s education level. A university master degree is hierarchically higher than high school, but lower than a PhD.

The interval level is a numerical level where the differences between the values are equal. However, it is based on a relative scale, which means that there is not an absolute zero value. A suitable example is degrees in Fahrenheit or Celsius. The difference between 20°C and 30°C is equal to the difference between -10°C and -20°C. In both cases the difference is 10°C. The scale is relative, though, because 20°C is not twice as much as 10°C. This is the result of the fact that there is not an absolute zero. The degrees scale Kelvin, on the other hand, does have an absolute zero value. Therefore, degrees in Kelvin can be seen as a ratio level of measurement. The ratio level is the highest possible level of measurement. Nominal and ordinal levels are non-metric, discrete and qualitative variables. The interval and ratio level are metric, continuous and quantitative variables. Table 12 summarises the differences between the four levels of measurements, including an example.

Nominal	Ordinal	Interval	Ratio
Distinction	Distinction	Distinction	Distinction
	Order	Order	Order
		Equal differences	Equal differences
			Equal proportions
<i>Gender</i>	<i>Hierarchy</i>	<i>Degrees in Celsius</i>	<i>Age or weight</i>

TABLE 12: SUMMARY OF THE LEVELS OF MEASUREMENTS AND THEIR DIFFERENCES (SOURCE: OWN TABLE)

As mentioned previously, the choice of possible statistical test depends on the level of measurement. The required risk reserve is present in all hypotheses and is a ratio-level variable, thus it is of the highest possible level of measurement. The techniques that are available are therefore dependent on the second variable in the hypothesis. A dichotomous variable result in a student t-test for differences in mean values. A nominal or ordinal variable is tested by means of the analysis of variance (ANOVA) test, while the correlation coefficient test can be used when the second variable is on the interval or ratio level. These tests are executed in order to determine if there is a correlation or association between the two variables in the hypothesis. Put differently, these tests are conducted to verify or falsify the defined hypothesis. Correlations can be tested for in metric or continuous variables, and associations can be determined in non-metric or discrete variables.

An important note to make is about causality. It is assumed in each hypothesis that there is an independent variable, the project characteristic, and a dependent variable, the required risk reserve. Consequently, causality is assumed. Important conditions for causality are as follows:

1. Statistical correlation, which can be measured;
2. Cause before effect;
3. No spurious relations (no third variable that can explain the correlation);
4. Theory: causal mechanism.

The fourth condition is extensively examined in the theoretical framework and practical research, which also counts for the second condition. However, during the final research phase, it is important to test for these first and third conditions. The third condition means that correlations between assumed independent variables have to be tested as well. Descriptive statistics can also be used to gather a better understanding of the different variables. Finally, the difference between regression and correlation is that regression analyses predict, whereas correlations only explain the strength. Regression analysis thus goes one step further and can be useful to predict the required risk reserves for future projects.

This sub-section ends with set of operationalisations of the twelve project characteristics. The parameter of the capital value and construction duration remain equal, but the classification is skipped.



The highest level of measurement is pursued. The capital value is still the project's bare costs, and the project duration is construction duration in calendar days. The parameter and classification of the location characteristic are still valid. The operationalisation and classification of the characteristic of construction pace were found not useful. Task density in the planning is still the parameter. However, the way it is measured was adjusted in two operationalisations. The first operationalisation of the construction pace characteristic is the project's daily turnover, which is the capital value divided by the construction duration.

Secondly, the size of the project organisation from the financial perspective is addressed. From the case studies, it has been concluded that additional staffing is required in order to cope with acceleration measures in the planning. The size of the staff in relation to the capital value and the construction duration is the second operationalisation. The size of the staff was determined by the budget reserved for UTA staff. The budget was used, as realised values are not known yet in the tender phase. The UTA staff was divided by the capital value. In this way, the comparability between the projects of different sizes is ensured. In order to include the time element, the found UTA staff ratio was divided further by the construction duration in years. This ensures the difference between the following three projects:

1. Project X: Capital value of €10 million, construction duration of 1 year and budgeted UTA staff of €750,000. This results in a 'construction pace' of 7.5%.
2. Project Y: Capital value of €10 million, construction duration of 1 year and budgeted UTA staff of €1 million. This results in a 'construction pace' of 10%.
3. Project Z: Capital value of €10 million, construction duration of 0.5 year and budgeted UTA staff of €1 million. This results in a 'construction pace' of 20%.

The current operationalisation distinguishes that project Z has the highest construction pace, as the amount for UTA staff is the highest and the construction duration is the shortest. Project Z is more likely to have a high task density as the same amount of UTA staff is required in only half of the time as project Y. The UTA staff includes multiple project team members, but they all are occupied with the preparations and execution of the project and process, either directly or indirectly.

The type of contract in three of the four projects was found to be associated with the project's risk profile. All three projects included a contractual maintenance element. However, the contractual design element in all projects was found to be a risk-increasing factor, so a difference can be spotted between the type of design responsibility. An engineering responsibility is different from a design responsibility. A D&C type of contract, for example, offers more freedom than an E&C type of contract. For that reason, the classification of the type of contract is as follows: (1) build, (2) DC/B(M), (3) EC/B(M) and (4) DBFM(O). Some contracts are defined as design and construct, while others are design and build. The B and C in this classification are thus the same responsibility, only stated differently.

The project organisation is the final characteristic of the original six features to operationalise. The parameter is changed to 'cooperation structure'. The number of disciplines was not found to be important to the risk profile of the project, only the difference between Dura Vermeer, a partnership and a 'split organisation'. The 'split organisation', however, is difficult to determine without extensive research. The class is included in the classification, but if it is found too difficult to determine, it is replaced by the 'regular' partnership. A new characteristic is the question of if the project is a renovation type of project or not. The characteristic seems straightforward, but the difference between a renovation or new project is difficult to discern in some cases. For example, the N279 project is a capacity expansion of a provincial road, which means that an existing road was upgraded or changed to the desired situation. From that point of view, it can be stated that the project was a renovation type of project. However, current operationalisation defines such project as not a renovation type of project. The project doubles the amount of driving lanes, where two new lanes are constructed beside the old lanes, thereby constructing new uneven crossings. The greatest portion of the N279 project is aimed at new constructions. The operationalisation therefore seeks the type of project, and if it is both new and renovation, then the largest portion determines the right class.

The concretisation phase is an element that has a positive effect on the risk profile of a project. Its goal is to get a clearer picture of what the client and contractor can expect from one another. The operationalisation is in regard to the presence of a concretisation phase exists or not. The tender duration is operationalised in terms of capital value divided by the number of months available to prepare the tender bid and any documents. The client structure and procurement strategy are operationalised based on the options found in the case studies. The classification of the client structure is through the following three classes: (1) own development, (2) single client and (3) multiple clients. The operationalisation of the procurement strategy is based on the following four classes: (1) non-public, (2) lowest bid, (3) MEAT and (4) BVP.

Finally, the design innovativeness characteristic is determined. Its operationalisation is different from the other eleven project characteristics. The parameter is the amount of experience that Dura Vermeer has. However, the parameter is not easily quantified or classified compared to, for example, reference projects. For that reason, expert judgement is required to determine the level of innovativeness in the design. The year of tendering, the construction method, used materials, new required equipment, construction shaping, architectural highlights or process innovations are the design aspects to be judged. Appendix G contains a more extensive elaboration of the scoring method, which also includes the frame of reference. Table 13 shows a summary of the project characteristic operationalisation.

Characteristic	Parameter	Quantity	Classification/quantification
Capital value	Construction costs	Euros	Ratio
Construction duration	Construction time	Calendar days	Ratio
Construction pace	Task density in planning	Euros/day	Ratio
		Percentage	Ratio
Type of contract	Number of contractual responsibilities	Category	<ul style="list-style-type: none"> • Build • DC/B(M) • EC/B(M) • DBFM(O)
Location construction site	Spatial environment	Category	<ul style="list-style-type: none"> • Urban area • Rural area • Natural area
Project organisation	Cooperation structure	Category	<ul style="list-style-type: none"> • Dura Vermeer • Partnership • (Split organisation)
Renovation project	Renovation phase	Category	<ul style="list-style-type: none"> • Yes • No
Concretisation phase	Preparation time	Category	<ul style="list-style-type: none"> • Yes • No
Tender duration	Tender phase intensity	Euros/months	Ratio
Client structure	Contractual relations	Category	<ul style="list-style-type: none"> • Own development • Single client • Multiple clients
Procurement strategy	Tender bid judgement	Category	<ul style="list-style-type: none"> • Non-public • Lowest bid • MEAT • BVP
Innovative design	Experience	Value	Interval

TABLE 13: OPERATIONALISATION OF THE PROJECT CHARACTERISTICS (SOURCE: OWN TABLE)

The quality of risk management influences the likelihood of project success. However, the current research does not provide a method to test this relation. The current quality in budgeting the risk reserve can be tested, which can be done by comparing the budgeted and required risk reserve. The



difference between both explains the quality of the budgeted risk reserve. This is important to determine if the approach examined in the current research indeed is to be an improvement of the current budgeting approach.

The external factors of market conditions and risk perception are defined in the validated model and influence the risk reserve as well. Risk perception and market conditions are difficult to operationalise and measure, and they fall outside the scope of the current research. The main focus is on the project's risk profile based on the unique character of the project. However, the difference between the budgeted and required risk reserve indirectly indicates these external factors. A budgeted risk reserve that is too low on average indicates a low risk perception or strong market conditions. A risk reserve that is too high can mean the exact opposite. However, this is also influenced by time and the maker of the decisions. A low budgeted profit margin, on the other hand, is a potential indicator of the market condition factor. A high budgeted profit margin can mean that there is little competition.

In the theoretical framework, a distinction has been made between direct and indirect costs. Those two cost categories together form the project's bare costs. The risk reserve is budgeted to cope with threats and opportunities in a project. The bare cost and the risk reserve together form the construction cost. However, after the four case studies, it has been found that the risk reserve is merely used for financial setbacks in the indirect costs. The assumption that the risks are evenly spread between the direct and indirect costs is therefore unlikely to be true. The theoretical framework does not describe the uneven distribution of the project risk profile. The indirect costs are expected to incorporate more risks than the direct costs. This risk profile distribution is examined in the following research phase as well.

4.4.3 Hypotheses

All operationalisations are elaborated, which means that the hypotheses can be formed as the final step in the current research phase. The list of hypotheses contains 12 statements on the relation between a project's risk profile and its characteristics. For this reason, there are two hypotheses defined to test two other relations. The relation between the market condition and the risk reserve is tested quantitatively. The quality of the current budgeting quality in the risk reserve is also tested quantitatively through an additional hypothesis. A third hypothesis is added to examine the project's risk profile with respect to the direct and indirect cost categories. The following 15 hypotheses are thus presented:

- Hypothesis 1: The capital value is correlated with the project's risk profile.
- Hypothesis 2: The project duration is correlated with the project's risk profile.
- Hypothesis 3: The construction pace is correlated with the project's risk profile.
- Hypothesis 4: The type of contract is associated with the project's risk profile.
- Hypothesis 5: The project location is associated with the project's risk profile.
- Hypothesis 6: The project organisation is associated with the project's risk profile.
- Hypothesis 7: A renovation project is associated with the project's risk profile.
- Hypothesis 8: A concretisation phase is associated with the project's risk profile.
- Hypothesis 9: The tender duration is correlated with the project's risk profile.
- Hypothesis 10: The client structure is associated with the project's risk profile.
- Hypothesis 11: The procurement strategy is associated with the project's risk profile.
- Hypothesis 12: The innovative design is correlated with the project's risk profile.
- Hypothesis 13: The budgeted risk reserve is correlated with the required risk reserve.
- Hypothesis 14: The budgeted profit margin is correlated with the budgeted risk reserve.
- Hypothesis 15: The project's risk profile is dominantly caused by the project's indirect costs over the direct costs.

5. Statistical analysis/research

The validated model defined in the previous chapter is ‘soft evidence’ of the real-world situation. The third step in the research focusses on turning this ‘soft evidence’ in ‘hard evidence’. The hypotheses are the starting point in verifying the relations that are assumed in the validated model. Data is collected on forty-nine projects in order to test a set of hypotheses in two separate rounds of statistical analysis. The research objective is to improve the accuracy and precision in the budgeted Risk reserve. These distribution parameters are tested and elaborated on in the final section of the current chapter. This is done through multiple regression analyses. The statistical research as a whole is included in appendix F. This chapter only elaborates on the main research steps and statistical findings. Figure 27 presents the research steps of this fifth chapter.

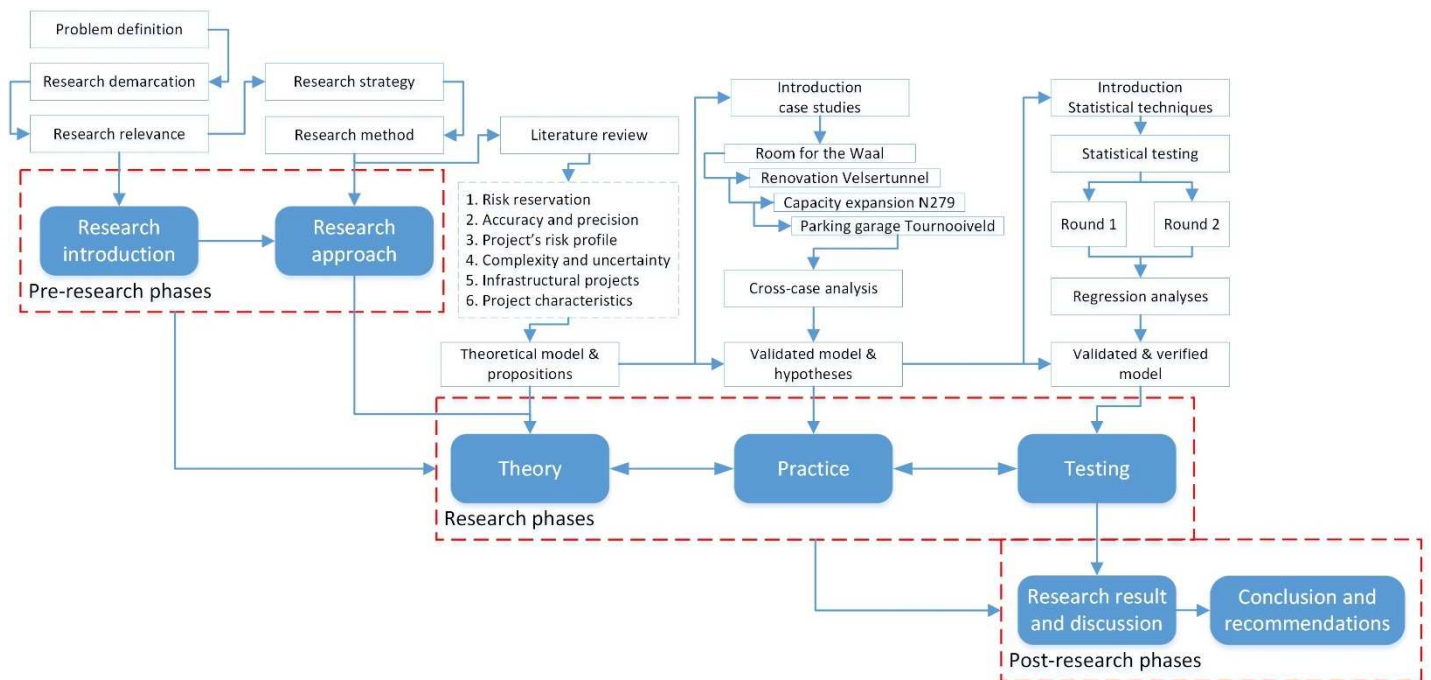


FIGURE 27: RELATIONS RESEARCH PHASES AND STEPS EXPLAINED GRAPHICALLY, TESTING PHASE (SOURCE: OWN ILL.)



5.1 Data collection

5.1.1 Database introduction

The chapter introduction explained that in the current research phase, the validated model is verified through quantitative, statistical tests. The starting point of these tests is a database of sufficient size, with valid data and an introduction towards the conditions of these statistical techniques. The first step in constructing the database is the definition of the project selection criteria. The database should be of sufficient size to execute the statistical tests, but this cannot be the main driver in selecting the projects to be added to the database. To keep the database homogenous and trustworthy, some project restrictions are set, namely:

- Building projects are excluded;
- Project should be completed for 95%;
- The project is procured in 2012 or later; and
- The project should have a capital value of €2.5 million or higher.

Based on these four criteria is a short list drafted of fifty-three projects realised by DVDI, including the four case study projects. One of the projects is procured before 2012 (2e Coentunnel), one is not completed for at least 95% (OPG Garenmarkt) and for one of the project it is not succeeded to acquire the right financial data (OPG Lammermarkt). the list of projects, type of project and year of procurement is presented on the in table 14. The projects that are highlighted in yellow are the projects excluded from the database.

1	Ruimte voor de Waal Nijmegen	Water project	2012
2	Renovatie Velsertunnel	Tunnel project	2013
3	Capaciteitsvergroting N279	Infrastructural project	2014
4	Tournooiveld parkeergarage	Civil project	2014
5	Zevenaar integraal spoorwerk	Rail project	2014
6	2e Coentunnel	Tunnel project	< 2012
7	IGO A73-A77 2015-2017	Infrastructural project	2015
8	Warmteleiding Rozenburg-Charlois	Civil project	2013
9	APM Maasvlakte Rotterdam	Rail project	2012
10	Dijkversterking Spui Oost	Water project	2014
11	Reconstructie Neherkade	Infrastructural project	2013
12	Reconstructie Rode Beek	Civil project	2014
13	Wintrack I 380kV Doetinchem - Niederrhein	Civil project	2016
14	Verdubbeling N244c	Infrastructural project	2015
15	Ongelijkvloerse kruising N276 Sittard	Infrastructural project	2015
16	N421 Ontwerp, aanleg, beheer en onderhoud	Infrastructural project	2013
17	Deventer Aanpassing Pijlers Spoorbrug (DAPS)	Civil project	2013
18	Treinhalte Goffert Nijmegen	Rail project	2013
19	OPG Lammermarkt Leiden	Civil project	2013
20	OPG Garenmarkt Leiden	Civil project	2013
21	Windmolenpark Urk	Civil project	2014
22	SAAL-Almere Centrum	Rail project	2014
23	N248a Parallelweg	Infrastructural project	2015
24	Reconstructie A44-N444	Infrastructural project	2012
25	Stadspark Ijmuiden	Civil project	2014
26	Zuidelijke Omliegging Oudenbosch	Infrastructural project	2014
27	Bedrijvenpark A1 Deventer	Infrastructural project	2013
28	Trajectaanpak N219a	Infrastructural project	2013
29	Herinrichting Leidseplein	Civil project	2016
30	Hart van Brabantlaan	Infrastructural project	2013
31	Alkmaar aanleg service paden	Rail project	2015
32	Heer Oudelands Ambacht Fase 1 Zwijndrecht	Civil project	2016
33	C vd Lelylaan Wilgenrijk	Civil project	2015

34	Vogelwijk fase 4 vervangen riool	Civil project	2013
35	Renovatie Buitenrustbruggen Haarlem	Civil project	2016
36	Herinrichting J. F. Kennedylaan	Infrastructural project	2013
37	RNO BBV deel Zuid 2013	Rail project	2012
38	Inrichting terrein OZG Scheemda	Civil project	2015
39	J.P. Thijssepark - Keverdijk West	Civil project	2015
40	Route van de Turf - Bergen op Zoom	Infrastructural project	2016
41	Rubis Terminal Rotterdam	Civil project	2014
42	Perceel 1 Willems- en Wilhelminaplein	Infrastructural project	2013
43	Verbreding Beatrixlaan	Infrastructural project	2013
44	Maasvlakte 2 buitencontour scope	Rail project	2013
45	Station Arnhem natuurstenen bestrating	Civil project	2014
46	Reconstructie Benedenkerkseweg	Infrastructural project	2013
47	Herinrichting Burg. Stemerdinglaan	Infrastructural project	2014
48	Missouriweg	Infrastructural project	2014
49	Brug te Zutphen - stille brug	Rail project	2014
50	380 kV Station Beverwijk	Civil project	2014
51	BBV Havenbedrijf Amsterdam	Rail project	2016
52	Tilburg - Loven DVRI	Rail project	2012
53	RNO BBV 2015 vrijebaan Arnhem - Nijmegen	Rail project	2014

TABLE 14: LIST OF PROJECTS IN THE PROJECTS DATABASE (SOURCE: OWN TABLE)

The required data is divided in two main categories. The first category of data is the data on project characteristics. The second category of data is both the budgeted and realised financial data of the projects. The required financial data is based on classified project information and therefore the cooperation of Dura Vermeer is critical. The document that are analysed for the financial data, are the financial cost control report. The last version is necessary for each individual project that is included in the database. Full access in the financial documentation system 'Cost Control' is granted in order to execute the current data collection step. The documents required in collecting the data on the project characteristics are the overall project planning, the procurement guidance document and the project contract. Besides, additional data is retrieved from the internet is used, like for example google and google maps.

5.1.2 Statistical techniques²

The statistical techniques to be used are briefly mentioned in section 4.4. The students t-test, the ANOVA test, correlation coefficient and regression analysis are the four statistical techniques that are applied in the current research. The level of measurement of both test variables determine which of these four techniques is used. The four techniques are elaborated on in full in appendix F. Important for the thesis are the preconditions that come with the usage of these techniques and the findings it produces.

The student's t-test requires a dependent parametric variable, the required Risk reserve, that follows a normal distribution and an independent dichotomous variable. This test is executed through a two-samples t-test, meaning two different sample sets in a single independent dichotomous variable. The null-hypothesis in this test is that the mean value is equal in both test groups of the dichotomous variable. The p-value lower than 0.05 means that the null-hypothesis is rejected and the alternative hypothesis is accepted. The alternative hypothesis is based on inequality in mean value of both groups. Important condition in this technique is equality of variances in the two datasets, if the datasets are different in size. The Welch's t-test is insensitive to unequal sample sizes in relation with variance inequalities and used under these conditions.

The Analysis of Variance test (ANOVA test) is, put simply, a t-test for more than two groups. However, besides testing the mean values, it also tests the variances within a group and between the different

² Information obtained from <https://en.wikipedia.org/wiki/> on October 11th 2017



groups. Again, the null hypothesis assumes equality in mean values of the dependent variable in the test groups. The Student's t-test is based on the T statistic, the ANOVA test is based on the F statistic. The p-value explains if the F statistic is significant in order to reject the null hypothesis. Important condition in the ANOVA test is normality in the dependent variable, thus the variable should follow a normal distribution. However, this also counts for the distribution of the dependent variable in each of the test groups. This is tested for in the Levene's test for normality. Sample sizes in the different test groups is not an important test criterion. Important is that all groups are based on a sufficient number of samples. There is not a minimum sample size for ANOVA, but the statistical power reduces with a small sample size. It can cause problems in the ability to reject a null hypothesis.

The correlation coefficient is the most 'powerful' technique, because it not only test for differences in means, but also correlations and dependence. Meaning that the correlation coefficient can determine how much dependence statistically exist between two variables, thus the strength of the relation. Correlation coefficient does not require a difference between dependent and independent variable. However, in the current research the dependent variable remains the required Risk reserve. The null hypothesis in the correlation coefficient assumes no correlation. A correlation with a p-value of 0.05 or less means that the null hypothesis is rejected and the alternative hypothesis is accepted. Meaning that there is indeed a correlation between the two test variables. The p-value is based on the sample size and the Pearson correlation coefficient. Roughly speaking, a sample size of 50 samples requires a coefficient of 0.3 to determine that the difference is significant. The sample size and level of measurements are important conditions, other conditions are linearity in the relation and no extreme values. Curvilinear relations cannot be tested for by means of a correlation coefficient. Values outside the mean value plus or minus three standard deviations should not be included in the calculations.

The regression analysis is the final statistical technique, but can be divided in two types of analysis. The simple regression analysis and the multiple regression analysis. The number of independent variables, or predictors, explains which type should be used. The simple regression analysis is based on a single predictor and dependent variable, the multiple regression analysis is based on more than one predictors and one dependent variable. Regression analysis goes one step further than the correlation coefficient. Regression analysis is aimed at predicting a single dependent variable based on the independent variable or variables. The correlation coefficient is descriptive and the regression analysis is predictive.

However, important conditions are the level of measurements of the test variables, but also the **causality** in the different variables. **Causality** is difficult to prove in the current research, as it requires test results over time. However, the 'explainability' of the predictor(s) towards the dependent variable is important. The predictor(s) should indeed be independent and qualitatively examined precede the dependent variable. Multiple regression corrects for correlation between predictors, but when the correlations become too high it causes a problem. It is called multicollinearity, meaning that the mutual correlation between the independent variables is higher than the correlation with the dependent variables. Correlating predictors can also be combined.

This multicollinearity asks for 'parsimony' within multiple regression analysis. Parsimonious models stand for models which explains the highest amount of variance, but with the least number of predictors. A sample is not the real world, it contains sampling errors. To many predictors can also result in over fitting and is less representative with respect to reality. A rule of thumb within multiple regression is that the fewer the predictors, the higher the generalizability. In order to overcome over fitting a method can be to stepwise introduce predictors in the analysis. First the predictor with the highest correlation coefficient is added to the regression analysis, then the predictor with the second highest partial correlation coefficient is introduced in the regression analysis. It is then testes if the first predictor is still significant. This continues after all predictors are introduced and tested. Significance is tested through null hypothesis and the t-test. Collinearity diagnostics can be used to test for multicollinearity.

A second rule of thumb is towards the sample size, it should not be too small but also not too big. A sample size of over 1000 observations will almost always result in statistically significant relations. A sample size with ten times the number of observation in relation to the independent variables is in most cases sufficient. However, fifteen or twenty times would even be better. Four predictors would than require 40 to 60 observations. Equal to the correlation coefficient, the relation between the dependent and independent variables should be linear. However, this is of course already tested for in the correlation coefficient.

Independence of observations is an assumption in the multiple regression as well. The Durbin-Watson statistic is calculated simultaneously with the regression analysis. A value between 1.5 and 2.5 means that there is independence between the observation. The final assumptions in multiple regression are homoscedasticity, also known as homogeneity, and normality of residuals. Homogeneity means that, the variance remains the same for all values of the independent variables. The regression analysis calculates a best fit line that explains the dependent variables, based on the significant predictors. As the input values for this best fit line change, the variance should remain the same for the dependent variable. These final two preconditions are tested graphically through scatterplots and histograms. Statistical programs are designed to produce such graphs along the statistical calculations. Current research uses SPSS software for the statistical tests.

5.1.3 Database analysis

The database is constructed in Excel and is based on the financial data and project characteristic data on fifty-three projects, of which fifty are used statistical tests. For each project is data collected to fill forty-six columns, besides the project name, type and year of procurement. Meaning that the database is based on almost 2500 cells of data. The complete dataset is added to appendix E, the financial part of the database is confidential. Not all columns are discussed in the current sub-section, the focus is on the 'column groups'. As can be seen in the database, the column groups are divided over the sections: Project characteristics and financial data. The database is thus built up in three layers. The data on the twelve project characteristics are explained in, logically, twelve column groups. The operationalization of each characteristic forms the basis of this data. As can be seen in the database, the first eleven column groups are straight forward, especially the categorical project characteristics. However, the final column group contains the data towards the design innovativeness of the project.

The score is on the scale between one and five and based on the judgement of three experts. The method in retrieving the final value included in the database is based on the statistical correlation coefficient and the average score. The three experts judged each of the projects individually through a score between one and five. The scoring method, frame of reference and actual judgements of the experts are included in appendix G. However, the three experts are chosen on their role within Dura Vermeer. The decision is primarily based on the differences in field of experience between experts and their general overview of projects executed within Dura Vermeer. The three experts are: Dura Vermeer's risk assurance manager (AS), process manager (MM) and design department leader (JS).

Correlations

		Innovative Design AS	Innovative Design MM	Innovative Design JS
Innovative Design AS	Pearson Correlation	1	.169	.194
	Sig. (2-tailed)		.247	.185
	N	49	49	48
Innovative Design MM	Pearson Correlation	.169	1	.556**
	Sig. (2-tailed)	.247		.000
	N	49	49	48
Innovative Design JS	Pearson Correlation	.194	.556**	1
	Sig. (2-tailed)	.185	.000	
	N	48	48	48

TABLE 15: CORRELATION TEST OF INNOVATIVE DESIGN EXPERT JUDGEMENTS SCORES (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)

** . Correlation is significant at the 0.01 level (2-tailed).



In addition, a score is determined for each project by the researcher before receiving the expert judgement scores. This score functions as a 'control score' to test for potential misunderstandings in the test method. The individual scores of the experts are not presented in the database, only the average score. The average score is determined only on those expert judgements that are positively correlated to each other. Table 15 shows the correlation test between the scores of the three experts. This is excluding the five projects that are used as frame of reference. The scores for these projects are fixed and only cause for a stronger correlation, without any input of the experts. What can be observed is that the expert judgement scores of MM and JS are correlated to one another, but the scores of AS are not correlated to the other experts.

Two of the three expert judgements on the innovative design are correlating. The first expert is after receiving the scores not found sufficient in testing for the innovative level within the design. Most projects were unknown for the expert and for that reason scored with a score of one. The average score is taken from the scores of the second and third experts. This average score is tested for potential judgement misunderstandings, through the control score. Table 16 displays the correlation coefficient and the two-tailed significance value between both variables. The Pearson correlation is .721, which is a high correlation, and is significant at the 0.01 level. It can be stated that the experts MM and JS did understand the judgement method and are representative to be used as independent variable in the statistical testing that follows.

		Innovative Design Average	Innovative Design TEST
Innovative Design Average	Pearson Correlation	1	.721**
	Sig. (2-tailed)		.000
	N	54	54
Innovative Design TEST	Pearson Correlation	.721**	1
	Sig. (2-tailed)	.000	
	N	54	54

** . Correlation is significant at the 0.01 level (2-tailed).

TABLE 16: CORRELATION TEST OF INNOVATIVE DESIGN AVERAGE AND TEST SCORE (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)

The financial data section is based on the column groups: Direct costs, indirect costs, project's bare costs, Risk reserve, profit margin, project organization, engineering and additional work. The result within a cost category or cost type is based on the difference between the working budget and the realised costs. The result is divided by either the working budget of the project's bare costs or the working budget of that particular cost category or cost type. However, percentages are always calculated based on the working budget rather than the realised costs. The statistical tests are based on percentages, in order to ensure comparability of the data. The most important financial data point is the required Risk reserve as a percentage. The operationalization is already extensively elaborated on and represents the project's risk profile of the hypotheses. It is the summation of the result in the project's bare costs and realised costs in the Risk reserve, divided by the working budget of the project's bare costs.

The structure of the database is elaborated on, but the actual content is not yet discussed. The conditions to which the data should comply is important in the execution of the different statistical tests. Important conditions in the student's t-test, ANOVA and correlation coefficient are the sample sizes and normality of the distribution of the test variables. Appendix F section 6.1 contains a full analysis of the database content, primarily aimed at sample sizes and normality of distribution. This analysis is aimed at both the financial data and the data on the project characteristics. Current sub-section only includes the highlights of the database content analysis. Descriptive statistics are used to analyse the different variables in the database. The distribution of the required Risk reserve is the most critical distribution and should be normal as required in the different tests.

Database manipulation can be a solution for a non-normal distribution, but such manipulation affects all variables in the database and cause changes in the descriptive statistics. For that reason, the required

Risk reserve is statistically examined first. The statistic parameters, like the minimum, maximum, mean, standard deviation, skewness and kurtosis describe the distribution of the variable. These are presented in table 17. The required Risk reserve summed up for all projects is €26.06 million (3.76%). The mean of the required Risk reserve is 3.46%, which is a little lower than the database average.

	N	Minimum	Maximum	Mean		Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic	Std. Error	Statistic	Std. Error
Required risk reservation	50	-12.72%	34.37%	3.4592%	1.22115%	8.63487%	1.191	.337	2.752	.662
Valid N (listwise)	50									

TABLE 17: DESCRIPTIVE STATISTIC OF THE REQUIRED RISK RESERVATION (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)

The first parameter that stands out, is the standard deviation parameter. The mean value is as said 3.46%, meaning that the 95% confidence interval is approximately between -13.8% and 20.72%. The 95% confidence interval is calculated by adding the standard deviation multiplied by -1.96 and 1.96. The large standard deviation means that there is a large spread around the mean and thus a large variance. This is also expected looking at the database, the project's bare costs show large financial losses, but also large positive results. The losses are greater than positive results, what becomes clear in the mean value of the required Risk reserve. A smaller percentage or a negative required Risk reserve would indicate that the project's risk profile is smaller or even on the opportunity side of risks, rather than the negative, threat side.

The other distribution parameters, and especially the skewness and kurtosis parameters, are an indication that the required Risk reserve follows a normal distribution. The skewness parameter is a measure of asymmetry around the mean. Skewness means that one side of the tail is larger than the other one. High positive and negative values are an indication of a non-normal distribution. The kurtosis parameter is also a descriptor of the distribution's shape. Kurtosis is a measure of the 'tailedness'. The higher the kurtosis value the more variance is explained by extreme values, thus extreme values are becoming more likely with respect to the intermediate values. Put simply, the higher the kurtosis parameter, the flatter the distribution and the fatter the tails are. The kurtosis of a normal distribution is 3. The skewness and kurtosis of the required Risk reserve are an indication of a normal distribution.

Table 18 displays the test of normality, as the name already suggest, does it test if the variable indeed follow a normal distribution. The Shapiro-Wilk test is mainly used for tests with small sample sizes (50 samples or less). The current database is exactly 50 samples and for that reason the Shapiro-Wilk test is used in the sub-sequent tests of normality. The final column contains the p-value, a value of 0.05 or higher means that the variable is normally distributed. The test in table 18 is thus not significant, the required Risk reserve does not follow a normal distribution.

The histogram, displayed in figure 29, show the frequencies of the values in the variable and graphically explains why the variable is not distributed normally. The histogram is shaped with a clear peak and two tails of more or less the same size. However, one extreme value on the right side disturbs the distribution. The normal Q-Q plot, which can be found in figure 28, also explains the non-normal distribution. The open dots represent the values within the variable and the straight line represents a normal distribution. The closer the dots to the line, the closer the variable comes to a normal distribution. The dot on the right side of the graph is too far distanced from the straight line.

	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Required risk reservation	.098	50	.200*	.930	50	.005

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

TABLE 18: TEST OF NORMALITY OF THE REQUIRED RISK RESERVATION (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)

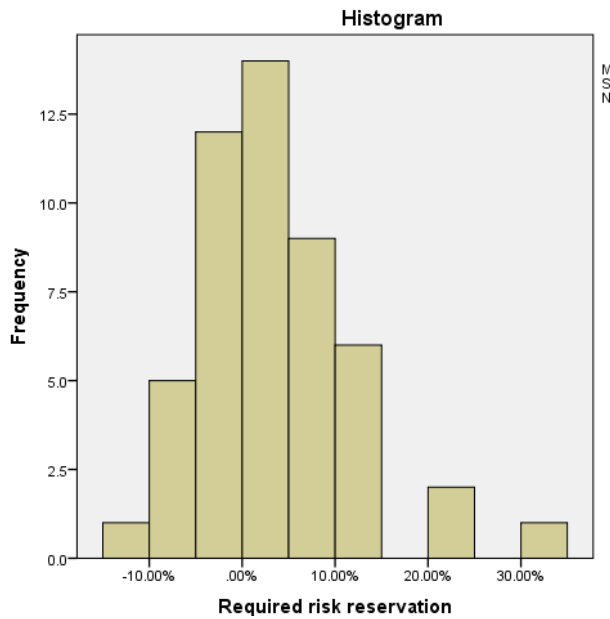


FIGURE 28: HISTOGRAM OF THE REQUIRED RISK RESERVATION (SOURCE: OWN GRAPH, EXTRACTED FROM SPSS)

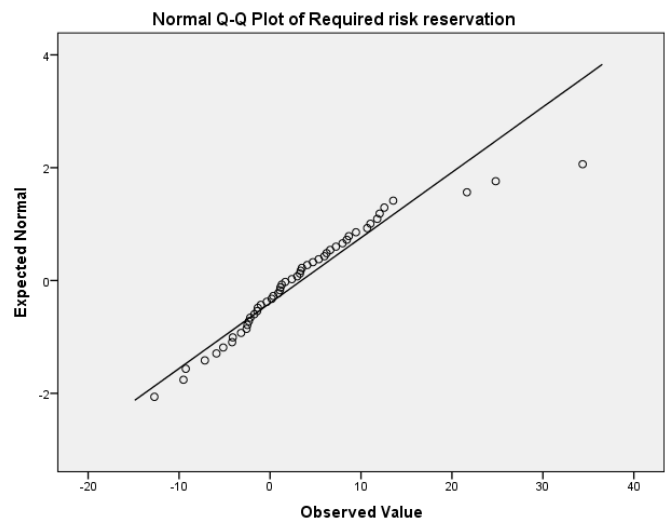


FIGURE 29: NORMAL Q-Q PLOT OF THE REQUIRED RISK RESERVATION (SOURCE: OWN GRAPH, EXTRACTED FROM SPSS)

Excluding the project with the extreme value in the required Risk reserve variable indeed result in a significant test with respect to a normal distribution. The removed project is project 37, RNO BBV ZUID 2013, what is a rail project procured in 2012. This descriptive statistic step is executed for all variables included in the database, based on the data of forty-nine projects. This resulted in two important database manipulations. The first is the exclusion of project 45, Station Arnhem natuurstenen bestrating, from the database. The capital value is only €2.34 million, what is below the project selection criterion of the minimal capital value.

The second manipulation is the split of project 1, Room for the Waal Nijmegen, into two sub-projects. The project's capital value is too large to be comparable with the other forty-seven projects in the database. The project is divided in project 1a, Room for the Waal Nijmegen (water), and project 1b, Room for the Waal Nijmegen (civil). This distinction is based on the in-depth knowledge that is acquired during the case studies. This division results in a sub-project that consists of all the work related to the bridges and a sub-project with the other work. The financial data and data on the project characteristics are adjusted for these two sub-projects. This project split resulted in a final project database with forty-nine projects. The required Risk reserve remained normal distributed, despite the two new database manipulations.

Further descriptive statistical research resulted in more in-depth knowledge in the sample sizes of the categorical variables and the distributions of the continuous variables. The project characteristics construction duration, construction pace 1&2 and tender duration all four required database manipulations to reach normality. These are however not valid for the entire database. Too much data manipulation will result in a database that reaches a situation in which the representativeness is no longer ensured. These data manipulations are executed solely on the variable to which it applies, thus not to the other variables. The adjustments that are made are explained and defended in appendix F section 6.1 and 6.2. The organization characteristic is divided in three classes, as explained in section 4.4.2. However, the splitted organization class only consists of one valid sample. This class is for that reason, as elaborated on earlier, combined with the partnership class.

The next section is the first round of statistical analysis, in which twelve hypotheses are tested that explain the relation between the assumed unique character of the project and the project's risk profile. The descriptive statistics are discussed in these statistical analyses, if found necessary. However, the basis of the statistical tests is a database of forty-nine project in which the required Risk reserve is normally distributed, after three database manipulations.

5.2 First round of statistical analysis

The first round of statistical analysis is aimed at the relation between the project’s risk profile and the unique character of the project, based on the twelve identified project characteristics. The project’s risk profile is quantified in the required Risk reserve and is the dependent variable in the hypotheses. The project characteristic is the independent variable in the statistical tests. The individual hypothesis tests are elaborated on in full detail in appendix F section 6.2. Current section only focusses on the hypotheses that are accepted, meaning that there is a relation or association between the independent and dependent variable. The section closes with findings after the first round of statistical analysis. The statistical tests are executed in SPSS from which the tables and graphs are extracted as well.

Four project characteristics are tested significant on a relation with the project’s risk profile, based on the current database. The construction pace, project organization, concretization phase and design innovativeness characteristics are correlated or associated with the required Risk reserve. The statistical test results are presented below for each accepted hypothesis.

1. Hypothesis 3: Construction pace is correlated with the project’s risk profile.

The third hypothesis is aimed at the correlation between the construction pace and the project’s risk profile. However, the construction pace is operationalized in two separate ways and thus divided in two different variables. The construction pace 1 variable is based on the daily turnover of the project and is not tested significant in the statistical tests in relation to the required Risk reserve. The construction pace 2 variable is based on the yearly expenses on project organization as percentage of the project’s bare costs. Both variables are tested for a significant correlation in table 19. The test is executed based on a sample size of N=49, but the correlations are based on a sample size of N=47. Two projects do not include data on the construction duration and therefore also not on the construction pace.

		Correlations		
		Required risk reservation	Construction pace 1	Construction pace 2
Required risk reservation	Pearson Correlation	1	.003	.017
	Sig. (2-tailed)		.983	.912
	N	49	47	47
Construction pace 1	Pearson Correlation	.003	1	-.035
	Sig. (2-tailed)	.983		.815
	N	47	47	47
Construction pace 2	Pearson Correlation	.017	-.035	1
	Sig. (2-tailed)	.912	.815	
	N	47	47	47

TABLE 19: CORRELATION ANALYSIS BETWEEN CONSTRUCTION PACE 1 AND REQUIRED RISK RESERVATION (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)

The test results show no significant correlations, what is strange as both construction pace variables are supposed to measure the same project characteristics and therefore are expected to be correlated. This appears to be not the case, based on the current database. However, an important condition of the Pearson correlation is that both test variables are normally distributed, which is for both variables not the case. The Kendall Tau coefficient can be calculated, which is not affected by a non-normal distributed variable. The construction pace 1 variable is still by far not significant, with a correlation coefficient of .049 and a two-tailed p-value of .627. However, the correlation between the construction pace 2 variable and required Risk reserve tends to become a significant correlation.

The Pearson correlation test is based on 47 valid samples, but the construction pace variables are not distributed normally. A third attempt in testing the correlation between the variables is made, based on a normal distributed construction pace variable. The first construction pace variable cannot be manipulated in a normal distribution with only few adjustments. Too much manipulations result in unreliable test results that are not generalizable to the ‘real world’. With few adjustments is meant that, only significant outliers in the dataset are excluded from the test. Three projects with extreme values for the construction pace, two with the highest value and one with the lowest value, are excluded in



		Construction pace 2	Required risk reservation
Construction pace 2	Pearson Correlation	1	.305*
	Sig. (2-tailed)		.044
	N	44	44
Required risk reservation	Pearson Correlation	.305*	1
	Sig. (2-tailed)	.044	
	N	44	46

*. Correlation is significant at the 0.05 level (2-tailed).

TABLE 20: CORRELATION ANALYSIS BETWEEN MANIPULATED CONSTRUCTION PACE 2 AND REQUIRED RISK RESERVATION (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)

with a p-value of 0.044. Two scatterplots are presented in figure 31 and 32. Figure 31 display the required Risk reserve as function of the construction pace 1. This is based on the original database, thus without further manipulations. The flat trendline explains that there is no correlation between the variables. It also explains why construction pace 1 is not normal distributed, with most of the data points positioned at the left side of the scatterplot. The scatterplot displayed in figure 32 is that of the manipulated construction pace 2 variable. Three projects are excluded from the database, what result in the presented scatterplot. The dots are slightly upwards sloping, what is graphically explained by the trendline. The trendline follows the following function:

$$\text{required risk reservation} = -2.01 + 0.83 * \text{construction pace}$$

The function means that with a low construction pace the required Risk reserve is negative and thus the project's risk profile is small. By each percentage of yearly UTA-staff costs higher, the required Risk reserve has to be 0.83% higher. The correlation coefficient is 0.305, what can be classified as a low correlation. A coefficient of 0.5 to 0.7 is moderate and above 0.7 can be interpreted as a high correlation. Homogeneity is not rejected after graphical examination of figure 32, with respect to the distribution of the data points around the trendline.

Hypothesis 3 is accepted, there is a correlation between the construction pace and the project's risk profile.

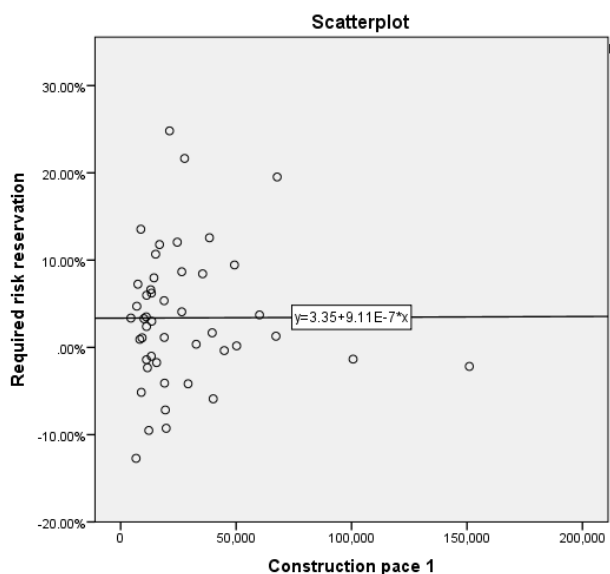


FIGURE 31: SCATTERPLOT OF CONSTRUCTION PACE 1 AND REQUIRED RISK RESERVATION (SOURCE: OWN GRAPH, EXTRACTED FROM SPSS)

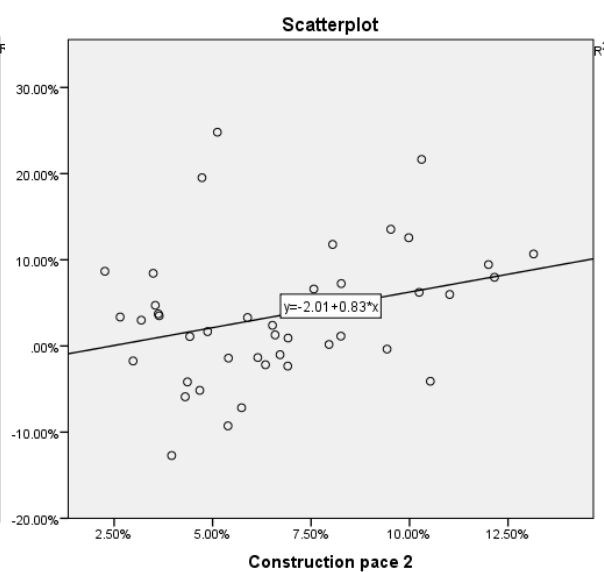


FIGURE 30: SCATTERPLOT OF MANIPULATED CONSTRUCTION PACE 2 AND REQUIRED RISK RESERVATION (SOURCE: OWN GRAPH, EXTRACTED FROM SPSS)

2. Hypothesis 6: The project organization is associated with the project's risk profile.

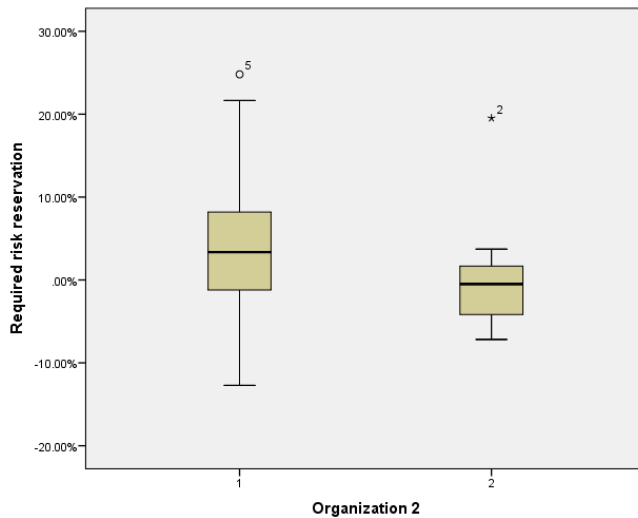
Report

Required risk reservation

Organization	N	Mean	Std. Error of Mean	Std. Deviation	Minimum	Maximum	Skewness	Kurtosis
Dura Vermeer	39	3.7763%	1.23671%	7.72323%	-12.72%	24.81%	.417	.898
Partnership	10	0.5796%	2.37245%	7.50236%	-7.17%	19.53%	1.962	4.962
Total	49	3.1239%	1.10166%	7.71165%	-12.72%	24.81%	.630	.790

TABLE 21: DESCRIPTIVE STATISTICS OF PROJECT ORGANIZATION GROUPS (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)

The project organization characteristic is based on three different groups. However, the splitted organization only contains a single project. The splitted organization and partnership group are therefore combined. Table 21 display the descriptive statistics of the required Risk reserve in the organization groups. The difference in mean value is large with almost 3.2%. Before testing if the difference in mean values is significant, first is tested if the required Risk reserve is in both groups normally distributed. This is not the case, what is explained by the two boxplots presented in figure 32.



The first boxplot is the Dura Vermeer organization group and what becomes apparent is the large spread around the mean, what is expected based on the low Kurtosis parameter. The opposite is through for the partnership organization group. The spread is small, what is explained by the high Kurtosis. In both boxplots one project outlier makes the distribution not normal distributed. Three projects are excluded from the database to come to a normal distribution in both groups. The projects 2 (Ruimte voor de waal Nijmegen Bruggen) and 5 (Parkeergarage Tournooiveld), which are displayed as outlier in the boxplots. However, by removing project 5, also project 39 (Perceel 1 Willems- en Wilhelminaplein) had to be removed for a normal distribution.

FIGURE 32: BOXPLOTS OF PROJECT ORGANIZATION GROUPS (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)

Group Statistics

Organization 2		N	Mean	Std. Deviation	Std. Error Mean
Required risk reservation	Dura Vermeer	37	3.6536%	6.56540%	1.07934%
	Partnership	9	-1.5260%	3.66658%	1.22219%

TABLE 22: DESCRIPTIVE STATISTICS OF THE MANIPULATED PROJECT ORGANIZATION GROUPS (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)

The descriptive statistics of the project organization groups after the database manipulation are presented in table 22. The Dura Vermeer group contains thirty-seven projects and the partnership group is based on nine valid samples. The difference in mean values is larger due to the manipulation, the difference is more than 5%. The partnership type of projects requires a negative Risk reserve. Meaning that the opportunity side of the risks is larger than that of the threats. The standard deviation is decreased in both groups as well, but in the partnership group it is approximately halved. The results of the independent samples T-Test are presented in table 23. First the results of the Levene's test, equality of variances is accepted with a F statistic of 2.469 and p-value of 0.123. The top row of the t-test is thus leading. The mean difference of 5.18% is tested significant. The t statistic is 2.269, with a two-tailed p-



Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Required risk reservation	Equal variances assumed	2.469	.123	2.269	44	.028	5.17957%	2.28241%	0.57967%	9.77947%
	Equal variances not assumed			3.177	22.327	.004	5.17957%	1.63056%	1.80085%	8.55828%

TABLE 23: INDEPENDENT SAMPLES T-TEST OF MANIPULATED ORGANIZATION VARIABLE (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)

value of 0.028. The 95% confidence interval of the difference is between 0.58% and 9.78%. This is a large confidence interval, mainly caused by the std. Error mean difference. However, there is a significant difference in mean values between the Dura Vermeer and Partnership project organization groups. Project realised solely by Dura Vermeer are riskier than project realised with a partner contractor.

Hypothesis 6 is accepted, there is an association between the project organization and the project's risk profile.

3. Hypothesis 8: A concretization phase is associated with the project's risk profile.

Report

Required risk reservation

Concretization phase	N	Mean	Std. Error of Mean	Std. Deviation	Kurtosis	Skewness	Minimum	Maximum
No	45	3.5951%	1.17339%	7.87132%	.654	.495	-12.72%	24.81%
Yes	4	-2.1768%	0.70796%	1.41593%	1.501	-1.356	-4.17%	-1.01%
Total	49	3.1239%	1.10166%	7.71165%	.790	.630	-12.72%	24.81%

TABLE 24: DESCRIPTIVE STATISTICS OF CONCRETIZATION PHASE GROUPS (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)

The concretization phase characteristic has two groups, a yes and a no group. There is a large difference in the group sizes, almost all projects do not have a concretization phase before the contract signing and the start of the actual project. Only four out of the forty-nine project includes a concretization phase. There is no minimum sample size, but with four samples the mean difference has to be large enough to test significant. Table 24 display the group statistics with respect to the required Risk reserve. The mean difference between the two groups is 5.77%, what can be classified as large. Especially with respect to an average budgeted Risk reserve of 2.53% and profit margin of 0.59%. The parameters of the distribution indicate that the required Risk reserve is in both groups normally distributed. Table 25 contains the results of the Shapiro-Wilk test, which show significance of a normal distribution of the required Risk reserve in both groups.

Tests of Normality

Concretization phase	Kolmogorov-Smirnov ^a			Shapiro-Wilk			
	Statistic	df	Sig.	Statistic	df	Sig.	
Required risk reservation	No	.075	45	.200*	.978	45	.529
	Yes	.250	4	.	.885	4	.361

TABLE 25: TEST OF NORMALITY OF CONCRETIZATION PHASE CHARACTERISTIC GROUPS (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Required risk reservation	Equal variances assumed	3.626	.063	-1.451	47	.153	-5.77193%	3.97801%	-13.77464%	2.23079%
	Equal variances not assumed			-4.212	27.811	.000	-5.77193%	1.37042%	-8.57996%	-2.96389%

TABLE 26: INDEPENDENT SAMPLES T-TEST OF CONCRETIZATION PHASE (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)

The independent samples t-test is presented in table 26, which shows that the variances are equal and that the difference in mean values is not significant. Assuming unequal variances results in a significant mean difference. However, the main driver of the not significant two-tailed t-test result, is the large variance in the ‘no’-group. The ‘yes’-group, however, shows a small variance. Equal variances can therefore not be assumed, as the large difference in sample sizes is the disturbing factor in the calculations. Database manipulation is used to exclude outliers in the ‘no’-group that have a disturbing effect on the Levene’s test. Homogeneity is rejected in the Levene’s test after exclusion of two outliers in the boxplot of the ‘yes’-group. Projects 5 (Tournooiveld parkeergarage) and 16 (N421 ontwerp, aanleg, beheer en onderhoud) are excluded to come to two boxplots without outliers. The Shapiro-Wilk test is still significant for normal distributions within the groups. The independent samples t-test results based on the manipulated database are presented in table 27.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Required risk reservation	Equal variances assumed	4.041	.050	-1.423	45	.162	-4.85873%	3.41482%	-11.73655%	2.01908%
	Equal variances not assumed			-3.889	22.059	.001	-4.85873%	1.24948%	-7.44959%	-2.26788%

TABLE 27: INDEPENDENT SAMPLES T-TEST OF MANIPULATED CONCRETIZATION PHASE (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)

Equality of variance is rejected with a F statistic of 4.041 and a p-value of 0.05 based on a sample size of N=47. The null hypothesis is rejected and equal variances is not assumed. The second row in the table is thus examined. The t-statistic is -3.89 with a p-value of 0.001. The null hypothesis of equal mean values is thus rejected. The mean difference is -4.86%, with a standard error of 1.25%, is significant. The 95% confidence interval of the mean difference is from -7.45% to -2.27%. Meaning that a project with concretization phase has a 7.5% to 2.3% lower required Risk reserve, over projects without a concretization phase. However, the significant test result is only a consequence of the database with less variance in the required Risk reserve. The presence of a concretization phase is thus associated with the project’s risk profile, without the extreme values within the required Risk reserve (>20%).

Hypothesis 8 is accepted, there is an association between the concretization phase and the project’s risk profile.

4. Hypothesis 12: The innovative design is correlated with the project’s risk profile.

The descriptive statistics of the innovative design characteristic are explained in the previous section. Both the required risk profile and the innovative design variable is a continuous metric variable and thus is the correlation coefficient tested. The Pearson correlation coefficient and the p-value are presented in table 28. The correlation is based on forty-nine valid samples and has a strength of .368 with a p-value of .009. The null hypothesis of no correlation is thus rejected at the 0.01 confidence level. There is a correlation between the projects risk profile and the innovative design characteristic.

		Innovative design	Required risk reservation
Innovative design	Pearson Correlation	1	.368**
	Sig. (2-tailed)		.009
	N	49	49
Required risk reservation	Pearson Correlation	.368**	1
	Sig. (2-tailed)	.009	
	N	49	49

TABLE 28: CORRELATION ANALYSIS BETWEEN INNOVATIVE DESIGN AND REQUIRED RISK RESERVATION (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)

** . Correlation is significant at the 0.01 level (2-tailed).



The scatterplot, presented in figure 33, gives a visual explanation of the correlation. On the x-axis is the score on the innovative design and on the y-axis the dependent variable, the required Risk reserve. The correlation strength is 0.368, what is a small correlation. The upwards sloping trendline in the scatterplot shows this small correlation. However, in order to reach this correlation coefficient and significance level, the database should normally be larger. Meaning that, despite the relative small sample size, the correlation is indeed highly significant. A simple regression analysis is required to test the presented function in the scatterplot that describes the trendline.

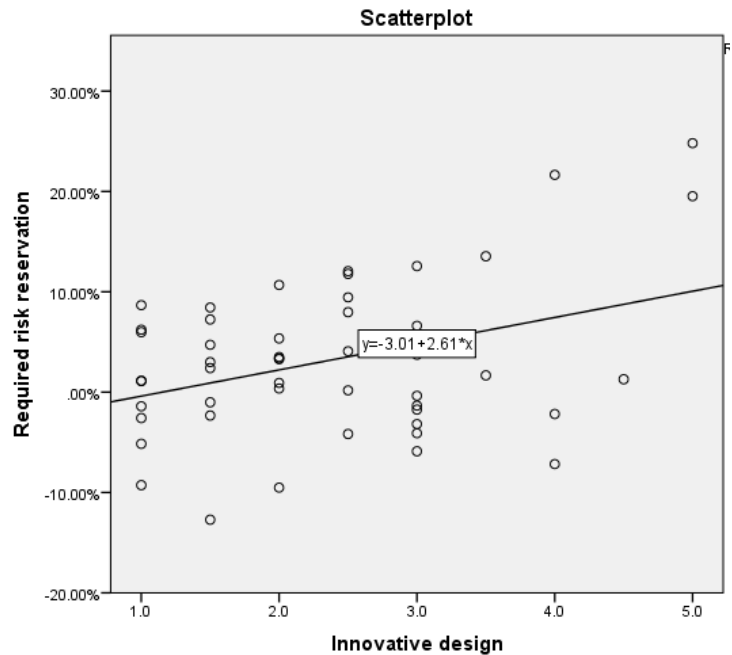


FIGURE 33: SCATTERPLOT OF INNOVATIVE DESIGN AND REQUIRED RISK RESERVATION (SOURCE: OWN GRAPH, EXTRACTED FROM SPSS)

However, the function can be used as good indication. The formula means that with a design that is not innovative, thus a score of 1, the required Risk reserve should be 0.4%. A design scored with a 4 for innovative results in a required Risk reserve of 7.43%. The bandwidth on this simple Risk reserve calculation is left out of consideration. The same counts for the effect of other variables that influence the required Risk reserve, which is analysed in the multiple regression analyses.

Hypothesis 12 is accepted, there is a correlation between the innovative design and the project's risk profile.

The first round of statistical analysis resulted in four accepted hypotheses and eight rejected hypotheses. The construction pace, project organization, concretization phase and design innovativeness project characteristics explain the unique character of the project and are also related to the project's risk profile. The higher the construction pace is, the more Risk reserve is required. This correlation is also expected, as a higher construction pace is likely to lead to a higher level of complexity and/or uncertainty and thus to a higher risk profile. The same counts for the innovativeness characteristic. The exact opposite was also expected for the concretization phase characteristic. Meaning that the presence of a concretization phase is associated with a lower project's risk profile. The causality of these relations is qualitatively analysed in the theoretical and practical research phase.

The causality of the project organization as independent variable and the required Risk reserve is more difficult to explain. The expectation of the relation is different from the test result. A project that is realised by Dura Vermeer requires a higher Risk reserve than a project realised in a partnership. However, the opposite was expected. More company's active in a project organisation was assumed to cause for more organizational complexity, but this does not come out of the test results. A different causal relation exists between these two variables. However, the explaining factor of the project organization characteristic towards the risk profile is quantitatively verified. Multiple regression analysis is required to test for multicollinearity between the assumed independent variables and must prove which are the actual predictors in the relation unique character project and project's risk profile.

The eight rejected hypotheses mean that these project characteristics are not related to the project's risk profile, based on the current database and operationalisations. However, reconsidering the distribution of the required Risk reserve. The variable shows a large variance, meaning that there are large differences between the different projects in the database. This large variance in the required Risk reserve is observed as disturbing factor in testing the hypotheses. The large variance means that only

'very' large differences between groups are tested significant. The rejected hypotheses based on an association between the project's risk profile and the project location is used as example to show this difficulty.

5. Hypothesis 5: The project location is associated with the project's risk profile.

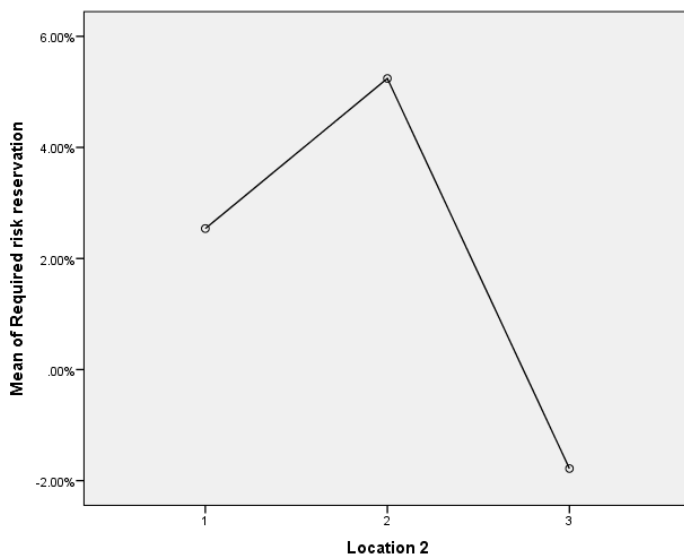
The project location is divided in three groups, a rural, urban and natural area group. The natural area group is with four samples small and expected to be too small for further analysis. First is tested if the required Risk reserve is normal distributed in the three different groups. The Shapiro-Wilk test is significant for a normal distribution in all three groups. Second, the contract type variable's group variances are tested for homogeneity. The Levene statistic is 1.392 and the p-value is .410, meaning that the group variances are homogeneous. Table 29 first shows the descriptive statistics of the three groups.

Descriptives

Required risk reservation

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Rural	28	2.5391%	7.14753%	1.35076%	-0.2325%	5.3106%	-9.52%	21.65%
Urban	17	5.2417%	8.77953%	2.12935%	0.7277%	9.7557%	-12.72%	24.81%
Natural	4	-1.7821%	4.46493%	2.23247%	-8.8868%	5.3226%	-7.17%	3.72%
Total	49	3.1239%	7.71165%	1.10166%	0.9089%	5.3390%	-12.72%	24.81%

TABLE 29: DESCRIPTIVE STATISTICS OF LOCATION GROUPS (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)



The mean values of the three groups show large differences. This is also graphically presented in figure 34, where the mean values are plotted for each group. The difference between the natural and urban group is more than 7% and the difference between the urban and rural group is little more than 2.7%. However, the standard deviation and variance are also large, causing for a large spread around the mean. The group ranges overlap and therefore is a significant difference in mean values less likely. Table 30 presents the results of the ANOVA test.

FIGURE 34: MEAN PLOT OF PROJECT LOCATION GROUPS (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)

ANOVA

Required risk reservation

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	182.095	2	91.048	1.567	.220
Within Groups	2672.441	46	58.097		
Total	2854.537	48			

TABLE 30: ANOVA TEST RESULTS PROJECT LOCATION (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)

The ANOVA test results in a F statistic of 1.567, with a p-value of .22 based on a N=49. Meaning that there is not a significant difference between the group's mean values. The mean differences between the individual groups is tested for as well and is presented in table 31. As already observed, the natural location group contains the largest mean differences with the two other groups. However, the urban group has the lowest combined p-value. A database manipulation mentioned in the operationalization step, with respect to the location variable, is to combine the rural and natural locations. This results in



a group of urban projects and group of non-urban projects. Looking at the p-values in the multiple comparisons table and the F statistic in the ANOVA, it is expected that even such manipulation does not result in a significant difference between the group means.

Multiple Comparisons

Dependent Variable: Required risk reservation
 Tukey HSD

(I) Location 2	(J) Location 2	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Rural	Urban	-2.70261%	2.34357%	.487	-8.3783%	2.9731%
	Natural	4.32112%	4.07419%	.543	-5.5459%	14.1881%
Urban	Rural	2.70261%	2.34357%	.487	-2.9731%	8.3783%
	Natural	7.02374%	4.23575%	.232	-3.2345%	17.2820%
Natural	Rural	-4.32112%	4.07419%	.543	-14.1881%	5.5459%
	Urban	-7.02374%	4.23575%	.232	-17.2820%	3.2345%

TABLE 33: MULTIPLE COMPARISONS MEAN VALUES LOCATION GROUPS (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)

The statistics of the location and required Risk reserve are re-evaluated in table 32. There are 17 urban projects compared to 32 non-urban projects. The difference in mean value is 3.24%, what is a large difference. Especially if the average budgeted Risk reserve is only 2.53%. The required Risk reserve for urban projects is almost double of the average budgeted Risk reserve. In table 31 are the results of the student's t-test presented. The groups are tested for a normal distribution, what is tested significant. In the t-test is a Levene's test executed, which tests for the equality or homogeneity of variances. Equal variances can be assumed, thus the first row in table 31 counts. The p-value is 0.163 and therefore the mean difference between the two groups is not significant, what is mainly caused by the large variances in the groups.

Group Statistics

Location	N	Mean	Std. Deviation	Std. Error Mean
Required risk reservation Non-urban	32	1.9989%	6.96654%	1.23152%
Required risk reservation Urban	17	5.2417%	8.77953%	2.12935%

TABLE 32: DESCRIPTIVE STATISTICS OF MANIPULATED LOCATION GROUPS (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Required risk reservation	Equal variances assumed	.493	.486	-1.416	47	.163	-3.24275%	2.29060%	-7.85086%	1.36535%
	Equal variances not assumed			-1.318	26.938	.199	-3.24275%	2.45983%	-8.29045%	1.80494%

TABLE 31: INDEPENDENT SAMPLES T-TEST OF MANIPULATED LOCATION (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)

Hypothesis 5 is rejected, there is a no association between the project location and the project's risk profile.

There is a difference in mean values between the three different project location groups, even a large difference looking at the average budgeted and required Risk reserve. The difference between both groups can be decisive in a project loss or project profit. The average profit margin is 0.59%, but the realised profit margin based on these forty-nine projects is -0.54%. An 1% difference between the budgeted and required Risk reserve can thus mean that a profit is generated, rather than a loss. This requires a model that detect small differences in project's risk profile, but these are not tested significant based on the current data. The large variance in the required Risk reserve result in statistical tests that can only explain large differences between mean values. Different operationalisations or a larger database can help overcome such testing difficulties.

5.3 Second round of statistical analysis

The twelve project characteristics are tested quantitatively for a relation with the project's risk profile. These hypotheses are defined based on the validated model that is displayed in figure 26 in section 4.4. Besides the relation between the unique character of the project and the project's risk profile, other external factors are defined that influence the construct presented in figure 26. First is examined if there is a correlation between the budgeted and required Risk reserve. The stronger the correlation is, the higher the quality of the current budgeting approach is. The second hypothesis is aimed at the relation between the profit margin and budgeted Risk reserve, as indication of the external factor market conditions. The third hypothesis to test in the current section is towards the difference between the direct and indirect cost category in relation to the project's risk profile. Finally, additional hypotheses are defined to explain the four, significant tested relations between the project characteristics and the project's risk profile.

- *Hypothesis 13: The budgeted Risk reserve is correlated with the required Risk reserve.*

The thirteenth hypothesis is based on the relation between the budgeted and required Risk reserve. A correlation coefficient of 1, would indicate, as already explained, that the budgeted Risk reserve follows the required Risk reserve **precisely**. However, the difference between the budgeted and required Risk reserve is already observed in the database averages and calculated mean values. The **accuracy** of the budgeted Risk reserve is thus already not perfect. The budgeted Risk reserve variable does not follow a normal distribution. Two outliers in the database are projects with extreme values in comparison to the other projects. The two removed projects are 7 (Warmteleiding Rozenburg-Charlois) and 35 (J.P. Thijsssepark - Keverdijk West). The results of the correlation analysis are presented in table 34 and the scatterplot of both variables is displayed in figure 35. The correlation is positive with a coefficient of 0.380 and significant at the 0.01 level, with a sample size of N=47. A higher budgeted Risk reserve means that the required Risk reserve is higher as well.

		Budgeted risk reservation	Required risk reservation
Budgeted risk reservation	Pearson Correlation	1	.380**
	Sig. (2-tailed)		.008
	N	47	47
Required risk reservation	Pearson Correlation	.380**	1
	Sig. (2-tailed)	.008	
	N	47	47

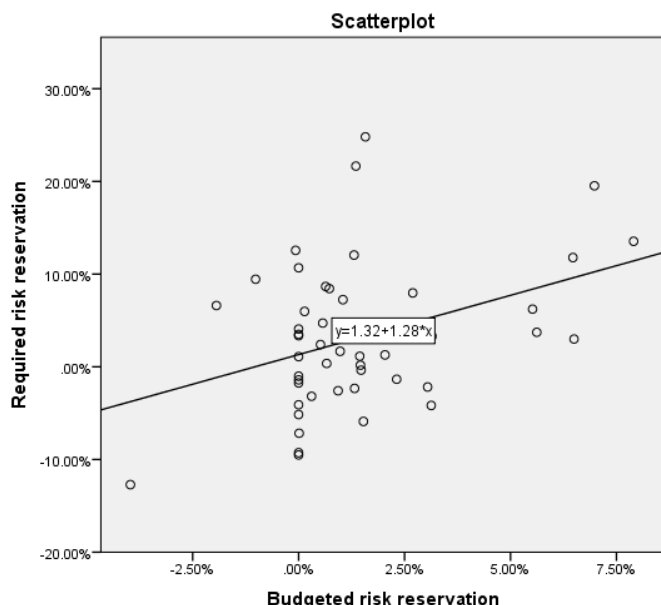


TABLE 34: CORRELATION ANALYSIS BETWEEN BUDGETED RISK RESERVATION AND REQUIRED RISK RESERVATION (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)

Hypothesis 13 is accepted, the budgeted Risk reserve is correlated with the required Risk reserve.

FIGURE 35: SCATTERPLOT OF THE BUDGETED RISK RESERVATION AND REQUIRED RISK RESERVATION (SOURCE: OWN GRAPH, EXTRACTED FROM SPSS)



- Hypothesis 14: The budgeted profit margin is correlated with the budgeted Risk reserve.

Both variables are not normally distributed, thus the Kendall's Tau-b correlation coefficient is calculated, rather than the Pearson Correlation coefficient. The Kendall's Tau-b correlation is not sensitive for not normal distributed variables. The results of the correlation analysis between the budgeted profit margin and Risk reserve are presented in table 35. Figure 36 displays the scatterplot of the two variables, with the budgeted profit margin on the x-axis and the budgeted Risk reserve on the y-axis. The correlation coefficient is 0.431 and significant at the 0.001 level, with N=49. There is thus indeed a positive correlation between the two budgeted project costs.

Correlations			Budgeted profit	Budgeted risk reservation
Kendall's tau_b	Budgeted profit	Correlation Coefficient	1.000	.431**
		Sig. (2-tailed)	.	.000
		N	49	49
	Budgeted risk reservation	Correlation Coefficient	.431**	1.000
		Sig. (2-tailed)	.000	.
		N	49	49

** . Correlation is significant at the 0.01 level (2-tailed).

TABLE 35: CORRELATION ANALYSIS BETWEEN BUDGETED RISK RESERVATION AND PROFIT MARGIN (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)

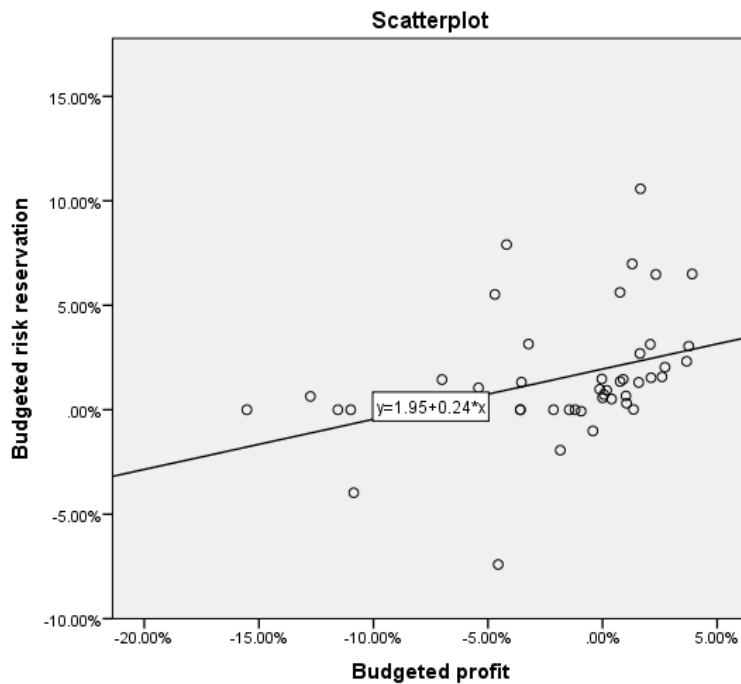


FIGURE 36: SCATTERPLOT OF THE BUDGETED PROFIT MARGIN AND RISK RESERVATION (SOURCE: OWN GRAPH, EXTRACTED FROM SPSS)

Hypothesis 14 is accepted, the budgeted profit margin is correlated with the budgeted Risk reserve.

- Hypothesis 15: The project's risk profile is dominantly caused by the project's indirect costs over the direct costs.

The project's risk profile is primarily based on the result booked in the project's bare costs. The case studies showed that the major budget overruns are booked in the indirect time-dependent cost types and thus in the indirect cost category. The hypothesis assumes that the indirect cost category has the greatest influence on the project's risk profile. The descriptive statistics of the direct, indirect and bare cost categories are presented in table 36. The mean values already underpin the made assumption, the

Descriptive Statistics

	N	Minimum	Maximum	Mean		Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic	Std. Error	Statistic	Std. Error
Direct costs	49	-16.08%	27.38%	2.1917%	1.09810%	7.68668%	.216	.340	1.964	.668
Indirect costs	49	-117.48%	9.04%	-29.0626%	3.68548%	25.79836%	-1.305	.340	2.363	.668
Bare costs	49	-24.8%	12.7%	-2.472%	1.0859%	7.6013%	-.708	.340	.937	.668
Valid N (listwise)	49									

TABLE 36: DESCRIPTIVE STATISTIC OF PROJECT’S DIRECT, INDIRECT AND BARE COSTS (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)

direct costs show a positive result, while the indirect costs category has a large negative mean value. A student’s t-test is executed to test if there exists a significant difference between the mean value of both variables. A paired samples t-test is executed, rather than the independent samples t-test. First is tested for a significant correlation between the two variables, which is not tested significant. The correlation is 0.249, with p-value of 0.084 and N=49.

The project’s bare costs is correlated with both the direct costs and the indirect costs, as is expected with the current calculation method. The largest correlation is found between the direct costs and the project’s bare costs, what is also expected. The reason for this assumption is that the direct cost category counts for approximately 75% of the project’s bare costs and thus also has the largest influence. However, the fact that the direct costs and indirect costs are not correlated means, that a project that performs good in the direct cost types does not necessarily performs good in the indirect cost types, or the other way around. Different factors influence these two cost categories. The results of the paired samples t-test are presented in table 37. There is indeed a difference between the variables, in which the indirect cost variable is predominantly causing for the project’s risk profile.

Paired Samples Test

	Paired Differences						t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference					
				Lower	Upper				
Pair 1 Direct costs - Indirect costs	31.22657%	25.00625%	3.57232%	24.04394%	38.40921%	8.741	48	.000	

TABLE 37: PAIRED SAMLES TEST OF DIRECT AND INDIRECT COST VARIABLES (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)

Hypothesis 15 is accepted, the project’s risk profile is predominantly caused by the project’s indirect costs over the direct costs.

The second round of analysis consisted of fifteen additional hypotheses, combined with the twelve hypotheses based on the unique character of the project, makes a total of twenty-seven hypotheses. The twelve other hypotheses tested in this second round of analysis are not in greater detail discussed, all statistical tests can be found in appendix F section 6.3. Only the main findings will be highlighted in the current section. The project organization cost type is correlated with the indirect costs category, as already was assumed after the case studies. The project organization therefore consists of a portion of the project’s risk profile. The engineering cost category is not correlated with the indirect costs category, what was assumed. However, important to mention is that the sample size of the engineering cost type is only N=25. The engineering and project organization cost types are not correlated.

The project type and year of procurement were also not associated or correlated with the project’s risk profile. Further testing is done towards the four significant project characteristics in relation to specific cost types. However, only the concretization phase is significantly associated with the amount of additional work. The presence of a concretization phase results in a significant mean difference of 9.47%. This proves the assumption that a concretization phase result in more mutual trust and a higher willingness by the client to accept additional work. Additional work is on the other hand not directly related to the project’s risk profile. The construction pace, project organization and design



innovativeness characteristics are not correlated to a specific cost type. Finally, the quality of risk management and the budgeted Risk reserve is assumed related to financial project success. However, due to the cost documentation inconsistencies, current research is unable to test this relation. What is possible to test based on the current database, is the quality of the budgeted Risk reserve over the last five years. The difference between the budgeted and required Risk reserve is added as additional test variable, which is tested for a relation with the year of procurement variable.

- *Hypothesis 16: The year of procurement is correlated with the difference between Risk reserves.*

The hypothesis is aimed at the difference between Risk reserves over the years and if the quality within the budgeting practices are improved. After excluding projects 4 (Parkeergarage Tournooiveld) and 15 (N421 Ontwerp, aanleg, beheer en onderhoud) both variables are normal distributed. The results of the correlation analysis are to be found in table 38. There is not a correlation between the two variables, meaning that the gap between budgeted and required Risk reserve remained the same over the years. Figure 37 shows the scatterplot of the two variables. The years are placed on the x-axis and the difference between Risk reserves on the y-axis. The dots are not placed in such way that an upward slope can be spotted visually. The interpolation line show that it is not possible to observe a learning curve. The drop after 2014 is especially interesting, after a positive slope towards 0% difference.

TABLE 38: CORRELATION ANALYSIS BETWEEN DIFFERENCE RISK RESERVATION AND REQUIRED RISK RESERVATION (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)

		Correlations	
		Quality risk management	Year of procurement
Quality risk management	Pearson Correlation	1	-.005
	Sig. (2-tailed)		.971
	N	47	47
Year of procurement	Pearson Correlation	-.005	1
	Sig. (2-tailed)	.971	
	N	47	47

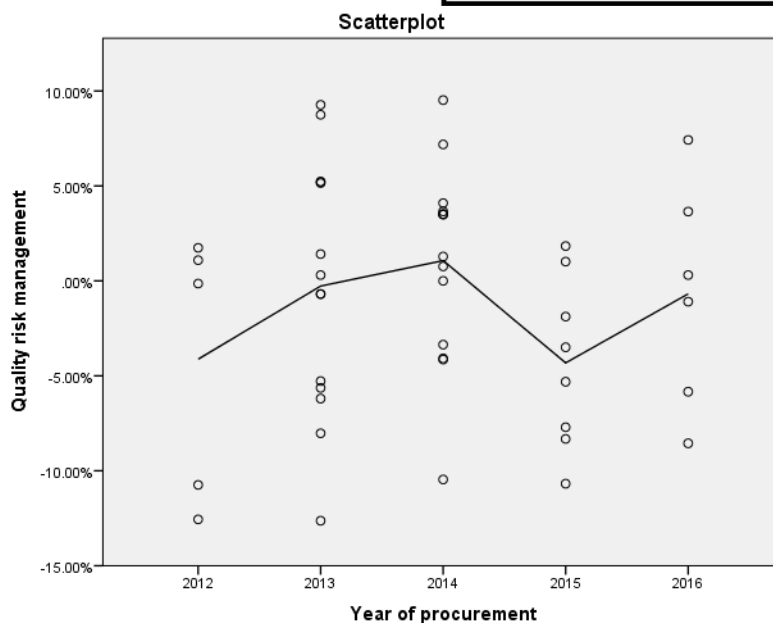


FIGURE 37: SCATTERPLOT OF THE YEAR OF PROCUREMENT AND DIFFERENCE RISK RESERVATION (SOURCE: OWN GRAPH, EXTRACTED FROM SPSS)

Hypothesis 16 is rejected, the year of procurement is not correlated with the difference between Risk reserves.

5.3.1 Findings second round

The four highlighted hypotheses in this second round of analysis provide further insight in the different relations defined in the validated model, presented in figure 26. The quality of the budgeted Risk reserve is tested in hypothesis thirteen. Table 34 and figure 35 present the test result and show a small correlation between the budgeted and required Risk reserve. This indicates low quality in the current

budgeting approach, but this is tested further in the sub-sequent section through regression analyses. Besides, the budgeted Risk reserve is on average also approximately 1% too low. This is an indication of a risk perception that is too optimistic and/or strong market conditions affecting the budgeted Risk reserve. The difference between the budgeted and required Risk reserve also did not improve over the last five years. Especially 2014 was a bad year with respect to the budgeted Risk reserve.

The external factor 'market condition' is operationalized through the budgeted profit margin and is significantly correlated with the budgeted Risk reserve, as is shown in table 35. The market conditions should not affect the Risk reserve that is budgeted, only the budgeted profit margin. High market conditions do not result in a lower project's risk profile. The risk profile remains the same, but there is less Risk reserve budgeted to cope for the financial risks in the project. Market conditions thus affects the accuracy in the Risk reserve.

The case studies showed that the budget overruns in the indirect costs were the main driver of the required Risk reserve. This is confirmed by hypotheses fifteen. The risk profile is predominantly caused by the indirect costs, with a mean value of -29.02%. The direct costs variable has a mean value of 2.19%, the difference is thus more than 30% based on the mean values. The difference in average values between the direct costs (2.34%) and indirect costs (-15.87%) is smaller with a difference of 18.2%. However, this is still a large difference and confirms the assumption that the indirect costs include the largest financial risks. The project organization cost type is correlated with the indirect cost category, meaning that this specific cost type consists of a large portion of the project's risk profile. The phenomena Student's syndrome and Parkinson's law are explained as external factors that mainly affect the indirect time-dependent cost types. The increased project's risk profile in the indirect cost category and project organization cost type are an indication of the influence of these phenomena.

The concretization phase is associated with the project's risk profile, in the sense that the presence of such phase results in a lower required Risk reserve. The amount of additional work is tested for an association with the concretization phase characteristic, which is indeed significant. Increased trust by the client in the contractor is expected to cause this association, because a concretization phase result in more additional work approved by the client. However, there is no direct correlation between the project's risk profile and the amount of additional work. Meaning that other factors influence the association between the concretization phase and the required Risk reserve. Based on the case studies can be expected that a clearer division of roles can be such reason.

To conclude the two rounds of statistical analysis, four project characteristics are significantly related to the project's risk profile. These characteristics are the construction pace, project organization, concretization phase and design innovativeness. The concretization phase is associated with amount of additional work, but the amount of additional work not directly to the required Risk reserve. The quality of the budgeted Risk reserve is not good and on average too optimistic. This indicates the effect of the risk perception and market condition factors. The budgeted profit margin is correlated with the budgeted Risk reserve, what is an indication of the influence of the market conditions. The quality in the budgeting approach did also not improve over the last five years. Finally, the project's risk profile is predominantly caused by the indirect cost category, and more specific, also the project organization cost type.



5.4 Regression and statistical findings

5.4.1 Introduction regression analyses

The final step in the statistical research, before the model is verified, is the regression analyses step. The individual statistical findings of the two quantitative testing rounds are combined in regression analyses. In the regression analyses is tested: (1) How the current budgeting quality is with respect to the Risk reserve, thus based on the 'inside view'; and (2) What the quality is of the project's risk profile based budgeted Risk reserve, thus following the 'outside' view. The first regression analysis is a simple regression analysis, with a single predictor. The second regression analysis is a multiple regression analysis, with more than one predictor. Recapitulating the conditions that apply to the multiple regression analysis:

1. All variables should be of the interval or ratio level of measurement;
2. The relation between predictor(s) and dependent variable has to be linear;
3. There has to be causality between predictor(s) to dependent variable;
4. Independence of observation has to be proved;
5. Homoscedasticity, or equality in variance, has to be proved;
6. (Multicollinearity must be excluded); and
7. Normality of residuals has to be proved;

The first condition is already a difficulty in the project characteristics concretization phase and project organization. However, a regression analysis with categorical independent variables is possible as well. It only requires that the categorical variables are replaced for 'dummy variables' in the form of a dichotomous, numerical variable. The dummy variable is thus either a 0 or a 1, based on the initial category. For the concretization phase, the yes group is transformed in a '1' and the no group in a '0'. The same is done for the organization characteristic, the partnership group is replaced by a '1' and the Dura Vermeer group by a '0'. Through these transformations, all five independent predictors (the four project characteristics and the budgeted Risk reserve) are now continuous variables. Linearity is already proved in the statistical analysis. Causality is also qualitatively judged based on theory and practical findings.

Independence of observations is an assumption in the multiple regression as well. In SPSS the Durbin-Watson statistic can be calculated simultaneously with the regression analysis. A value between 1.5 and 2.5 means that there is independence between the observation. Two other important assumptions in multiple regression is multicollinearity and homoscedasticity. Homoscedasticity means that the variance remains the same for all values of the independent variables. Based on the regression analysis a best fit line is calculated that explains the dependent variables, based on the significant predictors. As the input values for this best fit line change, the variance should remain the same.

A scatterplot of the dependent variable is used to determine if the data indeed shows homoscedasticity. The scatterplot is based on regression standardized residual values and regression standardized predicted values. The background of these parameters falls outside the scope of the current research. However, what is important is how to interpret this scatterplot. The dots in the scatterplot should be scattered in a rectangular shape for homoscedasticity. Heteroscedasticity means that the variance is not equal for all values of the best fit line. The scatterplot is in such case more triangular shaped. The scatterplot can be drawn by SPSS in the same process of the regression analysis.

Multicollinearity means that two or more independent variables are highly correlated to one another. Small correlations between independent variables can be accounted for in the regression analysis, but large correlations will lead to problems in understanding what characteristic has for influence on the dependent variable. SPSS includes an option called collinearity diagnostics that is able to measure the correlation between the variables. The Tolerance and VIF statistics are calculated in this collinearity diagnostics. The tolerance should be > 0.1 and the VIF < 10 . Finally, normality of residuals has to be

tested. A histogram (with a superimposed normal curve) and a Normal P-P Plot of the residuals can be plotted to test for this normality.

A final hurdle has to be taken before the multiple regression analysis towards the ‘proposed approach’ can be executed. All four independent variables that tested significant for a correlation or association are analysed individually. However, three of the four correlations required a database manipulation in terms of exclusion of multiple projects. For the construction pace, it was required to the following three projects:

- Project 35 - Renovatie Buitenrustbruggen Haarlem;
- Project 48 - Missouriweg; and
- Project 52 - Tilburg – Loven DVRI.

The association of the project organization required the exclusion of:

- Project 1b - Ruimte voor de waal Nijmegen (Bruggen);
- Project 4 - Parkeergarage Tournooiveld; and
- Project 42 - Perceel 1 Willems- en Wilhelminaplein.

The concretization phase resulted in an association after excluding two projects, namely:

- Project 4 - Parkeergarage Tournooiveld; and
- Project 16 - N421 ontwerp, aanleg, beheer en onderhoud.

The appropriate database manipulation is dependent on the predictors with the highest influence on the required Risk reserve. This is examined through the methodology of trial and error, thus through multiple attempts is searched for the best fit. The model that explains the dependent variable with the highest R statistic and is tested significant is considered further. This methodology thus result in four attempts, based on four different datasets. However, a regression model can be tested with and without a model constant. This is the constant term in the linear equation, the starting point of the equation with all variables set to zero, also called the intercept. Each model is also calculated with and without a constant, resulting in four regression analyses, each based on two variants. All eight attempts are described and analysed in appendix F sections 6.2 and 6.3. Current section only includes the model that is considered further. The stepwise method is used in the inclusion of the predictors, this to ensure a parsimonious model and overcome ‘overfitting’.

5.4.2 regression analyses

The model with the highest R statistic and R^2 is based on the construction pace manipulated database, without a constant. The constant was in all regression analyses not found significant and therefore excluded from the model. The regression analysis based on the construction pace manipulated database was expected to result in the inclusion of that independent variable in the model. However, only the innovative design and organization characteristics are included in the regression. This is true for all regression analyses, only these two characteristics are added to the model. After further examination of the correlation between the construction pace and the innovative design and organization variables it becomes clear why the construction pace is not included. The correlation is high between these

variables, the innovative design and organization thus already explains much of the correlation of the construction pace with

Model Summary^{d,e}

Model	R	R Square ^b	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.527 ^a	.278	.261	7.18927%	
2	.647 ^c	.419	.391	6.52502%	1.573

a. Predictors: Innovative design

b. For regression through the origin (the no-intercept model), R Square measures the proportion of the variability in the dependent variable about the origin explained by regression. This CANNOT be compared to R Square for models which include an intercept.

c. Predictors: Innovative design, Organization 2

d. Dependent Variable: Required risk reservation

e. Linear Regression through the Origin

TABLE 39: MODEL SUMMARY REGRESSION ANALYSIS WITHOUT CONSTANT, BASED ON CONSTRUCTION PACE MANIPULATED DATABASE (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)



the required Risk reserve. Table 39 present the model summary of the regression analysis without the constant. These results are based on a sample size of N=46.

Coefficients^{a,b}

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Collinearity Statistics	
	B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1 Innovative design	1.679	.414	.526	4.056	.000	.844	2.514	1.000	1.000
2 Innovative design	2.639	.480	.827	5.497	.000	1.670	3.607	.612	1.635
Organization 2	-8.924	2.782	-.482	-3.208	.003	-14.538	-3.310	.612	1.635

a. Dependent Variable: Required risk reservation

b. Linear Regression through the Origin

TABLE 40: COEFFICIENT STATISTICS OF REGRESSION ANALYSIS WITHOUT CONSTANT, BASED ON CONSTRUCTION PACE MANIPULATED DATABASE (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)

The model has a R statistic of .647 and R^2 of .419, meaning that the model explains 41.9% of the required Risk reserve. Table 40 presents the individual coefficients of the regression analysis. The standardized beta explains which variable has the greatest impact on the model. The innovative design is in this case the leading predictor in relation to explaining the dependent variable. The unstandardized beta's are the coefficients that are finally used in the determining the dependent variable, the slope parameters in the linear equation. A partnership as project organization thus result in a required Risk reserve that is -8.92% lower than in a project realised by Dura Vermeer alone. However, these are also stochastic variables. There is thus also a confidence interval around these unstandardized beta's. The smaller the confidence interval, the higher the precision of the influence of that specific predictor. The 95% confidence interval for the organization variable can be seen as large and that of the design innovativeness is normal.

The collinearity statistics is within the appropriate boundaries, based on the tolerance and VIF statistics. The same counts for the independence of observations, based on the Durbin-Watson statistic. Homoscedasticity and a normal distribution of the residuals are confirmed graphically as well. The stepwise method ensures that the largest amount of explanation of the dependent variable is reached with the least number of predictors. The method is checked by including the concretization phase variable in the regression analysis. The R^2 increased with 0.02, what is only a small improvement. However, the t-test did not result in a significant t-statistic for the added variables. The model based on the design innovativeness and project organization characteristics can thus explain the required Risk reserve for 41.9%. The standard error of the estimate is 6.53%, meaning that 95% prediction interval is plus and minus 13.06%. A R^2 of 0.7 or more can be seen as high, a R^2 between 0.5 and 0.7 is a moderate explaining factor and a R^2 between 0.3 and 0.5 is low. A R^2 below 0.3 is very low and therefore negligible. The quality of the regression model, based on the 'outside view' can thus be classified as 'low'.

A second regression analysis is conducted to determine quality in the current Risk reserve budgeting approach, based on the 'inside view'. The same procedure is followed as in the multiple regression analysis. However, only two regression analyses are executed, both having two variants. The first regression analysis is based on the complete database, with the two variants, with or without constant. The second attempt is based on the construction pace manipulated database, also with the two known variants. As in the multiple regression analysis, the regression model based on construction pace manipulated database without the constant resulted in the highest explaining factor. However, the R^2 of the model based on the complete database is only 0.005 lower. The results of the regression analysis are presented in table 41.

The R^2 of the regression model is 20.1%. Again, the Durbin-Watson test is correct and the ANOVA tested significant. Homoscedasticity and a normal distribution in the residuals is accepted as well. However, the R^2 of the model is very low and for that reason also negligible. The regression model

based on the project characteristics resulted in a R^2 .419. The difference in explaining power between both models is 21.8%, what is more than double of the budgeted Risk reserve regression model.

Model Summary^{c,d}

Model	R	R Square ^b	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.448 ^a	.201	.183	7.41718%	1.908

a. Predictors: Budgeted risk reservation

b. For regression through the origin (the no-intercept model), R Square measures the proportion of the variability in the dependent variable about the origin explained by regression. This CANNOT be compared to R Square for models which include an intercept.

c. Dependent Variable: Required risk reservation

d. Linear Regression through the Origin

TABLE 41: MODEL SUMMARY REGRESSION ANALYSIS WITHOUT CONSTANT, BASED CONSTRUCTION PACE MANIPULATED DATABASE (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)

The final regression analysis that is conducted combines the four project characteristics of the first regression analysis with the budgeted Risk reserve as predictors of the required Risk reserve. The regression shows which predictors are included in the model and the standardized Beta explains which of the predictors have the greatest influence on the predicted variable. The model summary of the regression analysis is presented in table 42. The second step in the regression analysis is based on the innovative design and organization predictors. Within the third and final step the budgeted Risk reserve variable is included as predictor. This indicates that the budgeted Risk reserve has a smaller influence on the required Risk reserve, than the two other predictors. However, the R^2 improved to 0.492, but also the standard error of the estimate reduced with 0.35%. The Durbin-Watson and ANOVA tests are significant.

Model Summary^{e,f}

Model	R	R Square ^b	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.526 ^a	.277	.260	7.19777%	
2	.647 ^c	.419	.391	6.52701%	
3	.702 ^d	.492	.455	6.17652%	1.690

a. Predictors: Innovative design

b. For regression through the origin (the no-intercept model), R Square measures the proportion of the variability in the dependent variable about the origin explained by regression. This CANNOT be compared to R Square for models which include an intercept.

c. Predictors: Innovative design, Organization 2

d. Predictors: Innovative design, Organization 2, Budgeted risk reservation

e. Dependent Variable: Required risk reservation

TABLE 42: MODEL SUMMARY REGRESSION ANALYSIS WITHOUT CONSTANT, BASED ON CONSTRUCTION PACE MANIPULATED DATABASE INCLUDING THE BUDGETED RISK RESERVATION VARIABLE (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)

Table 43 presents the individual coefficients of the predictors. The collinearity statistics are within boundaries, thus accepted. The t-test is for all three predictors at least significant at the 0.05 level, what is logical within the stepwise regression method. The standardized Beta coefficient is therefore comparable between the three predictors. The absolute value should be compared and thus ignoring the difference between negative and positive Beta's. As was expected after the inclusion of the budgeted Risk reserve in the third step, the budgeted Risk reserve has a smaller influence on the required risks reservation than the project characteristics innovative design and organization. The combination of the current approach and the proposed approach, resulted in larger explaining factor in the regression model. This put strength in the preferences of the interviewees in the case studies. Six of the seven interviewees opted for a combination of the 'outside view', based on historical data and the project's risk profile, and the 'inside view', based on the current approach with the risk register and expert judgement.



Coefficients^{a,b}

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1	Innovative design	1.679	.414	.526	4.056	.000	.844	2.514	1.000	1.000
2	Innovative design	2.639	.480	.827	5.497	.000	1.670	3.607	.612	1.635
	Organization 2	-8.924	2.782	-.482	-3.208	.003	-14.538	-3.310	.612	1.635
3	Innovative design	2.237	.483	.701	4.627	.000	1.261	3.213	.540	1.852
	Organization 2	-9.654	2.649	-.522	-3.644	.001	-15.004	-4.303	.604	1.656
	Budgeted risk reservation	.765	.315	.311	2.429	.020	.129	1.401	.756	1.323

a. Dependent Variable: Required risk reservation

b. Linear Regression through the Origin

TABLE 43: COEFFICIENT STATISTICS OF REGRESSION ANALYSIS WITH CONSTANT, BASED ON ALL PROJECTS (SOURCE: OWN TABLE, EXTRACTED FROM SPSS)

5.4.3 Statistical findings

The third research phase is closed with a summary of the findings produced in the statistical research and compares these with the validated model derived in the practical study. The two rounds of statistical analyses consisted of twenty-seven hypotheses, aimed at the different relations that are assumed in the validated model. From the twelve identified project characteristics, only four are tested significant in a relation with the project's risk profile. The construction pace, project organization, concretization phase and design innovativeness are these four characteristics. The concretization phase is associated with the amount of additional work, meaning that more additional work is accepted by the client in case of the presence of a concretization phase.

The budgeted Risk reserve is weakly correlated with the required Risk reserve, what indicates a poor quality in budgeting the Risk reserve. The quality of the budgeted Risk reserve, did also not improve over the last five years. The budgeted Risk reserve is on average 1% too low, which also explains the difference between the budgeted (0.59%) and the realised profit margin (-0.54%). The external factors risk perception and market conditions can potentially influence the accuracy and precision in the budgeted Risk reserve. However, only the market condition is tested significant through a correlation between the budgeted Risk reserve and profit margin. Final individual finding is that the project's financial risk profile is predominantly caused by the indirect time-dependent cost types, like for example the project organization cost type. The indirect cost category is thus critical for the project's risk profile and the required Risk reserve.

The regression analyses combine the individual findings of the two rounds of statistical analyses. Seven regression analyses are conducted in total, each divided in two variants. A variant with a constant included in the model and a variant without the constant. These regression analyses resulted in three regression models explaining the quality of the: (1) Current approach in budgeting the Risk reserve; (2) proposed approach in budgeting the Risk reserve; and (3) combined approach in budgeting the Risk reserve. The current approach is based on the risk register and expert judgement and tested through the regression analysis of the budgeted Risk reserve as predictor of the required Risk reserve. The regression model showed a R^2 of 20.1% and a standard error on the estimate of 7.42%. The 95% prediction interval is thus plus and minus 14.54%.

The regression model based on the construction pace manipulated database, with no constant included, explains the required Risk reserve better than the current approach. The design innovativeness and project organization characteristics are the two predictors in the regression model. The construction pace and concretization phase are excluded from the model. The highest explaining model resulted in a R^2 of 41.9% and a standard error on the estimate of 6.53%. The 95% prediction interval is thus plus and minus 13.06%. Based on the current database can be said, that the proposed model resulted in an improvement of 21.8% in predicting the required Risk reserve. The combined quality is tested through combining the four project characteristics and the budgeted Risk reserve in a single multiple regression analysis, based on the stepwise method without constant.

The design innovativeness and project organization characteristics are the predictors with the largest influence on the model, but the budgeted Risk reserve is also included as third predictor. The regression model has a R^2 of 49.2% and a standard error of 6.18%, resulting in a 95% prediction interval between plus and minus 12.11% of the estimate. The combined approach shows the best result in predicting the required Risk reserve. This approach had the largest preference within the opinions of the interviewees in the case studies. Six of the seven interviewees preferred the combined approach.

However, the difficulty of the combined approach, as presented in the regression model, is the budgeted Risk reserve as predictor of the Risk reserve. A Risk reserve has to be budgeted based on the traditional method, the 'inside view', in order to determine the actual height of the budgeted Risk reserve. This is a difficult construction in determining the Risk reserve and is also not goal of the current research. This research is aimed on historical data and the relation between the project's risk profile and the unique character of a project. Important is to quickly analyse the quantified or classified project characteristics, to determine the project's risk profile and Risk reserve. The Risk reserve can be calculated by the following equation, based on the proposed approach:

$$\text{EQUATION 9: } \textit{Required risk reservation} = 2.639 * \textit{innovative design score} - 8.924 * \textit{project organization dummy score}$$

The goal of the research is to improve the accuracy and precision in budgeting the Risk reserve. However, current statistical research only includes terminology like 'improved quality' or 'higher explaining factor', but not accuracy and precision. These parameters are discussed in greater detail in chapter six towards the research result. The theoretical model that is validated in the practical study, is verified in the current research phase. This quantitative research part used statistical techniques to test relations that are assumed in the validated model, presented in figure 26. The validated and verified model is discussed in section 6.1, as important part of the research result.



6. Research result and discussion

The research steps are graphically explained in figure 38. The three research phases are finished, which results in a model that is theoretically designed, qualitatively validated and quantitatively verified. The validation of the model is based on the practical findings, and the verification occurred through statistical testing techniques. The post-research section of the thesis is based on two phases. The first phase elaborates on the descriptive and predictive model, the accuracy and precision parameters and how to use the research results. The problem defined in the introduction phase is translated into a research objective. This objective, or goal, is evaluated by comparing it with the research results as a feedback loop. The research relevance is discussed in the introduction as well, and it is evaluated in the discussion. The discussion also elaborates on the validity of the results and limitations of the research.

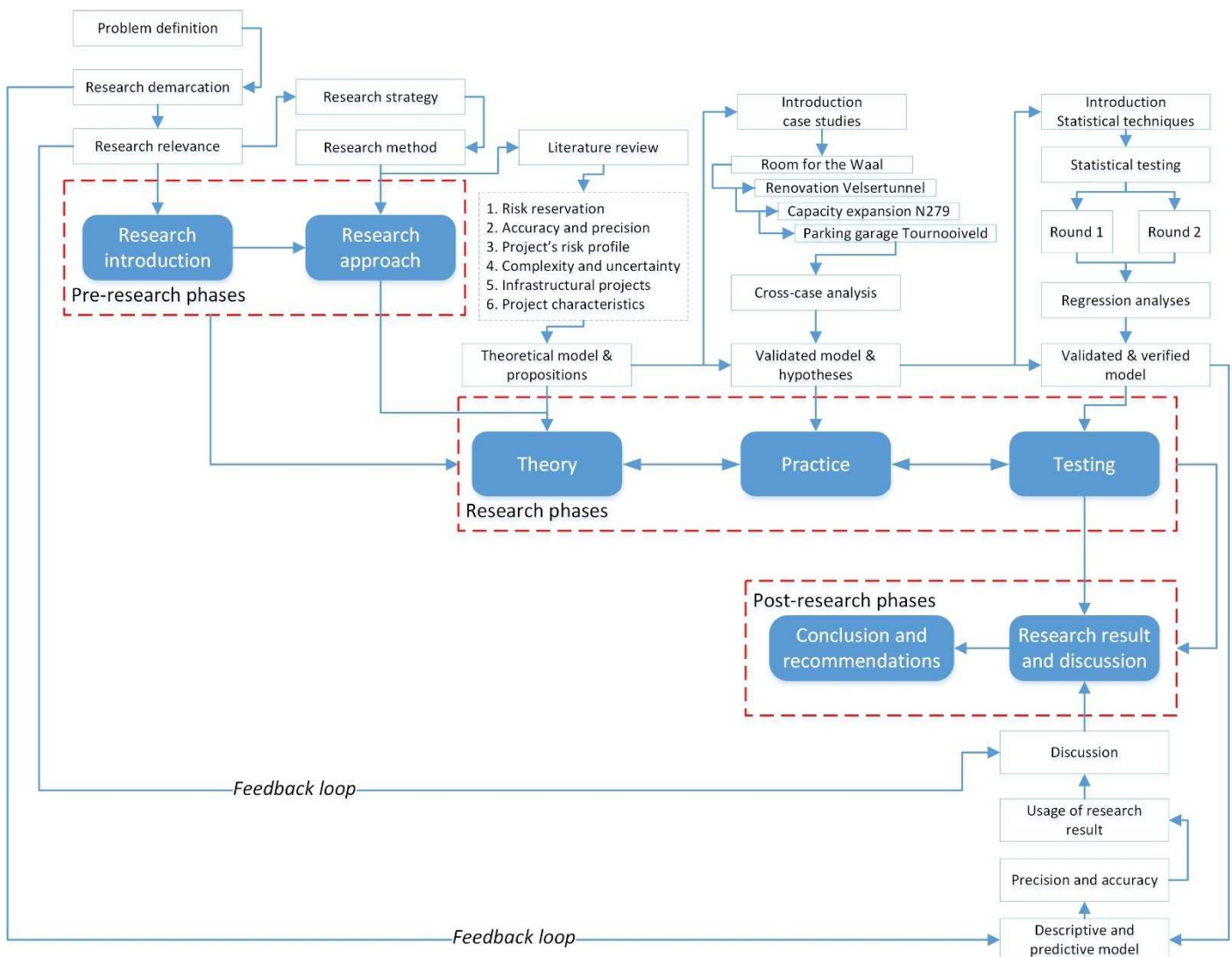


FIGURE 38: RELATIONS RESEARCH PHASES AND STEPS EXPLAINED GRAPHICALLY, RESEARCH RESULT AND DISCUSSION (SOURCE: OWN ILL.)



6.1 Descriptive and predictive model

The result of the current research is two-fold. The descriptive and predictive model is the first research result, but the second is the current thesis that contains the actual research that has led to the model. The abovementioned model is first elaborated on in relation to the research objective defined in section 1.2. The objective of the research is as follows:

To create a framework that can explain the relationship between a project and its complexity, uncertainty, risk profile and the required risk reserve in order to predict this risk reserve with improved accuracy and precision based on these relations for DVDI.

The research objective can be divided in three elements. The first element is the descriptive element, which asks for a framework that can explain the relationship between the project, complexity, uncertainty, risk profile and required risk reserve. The second element is the predictive element, which is based on calculating the required risk reserve through the explained relations. The final element is that of accuracy and precision. The prediction of the required risk reserve should lead to increased accuracy and precision for future projects realised within DVDI. The three elements are explained in the mentioned order. The section finishes with the usage of the model.

First, the descriptive part of the research results is discussed. The framework, or model, displayed in figure 39 presents the relations between project success, risk reserve, risk profile and the project's unique character. The model started as a theoretical framework that has been qualitatively validated based on practical findings and quantitatively verified based on statistical findings. Three major differences are observed in relation to the validated model, presented in section 4.4 in figure 26. The first is the unique character of the project. It is explained by the 12 project characteristics, but only four of these characteristics are significantly related to the project's risk profile. The X_1 to X_4 in the model stand for project characteristics: construction pace, project organisation, concretisation phase and design innovativeness. The second difference is observed in the influence of the phenomena of student's syndrome and Parkinson's law. These phenomena have a risk-increasing effect on the indirect cost category.

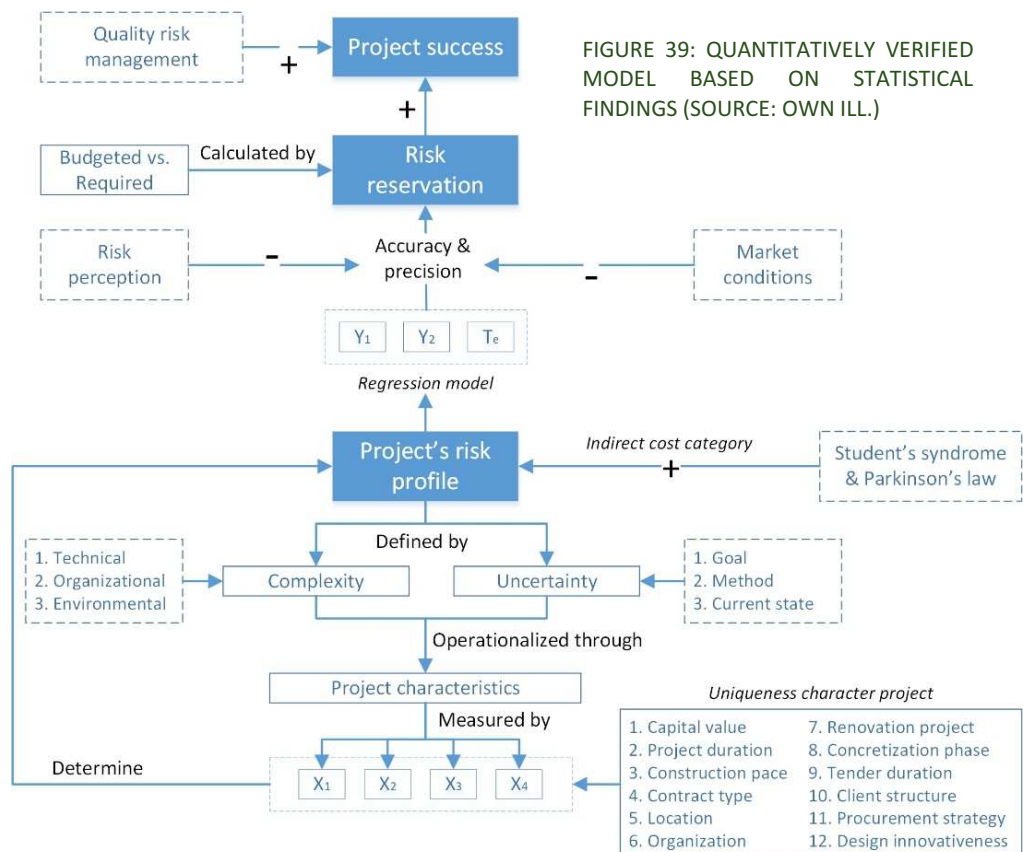


FIGURE 39: QUANTITATIVELY VERIFIED MODEL BASED ON STATISTICAL FINDINGS (SOURCE: OWN ILL.)

The external factors of market conditions and risk perception still negatively affect the accuracy and precision of the risk reserve. The budgeted risk reserves of the projects analysed in the statistical research are 1% too low on average. This is an indication of a risk perception that is too optimistic or an implication of fierce market conditions. The budgeted profit margin is correlated with the budgeted risk reserve, which is also an indication of the effect of market conditions on the risk reserve. The final difference can be seen in the 'regression model' element between the risk reserve and risk profile. This final difference in the model is also the second element of the research objective, the predictive element.

The predictive element of the research results is ensured through a multiple regression analysis in which the four critical project characteristics were included as predictors of the required risk reserve. The regression model with the highest explanatory ability of the required risk reserve is based on the characteristics of design innovativeness and project organisation. These characteristics are presented in the model by the Y_1 and Y_2 . The regression model has a R^2 of 41.9% and a standard error of 6.53%.

$$\text{EQUATION 10: Required risk reserve} = 2.639 * \text{innovative design score} - 8.924 * \text{project organization dummy score}$$

Besides the Y_1 and Y_2 , the regression model in figure 39 also includes a T_e . The final element of the research objective, improved accuracy and precision, is explained by this T_e . The parameters of accuracy and precision are closely related, but are not mutually dependent. Figure 40 graphically explains these two parameters. The accuracy of the of the regression model and equation 10 is the R^2 , thus 41.9%. The inaccuracy is thus 58.1%, which is presented in the regression model in figure 39 by the T_e . The statistical research used the term 'explaining factor', but it is actually the accuracy of the model's determination of the dependent variable, the required risk reserve. The precision of the regression model has also already been mentioned. The standard error of the estimate of 6.53% is the measure of precision.

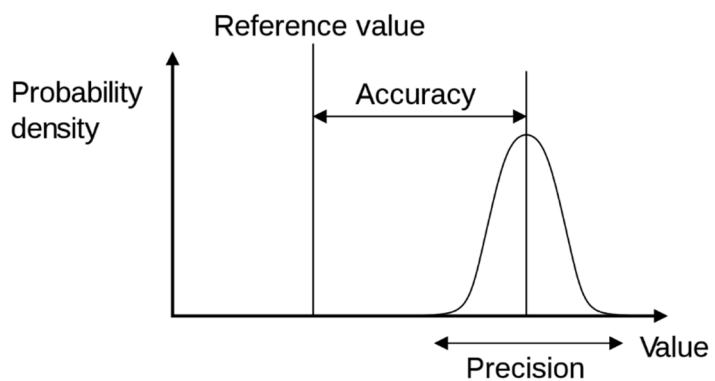


FIGURE 40: ACCURACY AND PRECISION IN A STOCHASTIC VARIABLE (SOURCE: ANTHONY CUTLER, 10-02-2007)

The accuracy of the proposed method, based on the 'outside view', is 41.9%, which is low. The precision of the model, however, is very small, with a standard error of 6.53%. The observations fall within 1.96 times the standard error from the regression line, which means that prediction interval is plus or minus 13.06%. The average required risk reserve is 3.53%, so the 95% prediction interval is thus approximately seven times larger than the mean value. The goal was to improve the accuracy and precision of the budgeted risk reserve in future projects. However, the regression model based on the unique character of the project does not result in reliable and valid predictions.

In order to judge the quality of the proposed model, the quality of the current approach is first measured, which means that the accuracy and, more importantly, precision are determined for the current approach in the budgeted risk reserve. The model summary of the regression model with the budgeted risk reserve as a predictor is presented in table 41. The R^2 of the current approach is only 20.1%, which indicates that the accuracy is very low. The proposed model thus shows an improved accuracy of more than 108%. The standard error of the current approach is 7.42%, which implies that precision is even worse in the current approach. The 95% prediction interval is nine times larger than the average required risk reserve. The improvement in the precision is 12%, which is substantive. However, despite the improved accuracy and precision, the proposed model, which is based on



historical data that explains the unique character and risk profile of the project, remains too unreliable to be used directly in future business practices.

This does not mean that the research result should not be used at all. On the contrary, the model and the descriptive framework should be used. It is important to note that the current approach is even worse and therefore questionable. During the interviews in the case studies, the interviewees' preference of a combined approach was observed. This is an approach in which the traditional method, based on the risk register and expert judgement, and the proposed method, based on historical data, are combined. A regression analysis was executed to determine the accuracy and precision of the two approaches combined. The R^2 of the model was found to be 49.2% and the standard error is 6.18%. This leads to an improvement of 17.4% in the accuracy and 5.4% in the precision. However, this not an improvement that results in an actual prediction model that is accurate and precise enough to be directly used. Consequently, the input of expert judgement is based on unquantifiable and subjective information. It is difficult to include such measures in a quantitative regression model.

The proposed model is thus too imprecise to be used directly, so the model should solely be initially used as 'thermometer'. The regression model should be used a quick reference to measure the project's risk profile to determine if the project is risky or safe. The predictive model requires more improvements to be directly used in budgeting the risk reserve, especially in terms of precision. The descriptive element of the research result, explained graphically in figure 39, is more valuable. The insights that the framework provides are important for future budgeting of risk reserves. The risk reserve accuracy and precision is important in order to achieve financial success in projects. However, the external factors of risk perception and market conditions affect these quality parameters, and the market conditions factor especially should be excluded from the decisions in the budget of the risk reserve. On average, the risk reserve is 1% too low, which results in an average profit margin of -0.5%.

The general practices in project and risk management during the realisation phase are also critical to the financial success of projects. This topic is omitted from the scope of the current research. What is discussed in great detail is the project's risk profile. The time-dependent indirect cost types, like UTA staff, engineering and construction site equipment, showed the largest budget overruns. The financial risk profile is mainly concentrated on these types of costs. The phenomena of student's syndrome and Parkinson's law, combined with the risk of not meeting the deadline, are the main reasons for this increased risk profile. The project aspects of complexity and uncertainty are interrelated and can be explained as the two dimensions of the project's risk profile. These two project aspects were defined in three different sub-dimensions, but more importantly, they were operationalised through a set of project characteristics.

The 12 identified project characteristics explain the unique character of the project. These project characteristics thus explain the 'fingerprint' of the project and enable the comparability of different projects. This unique character can therefore also be used for testing different relations between the project characteristics and test variable(s). However, for future projects, it is important to consider the effect of the construction pace, project organisation, concretisation phase and design innovativeness on the required risk reserve. These characteristics should be considered when budgeting the risk reserve. Other project characteristics also influence the risk reserve, such as the contract type and project site location. The mean value differences are just not high enough (more than 5%) to test as significant based on the current database. However, based on the current research results, it can be said that the budgeted risk reserve requires improvements to increase its accuracy and precision. Another important finding is that the level of innovativeness in the design has the greatest influence on the project's risk profile.

6.2 Discussion

The second section of the current chapter is aimed at the discussion. The discussion focusses on three discussion points with respect to the research. First, the validity and reliability of the research results are discussed. Secondly, the contribution of the research to the scientific world is explained. Finally, a discussion is presented about the limitations of the research.

6.2.1 Validity and reliability of research result

The research result presented in the previous section is divided into predictive and descriptive research results. The predictive model can explain the required risk reserve with an accuracy of 41.9% and a standard error of estimate of 6.53%. The accuracy is low, and the precision is very low, such that it can be said that the predictive model is 'unreliable' and 'invalid'. These two terms are graphically explained in figure 41. The predictions of the proposed regression model are shown in the first target, in which the final target is the actual goal of such regression model. The accuracy should be 70% or higher, and the prediction interval should not be more than 4%, thus the standard error would be 1%.

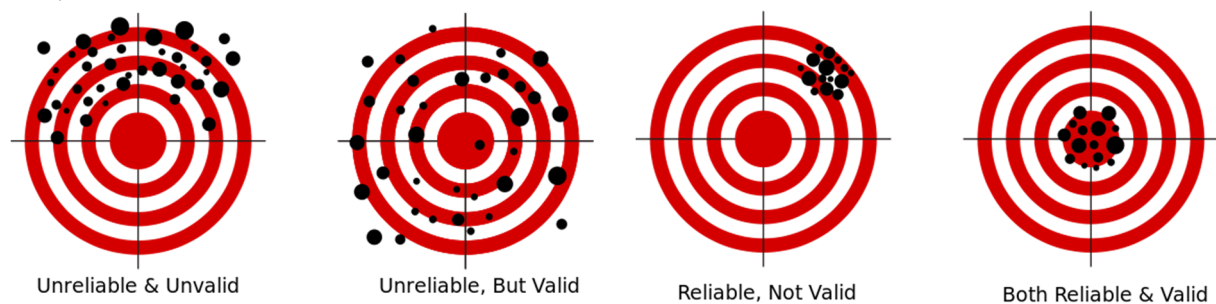


FIGURE 41: RELIABILITY AND VALIDITY IN OBSERVATIONS (SOURCE: NEVIT DILMAN, 2012, EXTRACTED FROM WIKIPEDIA)

Accuracy offers information about the difference between the estimate and the true value; accuracy can be described through statistical bias, and it is caused by systematic errors. Precision dictates the bandwidth of the estimate and can be described through statistical variability caused by random errors. Both concepts are independent from one another. Statistical variability due to random errors is the largest problem in the predictive model. The main cause of the imprecision is the large variance in the required risk reserve variable. The inconsistency in documentation of the costs due to risks is potentially a reason for this large variance. The initial operationalisation of the project's risk profile was not found to be usable due to the aforementioned inconsistency. Therefore, the required reservation was calculated to function as the operationalisation for the project's risk profile. However, this resulted in a large spread in the variable, which rendered such regression analyses difficult.

The descriptive research result is the framework presented in figure 39. It explains all of the identified relations between the unique character of the project and ultimately the risk reserve and financial project success. The validity and reliability of this second research result is ensured through the chosen research approach. The research strategy is based on both (1) deduction and induction and (2) validation and verification. The model was designed based on theoretical findings, validated qualitatively from a practical point of view and verified quantitatively through statistical testing techniques. These steps are also the three research phases, and each phase is based on different types of research methods.

The theoretical and practical phase provides the 'soft evidence', and the statistical phase offers the 'hard evidence'. To ensure the trustworthiness level in each research phase, besides the different research methods, different sources of information were also used. For example, the practical phase was based on three sources of information, namely a documentation review and two individual interviews. The research result is valid because it is based on theory, practice and statistics. However, the factor that most influences the reliability and validity is the researcher's preference and the ability to guide the research in a certain direction. Interpretations of the examined theory in the literature and



the findings in the case studies are sensitive to the influence of the researcher's preference. This sensitivity is counteracted through the application of multiple research methods and the examination of multiple sources of information. However, most importantly, the quantitative testing phase is used to overcome this potential problem of researcher preference. Finally, the database manipulations that were required for executing the testing phase reduced the validity of the research. However, the manipulations are based on grounded knowledge and are a necessity for conducting the statistical tests.

6.2.2 Scientific contribution

The research is relevant to both science and practice. There is already an extensive body of knowledge on the topics of project uniqueness, complexity and uncertainty, risk profiles of projects and risk management. However, there is extensive literature available only on these individual topics. The combination, as explained in the previous two sections, is underrepresented in literature, especially in combination with qualitative and quantitative research. The current research combines multiple research methods and strategies, which results in a framework that measures a project's risk profile based on its unique character and in relation to the risk reserve. In particular, the combination of the theoretical, practical and statistical elements makes this research unique.

The research contributes to the scientific world through its broad approach of describing a project's risk profile and relating it to the required risk reserve. The four case studies contributed to the theoretical framework by adding practical findings for a more thorough understanding of the potential relations. The statistical analyses are based on a database of 49 projects. This is the main power of this research. Most researchers do not have such large databases at their disposal, which results in studies that are based only on qualitative information. This research opportunity results from the collaboration with DVDI. However, this means that the data in the database are solely based on projects executed by Dura Vermeer. The generalisability of the research results to the entire construction sector is thus weak. The final regression model is based on two predictors, which was chosen in order to overcome database overfitting. The parsimonious model makes generalisations of the model to the construction sector as a whole somewhat simpler. However, the predictive model is still not reliable and valid enough to be used directly. The most valuable research result is the descriptive framework that explains the research topics and their relations.

6.2.3 Research limitations

The research result and the contribution to the scientific world are discussed. The final discussion topics are the research limitations. The first limitation is based on the project aspects, or project's risk profile dimensions, complexity and uncertainty. Both project aspects have been extensively studied in the literature review. However, the practical and statistical phase do not include an in-depth study of these aspects. The literature is divided over the exact relation of the aspects of complexity and uncertainty with a project's risk profile. The same holds for the definitions of complexity and uncertainty and their mutual relationship. The main difficulty rests within the relation between the project's risk profile and characteristics of the project aspects. Operationalisations of complexity and uncertainty fall outside of the scope of the current research and therefore these relations have not been statistically tested nor quantitatively verified.

The research resulted in four 'external factors' that influence the construct between the unique character of a project and the risk reserve. More in-depth research is required to precisely explain the relation of the factors to the theoretical framework. An operationalisation is required to test these relations quantitatively. The quality of risk management as an external factor is especially important and assumed to have the greatest influence on financial project success and the required risk reserve. A fifth factor that potentially influences the required risk reserve is 'experience'. The experience that the project team has with the particular type of project is assumed to influence the required risk reserve as well. This is only 'weak evidence' and not further considered in the remainder of the research.

The initial operationalisation of the required risk reserve is based on the realised costs due to the occurred risks. However, the case studies showed that this approach cannot be used in statistical tests. Inconsistencies in cost control with respect to costs due to risks makes it impossible to use the initial operationalisation. A new operationalisation is thus developed based on the results of the project's bare costs and, optionally, plus the realised risk reserve. The new operationalisation works, but it can be sensitive to more 'noise' in the data. Different factors can influence the result within the project's bare costs, which are unidentified in the framework. Another research limitation is the database size. The database consists of 49 projects. This sample size means that relations have to be strong in order to test significant. The current research is therefore only suitable for strong relations; weak relations can still be important but do not emerge. However, these weak correlations can be decisive in a sector with budgets profit margins of 0% to 3%.

Finally, an additional phase could have been included in the research to improve the quality of the research. The testing phase was based on a database of nearly 50 projects. A regression analysis was conducted to determine the predictive quality of the unique character of the project with respect to the required risk reserve. To overcome database 'overfitting', the stepwise method was applied in the regression analysis. This results in a parsimonious model that is less sensitive to overfitting. However, to test for this 'overfitting', statistics normally use only 50% to 80% of the database to calculate the regression model. The remainder of the database, 50% to 20%, is then used to test the regression model. This is final research step has not been conducted, and it is an opportunity for further research. The regression model and the descriptive framework can also be used in new projects, even outside DVDI, as an additional verification step to be able to answer the following the question: *"Did we build the system correctly?"* However, these are additional steps that are based on the actual implementation of the result in the organisation and is a research undertaking of its own.



7. Conclusion and recommendations

The final chapter of the thesis consists of two elements that are divided over three steps. Figure 42 explains these steps in combination with the other research steps already taken. This figure is also the final figure in the series of six, which are presented in advance of the chapters starting after the research approach. The answers to the sub-research questions and main research question are presented in the conclusion section of this chapter. The feedback loop in the figure means that questions are defined in the research demarcation step and answered after the research is completed. The research is completed after the introduction of the accuracy and precision parameters in relation to the research result. The five research sub-questions that are defined in section 1.2 are answered first. After all sub-questions are answered, the overall conclusion is given. The answer to the main research question is offered in the overall conclusion. The research limitations are a starting point for the first sub-section in the recommendations section. Further research is recommended based on the limitations of the current research. The accuracy parameter is discussed as an effect of further research. The thesis ends with recommendations for the usage of this research result by DVDI. A division is made between short- and long-term results of the recommendations. The second parameter, precision, is introduced in this final sub-section of the thesis.

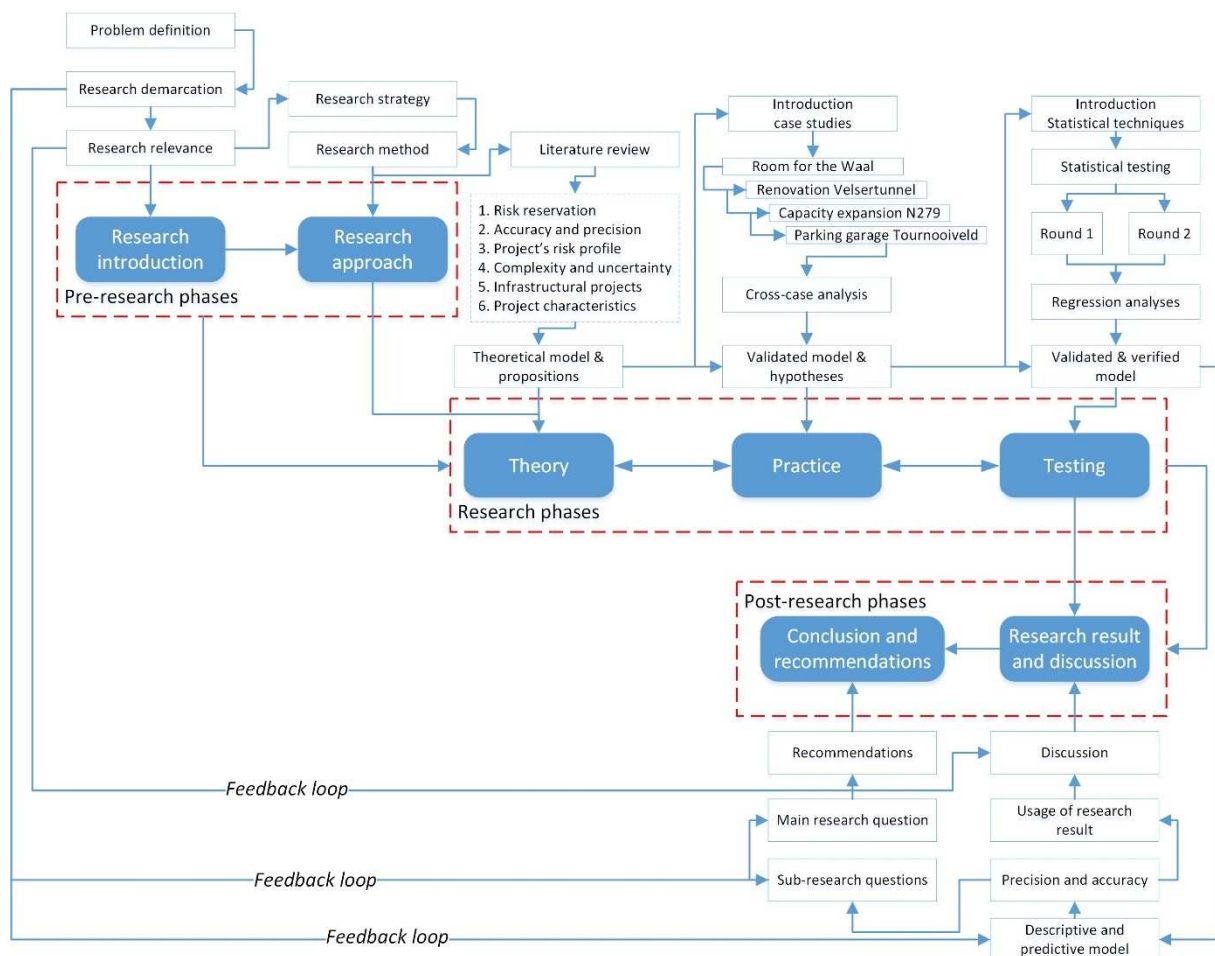


FIGURE 42: RELATIONS RESEARCH PHASES AND STEPS EXPLAINED GRAPHICALLY, AFTER CONCLUSIONS AND RECOMMENDATIONS (SOURCE: OWN ILL.)



7.1 Conclusion

7.1.1 Answering sub-research questions

The five research sub-questions are answered before the overall conclusion is presented. The answers of the research sub-questions are ‘puzzle pieces’ that, when combined in the right way, form the answer to the main research question. The five sub-questions are answered with the help of figure 39, which is presented in section 6.1.

Sub-question 1: How do the project aspects of uncertainty and complexity influence a project’s risk profile, and are these the only two influential aspects?

Figure 43 answers the first research sub-question graphically. The introduction explains that projects are unique ventures and thus potentially cause a certain level of uncertainty and complexity. It is assumed that more uncertainty in projects or more complex projects cause more risks and therefore induce a higher risk profile. Complexity and uncertainty are the only two project aspects and are defined as the dimensions of the project’s risk profile. These dimensions are defined in the current research as follows:

Complexity is the sum of the individual elements and the interdependencies between those elements within a project, measured in terms of technical, organisational and environmental aspects of the project.

Uncertainty is based on either lacking knowledge (epistemic) or randomness (variability) and can be divided in uncertainty on the starting point of the project (current state uncertainty), uncertainty about the goal of the project (goal uncertainty) and uncertainty in the method to reach the goal of the project (method uncertainty).

Complexity and uncertainty are assumed to be three-dimensional project aspects that are measurable by two types of complexity or uncertainty. The relation of complexity and uncertainty with the project’s risk profile is explained in figure 18 in sub-section 3.2.2. Complexity and uncertainty are presented as two interrelated dimensions of a project’s risk profile through a Venn diagram. Scientific research lacks quantitative research that can explain the relation between both risk profile dimensions. However, qualitative research shows that both complexity and uncertainty are project measures on their own, but are also related to one another.

Science is currently unable to confirm or accept the assumption that uncertainty and complexity are independent measures. Different studies have offered different explanations of which project aspects cause the project’s risk profile, but the majority have concluded that complexity and uncertainty are the reason for higher project difficulty or a larger project risk profile. Complexity and uncertainty are also explained as dependent project measures rather than independent project characteristics. Qualitatively, from a practical perspective, it can be confirmed that complexity and uncertainty are the two only project dimensions that influence the project’s risk profile. Examining the project’s risk profile results in the project aspects of uncertainty and complexity being used interchangeably. A clear understanding of what both project aspects entail is missing from a practical point of view.

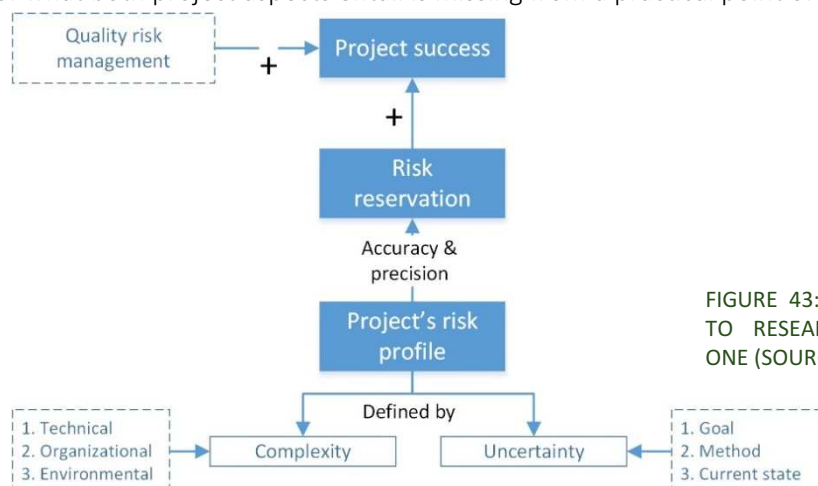


FIGURE 43: GRAPICAL ANSWER TO RESEARCH SUB-QUESTION ONE (SOURCE: OWN ILL.)

Sub-research question 2: How can the project aspects of uncertainty and complexity be measured through project characteristics?

Again, the research sub-question is answered graphically in figure 44. As previously elaborated, uncertainty and complexity aspects are dependent on other independent elements. The two definitions of uncertainty and complexity provide a starting point to determine how to operationalise these two project aspects. The operationalisation of the dependent project aspects was done through the uniqueness character of a construction project. This uniqueness character is ‘fingerprint’ of the project that makes it comparable to other projects. The unique character is measured by means of independent project characteristics. Characteristics are the measurable elements of projects that distinguish one project from another. The final set of independent project characteristics is based on (1) the comparison of different studies on project characteristics and (2) the cross-case analysis of the findings from the four case studies.

Twelve project characteristics are suggested as operationalisations of the level of uncertainty and complexity in projects and thus as operationalisations of a project’s risk profile. Each of the 12 project characteristics are further operationalised in a quantifiable or classifiable parameter. The 12 independent project characteristics are capital value, construction duration, construction pace, contract type, location construction site, project organisation structure, renovation project, concretisation phase, tender duration, client structure, procurement strategy and design innovativeness. The project’s risk profile is defined by complexity and uncertainty and operationalised through the unique character of a project, and it is measurable through independent project characteristics.

The relation between the project characteristics and the project’s risk profile dimensions has been examined through a set of hypotheses regarding the risk profile of the project and the project characteristics. Proving a relation between these two subjects is indirect proof of the relation between the project characteristics and complexity and uncertainty. However, it is a suitable indication of an actual relation. This research does not provide a division in which project characteristics influence the level of complexity and the level of uncertainty.

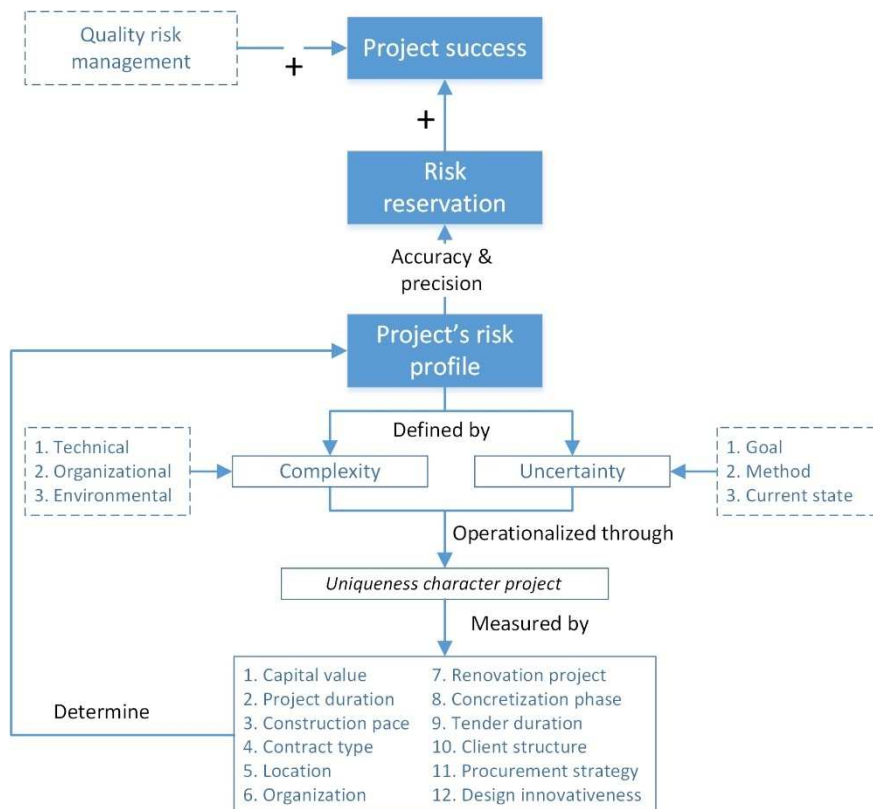


FIGURE 44: GRAPICAL ANSWER TO RESEARCH SUB-QUESTION TWO (SOURCE: OWN ILL.)



Sub-research question 3: What are the most critical risks for a project's risk profile and risk reserve?

The third research question is graphically answered in figure 45. The phenomena of student's syndrome and Parkinson's law are added to the model. These phenomena have a risk-increasing effect on the project's risk profile and more precisely on the time-dependent indirect cost types. The project costs can be divided in six types: direct costs, indirect costs, risk reserve, the company costs, profit margin and maintenance costs. The direct and indirect costs are the largest cost types and together make the project's bare costs. The risk reserve is calculated to cope with the costs due to risks and potential setbacks or windfalls in the project's bare costs.

The project database with financial data of 49 projects explains that there is a difference in risk profiles with respect to the direct and indirect costs. The result booked into the project's bare costs is -2.40% on average. The direct costs show a positive cost result of 2.34% based on all projects. The result of -15.87% in the indirect costs thus causes the budget overrun in the bare costs. The indirect cost category predominantly causes the financial project's risk profile. The engineering and project organisation cost types are typical indirect costs and dependent on time. These cost types show a result of -18.90% and -34.95%, respectively. Although the indirect costs only account for 25% of the bare costs, these are the cause of the large financial setbacks in projects. The threat of not meeting the deadline is certainly a critical risk in the risk profile of the project and is closely related to the abovementioned phenomena.

The current practices with respect to the documentation of risks and costs due to risks makes it difficult to quantitatively determine which risks are most critical for the project's risk profile and the risk reserve. Costs that are potentially incurred due to risks are not documented in the risk reserve but rather in the cost type affected by the risk. This cost documentation inconsistency is the reason that the critical risks are not quantitatively determined. However, qualitatively, it can be said that the threat of not meeting the contractual deadline is a critical risk in almost all projects. Other critical risks in projects are obtaining permits, flora and fauna, archaeology, cabling and piping, soil conditions and uncertainty of the current state of the site. However, these risks are not universal for all projects, only for particular projects. Again, the relationships are difficult to determine, with respect to costs. The research therefore shifted towards the project characteristics and their possible relation to the risk reserve.

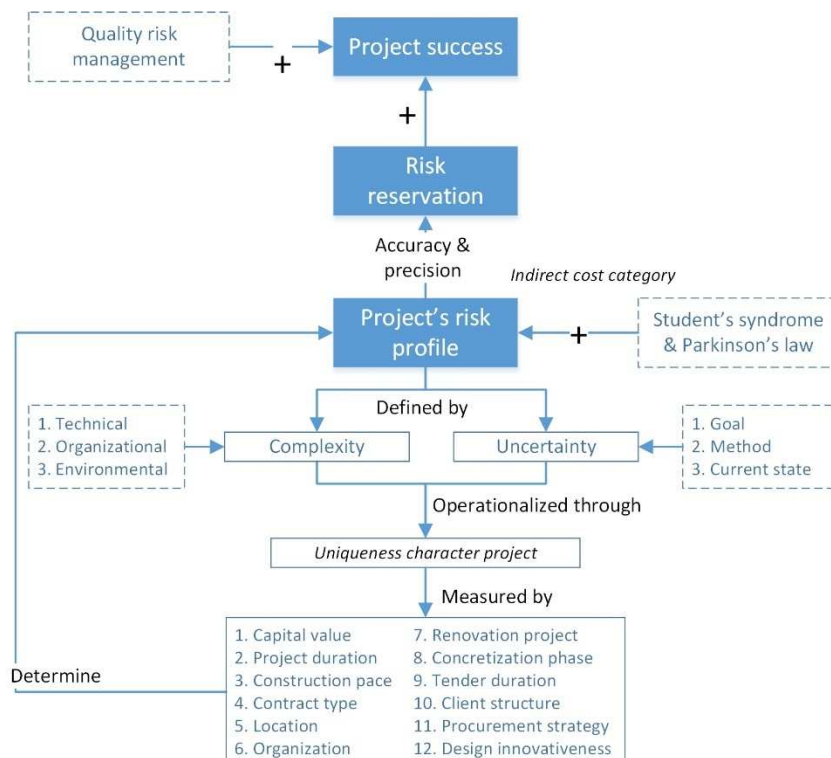


FIGURE 45: GRAPICAL ANSWER TO SUB-RESEARCH QUESTION THREE (SOURCE: OWN ILL.)

Sub-research question 4: What are the current practices of budgeting the risk reserve?

As identified in the introduction, risk management is an important practice in project management, and it positively influences the likelihood of project success. Allocating the risk reserve is a measure used in risk management to cope with uncertain events. It is a contingency added to the budget and can contribute, if perfectly attuned to the project's risk profile, to the financial part of project success. A risk can be negative, as a threat, or positive, as an opportunity. A second distinction to be made is the difference between the known unknowns and unknown unknowns. Theory suggests one type of risk reserve for each of type of risk. The contingency reserve is budgeted to cope for the identified risks (the known unknowns), and the management reserve is budgeted for the unidentified risks.

Practice has shown, however, that there is not such a division in risk reserves. In most projects, only a contingency reserve is budgeted. Dura Vermeer's practices with respect to risk management in the tender phase are uniform to a large extent. On the contrary, the realisation phase does not show such risk management practices that are executed in all projects. Each of the projects has their own method for monitoring and reporting on risks. With the exception of booking the made costs due to risks, these are not consistently booked in the risk reserve budget line of the cost control document.

In the tender phase, risks are identified, quantified and documented in a risk register. The risk register is mostly probabilistically evaluated and based on a predetermined confidence level that determines how much risk reserve is budgeted. The final decision on the actual depth of the risk reserve is determined through expert judgement. The identification and quantification of the risks is not 'hard science' and neither is expert judgement. This leaves room for interpretation and other external factors. Risk perception and market conditions are two such external factors that negatively affect the accuracy and precision of the budgeted risk reserve.

The result of the inconsistency in cost control is that the envisioned quantification of the project's risk profile is not usable. The realised risk reserve is too low, as many costs due to risks or other setbacks are documented in different cost types. The required risk reserve is a different measure that incorporates both the costs made in the risk reserve and the result booked in the project's bare costs. The required risk reserve is based on equation 11.

EQUATION 11: $Req. risk res. = \frac{(Realised bare costs - Budget bare costs) + realised costs risk reserve}{Budget bare costs} * 100\%$

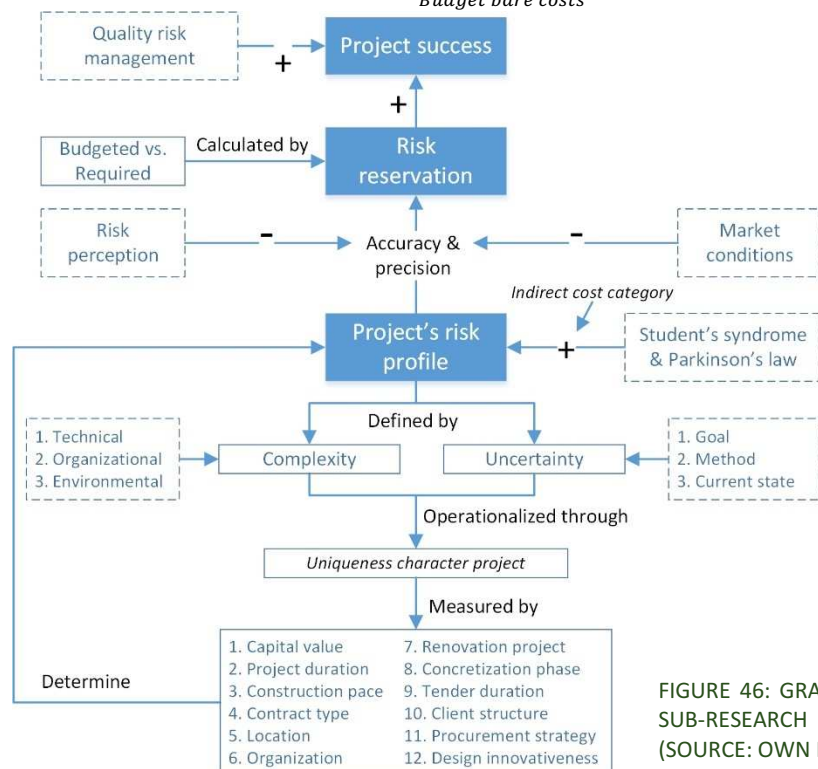


FIGURE 46: GRAPICAL ANSWER TO SUB-RESEARCH QUESTION FOUR (SOURCE: OWN ILL.)



Another positive result of the current equation is that the required risk reserve can also be negative, which means that the project opportunities are larger than the project threats. The new approach thus does not automatically result in a higher risk reserve for future projects. Construction projects are procured in tough market conditions and a sharp offer is necessary in order to win the contract. The project database shows an average risk reserve of 2.53%, but a required risk reserve of 3.53%. The difference means that the average budgeted profit margin of 0.51% turned into a financial loss based on all projects investigated. The budgeted risk reserve is too low on average, but this is based on averages. The individual differences between budgeted and required risk reserve is more important.

Perfect budgeting of the risk reserve means no individual differences and thus a perfect correlation between budgeted and required risk reserves. A perfect positive correlation can also exist if the differences between the risk reserves is equal for all projects, which would only indicate a risk perception that is too optimistic or pessimistic. However, the Pearson correlation coefficient between the budgeted and required risk reserve is 0.38; it is significant at 0.01 level and $N = 47$. The database is relatively small, so a correlation coefficient of 0.38 is only a weak correlation. A regression analysis was conducted with the budgeted risk reserve as predictor and the required risk reserve as predicted value. The found model was significant, but only has an R^2 of 0.201. This means that Dura Vermeer's current risk reserve budgeting method only explains 20.1% of the required risk reserve. This can be seen as very low accuracy. The precision is even worse; the standard error of the estimate is 7.42%. The 95% prediction interval is nine times larger than the average required risk reserve. It can be concluded that the current level of budgeting the risk reserve is poor and requires improvement.

Sub-research question 5: How can the determined project's risk profile lead to improved accuracy and precision in the risk reserve?

The model, displayed in figure 47, is a copy of the model presented in figure 39 in section 6.1, but it answers the final research sub-question graphically. The unique character of the project is described by the twelve project characteristics, but only four characteristics are significantly correlated or associated with the project's risk profile. The X_1 to X_4 in the model stand for the project characteristics: construction pace, project organisation, concretisation phase and design innovativeness.

Regression analysis was used for these four critical project characteristics in relation to the predicted variable, the required risk reserve. A series of multiple regression analyses was executed in order to come to the regression model with the highest explanatory percentage. The four predictors were entered into the model following the stepwise method, which resulted in a model that is based only on the independent variables that have significantly contributed. This ensures a parsimonious model that is more easily generalisable. The regression model is based on two project characteristics that are graphically explained by the Y_1 and Y_2 in figure 47. The model is based on the design innovativeness and project organisation characteristics without an included constant. The R^2 of the model is 0.419, and thus the required risk reserve can be explained with an accuracy of 41.9%. The standardised betas of the individual predictors explain that design innovativeness has a higher impact on the required risk reserve. The model is based on the unstandardised betas and resulted in the following equation:

$$\text{EQUATION 12: } \textit{Required risk reserve} = 2.639 * \textit{innovative design score} - 8.924 * \textit{project organisation dummy score}$$

The T_e in figure 47 explains the systematic errors in the model, or the inaccuracy of the model, which is 58.1%. The improvement of the proposed model, based on historical data and the unique character of projects, is more than 108%. However, the accuracy of the proposed method, based on the 'outside view', is 41.9%, which is low. Accuracy dictates the difference between the estimate and true value and can be described through statistical bias; it is caused by systematic errors. However, closely related to accuracy is precision. Precision offers information about the bandwidth of the model estimate and can be described through statistical variability caused by random errors. The precision of the regression model is the standard error of the estimate, which is 6.53%.

The improvement in the model precision is 12%, which is a substantive improvement. However, the precision remains very small, with a standard error of 6.53%. The 95% prediction interval explains that the predicted value falls within 1.96 times the standard error from the regression line, which means that prediction interval is plus or minus 13.06%. The average required risk reserve is 3.53%. The 95% prediction interval is thus approximately seven times larger than the mean value. The accuracy and precision can be improved by calculating the risk reserve based on historical data. However, both parameters are not sufficiently improved to directly use the prediction model. The precision in particular requires further improvement.

Dura Vermeer currently bases the budgeted risk reserve on the probabilistic simulation of the risk register in relation to a decided-upon level of confidence, combined with expert judgement. Historical data are neglected in the current approach, which has resulted in budgeted risk reserves that can only explain 20.8% of the required risk reserve. This low percentage means a poor level of accuracy and precision, and it leaves room for much improvement. The budgeted risk reserve is 1% too low on average, which results in a realised profit margin of -0.54% instead of the budgeted profit margin of 0.59%. However, adding more budget to the risk reserve by default is not the solution. Different projects mean different risk profiles, thus different required risk reserves, and a sharp bidding price is required to win contracts. The descriptive element of the research result is presented in figure 47 as a framework that explains the relations that influence the risk reserve's accuracy and precision. This research result is even more valuable in future projects for budgeting the risk reserve.

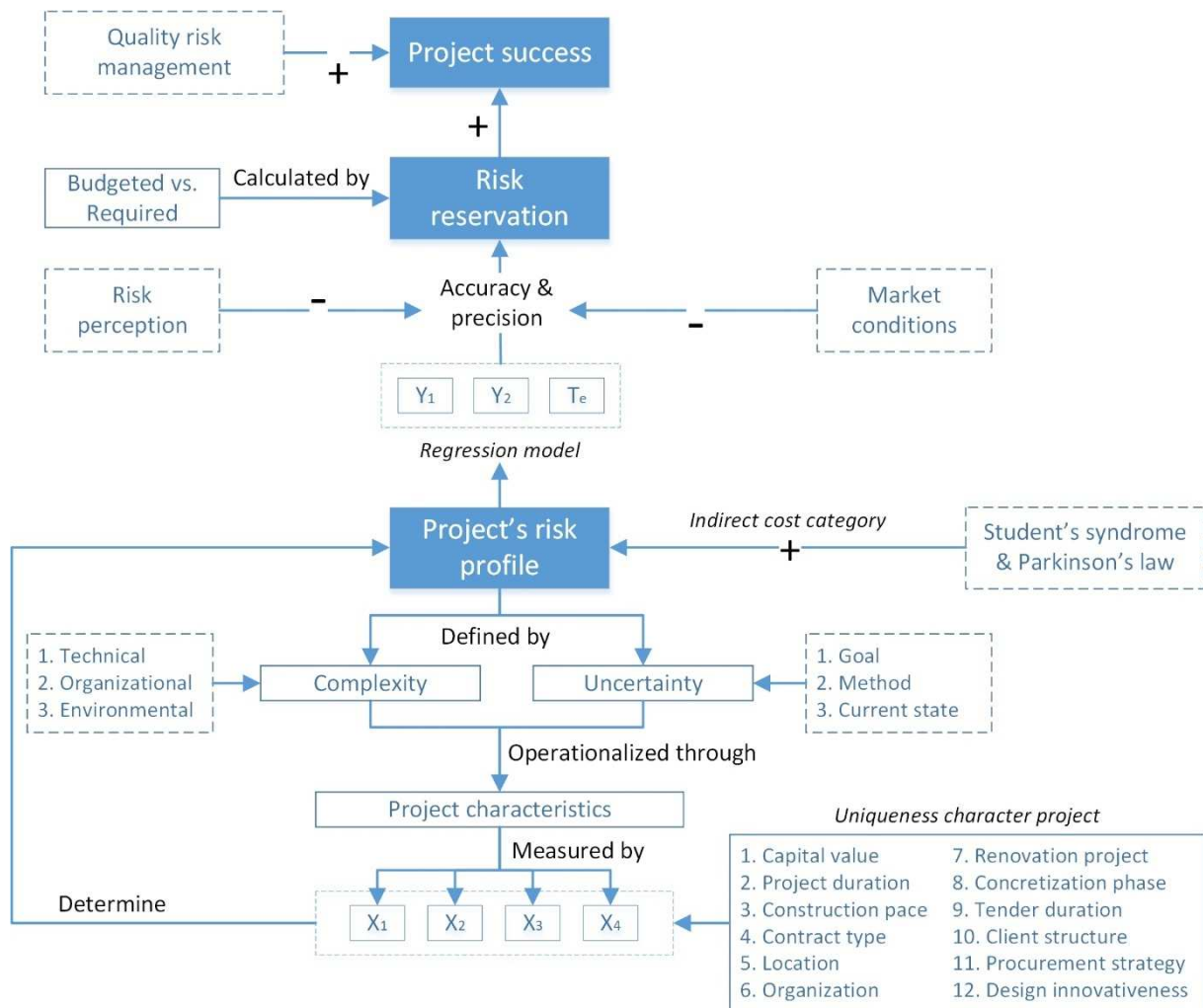


FIGURE 47: GRAPHICAL ANSWER TO RESEARCH SUB-QUESTION FIVE AND THE MAIN RESEARCH QUESTION, IDENTICAL COPY OF FIGURE 39 (SOURCE: OWN ILL.)



7.1.2 Overall conclusion

The research sub-questions are all answered, so it is possible to draw the overall research conclusion in order to answer the main research question. The answer to the question is already graphically presented in figure 47.

How can a project's risk profile be determined through the project characteristics and aspects of uncertainty and complexity for infrastructural projects so that the accuracy and precision of the budgeted risk reserve can be improved?

The risk reserve is currently budgeted based on the risk register and expert judgement. This approach is known as the 'inside view', such that the specific project is the driver of the risk reserve budget. The quality of the current approach in budgeting the risk reserve is very poor. The accuracy of the budgeted risk reserve in relation to the required risk reserve is only 20.1% and shows a 95% prediction interval that is nine times larger than the average required risk reserve of 3.53%. The precision is thus also very low. The budgeting approach, as mentioned in the research question, is known as the 'outside view', and it refers to a risk reserve budgeted based on historical data of comparable projects. The proposed approach improves the accuracy by 108% to a prediction accuracy of 41.9%. The standard error of the estimate of the regression model is 6.53%, which is an improvement of 12%. The precision is still very low with a 95% prediction interval, which is seven times the average required risk reserve.

The predictive element of the research result substantially improves the accuracy and precision. However, the precision of the model especially requires further improvement before it can be directly used in future management practices. The main reason for the imprecision is the chosen operationalisation of the required risk reserve. The inconsistency in documentation of costs due to risks resulted in a required risk reserve calculated partially based on the result in the project's bare costs. It is important to note that the proposed method indeed improves the quality of the budgeted risk reserve. However, even more important is the descriptive element of the research result. The framework presented in figures 39 and 47 explains the descriptive research result.

The proposed method is thus based on historical data of comparable projects. This comparability aspect is based on the unique character of each project. The 'fingerprint' of the project is measured by the project characteristics. These project characteristics are the independent measures that explain the levels of complexity and uncertainty and determine the project's risk profile. The project characteristics that significantly influence the project's risk profile and thus the required risk reserve are as follows: construction pace, project organisation, concretisation phase and design innovativeness. The final model to predict the required risk reserve is based on two predictors, the design innovativeness and project organisation. Equation 11 presents the calculation method of the required risk reserve.

The phenomena of student's syndrome and Parkinson's law have a risk-increasing effect on the project's risk profile. This primarily affects the time-dependent indirect cost types, like project organisation and engineering cost types. The project's risk profile is dominantly positioned in the indirect cost category rather than the direct cost category. Other external factors that are expected to affect the budgeted risk reserve are risk perception and market conditions. These factors negatively influence the accuracy and precision in the budgeted risk reserve. The influence of market conditions is a particularly disturbing factor after observing a correlation between the budgeted profit margin and risk reserve.

The risk reserve is 1% too low on average, which indicates a risk perception that is too optimistic or fierce market conditions. However, adding 1% of the budget to the risk reserve is not the solution. A risk reserve that is 1% higher can mean the difference between winning and losing a contract. A competitive bidding price is important in the construction sector, and an unsubstantiated higher risk reserve only results in a higher bidding price. The risk reserve has to be attuned to the project's risk profile with precision and accuracy. The proposed method already shows strong improvements with respect to the current approach, but it requires further adjustments to be able to be used directly in future projects.

7.2 Recommendations – reliability and validity

The final section of this chapter offers recommendations and is divided into two sub-sections. The first sub-section elaborates what further research is required in order to improve the research result of the current research. It is primarily focussed on improving the accuracy in the research result through science. The second sub-section contains the recommendations for Dura Vermeer regarding the usage of the research result. The recommendations are aimed at the precision of the predictive model.

7.2.1 Further research

The predictive model is unreliable and invalid because of inaccuracy and imprecision. The imprecision of the model is primarily a problem for further usage of the model. This is discussed in the subsequent sub-section. However, the accuracy requires further development as well. Further research is required to improve the accuracy in the regression model to ensure the validity of the predictive research result. Inaccuracy is statistical bias, and it is caused by systematic errors. Future research should be aimed at addressing these systematic errors. The inclusion of more significant predictors can result in higher accuracy. The difficulty of the current research is the large variance in the required risk reserve; the large spread caused for multiple project characteristics not testing significant in a correlation or association with the project's risk profile was also an issue. However, some project characteristics did show differences in mean values.

Further research is recommended for the set of project characteristics and defined operationalisation. A different operationalisation of the uniqueness character of a project can result in more project characteristics and different quantifiable or classifiable parameters. A different operationalisation can result in more significant correlations or associations with the project's risk profile. The same counts for the precise influences of the external factors market conditions and risk perception. More in-depth research can result in a better understanding of the exact influence of these factors. The amount of experience in the project team is identified as a potential influence on the required risk reserve. Experience in a project team is a large and wide topic and, for that reason, deserves a study of its own.

Complexity and uncertainty are the two project aspects that are operationalised as the project's risk profile dimensions. However, these are underrepresented in the practical and testing research phase. The main reason is that a different operationalisation should be made for both the level of project uncertainty and the level of project complexity. Further qualitative and quantitative research on uncertainty and complexity is required in order to find 'hard evidence' for their actual relations with projects' risk profiles and characteristics.

Current practices in cost control do not allow for precise analyses of one-to-one relations between a project's risk profile and the required risk reserve. Further research on cost control processes with respect to costs due to risks is recommended. Consistent cost reporting in combination with risk categories that are generalisable for almost all projects can form the basis of this one-to-one research. Different project characteristics can potentially be linked to risk categories to explain the required risk reserve even better. Another recommendation aimed at the cost control process is in regard to cost categories. The current research accomplished the identification of the differences between direct costs, indirect costs, risk reserve, company costs, profit margin and maintenance costs. However, further research can be conducted towards generalisable cost types, one level below the direct and indirect cost category levels. The project organisation and engineering cost categories are suitable examples of such cost types. These categories can result in a more in-depth understanding of the project's risk profile and in which cost categories it is primarily located.

7.2.2 Recommendations usage research results

The accuracy of the model can be improved by further research, as discussed in the previous sub-section. However, the largest hurdle to overcome is the high imprecision in the predictive model. The precision dictates the bandwidth of an estimate. It is described through statistical variability and is caused by random errors. Further research recommendations are primarily aimed at the accuracy, but



changes in accuracy will accordingly influence the precision of the model. However, this is only true to a small extent. Dura Vermeer has the largest influence on this level of precision. Dura Vermeer can lower the statistical variability in two ways: through a short-term approach and a long-term approach. The short-term approach is to enlarge the size of the database. A larger database results in less statistical variability and therefore higher precision. This result can be reached in a period of one to two years.

The increased accuracy due to further research and increased precision as a result of a larger database can already result in a predictive model that is more useful in calculating the required risk reserve. However, the long-term recommendation for Dura Vermeer is to improve the precision even further. The operationalisation of the project's risk profile is based on the required risk reserve, calculated through equation 11. However, this operationalisation is sensitive to 'noise', more so than the initially identified operationalisation. The initial proposition is based on the actual costs incurred due to occurred risks. Cost control inconsistencies rendered this proposition useless. It is recommended to facilitate further research on a cost control process for Dura Vermeer that recognises costs due to risks.

A different cost control process can result in risk reserve allocation that indeed include incurred costs. The initial operationalisation of the project's risk profile is less sensitive to observation noise. This reduced noise means that the variance within the dependent variable is likely to be reduced. The direct result is that the precision of the predictive model increases even further. The reduced spread in the predicted variable is also likely to result in more significant correlations or associations between the unique character of the project and the project's risk profile. This can further improve the accuracy in the model and result in a predictive model that is both reliable and valid. Actual usage of this model in future projects in budgeting the risk reserve is then a serious possibility. However, this is called the long-term approach, as it requires a longer period to establish. First, the cost control process should be changed, then the project database needs to start from zero. The long-term approach can begin to be valuable after at least three years of data collection. The sooner the cost control process is adjusted, the earlier the predictive model can be valuable to Dura Vermeer.

To conclude this sub-section, there is a quick victory for improving the accuracy and precision of the predictive model. This can be reached through further research and a larger database. However, the question remains if these quick wins are sufficient to end with a model that produces valid and reliable predictions. A long-term approach is aimed at an improved cost control process to enable the detection of incurred costs due to risks. This approach results in a required risk reserve that is less sensitive to 'noise' and shows a smaller variance. The approach ensures that mainly the precision, but also the accuracy, of the predictive model can be greatly improved, likely to a sufficient enough degree that the model can be used for the practice of budgeting the required risk reserve. Besides these recommendations, Dura Vermeer should use the descriptive framework in their decisions on the risk reserve budget.

VII. Bibliography

- Antoine, A. L., & Molenaar, K. R. (2016). Latent class analysis for highway design and construction project categorization. *Procedia Engineering*, 145, 1314-1321.
- Baccarini, D. (1996). The concept of project complexity - A review. *International Journal of Project Management*, 14(4), 201-204.
- Baccarini, D. (2004). *Accuracy in estimating project cost construction contingency: A statistical analysis*. London, U.K: Construction and Building Research Conf. of RICS.
- Baccarini, D. (2005). *Estimating project cost contingency: Beyond the 10% syndrome*. Sydney, Australia: Australian Institute of Project Management.
- Bakhshi, P., & Touran, A. (2014). An overview of budget contingency calculation methods in construction industry. *Procedia Engineering*, 85, 52-60.
- Baldwin, A., & Bordoli, D. (2014). *A Handbook for Construction Planning and Scheduling*. West Sussex: Wiley Blackwell.
- Belassi, W., & Tukel, O. I. (1996). A new framework for determining critical success/failure factors in projects. *International Journal of Project Management*, 14(3), 141-151.
- Bosch-Rekvelde, M. G. (2011). *Managing project complexity: A study into adapting early project phases to improve project performance in large engineering projects*. Delft, The Netherlands: Delft Centre for Project Management.
- Buchanan, D. A., & Boddy, D. (1992). *The expertise of the change agent: public performance and backstage activity*. London: Prentice-Hall.
- Chan, D. W., & Kumaraswamy, M. M. (1995). A study of the factors affecting construction durations in Hong Kong. *Construction Management and Economics*, 13(4), 319-333.
- Craft, R. C., & Leake, C. (2002). The Pareto principle in organizational decision making. *Management Decision*, 40(8), 729-733.
- Creemers, S., Demeulemeester, E., & Van de Vonder, S. (2014, February). A new approach for quantitative risk analysis. *Annals of Operations Research*, 213(1), 27-65.
- de Meyer, A., Loch, C. H., & Pich, M. T. (2012). Van variatie tot chaos: Het managen van projectonzekerheid. *Management Select*, 55-64.
- Denscombe, M. (2014). *The good research guide: For small-scale social research projects* (5th ed.). Maldenhead, Berkshire, England: McGraw-Hill Education.
- Dubois, A., & Gadde, L. A. (2002). The construction industry as a loosely coupled system: implications for productivity and innovation. *Construction Management and Economics*, 20(7), 621-631.
- Dura Vermeer. (2017). *Jaarverslag 2016*. Rotterdam: Dura Vermeer Groep NV.
- Duzkale, A. K., & Lucko, G. (2016a). Exposing Uncertainty in Bid Preparation of Steel Construction Cost Estimating: I. Conceptual Framework and Qualitative C-I-V-I-L Classification. *Journal of Construction Engineering and Management*, 142(10).
- Duzkale, A. K., & Lucko, G. (2016b). Exposing Uncertainty in Bid Preparation of Steel Construction Cost Estimating: II. Conceptual Framework and Qualitative C-I-V-I-L Classification. *Journal of Construction Engineering and Management*, 142(10).
- Dziadosz, A., & Rejment, M. (2015). Risk analysis in construction projects - chosen methods. *Procedia Engineering*, 122, 258-265.



- Eldosouky, I. A., Ibrahim, A. H., & Mohammed, H. E.-D. (2014). Management of construction cost contingency covering upside and downside risks. *Alexandria Engineering Journal*, 53, 863–881.
- Evans, J. S., Newstead, S. E., & Byrne, R. M. (1993). *Human reasoning: The psychology of deduction*. Hove: Lawrence Erlbaum Associates.
- Factor analysis*. (2017, April 18). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Factor_analysis
- Fijnvandraat, M., & Bouwman, H. (2010). Predicting the unpredictable: dealing with risk and uncertainty in broadband roll-out. *Foresight*, 12(6), 3-19.
- Flyvbjerg, B., Holm, M. S., & Buhl, S. (2002). Underestimating Costs in Public Works Projects: Error or Lie? *Journal of the American Planning Association*, 68(3), 279-295.
- Flyvbjerg, B., Holm, M. S., & Buhl, S. (2004). What Causes Cost Overrun in Transport Infrastructure Projects? *Transport Reviews*, 24(1), 3-18.
- Grey box model*. (2017, April 18). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Grey_box_model
- Hagan, G., Bower, D., & Smith, N. (2011). Managing complex projects in multi-project environments. *Procs 27th Annual ARCOM Conference* (pp. 787-796). Bristol, UK: Association of Researchers in Construction Management.
- Härdle, W. K., & Simar, L. (2015). *Applied multivariate statistical analysis* (4th ed.). Heidelberg: Springer Verlag.
- Haynes, P. (2008). Complexity Theory and Evaluation in Public Management. *Public Management Review*, 10(3), 401-419.
- He, Q., Luo, L., Hu, Y., & Chan, A. P. (2015). Measuring the complexity of mega construction projects in China - A fuzzy analytic network process analysis. *International Journal of Project Management*, 33, 549-563.
- Hertogh, M. J., & Westerveld, E. (2010). *Playing with Complexity: Management and organisation of large infrastructure projects*. Amsterdam: Thieme Amsterdam BV.
- Jonkman, S. N., Morales-Nápoles, O., Steenbergen, R. D., Vrijling, J. K., & Vrouwenvelder, A. C. (2015). *Probabilistic Design: Risk and Reliability Analysis in Civil Engineering*. Delft: Delft University of Technology.
- Kahneman, D., & Tversky, A. (1977). *Intuitive prediction: Biases and corrective procedures*. Eugene, Oregon: Decision research - A branch of perceptronics.
- Kasper, E. (2015). *A Definition for Infrastructure - Characteristics and Their Impact on Firms Active in Infrastructure*. München: Technische Universität München.
- Kauffman, S. (1995). *At Home in the Universe: The Search for the Laws of Self-Organization and Complexity*. Oxford: Oxford University Press.
- Khamooshi, H., & Cioffi, D. F. (2013). Uncertainty in Task Duration and Cost Estimates: Fusion of Probabilistic Forecasts and Deterministic Scheduling. *Journal of Construction Engineering and Management*, 139(5), 488-497.
- Kremers, T. (2013). *Dealing with project reserves: Insights into the project circumstances that influence the estimation and expenditure of project reserves in Dutch road-widening projects*. Baarn: Delft University of Technology.
- Kremers, T. (2014). Het zekere van het onzekere? Evaluatie van gebruikte uitgangspunten om de post onverzien te bepalen in infrastructuurprojecten. *Cost and Value*, 3(6), 18-23.

- Lawson, A. E. (2005). What Is the Role of Induction and Deduction in Reasoning and Scientific Inquiry? *Journal of research in science teaching*, 42(6), 716-740.
- Lee, K.-P., Lee, H.-S., Park, M., Kim, D. Y., & Jung, M. (2017). Management-Reserve Estimation for International Construction Projects Based on Risk-Informed k-NN. *Journal of Management in Engineering*.
- Linear regression*. (2017, April 18). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Linear_regression
- Manley, K., & Chen, L. (2016). The impact of client characteristics on the time and cost performance of collaborative infrastructure projects. *Engineering, Construction and Architectural Management*, 23(4), 511-532.
- Maylor, H. (2005). *Project Management* (3rd ed.). Essex: Pearson Education.
- McDonnell, A., Jones, M. L., & Read, S. (2000). Practical considerations in case study research: the relationship between methodology and process. *Journal of Advanced Nursing*, 32(2), 383-390.
- McLain, D. (2009). Quantifying Project Characteristics Related to Uncertainty. *Project Management Journal*, 40(4), 60-73.
- Nguyen, A. T., Nguyen, L. D., Le-Hoai, L., & Dang, C. N. (2015). Quantifying the complexity of transportation projects using the fuzzy analytic hierarchy process. *International Journal of Project Management*, 33, 1364-1376.
- Nicholas, J. M., & Steyn, H. (2012). *Project Management for Engineering, Business and Technology* (Fourth ed.). New York: Routledge.
- Parkinson, C. N. (1957). *Parkinson's law and other studies in administration*. New York: Random House.
- Pawan, P., & Lorterapong, P. (2016). A Fuzzy-Based Integrated Framework for Assessing Time Contingency in Construction Projects. *Journal of Construction Engineering and Management*, 142(3), 1-9.
- PMI. (2008). *Guide to The Project Management Body Of Knowledge* (4th ed.). Newtown Square, Pennsylvania, USA: Project Management Institute.
- Purnus, A., & Bodea, C. N. (2014). Correlation between time and costs in a quantitative risk analysis. *Procedia - Social and Behavioral Sciences*, 85, 436-445.
- Purnusa, A., & Bodea, C. N. (2013). Considerations on Project Quantitative Risk Analysis. *Procedia - Social and Behavioral Sciences*, 74, 144-153.
- Sadeghi, N., Fayek, A. R., & Seresht, N. G. (2015). Queue performance measures in construction simulation models containing subjective uncertainty. *Automation in Construction*, 60, 1-11.
- Schultz, C. S., Jørgensen, K., Bonke, S., & Rasmussen, G. M. (2015). Building defects in Danish construction: project characteristics influencing the occurrence of defects at handover. *Architectural Engineering and Design Management*, 11(6), 423-439.
- Sehrawat, S. (2014). Risk management strategies in large telecom companies: With special reference to Nokia. *International Journal of Commerce, Business and Management*, 6(3), 830-840.
- Selviaridis, K., & Wynstra, F. (2015). Performance-based contracting: a literature review and future research directions. *International Journal of Production Research*, 53(12), 3505-3540.
- Serpella, A. F., Ferrada, X., Howard, R., & Rudio, L. (2014). Risk management in construction projects: a knowledge-based approach. *Procedia - Social and behavioral science*, 119, 653-662.
- Serpellaa, A. F., X. F., Howarda, R., & Rubio, L. (2014). Risk management in construction projects: a knowledge-based approach. *Procedia - Social and Behavioral Sciences*, 119, 653-662.



- Simon, H. A. (1962). The architecture of complexity. *Proceedings of the American Philosophical Society*, 106(6), 467-482.
- Sommer, S. C., & Loch, C. H. (2004). Selectionism and learning in projects with complexity and unforeseeable uncertainty. *Management Science*, 50(10), 1334-1347.
- Songer, A. D., & Molenaar, K. R. (1997). Project Characteristics for Successful Public-Sector Design-Build. *Journal of Construction Engineering Management*, 123(1), 34-40.
- Straub, A., Prins, M., & Hansen, R. (2012). Innovative Solutions in Dutch DBFMO Projects. *Architecture science*, 5, 49-66.
- System identification*. (2017, April 18). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/System_identification
- Tashakkori, A., & Teddlie, C. (1998). *Mixed Methodology: Combining Qualitative and Quantitative Approaches*. London: Sage Publications.
- Touran, A., & Liu, J. (2015). A method for estimating contingency based on project complexity. *Procedia Engineering*, 123, 574-580.
- Trost, S. M., & Oberlender, G. D. (2003). Predicting accuracy of early cost estimates using factor analysis and multivariate regression. *Journal of construction engineering and management*, 129(2), 198-204.
- Turner, P., & Turner, S. (2009). Triangulation in practice. *Virtual Reality*, 13, 171-181.
- van der Heijden, J., & van Bueren, E. (2011). European Sustainable Construction Regulation: Homogeneity and Attention. *ANU Centre for European Studies Briefing Paper Series*, 2(4).
- van Rijn, R. M. (2010). *Towards a New Model for Collaboration: Evaluation of the effectiveness and efficiency of the "Aronsohn contracting vision"*. Delft: Delft University of Technology.
- van Veen, P. (2016). *Probabilistic methods and risk management*. Delft: Technical University Delft.
- Wasson, C. S. (2006). *System Analysis, Design and Development: Concepts, Principles, and Practices*. Hoboken, New Jersey: Wiley-Interscience.
- Williams, T. M. (1999). The need for new paradigms for complex projects. *International Journal of Project Management*, 17(5), 269-273.
- Wilson Van Voorhis, C. R., & Morgan, B. L. (2007). Understanding Power and Rules of Thumb for Determining Sample Sizes. *Tutorials in Quantitative Methods for Psychology*, 3(2), 43-50.
- Wong, J. S. (2015). *Integration of probabilistic costing and scheduling in management and control of infrastructure projects*. Master Thesis, Delft University of Technology, Construction Management and Engineering, Delft.
- Xenidis, Y., & Stavrakas, E. (2013). Risk Based Budgeting of Infrastructure Projects. *Procedia - Social and Behavioral Sciences*, 74, 478-487.
- Zadeh, L. A. (1965). Fuzzy sets. *Information and control*, 8, 338-353.

VIII. Appendix

The appendices important to this research are added to a separate document. The following documents are added to the appendix:

1. Appendix A - Literature review;
2. Appendix B - Case studies;
3. Appendix C - Financial data case studies; (confidential)
4. Appendix D - Interviews case studies;
5. Appendix E - Database project information; (confidential)
6. Appendix F - Statistical research;
7. Appendix G - Scoring design innovativeness.