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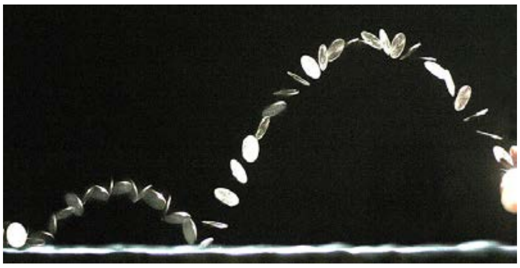

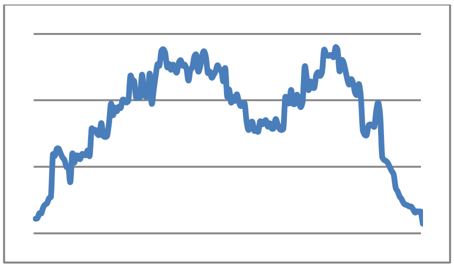

Operator at Risk

A statistical risk management model to assess new operation and maintenance contracts and quantify the associated financial risks

[MASTER THESIS]

Research for a statistical risk management model to help NedMobiel assess financial risks in future new operation & maintenance road infrastructure contracts and quantify their gut feeling. Applying this knowledge specifically to NedMobiel and subsequently designing the risk model that will be used in the tender phase.

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Preface

Ironically, these words will most likely be the first words that you will read, while they are the last words that I will write. What seemed to become a long (but fun) period at the beginning of this year, looks like a short period reflecting on it. I certainly have enjoyed student life, both the 'relaxing' parts as well as my challenging and in-depth study. Maybe it sounds cruel, but it is very interesting to follow the master Financial Engineering & Management when there is a financial crisis. However, I feel relieved to write these last words knowing that my graduation is close at hand and that my 'professional' life can finally begin.

Performing research at NedMobiel was very pleasant. The location is the first thing you notice, a church which houses the office of NedMobiel. It truly is a very unique and inspiring place to work at, a location which I probably will not encounter soon again. Having the freedom and resources to perform this innovative research at NedMobiel was also a privilege for which I am very grateful.

Starting this research, I was astonished by the simplicity which even larger companies use to calculate the risk premium. One person deciding purely on tacit knowledge which percentage to take as the premium on a contract of almost 1 billion euros sounds very unreal (but it is true). Especially with a background as a financial engineer, in which modeling and using data is the rule rather than the exception. Knowing that this research would be totally new for this sector and could really make an impact is something you can only wish for as a graduate student. This really made the research a worthy closure of my student life.

I want to use the rest of this page to thank some people whose help was very pleasant in finishing this master thesis. First and most of all my gratitude goes to Maarten Hellemans, supervisor from NedMobiel. The time and effort he has put in is enormous and without it, the outcome of this research would not have been what it is today. Thanks for the countless formal as well as informal discussions about this and other subjects. Also many thanks to Piet de Vries and Wilco Tijhuis, supervisors from the University of Twente. The time taken to review and discuss all the drafts and the advises you gave are also very much appreciated.

Furthermore, thanks to my parents and sister for their support and advices. Not only during the writing of my master thesis but throughout my whole (student) life. Also thanks to Roel Scholten for supporting this research and giving me the opportunity to write my master thesis at NedMobiel. I sincerely hope that the ambition to become an operator will soon become reality. And of course thanks to my friends for the support, even when I did not need it.

Enjoy reading my master thesis!

Ivo Schutz

Breda, October 2011

Summary

This research focuses on operation and maintenance (O&M) contracts in the road infrastructure sector. It specifically addresses the risk management model which is part of the risk dossier in assessing a new O&M contract which will be used to calculate the risk premium. There is currently no formal risk model to assess these contracts and by performing external interviews it became apparent that there are no such methods at other companies. The model needs to be designed such that specific risks are addressed to make a detailed assessment of the risk premium in an O&M contract. Currently, the risk premium is determined by the people responsible for a tender who assign a single 'risk' number to the sum of the project based on tacit knowledge. Having projects that cost billions of euros, this is not a desirable situation.

The desired situation is a statistical risk model that formalizes the process of calculating the risk premium of an O&M contract and which will support the gut feeling of NedMobiel. It is furthermore convenient that it can be used to build a database for the future.

To meet the desired situation, a model is designed which calculates the risk premium for the operator. The model is designed by following a few steps.

- a list of thirty risks that should be taken into account is made and specifically tailored to the needs of NedMobiel, where risks can easily be in- and excluded in the model;
- from a multi criteria decision analysis it became clear that a probabilistic model will be most suitable to the wishes of NedMobiel;
- the parameters impact, chance and timing are calculated per risk and each risk is assigned a statistical distribution which specifies the three aforementioned parameters;
- everything is modeled in Excel and Visual Basic for Applications, the risks and the associated parameters are admitted in the model;
- NedMobiel can adjust the model to specific needs per project; and
- the model calculates the expected risk premium in becoming an operator thereby quantifying the gut feeling of NedMobiel.

NedMobiel will be able to add and adjust risks and their parameters to fine-tune the model over the years and make sure that the model can be used in every tender where NedMobiel will act as operator. This ensures that the gut feeling of NedMobiel is quantified and the financial consequence of risks in future O&M contracts are clear, such that NedMobiel will be able to take on the role as operator while still being able to 'sleep at night'.

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Chapter 1

Chapter 1 describes what public-private partnerships (PPP) encompasses, what the relation with NedMobiel and the current problem is and what this research embodies to solve that problem. First an overview is given what PPPs are (§1.1). Then the relation in a PPP between Rijkswaterstaat (RWS) and a Special Purpose Vehicle (SPV) (§1.2) and the relation between the SPV and NedMobiel (§1.3) are described. Subsequently the current situation is described and it is argued why the current method is not sufficient (§1.4) and what the new model should be capable of (§1.5). The problem is restated in research questions (§1.6) and the methodology to answer the research questions is given (§1.7).

1. Outline of the research

1.1 The essence of public-private partnerships (PPPs)

This research has been performed for NedMobiel, a consulting firm in the area of (road) infrastructure with the ambition to become an (operation & maintenance) operator. NedMobiel was founded in February 2006 and arose out of a few core employees of the business development department from the NV Westerscheldetunnel. NedMobiel advises governments, companies and interest groups in the area of (private) infrastructure and transport. As well as consultancy and project management for such parties, NedMobiel works to actually execute designed solutions through risk-bearing participation in projects and companies. NedMobiel works from three areas of expertise (NedMobiel, 2011):

- Tolls and pricing;
- Operation and maintenance of complex infrastructure; and
- Public-private partnerships (PPP).

PPPs are the main focus area of this thesis, which the commission of the European communities (2009) defines in their European PPP Report as: “the range of structures used for PPPs varies widely: in some countries, the concept of a PPP equates only to a concession where the services provided under the concession are paid for by the public. In others, PPPs can include every type of outsourcing and joint venture between the public and private sectors”. See e.g., the definition of Yescombe (2007) for the boundary conditions that define a PPP:

- “long-term contract (a ‘PPP Contract’) between a public-sector party and a private-sector party;
- for the design, construction, financing, and operation of public infrastructure (the ‘Facility’) by the private-sector party;
- with payments over the life of the PPP Contract to the private sector party for the use of the Facility, made either by the public-sector party or by the general public as users of the Facility; and
- with the Facility remaining in public-sector ownership, or reverting to public-sector ownership at the end of the PPP Contract.”

Or, as Kappeler & Nemoz (2010) put it in one sentence, a PPP counts as such if the "project [is] based on a long term, risk sharing contract between public and private parties based on a project agreement or concession contract". Benefits of using PPPs include the following (Regan, Smith, & Love, 2011):

- "The delivery of projects on time and on budget;
- Reduced procurement costs and improved VfM [Value for Money] outcomes;
- Improved project management-integration of design and construction processes and full life-cycle costing;
- Adoption of an output specification to encourage design and construction innovation and new technologies; and
- Improved public services and qualitative user outcomes."

Public-private partnerships are based on a contractual relationship between a public agency and one or more organizations in the private sector which will deliver a particular policy, project or range of service. The specific public-private partnership where this research focuses on is called the private finance initiative (PFI), where the private sector provides both the capital and a range of services to operate the facility. A critical note has to be placed that if the private party defaults, the public sector ends up paying for recovery costs. The partnership will be involved in both policy development and executive delivery (Geddes, 2005). The PFI is about realizing a certain risk allocation, depending on the contract type, which achieves the best value for money (Nisar, 2007). For clarity and consistency, the term PPP will be used throughout this report.

Above description of the PPP contract type is considered as the 'design-build-finance-maintain-operate' (DBFMO) type. The essence of this contract is the definition of the 'output' by the government after which private sector bidders present their solutions to meet the service needs (Nisar, 2007). Table 1, adjusted from Yescombe (2007), provides a short overview of the responsibilities in a DBFMO contract:

Contract type	*Design-build-finance-maintain-operate (DBFMO)*
Construction	Private sector
Operation	Private sector
Ownership	Private sector during contract, then public sector
Who pays?	Public sector or users (depends on the specific project)
Who is paid?	Private sector

Table 1 Public and private provision of infrastructure

The process through which a project is developed can be split in four 'rough' tasks (de Bettignies & Ross, 2004):

1. Defining and designing the project;
2. Financing the capital costs of the project;
3. Building the physical assets (e.g., road, school, etc.); and
4. Operating and maintaining the assets in order to deliver the product/service.

In a PPP the government has to decide to whom these tasks should be allocated. The operation & ownership contract type is the specific contract that this research focuses on, task four in the list above.

1.2 PPP creates a higher value for money for the taxpayer

A PPP will only be successful if, as a result of its existence, there is value for money (VFM) which is achieved through (among others) the lifecycle management of a project. VFM can be defined as the added value for the taxpayer in terms of the benefits that follow from a PPP in relation to the situation in which no PPP is set up. Benefits are more or better infrastructure for the same or less amount of public funds (i.e., the taxes paid) and consist of cost of goods and services, quality of the work process, resources used, timeliness and long-term service needs (Hui, Ying, & Zhi-Qingn, 2010). The measurement of these benefits can be quite subjective and need to be tested in each PPP contract. To do this, an ex-ante study of the public sector comparator (PSC) needs to be done (Merna & Njiru, 2002). As can be read in documents of RWS (2009a) (2009b), the PSC is actively used in the Netherlands to assess private parties on their VFM. Figure 1 shows how this comparison is done. The PSC column is the situation when no PPP is set up, which is compared to the situation if a PPP is set up. The difference in net present costs between the two options is the value for money.

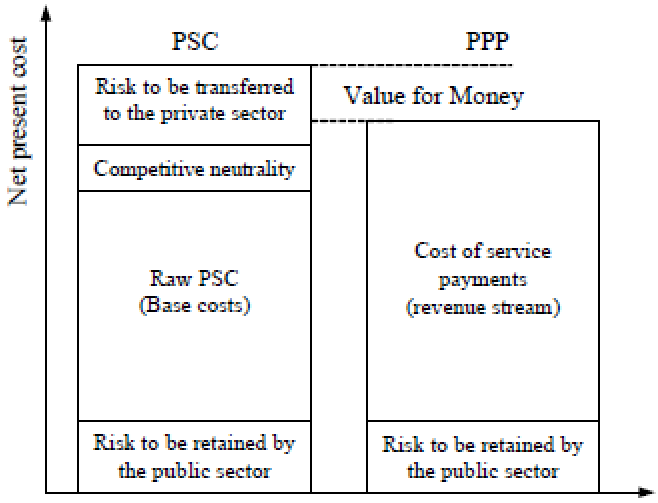


Figure 1 Test with the public sector comparator for value for money in a PPP (Hui, Ying, & Zhi-Qingn, 2010)

Part of the relation between RWS and the private sector is to decide how to allocate the risks. This allocation and how to optimally allocate the risks is not part of this research since this involves much more than the design of the statistical risk management model (e.g., politics and a trade-off between risk and return). The model that will be the output of this research will however contain a function in which NedMobiel can manually and per project set the allocation of a certain risk. An example is that if a risk in a project is fully allocated to another party, then NedMobiel could set that risk to zero percent such that it is not accounted for.

In the VFM discussion the transfer of risks is a substantial argument in favor of PPPs; it is argued that the risk transferred can be better *managed* by the private sector (Yescombe, 2007). PPP projects are in fact risk allocation methods in public infrastructure projects (Li, Akintoye, Edwards, & Hardcastle, 2005). Of course, if the private sector bears the risks, then it is paid a premium to do so. This should, *ceteris paribus*, attract higher financial returns (Hodge, 2004). Although the risks will (mostly) be transferred to the private sector party, the government retains ultimate responsibility (Grimsey & Lewis, 2005).

A large concern of a PPP construction is that the government can in general lend money at cheaper interest rates than private institutions due to a better credit rating, and thus can execute the project at a different price. In the beginning of PPP it was thought that this was a factor that possibly deteriorates VFM (Merna & Njiru, 2002). The private sector has to make up for this difference by operating more efficient. However, Bing et al. (2005) and the National Audit Office (2010) did research on this issue and found that the actual impact of non-government borrowing is much less than first supposed and clearly offset by the efficiency gain. An explanation for this is that when there is a long-term contract with a government buyer, the private borrower can most likely lend at a lower rate compared to the situation where there would be no contract with a government buyer (de Bettignies & Ross, 2004). The lenders most likely assume that the public party still bears some of the risks involved and know that the government bears ultimate responsibility.

Furthermore, if there are large transfers of risk from the government to the private sector, the private sector will of course price this risk. It has to be taken into account that risk transfer must not be excessive (Merna & Njiru, 2002), risks that could better be taken by the government should be allocated there and not by the private sector. By taking this risk and the corresponding premium, the private sector can use its experience and skills in order to bring innovative alternatives to public service provision (Nisar, 2007). Overall, in the literature there seems to be consensus that PPPs (and PFIs) are in fact VFM when the PSC indicates this, and it seems reasonable to assume that PPPs will continue to exist in the future. This does not take the criterion away that future PPPs need to be tested on its VFM, both before and during/after the PPP contract period.

If a PPP is undertaken, focusing on the operation and maintenance part, there are two most common used forms. A split can be made between new infrastructure and existing infrastructure. When new infrastructure has to be build, it includes the Design & Build phase as well as the Maintenance and Operation phase. This is in this case defined as a DBFMO contract. If the infrastructure already exists, only the contracts to maintain and operate the infrastructure are closed.

In the former case, new infrastructure, a SPV is set up which will act as the project company. One of the reasons to create a SPV for building, operating and financing new infrastructure is that the original company is ‘shielded’ if the project fails. The SPV is a separate company from the promoter’s organization and is usually highly leveraged (high debt/equity ratio) (Merna & Njiru, 2002). The SPV is the contractor to the government or some other public sector organization. There are various kinds of organizations in a SPV, which together provide the essential elements of a project such as design, construction, finance and specialist facilities (Tranfield, Rowe, Smart, Levene, Deasley, & Corley, 2005). This makes sure that the client organization has a single point of contact through the project life. The SPV has no activity other than the activity which it was set up for (Yescombe, 2002). Tranfield et al. (2005) also state that most service-delivery-focused projects are currently managed by a formally configured SPV to form a successful PPP. In this SPV, the builder (responsible for the design & build phase) as well as the operator (responsible for the operation & maintenance phase) take place.

In the latter case, existing infrastructure, there is no need for a SPV, since the contract for the infrastructure only needs to be (re)tendered for the maintenance and operating period. Thus the concession agreement is either between the public authority (being RWS in the Netherlands) and the SPV or the operator (in this case NedMobiel).

The main difference between the two forms is the method of financing. In a SPV, financing is usually done by taking on a huge amount of debt (~90%) and a small part equity (~10%) which changes the way the risks are treated. When you have a large amount of debt, the lenders have a big stake in the decision where to allocate the risk. Most of the time these lenders are banks, which do not want to take on unexpected risks. Since the SPV is set up for a sole purpose, the revenues that follow from the project are the only way to get the investment back. These cash flow will be used as the guarantee for the lenders. Given these facts, the SPV will transfer its (cost) risks to the subcontractors, being NedMobiel as the operator. On the other hand, with existing infrastructure there is no need to set up a SPV, the financing amount required is limited and can be done with mostly equity. The financing risk is in this case not an issue because of the debt/equity ratio, there is in general more equity and less debt than in the SPV scenario.

Let's define scenario ① to be new infrastructure where the relation is between RWS and the SPV. Then scenario ② is the case where there is existing infrastructure and the relation is between RWS and NedMobiel. Drawn into a diagram gives Figure 2.

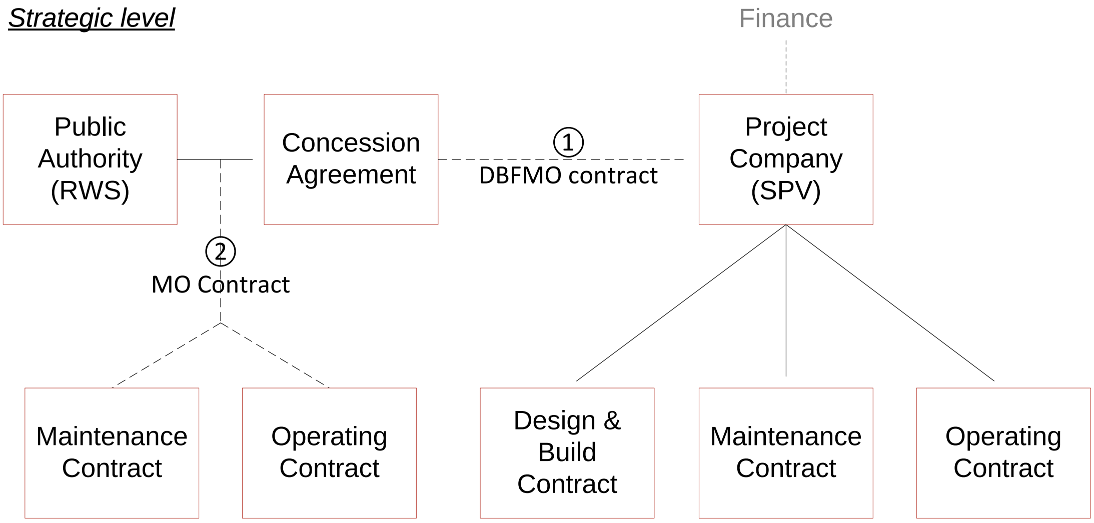


Figure 2 Most common relationship between the public authority and the operator given two scenarios

This research will focus purely on new infrastructure and will thus follow scenario ①. A detailed structure is shown in the next paragraph.

Given the new situation, there will be a relation between RWS and the SPV. NedMobiel will take place in the SPV as the operator (operating & maintenance contract), where a construction company will take on the role of the builder (design & build contract). They together form the SPV. The risk dossier that NedMobiel needs to set up is focused on the relation between the SPV and NedMobiel. The risk dossier is important for the lenders because the SPV is mainly financed by them and thus the SPV has a huge debt and low amount of equity.

1.3 The PPP is managed using a special purpose vehicle

Now that the purpose of a PPP is clear, the actual 'arrangement' of such a PPP needs to be clear. Figure 3 clarifies this, adjusted from Yescombe (2007), showing a simplified construction of a PPP. Not all elements which are presented in Figure 3 have to be included in reality and of course there can be additional structures. Given the fact that this research is about new infrastructure, as defined in the previous paragraph, the structure will not deviate too much from the figure.

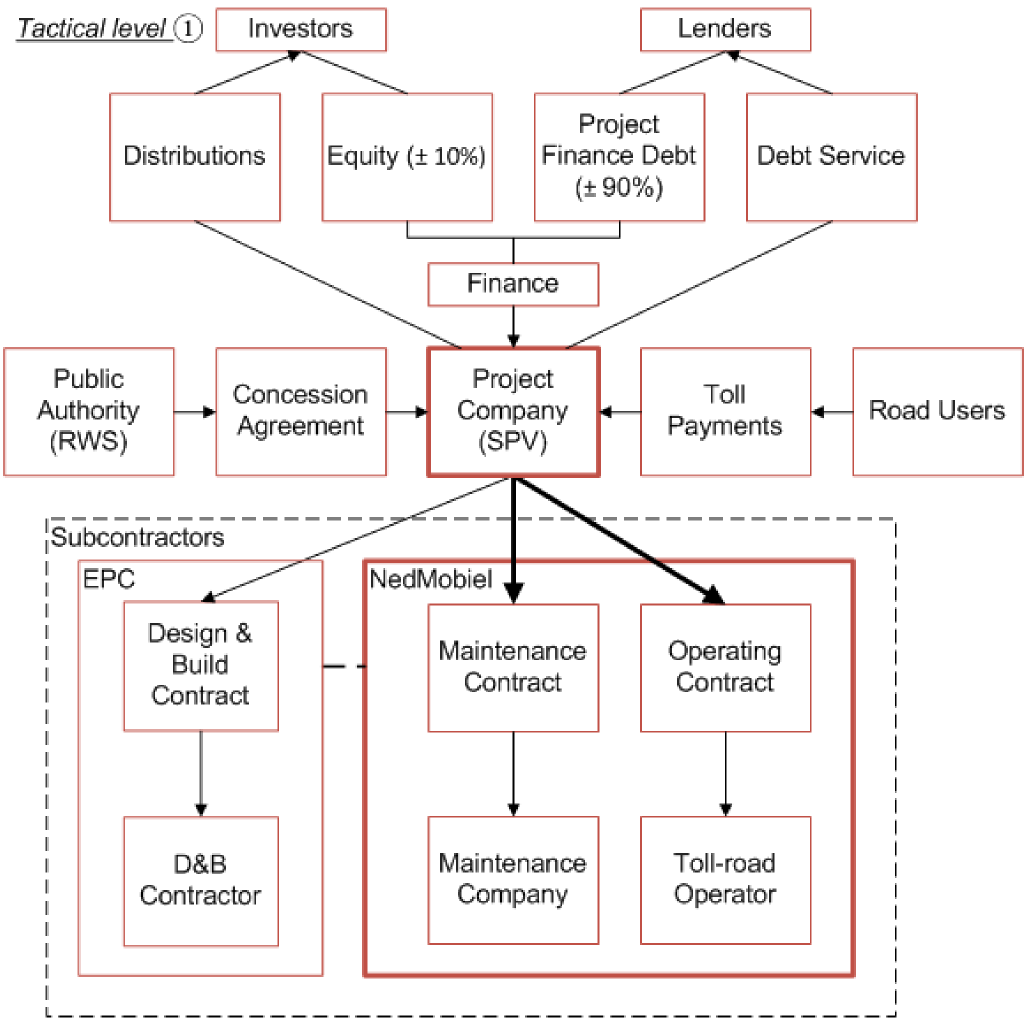


Figure 3 Project finance for a new road concession

The operating and maintenance contract is the specific part that would be managed by NedMobiel. Although this research focuses on the operation & maintenance (O&M) part of the contract, it must be noted that the interaction between the design & build (D&B) contractor and the party that manages the operating and maintenance contract is important. An example is that if the builder uses inferior quality asphalt because it is cheaper but this means that the lifetime is reduced, it will have an influence on the costs for the operator. In this research it is assumed that NedMobiel is able to work closely together with the builder and work out a situation that is 'optimal' for both parties. In determining the risks in chapter 2, the aforementioned risk is also taken into account.

As said before, the SPV will have to lend a considerable amount of money from lenders, most of the time around 90%. This is mainly due to the fact that the contracts are of such a large size that they cannot be financed by the operator and builder alone. The 10% equity is a requisition of the banks to ensure that the parties in a SPV are dedicated to the project. Now that the structure of a SPV is described, the next paragraphs will focus on the challenge for NedMobiel to assess the risk premium if they take on the role of operator.

1.4 Current risk management model is not useful to calculate the risk premium

Before you can arrive at a structure as defined in the previous paragraph, you first need to be awarded (*'gegund'* in Dutch) a project after having been through the tender phase. After the tender phase you have the Engineering, Procurement & Construction (EPC) phase in which the infrastructure is build. When this is done the Maintenance & Operation phase begins and after this you have the Rest of the lifetime. Going back to Figure 2, the EPC and the Maintenance & Operation phase combined is represented by scenario 1, the Rest of lifetime is scenario 2. This research focuses on developing a risk model that will be used in the tender phase to assess the risks associated with the Maintenance & Operation contractor, see Figure 4.

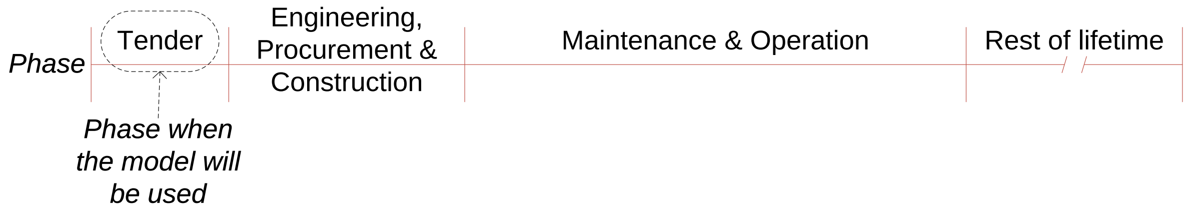


Figure 4 Different phases in the lifetime of road infrastructure

In the steps before and in a tender, from the point of being a candidate to submit an offer (*'gegadigde'* in Dutch) to financial close, there are a number of criteria that are assessed in choosing the winner. In the selection procedure of the party that grants the project (e.g., for the Netherlands this would be RWS) the amount of money is not the only variable that plays a role, but they look at the overall quality of the bid and subsequently choose the economic most valuable candidate (*'economisch meest voordelige inschrijving'* or *'EMVI'* in Dutch). To give a broad overview of the criteria, without the intention to deliver a full list of criteria but with the intention to show the most important ones and where the risk management model comes in place:

- Price;
- *Risk dossier;*
- Approach of the project;
- Optimization phase; and
- Planning.

Total proposal in the tender phase

These criteria are of course no stand-alone issues but all play a part in assessing the economic most valuable candidate.

Sharp (1964), a Nobel prize winner in economics, modeled that a higher expected rate of return can only be achieved by having additional risk. And it can be argued that having large optimization phases are not without risk. In this case, optimization is defined as the adjustments made to the EMVI that will affect the expenses of the operator. Regarding these criteria, this research will focus on the risk dossier, and the risks that need to be determined for the risk dossier. NedMobiel wants this quantitative part to be able to assess the pricing of the risk *while in the tender phase*.

Based on internal (NedMobiel) as external (other companies) interviews and literature, the main method that is currently used to define and measure risks is the RISMAN method. This method is useful to define the risks for the risk dossier *after the tender phase*, i.e., the project is awarded to NedMobiel. The RISMAN method comprises four global steps (Kennisnetwerk Risicomanagement RISNET, n.d.):

- Define the goal of the project;
- Map the risks belonging to the project;
- Identify the most important/biggest risks; and
- Define how to manage these risks.

In defining the goal of the project, the different management measures, the level of depth and the different employees who are performing the RISMAN method are determined. The next step comprises the analysis of the different risks that belong to the project via several brainstorm sessions and listing these risks in a matrix. The matrix comprises the risks in the first column and the risk description, possible cause and effect, management action to restrict the severity of the risk and the status, deadline and responsible persons are listed. In the third step the matrix is filled and the most important risks are determined. As a last step, the management actions of the most important risks are described in detail. These steps are done qualitatively, most of the time by putting the project team together and using a brainstorm session to achieve the list of risks. The outcome is a list of risks that need to be managed and an overview of the most important ones including different management actions.

After making a list of management actions according to the defined risks, a decision needs to be taken which action per risk should be implemented, if any action is necessary. The RISMAN process is an ongoing cycle of choosing, implementing and evaluating the management actions (Bouwend Nederland, n.d.) (Twynstra Gudde, n.d.). The process focuses mainly on the relation between the public authority and the operator. By having this report, the public authority can qualitatively check the management actions of the risks.

As said before, the lenders are in need of a risk management model that will show them that the operator in the SPV can judge the financial impact of risks accurately. The RISMAN process is not practical for this. The first reason is because the outcome of the RISMAN process is too detailed and too specific for the lenders. Furthermore, it is not taken into account what the occurrence of risks over time is and how that translates to the overall picture (currently, risks are treated as stand-alone issues and are treated as if it is equally likely that a risk will happen in the, say, first year or the last year). A second reason is because it is not efficient to perform the RISMAN process in a tender. It is in terms of time/payoff not beneficial for both the operator and the public authority to go through the RISMAN process with each party that wants to submit an offer. The conclusion is that the RISMAN process is unsuitable for the purpose of assessing operation and maintenance contracts in terms of risk management and focusing on the relation between NedMobiel and the SPV.

In the current contracts there is of course a price for the risk, which is done on a quite subjective basis and is very simple. One person will in general come up with a single percentage for the risk premium, which is added to the price. This percentage is not based on, for instance, a formal list of risks but purely drawn up on basis of tacit knowledge. In practice this means that it is most of the time an integer (1%, 2%, 3%, …) because it is useless to define a risk premium of, say, 2.38% if this is not based on (formalized) data.

Put into an example: if we have a contract of 500 million euro, it is currently said that an *x* percent of this price is added to cover the potential loss of the risks. Let's say it is 2%, then the price will go to $500\ M€ * (100\% + 2\%) = 510\ M€$. We can thus say that the risks are priced at 10 M€ (called the risk premium), see Figure 5 for a graphical explanation.

This approach is called deterministic; these deterministic models describe exactly how the system will evolve over time. When put in simpler words, this means that you only deal with one possible reality of how a process will work out over time ("single-point estimate"). One possible reality means the risk occurs or it does not occur, which is certainly not the case in the real world. The opposite is a stochastic process which means that there is a whole range of possible solutions. In this stochastic process, the risk has different probabilities of occurring instead of just one possibility. It can be easily seen that (the effect of) risks is not that black and white in reality, it is not deterministic but rather stochastic. In reality risks will not just occur or do not occur, there is a wide range of possibilities between these options. So there is a mismatch between the current situation of pricing the risks (deterministic) and reality (stochastic).

Probably the simplest example of a deterministic process is flipping a coin; it is either heads or tails with both 50% probability. An example of a stochastic process is the path of the price of a stock, the chance of a large movement is less likely than a small movement. You however do not know what it will be, but based on historic information you have an idea of the so called probability distribution.

If we recall the simple (but very real (!)) example, the risk is priced at 2% of 500 M€ (= 10 M€). Pricing the risk with a deterministic probability, the risk has either 98 % probability of occurring at zero costs or 2 % probability at 10 M€ costs. So in the current situation of estimating the risk premium, it is estimated as having a 2% chance of a loss of 10 M€ and a 98% chance of a loss of 0 M€. This method is currently used to add the risk premium to the contract price. Obviously these two possibilities (either 0 M€ or 10 M€) do not represent all the possibilities that can happen in the real world. Figure 6 shows these numbers in a graphical explanation.

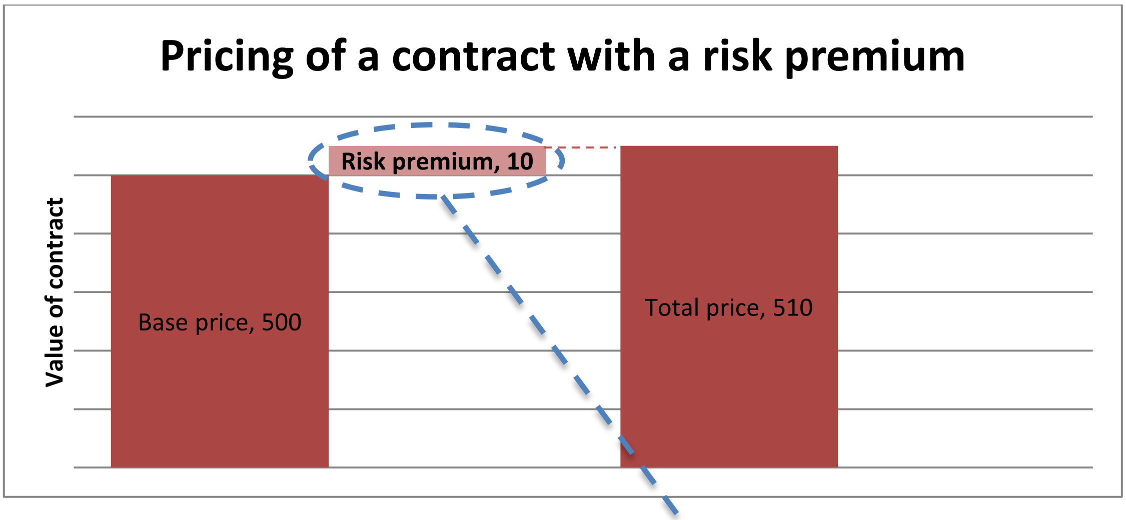


Figure 5 Example of the price of a contract and the risk premium part

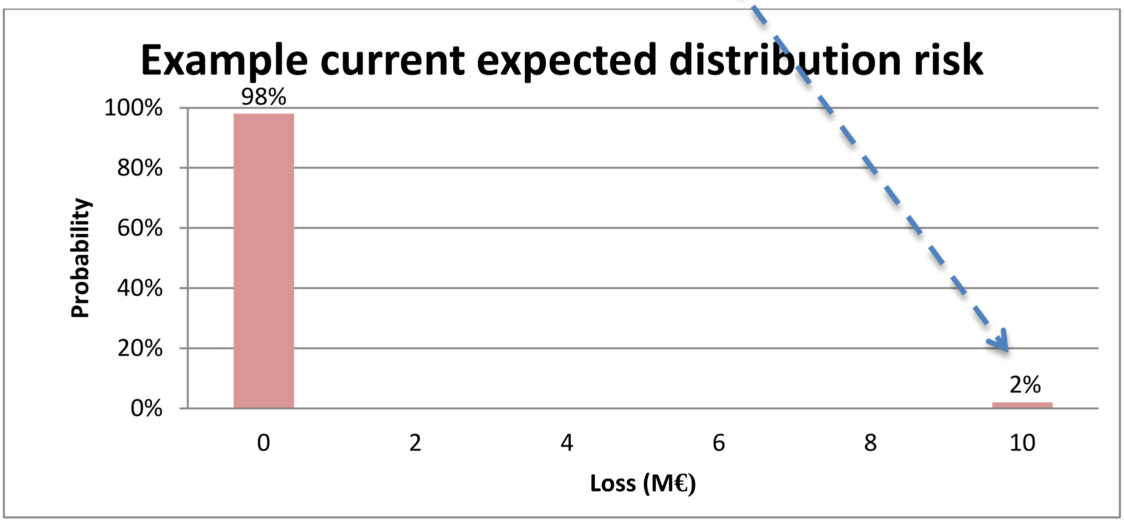


Figure 6 Example current risk model

This deterministic approach can be used if there are enough projects to diversify the risks. This is not the case for NedMobiel, since it is not likely that RWS will place large amounts of PPP contracts and that many of these contracts will be awarded to NedMobiel. Thus there is need for a new risk model. NedMobiel wants a model that will capture 'reality' in a better way opposed to the current deterministic ('binary') model.

1.5 The desired risk model is statistically a better representation of reality and calculates the risk premium

This risk model will be used as a tool to assess future O&M contracts to make a well-founded decision whether it is acceptable to close the O&M contract. In the whole range of risk management practices, this model will assess the financial risks for NedMobiel when taking on the role of operator.

It is reasonable to assume that the probability of a risk occurring will have a certain distribution instead of a finite (small) set of points, as is the case in the current situation of estimating the risk premium. Figure 7 shows an example of the (stochastic) probability distribution of this new model. The area under the probability density function (solid line) represents the probability that a certain loss will occur. The outcome of modeling the new risk model will be more like a distribution as shown in Figure 7 than a distribution as shown in Figure 6, so more disperse instead of binary.

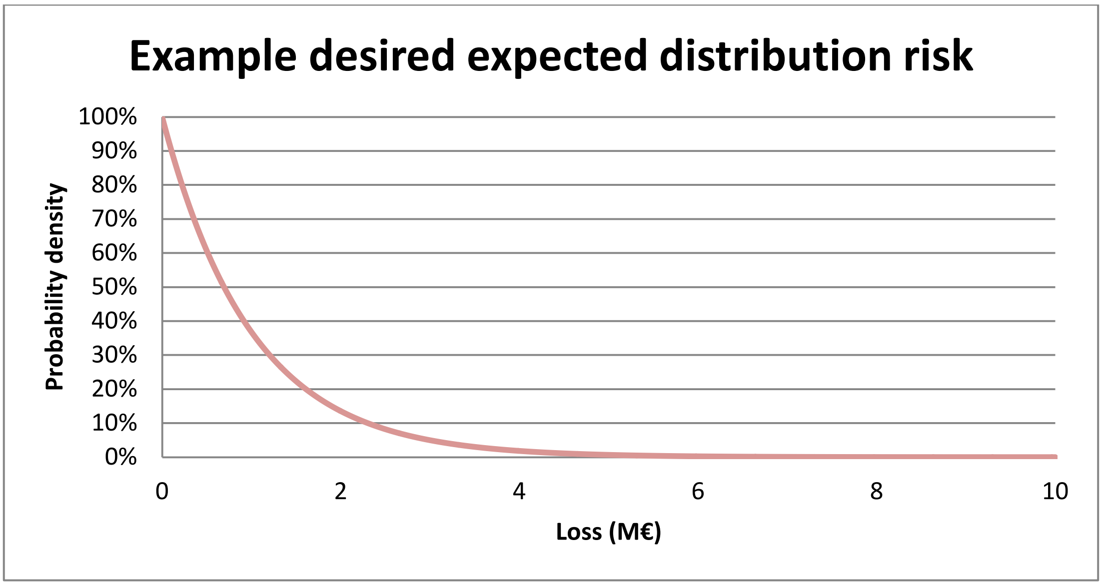


Figure 7 Example desired risk model

The main difference with the old model is moving from two possible outcomes to multiple possible outcomes. Recall the example, it is in the current situation estimated that there is a 2% chance of a loss of 10 M€ and a 98% chance of a loss of 0 M€. This implies that there is a zero percent chance of a loss of (say) 5 M€ or 15 M€ in the current situation, which is obviously nothing like reality. The new situation will say that the *expected* loss will be 10 M€, but it will be spread out over different losses. The whole surface under the graph represents the probability of the risk occurring. Looking at Figure 7, you have for instance a 50% chance of a loss between 0 - 0.685 M€, a 25% chance of a loss between 0.685 M€ - 1.367 M€, a 24.995% chance of a loss between 1.367 M€ - 10 M€ and a 0.005% chance of a loss > 10M€.

An advantage is that seeing such a distribution gives a better idea of the riskiness of a project versus the current model. This is something you cannot see in the current model, since you only have a few points (in the example in Figure 6 this is either a 0 or 10 million euro loss). This is essential because a company should have a clear and unambiguous model that assesses the financial risks that can be taken (Hull, 2010).

1.6 The new risk model specifically designed for NedMobiel

To summarize the desired situation: NedMobiel is currently in need of a statistical tool to assess future O&M contracts to make a well-founded decision whether it is acceptable to close the O&M contract in terms of risk. The criteria reporting, usability, feasibility, correlation between risks, awareness and adding data and risks will be used to choose and subsequently build an appropriate risk model.

1.6.1 Purpose of this research

The purpose of this research, as defined by the management of NedMobiel, is:

To have a statistical model that can be used by the management of NedMobiel in a tender, specifically in the calculation of the maintenance phase, which gives a financial risk assessment of the O&M phase of a specific project.

So the specific criterion of this risk model must be in line with the purpose and is defined as the ability to assess financial risks in O&M contracts.

1.6.2 Research question

The research question is defined as:

How to design a statistical risk model, specifically designed for NedMobiel, to assess risks associated with Operation & Maintenance contracts while being the operator in a Special Purpose Vehicle, concerning new road infrastructure, to quantify their gut feeling.

The specific part of the O&M contract in question is the operator part, i.e., the actual operation and maintenance of new road infrastructure project. So it is about executing the O&M contract (being the operator), which is different from building the infrastructure (Engineering, Procurement & Construction provider) or advising on the O&M contract (e.g., performing the capital- or operational expenditures (CAPEX/OPEX) calculations).

During the research, the author was given the opportunity to participate in a tender to experience firsthand what this gut feeling ('*onderbuikgevoel*' in Dutch) actually encompasses. It was not a tender for an O&M contract but the process is comparable to the process of an O&M tender. The tender required a subscription price ('*inschrijfprijs*' in Dutch) and a description of the project organizational details, planning and the quality of the provision of services. All these factors were taken into account by using an EMVI, such that the fictional price could be lower than the subscription price. The planning and quality of the provision of services included, among others, a risk dossier. This risk dossier was drawn up purely on the basis of tacit knowledge obtained from other projects and the risks were thought of on an individual basis. It furthermore was more a qualitative judgment and there were no calculations of, for instance, the chance or impact of the risk occurring. It was rather a statement of what would be done to minimize the risk from occurring and/or the control measure. The risk was priced purely on basis of a 'guesstimate' and was a percentage of the subscription price. There was no relation between the risks and the price, let alone be a decomposition of the individual risks and their impact (costs) and chance of occurring. One of the biggest negative consequences of this method was that there was no overview of the total risk of the project (other than the estimated single percentage) and a positive consequence was the speed with which this 'risk increase' could be included in the price.

The gut feeling of identifying and quantifying the risks can be seen as 'commercial satisfaction'. In other words, does it feel right to take the commercial risk related to the extra 'profit' you can make. After budgeting and adding all the budgets up, there was a percentage used that 'felt' right in terms of security that the firm would still make a profit.

The answer to the main research question can be achieved by answering the subsequent sub questions.

1.6.3 Sub questions

1. How does the qualitative risk model currently used to assess risks for the operator part in an O&M contract work (chapter 1);
2. What risks should be in- and excluded based on the criterion which risks directly influence the cash flow (chapter 2);
3. How could a statistical risk model for the infrastructure sector and specifically for NedMobiel be designed, such that it captures reality in a more sophisticated way than the current method (chapters 3-5); and
4. What data are required for the model and how can NedMobiel acquire these data in the future (chapter 4-5).

These sub questions will be answered by following the methodology that is described below.

1.7 Methodology to answer the research question

The sub questions reveal part of the methodology used as described by Verschuren & Doorewaard (1998). Verschuren & Doorewaard describe that to come to a research design, you need a concept design which determines what, why and how much the research will embody. The second step is technical research design which answers the where and when you are going to research. Although their methodology is followed, the research design is fitted in a custom design. This can be seen in Figure 8, which gives an overview of the several steps in this research and to which chapter the different steps correspond.

The process of making the model is an iterative process. The steps are interwoven and for clarity defined into four chapters:

- Identification of the key risks in an O&M contract;
- Choice of a statistical risk model;
- Data sorting; and
- Building the statistical model.

These subjects will not be treated as stand-alone issues but as the whole process of getting to the statistical risk model. So although the different chapters are described as being ‘steps’, they are not single points in a sequence of actions, but part of the iterative process in which each step is passed through multiple times.

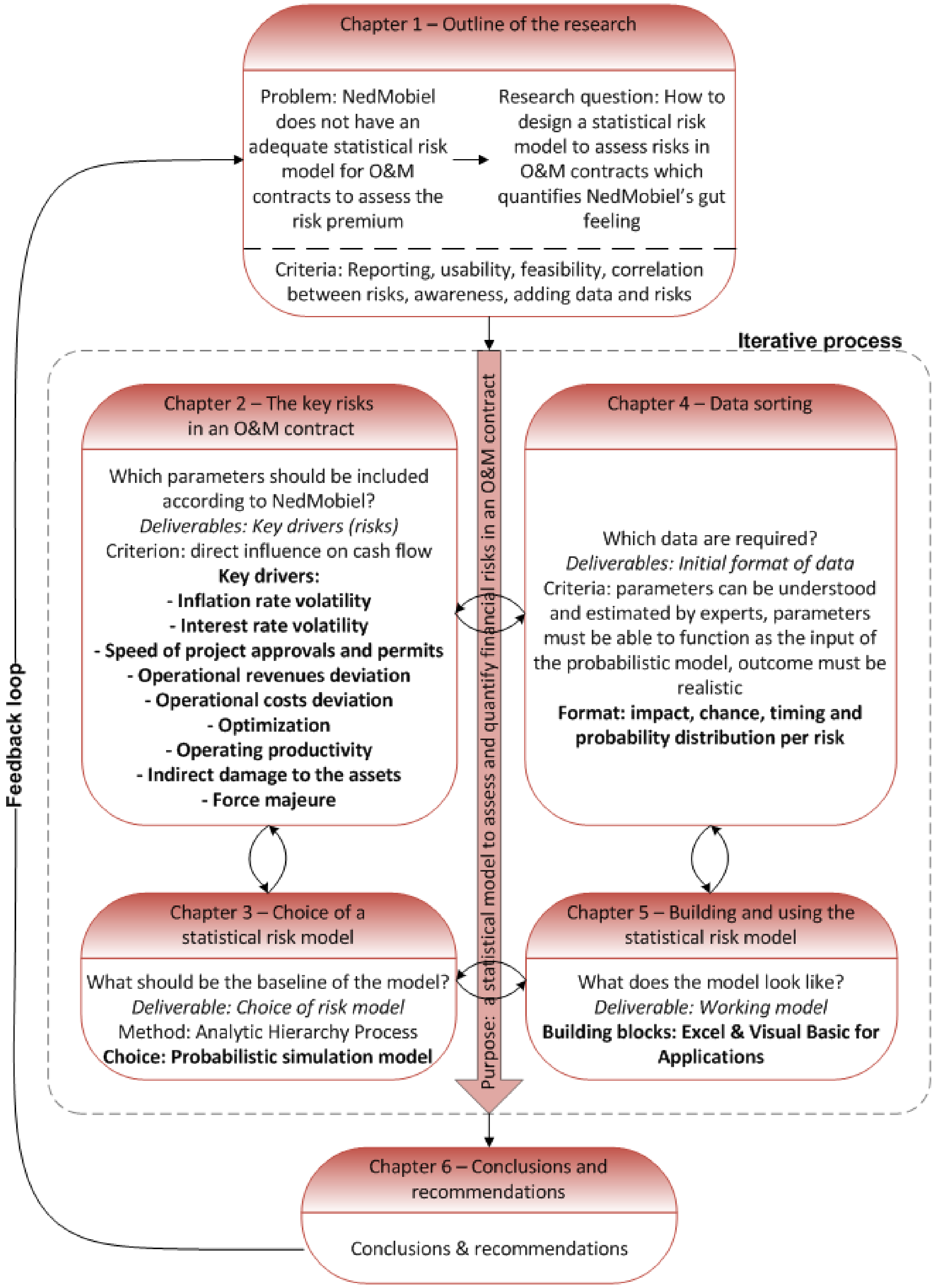


Figure 8 Overview of the different chapters

First of all, the project variables and key risks concerning an O&M contract will be assessed. The main problem is that an endless list of different kinds of risks can be produced. However, the model needs to be simple enough such that it will not take ages to get the desired input per project. On the other hand; it cannot be too simple such that it will not generate a reliable measure of reality, thus an optimum must be found. At the same time a specific and appropriate risk model needs to be chosen that will be used by NedMobiel in the future. By looking at the direct influence on the cash flow and performing many internal and external interviews, it is determined which risks are particularly important for NedMobiel. Within the structure of a contract as shown in Figure 3 there are various contracts, and especially the allocation of risks, possible. By allowing NedMobiel in later stages to manually adjust the risks in the model, the model can be corrected for individual cases.

Second, a suitable risk assessment model will be chosen to be researched. Appropriate risk models for the subject researched will be listed. The analytic hierarchy process will be used to operationalize the criteria; reporting, usability, feasibility, correlation between risks, awareness and adding data and risks and rank the various models accordingly. From this ranking the appropriate risk model will be chosen.

When the key risks are clear, the third step is to find data using expert views on this topic, both from within and outside the infrastructure sector, or information about past projects. This can be done either by: looking at the current qualitative method, to get an idea and building further on this by looking at expert views; or by synthetically determining the distribution, using a database of projected risks and outcomes of past projects. The former method will in this case be used because a database is not readily available and needs to be build the coming years. This implicitly means that you must quantify the risks based on (tacit) knowledge. Thus the main method of gathering data is by consulting experts and going through the list as defined in the second chapter. The experts will judge every risk on its impact, chance, timing which is aggregated to fit a probability distribution per risk.

A standard contract will be used to gather data. This standard contract is defined as an O&M contract in the Netherlands with:

- a duration of 20 years (i.e., excluding 5 years EPC);
- a contract price of 1 billion euro;
- not transferable and no prolongation;
- light maintenance (vs. heavy maintenance);
- frequency based maintenance (vs. performance based maintenance);
- having an availability fee (i.e., no tolling); and
- no readjustments during the lifetime of the contract.

The fourth step is the building of the model which will be done in Visual Basic for Applications (VBA) and Microsoft Excel. Microsoft Excel (and its underlying method of modeling, VBA) will be used since this is the program that NedMobiel is familiar with. By ensuring that a familiar program is used, it is more likely that NedMobiel will be able to work with and adjust the model after delivery.

The fifth step is describing what the model encompasses. NedMobiel should be able to apply the model to assess future O&M contracts, but they also asked how to build up such a model when advising other companies. This is generally a summary of the steps taken in this research and applied to practice in which the building blocks of the model are explained. This also comprises how to fine-tune the model in the years thereafter. The model needs to be designed in such a way that NedMobiel can import found data which results in a better reflection of risks in O&M contracts.

When these steps are completed, NedMobiel will have the foundation of a statistical risk management model that will support its gut feeling and tacit knowledge. The outline of this improved risk model should be clear and in the future it should just be filled with data to make it more accurate. As Gatti et al. (2007) put it nicely: “a [risk model] simulation approach, albeit complex, should be seen not as a complex approach to a simple transaction but rather simply as a method for properly handling the inherent complexity typical of most project finance deals”.

Chapter 2

Chapter 2 describes the key risks that will be used. First, the method to define the key risks is stated (§2.1) after which the key risks at a broad level are determined (§2.2). The next paragraph states the specific key risks which will be used and these risks will be split out in more detail (§2.3). The chapter ends with a conclusion (§2.4).

2. The key risks in an O&M contract

2.1 Method to define the key risks

In this chapter the key risks are identified that play a role in operation & maintenance (O&M) contracts. It is difficult to compose a list that is both comprehensive and feasible in terms of usability in this research as well as for NedMobiel. A list of literally every risk thinkable is surely comprehensive, but not at all feasible to model in this research or use in practice. From another point of view, a list of too little risks is both not comprehensive as it is not useful in practice (but it may be quick to model). So an optimum has to be found, where the word 'optimum' is quite subjective. To define optimum in this case; a list of risks is comprehensive and feasible if the list is both extensive enough as defined by NedMobiel (it can be used in practice) as well as narrow enough (that it can be modeled) as defined by the author. The reason that the former decision maker is NedMobiel is because this research is conducted for NedMobiel. The latter decision maker is the author because this research has a limited time and scope which certainly needs to be taken into account.

The method to find a complete list is to approach the project from different angles: from the 7S framework, RISMAN, scientific literature, interviews and existing O&M contracts (see Figure 9). The 7S framework, RISMAN and existing O&M contracts are used to get an idea of the categories that could be formed. Scientific literature is used to come up with a raw list of risk which is fine-tuned in interviews. Concluding sessions were used to be sure that the list of risks was compliant with the needs of NedMobiel. Using these five different angles, it is ensured that a good qualitative list is gathered.

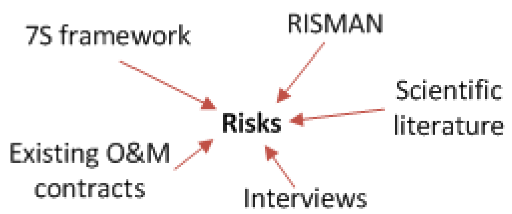


Figure 9 Different perspectives to define a complete list of risks

The 7S framework (Rasiel & Friga, 2001) is a McKinsey management model to describe how a company operates and it has seven categories. The RISMAN method of working is already described in the first chapter, to use the method there are several categories (van der Tak & Lindenaars, 2008). Table 2 shows the categories for both methods, which are not linked.

Method	7S framework	RISMAN
	Shared values	Demographic
	Strategy	Economic
	Structure	Environment
	Systems	Politics
	Staff	Technology
	Style	Laws and Regulation
	Skills	Society
		Organizational

Table 2 Different categories of the 7S framework and RISMAN

For the determination of the risks, the scope will not only be O&M contracts but it will also be extended to the risks that come in play when designing or constructing the project. It is reasonable to assume that if there is a design flaw or a construction error, there will likely be some consequences for the operator as well. So instead of just looking at O&M contracts, the focus will be on PPP projects as a whole and all the (relevant) risks that can be in place. There were no contradictions found in the literature and to the authors knowledge there is not yet a 'standard' list available.

A check was done internally at NedMobiel with various employees to check for completeness at the various levels. Risks are defined at different levels to be able to keep a clear overview. The 1st level consists of the macro, meso and micro level. Macro level risks are autonomous processes of the entire economy around a project. The micro level risks look at the individual projects and how several forces are at play there. The meso level risks lie between the macro and micro level and look at the interaction between the project and various other aspects. Li (2003), as presented in Li, Akintoye, Edwards & Hardcastle (2005), puts it in the following way:

1st level	*Description*
Macro	The *macro* level of PPP risk comprises risks source *exogenously*, i.e., external to the project itself.
Meso	The *meso* level of PPP risk includes risks sourced *endogenously*, e.g., the communication risk between the EPC and O&M contractor.
Micro	The *micro* level of PPP risk represents the risks within a certain project, e.g., the risk of organizational capabilities of NedMobiel.

Table 3 Description of the macro, meso and micro level

The levels are meant as an in-depth way of describing the risks. The second level comprises broad categories while looking at the first level. The third level consists of more detailed risks based on the second category, etcetera. Figure 10 gives a graphical example how a specific risk is comprised from the different levels. Another explanation in words could be: define 'Meso level risk' which could be further specified as 'Ownership risk' which could be further specified as 'Indirect damage to the assets risk' which could in turn be further specified as 'Weather conditions'. As said before, it is possible to continue this specification and arrive at a very specific level of risk. A very specific example is for instance: the chance that a landslide in a specific country in a specific time period on a certain section of the road would occur, which is obviously not sensible to model.

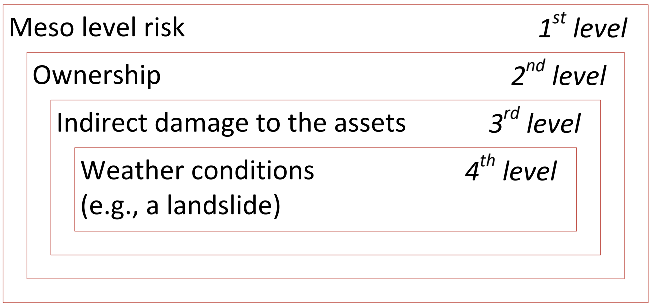


Figure 10 Example of the four different risk levels

The specification is done until the fourth level. The fourth level is deducted from the third level, which is derived from scientific literature. Since there was little to no research available for the fourth level risks, this level was created by brainstorming internally with various employees at NedMobiel. Again, a check was made for consistency and completeness.

To determine which risks should be included in the model, there will be a specific focus on the internal risks. These internal risks are defined as the risks that influence the cash flow of the operator directly during the concession period and are in place *after* closing the contract. The external risks are the risks that influence the cash flow indirectly and qualify as the 'unknown unknown' risks. In other words, risks that you do not know that will be there and cannot be quantified. These definitions are tailored specifically to the wishes of NedMobiel, such that the final model fits these specific wishes. In practice this means that NedMobiel will determine which risks qualify as internal risks.

The internal risks will be specified up to the aforementioned fourth level risks and the gathering of data belonging to these risks will be treated in chapter four. These internal risks account for a substantial part of the risks that come in play when looking at the cash flow. Beforehand it is expected that data about the external risks will cost too much effort to find while the impact of finding the data is marginal compared to the internal risks. The external risks will be treated as more fixed and a fixed percentage will be taken for these risks. These risks will in practice be treated at the first level due to the fact that data is not (at all) available. A follow up of this research would be to subtract data from future (or current) O&M contracts or by performing additional research on these risks.

This list is in no means a way of describing how much risk NedMobiel should allocate to itself, since that is up to the company to decide. There is a trade-off between risk and return; i.e., the higher the risk taken, the higher the return that *can* be realized. This is due to the fact that there is also a higher risk at a downturn, i.e., a loss. An important note is that this trade-off is between risk and expected return, not the actual return. The expected return is defined as the mean value of the 'return' variable (Hull, 2010). This determination of risk preference is explicitly not part of this research. The model will assist NedMobiel in determining the risks of future O&M contracts.

2.2 Key risks up to the third level and the distinction of internal risks

For the formulation of the key risks up to the third level, eighteen scientific literature sources in the area of risk management on PPP are combined. Obviously quantity does not mean quality, but since there were no contradictions and no new risks found (after a certain amount of literature), it is assumed that this list is qualitatively sound. The fact that the articles where not just based on research by universities but also from the private sector (both credit agency reports as research performed by companies) enhances this statement. The sources varied in the way of assessing risks and most of them did not categorize risks at different levels.

An existing contract was used to check the combined list. Internal and external interviews where performed to verify the applicability of the list in practice. The list was then reviewed and discussed internally with a risk manager & managing partner, director & managing partner, senior project manager & managing partner, project managers and the operations manager PPP. Given the scope of the third level, this list is according to both the author as NedMobiel comprehensive and feasible.

Being an operator for so many years clearly puts a major focus on the deviations (Δ) of the cash flow of the organization. As stated earlier, the standard model as defined by NedMobiel does not take the investments into account as this is about 'light' maintenance. This cash flow will be the standard to determine the third level risks that are relevant for the risk model. For the cash flow of the operator during the O&M period, a simple formula can be defined:

$$\Delta Cash\ Flow = \Delta Revenue - \Delta Expenses \pm Bonus/Malus$$

The internal factors that play a direct role in determining the cash flow are marked in the table. Recall that these internal risks are selected by NedMobiel and that these (and other) risks can easily be in- and excluded in the model, depending on the wishes of NedMobiel that may vary per project. The criterion to select the internal factors is: influence on the direct cash flow of the operator. These internal factors will be specified further on in this document to a fourth level. Note that the term 'internal' refers to the risks that NedMobiel wants to take into account which in turn is defined as the risks that have a direct impact on the cash flow of being an operator.

The list of risks that followed from the literature search, the check with and existing O&M contract, multiple interviews and brainstorm sessions is shown in Table 4.

1st level risks	*2nd level risks*	*Internal*	*3rd level risks*
Macro level risks	Country		Government stability
			Corruption
			Public decision-making process errors
			Credit risk of the public sector entity
			Political point of view regarding the project
	Macroeconomic		Financial market health
		√	Inflation rate volatility
		√	Interest rate volatility
			Competition (exclusive right)
			Influential economic events
	Legal		Legislation change
			Contractual risk
			Change in tax regulation
			Industrial regulatory change
	Social		Level of tradition of private provision of public services
			Public point of view regarding the project
	Natural		Geotechnical conditions

			Weather conditions
			Archeological findings
Meso level risks	Project selection		Land acquisition (site availability)
			Level of demand for project (competitors)
	(Project) finance		Availability of finance
			Financial attraction of project to investors
			Maintaining finance (including changes to loan conditions)
			Foreign currency exchange
			Level of financing costs
	Design	√	Speed of project approvals and permits
			Design quality
			Knowledge of engineering techniques
	Construction		Completion time
			Construction costs deviation (compared to predictions)
			Environmental events
			Material/labor availability
			Level of design changes
			Quality workmanship
			Level of contract variation
			Solvency of sub-contractors and suppliers
	Operation	√	Operational costs deviation (compared to predictions)
		√	Availability fee
			Environmental events
		√	Optimization
			Condition of facility
			Operator solvability
			Staff training
			Tariff change
		√	Operational revenues deviation (compared to predictions)
		√	Operating productivity
	Ownership	√	Indirect damage to the assets
			Technology change
			Concession changes by the government
			Federal and state legislation/regulation changes
			Public/third-party liabilities
			Realization of the residual value of assets
	Residual/force majeure	√	Force majeure
Micro level risks	Relationship		Organization and co-ordination risk

		Experience in PPP
		Distribution of responsibilities and risks
		Distribution of authority in partnership
		Differences in working method and know-how between partners
		Level of commitment from either partner
	Third party	Third party tort liability
		Staff events

Table 4 Key risks up to the third level

Table 4 is composed using the following sources: (Dailami, Lipkovich, & van Dyck, 1999), (Lessard & Miller, 2001), (Yescombe, 2002), (Yescombe, 2007), (Grimsey & Lewis, 2002), (Grimsey & Lewis, 2004), (Li, 2003), (Li, Akintoye, Edwards, & Hardcastle, 2005), (Flyvbjerg, Bruzelius, & Rothengatter, 2003), (Flyvbjerg, 2006), (Hodge, 2004), (Ng & Loosemore, 2006), (Gatti, Rigamonti, Saita, & Senati, 2007), (Roumboutsos & Anagnostopoulos, 2008), (Tinsley, 2009), (Ke, Wang, & Chan, 2010), (Ke, Wang, Chan, & Lam, 2010), (Xu, Chan, & Yeung, 2010). This list is set up by looking at already published articles/books about risk management in PPPs, while taking the categories of the 7S framework and RISMAN in mind. The criteria on which the papers are selected are: fit in research scope, year of publication and relevance/application to risk management in PPPs. A summary was made from the remaining appropriate articles and there was a check on consistency (no contradictions between articles) and completeness (how many new risks were found). Key criterion to compose the list was that it should be collectively exhaustive. All of the categories taken together should deal with all possible options without leaving any gaps (Rasiel E. M., 1999). The list that was created from this search was checked with an existing O&M contract. In subsequent internal interviews and brainstorm sessions, the list was checked again with several people. This process led eventually to the list in Table 4.

In most contracts, there will be risk allocation. Optimal risk allocation is about distributing risks to parties that can best manage the specific risk. Where managing stands in this case for measuring and, through their actions, minimizing the risk (de Bettignies & Ross, 2004). This minimization of risks for the government does not mean that all risks should account with the private sector, which is often a misperception in countries that are not yet familiar with PPPs (Jin & Zhang, 2010). It has been specifically chosen not to allocate risks beforehand. The main reason is because NedMobiel does not want to assume that risks can be allocated to another party (i.e., the government) at zero costs and that allocation will vary for different projects. For this reason, NedMobiel wants to include all the risks in the model if they *can* be allocated to them.

Figure 11 shows the third level internal risks per category (revenue, expenses and bonus/malus) related to the cash flow, although inflation and interest can be placed under revenue and expenses:

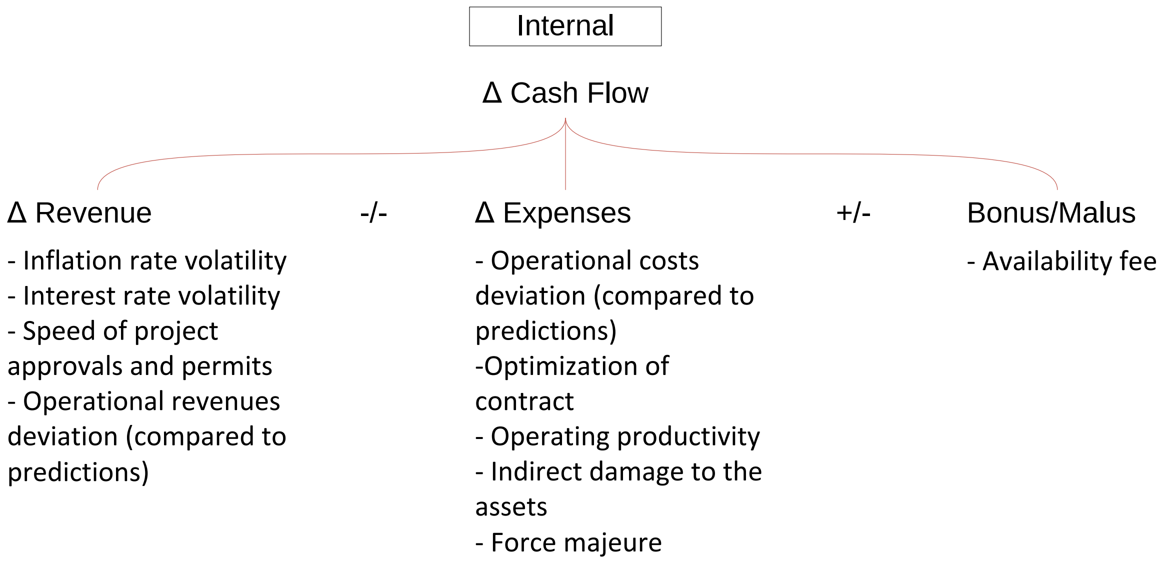


Figure 11 Internal risks at the second level related to cash flow

Bonus/malus is at request of NedMobiel a separate category. The measurement of these risks depends on specific contracts and is treated in chapter 4. A short explanation per risk is given in Table 5.

Risk	*Explanation*
Inflation rate volatility	A measure of fluctuations in inflation rate.
Interest rate volatility	A measure of fluctuations in interest rate.
Speed of project approvals and permits	If there is a delay in the start date of operation & maintenance contract, there will be a loss of revenue.
Operational revenues deviation (compared to predictions)	The demand of traffic can affect the revenues for the operator.
Operational costs deviation (compared to predictions)	Costs associated with operating and maintenance can deviate from predictions and thus adjust the expenses.
Optimization of contract	The adjustments made to the EMVI that will affect the expenses of the operator.
Operating productivity	Deviations from the productivity as predicted will adjust the expenses.
Indirect damage to the assets	Direct damage will likely be insured, but the associated indirect damage will affect the expenses of the operator.
Force majeure	An event that affects the ability of one party to fulfill its contract, but that is not the fault of, and could not reasonably have been foreseen by, that party.
Availability fee	If the percentage availability deviates from predictions, there can be a bonus/malus for the operator.

Table 5 Explanation of the internal risks

The internal risks at the third level are now clear, the next paragraph will elaborate on the fourth level risks.

2.3 Key internal risks at the fourth level

The reason that a fourth level is necessary is because the third level is inadequate to determine the corresponding parameters per risk. The determination of the parameters that will be used is described in chapter 4 and comprises the impact, chance and timing per risk.

One reason that the third level is inadequate is because the third level risks are multi-interpretable and the perceptions to different people would differ too much to get accurate results. Thus, the risks need to be defined one step deeper to come to detailed results which are useful and adequate.

As said before, literature did not get deeper than the third level. Thus, brainstorm sessions with operational managers were organized to find the third level risks based on the internal second level risks. The boundary conditions of the sessions were the determination of the fourth level risks of the corresponding internal risks. Criteria on which the fourth level risks were assessed: collectively exhaustive, specificity (deeper than the third level but not too deep) and influence of the cash flow for the operator.

Both inflation and interest rate volatility are already specific enough to gather country specific data. The other third level risks were specified such that it is possible to determine a chance, impact and time aspect of the risk. These three parameters are the data that will be collected as can be read in chapter four. Chance (X_i) refers to the possibility expressed in percentages that a certain risk will occur. Impact (Y_i) will be the amount of money involved if the risk occurs, expressed in a percentage of the contract price. The time aspect refers to the point in time that a certain risk, given its chance and impact, will occur. The time aspects (Z_i) is measured in a percentage of the total time of the project were there is the largest chance that the risk will occur. The notation *i* refers to a specific fourth level risk. Table 6 shows the outcome of the sessions and the fourth level risks.

3rd level risks	*4th level risks*
Inflation rate volatility	-
Interest rate volatility	-
Speed of project approvals and permits	EPC to O&M transfer of property
	Communication risk: expectations about deliverables
	Time to get an approval
Operational revenues deviation (compared to predictions)	Number of cars on the road
	Quality of maintenance
	Availability of the road
	Measuring availability
Operational costs deviation (compared to predictions)	Maintenance costs deviation (compared to predictions), e.g., extra incidents, loan changes, weather conditions, price of materials, electricity prices, extra traffic, etc.
	Maintenance frequency deviation (compared to predictions)
	Technological developments
	Working hours
Optimization of contract	Intellectual Property Rights
	Taking part in the EPC period
	Costs of optimization higher than savings

	Safety issues, e.g., changing the maximum speed
Operating productivity	Efficiency of organization, e.g., communication, techniques, supply route, etc.
	Weather conditions
	Low level of education
Indirect damage to the assets	Weather conditions, e.g., dust, mud, landslides, etc.
	Cause of damage unidentifiable
	Overhead costs, e.g., office and staffing costs
Force majeure	Natural disasters
	Terrorist attack
	Labor disputes and strikes
Availability fee	Credit risk of the public sector entity
	Measuring method, e.g., how to measure additional performance
	Costs of measuring higher than bonus
	Due to culture no motivation to achieve the bonus

Table 6 The 4th level risks corresponding to the internal risks

2.4 Conclusion of the key risks in an O&M contract

By using different perspectives, a list of key risks is composed that will serve as the components of the model. A literature study was used to come up with a rough list of risks. These risks where then split into different levels of specificity. Performing internal and external interviews made sure that the list was compared with practice. Several internal brainstorm sessions were then set up to ensure that the list of key risks was tailored to the specific needs of NedMobiel. Key risks were selected by NedMobiel by looking at the risks that were directly of influence at the cash flow when being an operator. These ten key risks were specified further which resulted in a list of thirty risks that will be used in the model. The model will be flexible enough to easily add or delete risks, such that NedMobiel can tailor the model for each specific project.

Chapter 3

Chapter 3 describes the choice for a certain kind of risk model. A list of risk models that will be part of the evaluation process is given (§3.1) after which the multi criteria decision analysis method how to choose the most appropriate risk model is given (§3.2). The outline of this method is given including the criteria which are used to assess the models (§3.3) and the actual results from the application of the method is presented (§3.4). Lastly there is a wrap-up and a conclusion (§3.5).

3. Choice of a risk model

3.1 Various risk models to choose from

A choice for a specific risk model will be made in this chapter. It has to be taken into consideration that the model will not provide ‘the’ answer, but that it will be the *foundation* to or an *indication* for an answer. As already shown in section 1.4 the model will give rise to a risk dossier which will be part of the decision making process.

This research is about developing a statistical model for NedMobiel. This does not mean that such a model is enough for a risk dossier. Given the nature of operation & maintenance (O&M) contracts a qualitative analysis should always be made. A list of *possible* and *feasible* risk models is chosen in dialogue with NedMobiel. Criteria used to make an initial assessment of the models were: applicability to O&M contracts; general feasibility in terms of time, money and usability for NedMobiel; and the possibility to include all the risks. For instance, a checklist is also a risk model but is as a stand-alone model clearly not a suitable method in identifying and assessing all the risks that come with an O&M contract. The risk models that remained are shown in Table 7.

Risk Models	*Description*
Mathematically simple models	
EGAP (Everything goes according to plan)	Model that looks at risks with an ex-ante optimism bias
RISMAN/MLD (Most likely development)	Focus is on identifying the most likely risks
FMECA (Failure mode effect and criticality analysis)	Bottom-up, inductive analytical method including a criticality analysis, which is used to chart the probability of failure modes against the severity of their consequences
IPRA (International project risk assessment model)	A risk breakdown structure which puts risks in certain categories
Cause-and-effect diagrams	Illustrate the interrelations between risks and their causes
Statistically sophisticated models	
VaR/CFaR (Value at Risk/Cash Flow at Risk)	Computer algorithms are used to calculate the maximum that the institution could lose in a given time period given a certain confidence level
ES (Expected Shortfall)	An alternative to VaR focusing on the expected loss *given* that a loss occurs at a certain confidence level

Probabilistic/stochastic model simulation (e.g., Monte Carlo method)	To obtain the cumulative likelihood distributions of the project's objectives using probabilistic estimation of the input parameters
Sensitivity analysis	Discover the criticality of various project parameters

Table 7 Various risk models to choose from

From this list, a statistically sophisticated model will be chosen using the AHP method as described in the next paragraph. Given the fact that RISMAN is already used widely as a qualitative risk model and there is not yet an alternative, it is assumed that the RISMAN method will be continued in the (short) future. The quantitative model that is the output of this research will be used to determine the risk premium. The model that will be chosen is explained in detail in chapter five.

3.2 Choosing a risk model is done by using the Analytic Hierarchy Process (AHP) method

A first note about the mathematically simple models is the fact that they are not mutually exclusive. For the use of for instance a VaR/CFaR or ES model, a model simulation is also used. Simplistically saying, model simulation is a simple version of the former models. In the choice of a statistical model, the distinction between microstructural and reduced form models can be made. The former models are fully pre-specified, meaning that the input of the model is fixed and that all parties involved know the distribution of the input parameters. An advantage is that you know that everything is accounted for, but the clear disadvantage is the fact that such a model is not possible for O&M contracts. The reduced form models are less ambitious. They can describe all the underlying parameters but will look at them at an aggregate level. This basically means that you look at a broad level to the model without specifying the details. An advantage is that such a model is less assumption based, whereas a disadvantage is that they are only useful for 'stable' environments due to the fact that you cannot see whether some conditions will not apply (Rebonato, 2010). For this research, a model will be made that is a mix between a reduced form and a microstructural model. In other words: a model that is detailed enough according to NedMobiel and broad enough such that it can be set up. Based on this criterion, all the previously mentioned models still apply and thus will be taken into account when making a decision.

The multi criteria decision analysis methods considered to choose a risk model are the Analytic Hierarchy Process (AHP), Multi Attribute Utility Theory (MAUT) and Simple Multi Attribute Ratings Technique (SMART). These methods are all useful in making a decision between alternatives and are preferred above simpler methods, such as direct rating, because of the high impact of the decision. The decision is of such importance because the chosen method will be used the coming years in complex O&M contracts.

The method to choose a statistical model will be the AHP. First the reasons why MAUT and SMART are not used are given and then the reasons why AHP is most useful are stated. MAUT is used when there is uncertainty in place, for instance when there is an X% chance that a certain situation will occur, which is not the case since all methods described in Table 7 are readily available. The outcome of this method is the attitude towards risk, which is in this case not useful and thus MAUT is not favorable. SMART has much of the same characteristics as AHP but is particularly useful to choose between alternatives in terms of cost versus benefit. Since all methods described in Table 7 can be implemented with virtually zero cost, SMART is not favorable. With AHP, you can make a prioritization amongst the different pre-selected models (Saaty, 2008). They will be ranked relatively to one another, which is a favorable method above *direct* (individual) scoring because of the pre-selection already made and the need to know how favorable a certain model is as opposed to the others. Another advantage of this method is the fact that it is fully compensatory; a bad score on a criterion can be compensated by performing well on another criterion. AHP also gives the consistency of the answers.

The models will be evaluated on a few criteria which will test whether the model will serve the objectives of the decision maker. In this case, the author is the decision maker and NedMobiel will provide the objectives that the model will need to live up to, which are to have a statistical risk model to support the decision making process and its gut feeling. By performing the AHP method, the thinking process is formalized so that the decision of a model is transparent and understandable for others (Saaty, 2008).

3.3 Outline of the AHP method

Saaty (2008) developed his AHP method in the 1970s and defines it as: "(…) a theory of measurement through pairwise comparisons and [it] relies on the judgments of experts to derive priority scales". The judgments are made for different criterions comparing two models at a time. The scale of the judgment runs from one to nine, where a one stands for equal importance and a nine for extremely more important. Of course, if we say that A scores a nine compared to B, then B must score the reciprocal of nine compared to A (i.e., $\frac{1}{9}$). See Table 8 for the complete scale and definitions (Saaty, 2008).

Intensity of importance	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption

Table 8 Scale of judgments to be used in the AHP method

The nine point integer scale is used in the AHP after extensive research by Saaty (2001). Integers are chosen because a comparison with decimals would not be understandable and clear. The nine point scale is chosen because research shows that people cannot cope with more than a nine point scale and fewer points would not be comprehensive. The formal definition of reciprocity would be as follows (Saaty, 2003): if we let a_{ij} to be the intensity of importance of activity *i* compared to activity *j*, then a positive *n* by *n* matrix is said to be reciprocal if $a_{ij} = \frac{1}{a_{ji}}$.

3.3.1 Criteria on which the models will be evaluated

The different criteria on which the mathematically sophisticated risk models are evaluated are listed in Table 9. The table is composed by the author in cooperation with NedMobiel.

Criterion	*Sub criterion*	*Explanation*
Ease of use	Reporting	The model should be able to produce a report that is clear to the user(s)
	Usability	The model should be simple enough to use by the user(s)
Building blocks of the model	Feasibility	Given the (time) constraints of this research, it should be feasible to build the model
	Correlation between risks	The correlation between risks should be taken into account
Awareness		How much awareness among employees/users does the model create about the risks involved
Adding data and risks		It should be possible to add data and even risks alongside the process

Table 9 Criteria to be used in the AHP method

The five aforementioned sophisticated risk models will be tested on these criteria. The goal is to select the most suitable risk model for assessing risks in O&M contract. Figure 12 gives an overview of the AHP method.

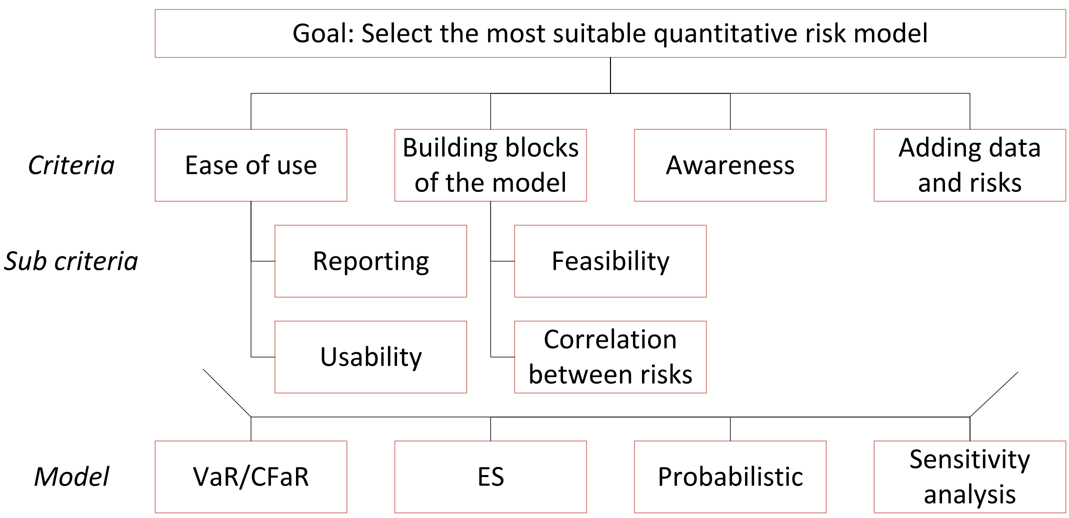


Figure 12 Overview AHP method

The steps that will be taken are to make nine pairwise comparison matrices. One for the four criteria with respect to the goal. Two for distinguishing the importance between the sub criteria in relation to each other. And last but not least six matrices for the five models with respect to all lowest level criteria. The last matrix is not a comparison matrix but an overview of the results from the nine pairwise comparison matrices.

3.3.2 Checking the answers for consistency

It is important to check that the answers given are consistent. This basically means that if we say that A is more important than B and B is more important than C, then A should be more important than C. In mathematical term this translated to the matrix being consistent if for all $i, j, k, \ldots = 1, \ldots, n$ the multiplication $a_{ij}a_{jk} = a_{ik}$ is true. This consistency implies also reciprocity since $a_{ji} = \frac{a_{jk}}{a_{ik}} = a_{ij}^{-1}$ follows from $a_{ij} = \frac{a_{ik}}{a_{jk}}$ (Saaty, 2003). A true consistent matrix is almost impossible because people are not purely rational. This does not mean that you still do not have to check whether the consistency is high enough to make correct conclusions.

Without going to deep into the mathematics, the consistency can be checked by calculating the Consistency Ratio (CR). If the CR is smaller than 0.1, the judgments seem to be consistent. If it is larger than 0.1, the judgments seem to be too dispersed and random to comfortably say they are consistent. The CR is calculated using the following formula: $CR = \frac{CI}{RI}$ where CI = Consistency Index $= \frac{\lambda_{max} - n}{n-1}$, RI = Random Consistency Index, λ_{max} = principal eigenvalue and n = size of the matrix. If these formulas do not appeal to the reader, forget the formulas and just remember the fact that the CR has to be smaller than 0.1 to have consistent judgments. The Random Consistency Index is generated by Saaty from very large samples of random judgments and given in Table 10.

n	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
RI	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Table 10 Numbers from the Random Consistency Index (RI)

The principal eigenvalue is a complex principle and it goes beyond this research to elaborate on this, since it would consist of a stand-alone chapter to comprehensively explain the meaning of and every concept behind it. It furthermore would greatly reduce the readability of this report. A very simplified explanation (without giving any proof) is that the principal eigenvalue is the largest vector by which the matrix stays unchanged when multiplied by a positive constant. If we continue our very simple example given in the start of this paragraph it would mean as much as: if you multiply every statement, the result should be the same. This would mean that if (2 x A) is more important than (2 x B) and (2 x B) is more important than (2 x C), then (2 x A) should (still) be more and relatively equally important than (2 x C). This looks logical in this simple 3x3 example but when working with matrices with $n > 3$ it is not obvious. That is why you need to calculate the principal eigenvalue and the CR and check whether the CR is smaller than 0.1. That being said, the actual calculations and matrices are described in the next paragraph.

3.4 Application of the AHP method and choice of the risk model

As already mentioned, the next step is to make nine pairwise comparison matrices. The first one is to determine the priority of each criterion. The scale as described in Table 8 is used. An example: if we compare 'ease of use' with 'awareness', then 'ease of use' is favored very strongly over 'awareness' thus scoring a 7. And the other way around, 'awareness' scores $\frac{1}{7}$ compared to 'ease of use'. When making all the comparisons, Table 11 is composed.

Comparing the criteria to each other

	Ease of use	Building of the model	Awareness	Adding data and risks	Relative priority
Ease of use	1	6	7	2	0.50
Building of the model	1/6	1	1/2	1/6	0.06
Awareness	1/7	2	1	1/3	0.11
Adding data and risks	1/2	6	3	1	0.33
Sum	1 4/5	15	11 1/2	3 1/2	1

Table 11 Comparison of the criteria ease of use, building the model, awareness and adding data and risks

The relative priority is calculated by adding the row and dividing it by the sum of the whole matrix. An example for 'ease of use' (numbers of one row are put between brackets for clarity):

$$\frac{(1+6+7+2)}{(1+6+7+2)+\left(\frac{1}{6}+1+\frac{1}{2}+\frac{1}{6}\right)+\left(\frac{1}{7}+2+1+\frac{1}{3}\right)+\left(\frac{1}{2}+6+3+1\right)}=\frac{16}{31\frac{4}{5}}\approx 0.50$$

This is of course the same as dividing the sum of the row of the criterion by the sum of the row 'Sum'. When repeated for all criteria, the relative priorities add (logically) up to one. Note that due to rounding there can be minor differences in the matrices and equations shown here, in the underlying calculations exact figures were used.

Subsequently, we need to check for consistency by calculating the CR. The size of the matrix (*n*) is 4 and the principal eigenvalue (λ_{max}) is calculated by multiplying, per criterion, the sum of a row times the sum of a column and adding all these numbers. For Table 11 this gives:

$$\lambda_{max}=0.50*1\frac{4}{5}+0.06*15+0.11*11\frac{1}{2}+0.33*3\frac{1}{2}\approx 4.19$$

The CI is then calculated by:

$$CI=\frac{\lambda_{max}-n}{n-1}=\frac{4.19-4}{4-1}=\frac{.19}{3}=0.06$$

Performing the last calculation gives us the CR and tells us something about the consistency, remember that the RI can be looked up in Table 10:

$$CR=\frac{CI}{RI}=\frac{0.06}{0.90}=0.07$$

Since $0.07 < 0.10$ we can say that the matrix is filled in consistently and the outcome is reliable in terms of judgment. The key figures calculated above are:

n	4
λ_{max}	4.19
CI	0.06
CR	0.07

Table 12 Numbers to calculate the Consistency Ratio (CR)

The priorities of the criteria opposed to each other are now know, the next step is to calculate the relative importance of the sub criteria.

Comparing the sub criteria of 'ease of use' to each other

	Reporting	Usability	Relative priority
Reporting	1	3	0.75
Usability	1/3	1	0.25
Sum	1 1/3	4	1

Table 13 Example comparison of the sub criteria for the criterion 'ease of use'

Since it is a 2x2 matrix, it is per definition consistent (given the 'rules' as defined). The sub criteria are part of the criterion 'ease of use', which means that the criterion 'reporting' counts for $relative\ priority\ reporting * relative\ priority\ ease\ of\ use = 0.75 * 0.50 = 0.375$ of the total score for an alternative. This is also done for the sub criteria of 'building the model'. Note that not all matrices are given here since this would greatly reduce readability. A detailed overview of all matrices can instead be found in appendix A.

Next are the matrices, six in total, in which the different models are compared to each other for each (sub) criterion. The first matrix for the sub criterion 'reporting' is given in Table 14 and the check for consistency in Table 15.

Comparison of the models for the sub criterion 'reporting'

	VaR/CFaR	ES	Probabilistic	Sensitivity Analysis	Relative priority
VaR/CFaR	1	2	3	6	0.44
ES	1/2	1	2	4	0.28
Probabilistic	1/3	1/2	1	4	0.22
Sensitivity Analysis	1/6	1/4	1/4	1	0.06
Sum	2	3 3/4	6 1/4	15	1

Table 14 Example comparison of the models for the sub criterion 'reporting'

n	4
λ_{max}	4.21
CI	0.07
CR	0.08

Table 15 Example calculation of the CR for the sub criterion 'reporting'

The matrix tells us that for the sub criterion 'reporting' the VaR/CFaR scores best and is followed by the ES and Probabilistic model which score approximately half as good on this sub criterion. The Sensitivity model is the least attractive model when looking at this sub criterion. This is done for all other (sub) criteria and as said before, the matrices can be found in Appendix A.

Synthesizing the results gives Table 16. The table shows the overall priority, which is calculated by multiplying the score on a criterion with the weight of the criterion and then taking the sum of all priorities. In mathematical terms:

$$\sum_{i=1}^{4}\sum_{j=1}^{2}\sum_{k=1}^{5} I_{A[0,1]} w_i x_{ik} + I_{B[0,1]} w_i v_j x_{jk}$$

Where w_i is the weight of criterion *i*, v_j is the weight of sub criterion *j*, x_{ik} is the score of criterion *i* on model *k* and x_{jk} is the score of sub criterion *j* on model *k*. $I_{[0,1]}$ is an indicator function, either taking the value of zero or one.

Here $I_{A[0,1]} \begin{cases} 0\ , if\ a\ sub\ criterion\ exists \\ 1\ , if\ no\ sub\ criterion\ exists \end{cases}$ and $I_{B[0,1]} \begin{cases} 0\ , if\ no\ sub\ criterion\ exists \\ 1\ , if\ a\ sub\ criterion\ exists \end{cases}$.

This translates to the calculation of, for example, the score for the Probabilistic model as follows:

$$0.50 * (0.22 * 0.75 + 0.53 * 0.25) + 0.06 * (0.59 * 0.80 + 0.11 * 0.20) + 0.11 * 0.49 + 0.33 * 0.53 = 0.41$$

Synthesizing the results (1/2)

	Ease of use 0.50		Building the model 0.06	
	Reporting 0.75	Usability 0.25	Feasibility 0.80	Correlation 0.20
VaR/CFaR	0.44	0.08	0.05	0.44
ES	0.28	0.08	0.16	0.39
Probabilistic	0.22	0.53	0.59	0.11
Sensitivity Analysis	0.06	0.31	0.19	0.06

Synthesizing the results (2/2)

	Awareness 0.11	Adding data and risks 0.33	Overall priority	**Normalized overall priority**
VaR/CFaR	0.31	0.10	0.25	**0.62**
ES	0.15	0.05	0.16	**0.40**
Probabilistic	0.49	0.53	0.41	**1.00**
Sensitivity Analysis	0.05	0.31	0.18	**0.44**

Table 16 Summary of all comparison matrices

All matrices had a $CR < 0.1$ and were thus filled in consistently. It can be seen that the Probabilistic (also called stochastic simulation) model is the favorable model, having the highest overall priority. When normalized (giving the highest overall priority a score of one), it can be easily seen that the probabilistic model is far more preferred compared to the other models. We can say that, for instance, the AHP model is 71% as good as the Probabilistic model given the criteria and scores as defined respectively given.

3.5 Conclusion why to use the probabilistic model

After initial analysis, four models were chosen to be suitable as a statistically sophisticated risk model. The models were compared to each other using the AHP method and using six different (sub) criteria. The first step was to look at the relative importance of the different (sub) criteria and the second step was to compare the five models with each other on these six criteria. This gave the result that a probabilistic simulation model is the most favorable option to be used as a statistical risk model. The building and contents of the model are described in chapter five and the format of the data needed for the model is given in the next chapter.

Chapter 4

This chapter describes the outline of the data and to give an explanation in words and numbers as well as in mathematical terms. If the reader does not feel comfortable with the mathematics, this chapter can be skipped and the summary (§4.5) is enough to continue using and have an understanding of the model in later chapters. A short review of the existing methods is given (§4.1) after which the mathematics of the data for the new situation are stated (§4.2). The format of the data that will be gathered is described (§4.3) and the actual format in which the data will be gathered is presented (§4.4). Lastly there is a wrap-up and a conclusion (§4.5).

4. Data sorting

4.1 Existing methods or databases in the infrastructure sector are not sufficient to build upon

Having determined the relevant risks in chapter two and the model that will be used in chapter three, this chapter focuses on the format of the data. There are currently no databases available for risks in operation & maintenance (O&M) contracts, let alone for the risks as defined earlier. Recalling the needs from chapter one, the transition of a deterministic ('binary') model to a statistically stochastic model is sought after. The question remains what input is needed for the new situation.

Several sources were used to find whether the new model could build on existing ideas. When looking at scientific literature, Bent Flyvbjerg is a researcher who has focused much of his work on (among others) risk management and laying the foundation of a database by calculation the outcomes of risks. Flyvbjerg has done a considerable amount of research on budget overruns in building the infrastructure. His way of combining data could be useful to look into, although the specific subject of cost overruns is of less interest for the operator. Unfortunately, after contacting him the response was that "[he] cannot make the database publicly available".

In interviews with other operators and builders, it became apparent that no database was used and only the deterministic approach was used to assess financial risks. One of the largest builders in the Netherlands was interested in the idea of the transition to a statistical risk model but did not have the tools and data to do so. Their idea of the risk premium in a contract was the fact that if no risk occurred, the premium was seen as 'additional profit'. So the premiums were not added to a general risk pool to withstand future losses (i.e., a reserve). Furthermore, the method to assess the risk was still the deterministic way.

In interviews with the public authority of the Netherlands, i.e., Rijkswaterstaat, it became apparent that they also could not help in this problem. Their focus was especially on the management control measures of risks in general or they used a program to calculate the expected amount of deaths in tunnels. This program used a linear approach to define the number of deaths which was not useful for this research. The input parameters were furthermore to detailed to be of use. The process of defining the risks and make management control measures was to follow (more or less) the RISMAN method. And they neither kept track of past estimated and occurred risks.

As already pointed out in chapter 1, current methods are thus insufficient to help arrive at the new situation and since there is no data available, other sources of data need to be found. The next paragraph will describe the mathematical characteristics of the data that will be gathered.

4.2 The mathematics behind the gathering of the data

Before gathering the data from the so called subject matter experts (SME), it is first necessary to define in what kind of format the data is needed. For this format, the mathematics behind it are necessary to address. A categorization of the distributions when modeling expert opinions is the difference between parametric and non-parametric distributions (Vose, 2007).

Parametric distributions are difficult to observe from data, they follow from mathematical functions whose input are several parameters. Most processes 'in the real world' tend to be parametric distributions. The most well-known parametric distributions are: Lognormal, Normal, Pareto and Hypergeometric. The lognormal distribution is the one used as an example for the desired situation, recall Figure 7 in chapter 1. Figure 13 gives a graphical explanation of these distributions.

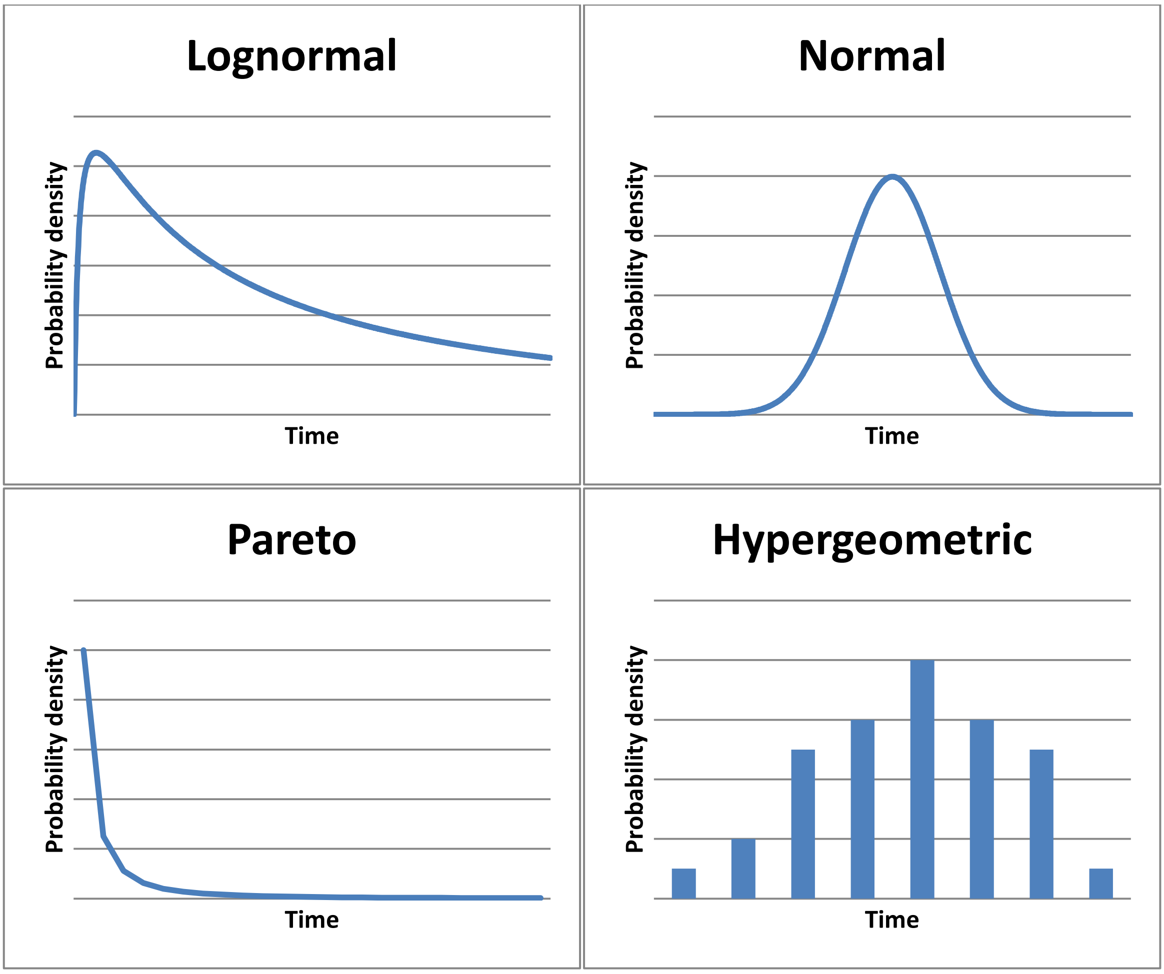


Figure 13 Four graphical examples of parametric distributions

The specific PDFs for the parametric distributions, necessary for designing the model, are shown in Table 17 (Alexander, 2001) (MathWorks, 2011) (Purplemath, 2011) (WolframMathWorld, 2011):

Distribution	Probability density function
Lognormal	$f(x\|\mu,\sigma) = \frac{1}{x\sqrt{2\pi\sigma^2}} e^{-\frac{(\ln x-\mu)^2}{2\sigma^2}}$ for $-\infty < x < \infty$
Normal	$f(x\|\mu,\sigma) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$ for $-\infty < x < \infty$
Pareto	$f(x\|x_m,\alpha) = \frac{\alpha x_m^\alpha}{x^{\alpha+1}}$ for $x > x_m$
Hypergeometric	$f(x\|M,K,N) = \frac{\binom{K}{x}\binom{M-K}{N-x}}{\binom{M}{N}}$ for $M,K,N > 0$ and $N > M$

Table 17 Probability density functions of the parametric distributions

Non-parametric distributions are easier to observe directly from the data. They can be described in a fairly simple mathematical way. Most processes 'in the real world' are not as simple as these non-parametric distributions. The most well-known parametric distributions are: Uniform, Triangle, Cumulative and Discrete. The discrete distribution is the one currently used when determining the risk, recall Figure 6 in chapter 1. Figure 14 gives a graphical explanation of these distributions.

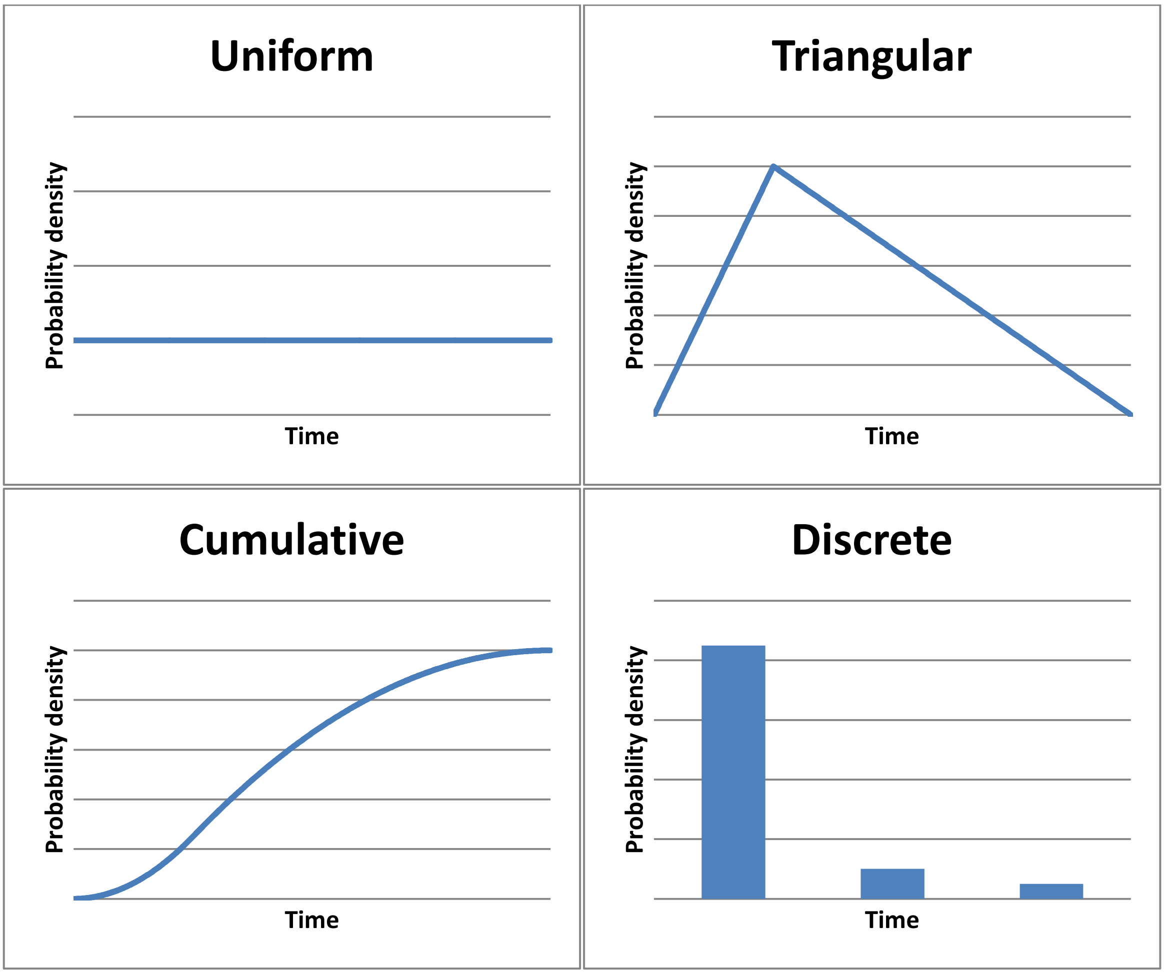


Figure 14 Four graphical examples of non-parametric distributions

The specific PDFs for the non-parametric distributions, necessary for designing the model, are shown in Table 18 (Alexander, 2001) (MathWorks, 2011) (Purplemath, 2011) (WolframMathWorld, 2011):

Distribution	Probability density function
Uniform	$f(x\|a,b) = \frac{1}{b-a} I_{[a,b]}(x)$ for $b > a$
Triangular	$f(x\|a,b,c) = \begin{cases} 0 \text{ for } x \leq a \\ \frac{2(x-a)}{(b-a)(c-a)} \text{ for } a < x < c \\ \frac{2}{b-a} \text{ for } x = c \\ \frac{2(b-x)}{(b-a)(b-c)} \text{ for } c < x < b \\ 0 \text{ for } b \leq x \end{cases}$
Discrete	$f(x\|Q) = \frac{1}{Q} I_{(1,\ldots,Q)}(x)$
Cumulative	$F_X(x) = P(X \leq x)$

Table 18 Probability density functions of the non-parametric distributions

The explanation of the parameters from Table 17 and Table 18 are given in Table 19.

Parameters	Explanation
x	Random variable, an outcome of some type of random process
μ	Mean, expected value or average of a set of numbers
σ	Standard deviation, measure how close the data is clustered around the mean
x_m	Minimum possible value of x
α	Positive parameter (‘Pareto index’)
M	Size of the population
K	Number of units with the desired characteristic in the population
N	Number of samples drawn
a	Minimum value
b	Maximum value
c	Mode, the value that occurs most often
Q	Maximum observable value
P	Probability

Table 19 Explanation of the parameters given in the probability density functions

With these eight distributions, all the basic ‘shapes’ are covered. There are countless other distributions but they are most of the time an adjustment of the distributions shown.

An example of a Pareto distribution is the risk of ‘EPC to O&M transfer of property’. Most of the risk is at the start of the O&M period, around the transfer point of the EPC to the O&M company. Some examples; The hypergeometric could be used for the risk ‘costs of measuring higher than bonus’. Only at certain points in time is checked whether the operator receives a bonus or not. The uniform distribution is appropriate for the risk ‘terrorist attack’. The risk of a terrorist attack is more or less the same throughout the lifetime of the O&M contract. A discrete distribution could be used for the risk ‘costs of optimization higher than savings’. These optimizations only take place when there are large adjustments to the infrastructure, which is in the beginning of and, say, twice during the lifetime of the infrastructure.

The overall characteristic is the fact that the most likely, minimum and maximum can be estimated. All shown distributions are continuous except the discrete and hypergeometric distribution which are discrete. Discrete means that there are a finite or countable infinite number of values. Continuous means that there are, within a given range, an infinite amount of possibilities.

Let's define a random variable *X* to be an outcome of a certain discrete or continuous process. Then the graphs above show the probability density functions (PDFs) of this random variable. The PDF is denoted in the discrete case as $p_x(k)$, where $p_x(k) = P(\{s \in S | X(s) = k\})$, k = time and $P(.)$ stands for the probability. If we have a real number *t* then the probability that *X* takes on a value $\leq t$ is called the cumulative distribution function (CDF). The CDF is written as $F_x(t)$ where $F_X(t) = P(\{s \in S | X(s) \leq t\})$.

The continuous case is a little different, let's define a random variable *Y*. Then we can define that function as $f_Y(y)$ having the property that for any numbers *a* and *b*, $P(a \leq Y \leq b) = \int_a^b f_Y(y)dy$ where $\int(.)$ can be interpreted as the area under a function in a given interval.

The expected value μ can be defined as the most likely outcome, also called the mean. The expected value of *X* is denoted *E(X)*, μ or μ_X and is given by $E(X) = \mu = \mu_X = \sum_{all\ k} k * p_X(k)$. Similarly, the expected value of Y is given by $E(Y) = \mu = \mu_Y = \int_{-\infty}^{\infty} y * f_Y(y)\, dy$.

Then the variance σ^2 can be defined as the spread of the outcomes, how much difference there is between the expected value and the other outcomes. The variance of a random variable is the expected value of its squared deviations from μ. If *X* is discrete with pdf $p_X(k)$, $Var(X) = \sigma^2 = E[(X - \mu)^2 = \sum_{all\ k}(k - \mu)^2 * p_X(k)$. If *Y* is continuous with pdf $f_Y(y)$, $Var(Y) = \sigma^2 = E[(Y - \mu)^2] = \int_{-\infty}^{\infty}(y - \mu)^2 * f_Y(y)dy$. This could also be generalized, therefore we define *W* as a random variable, discrete or continuous, having mean μ and for which $E(W^2)$ is finite. Then the generalized variance can be defined as $Var(W) = \sigma^2 = E(W^2) - \mu^2$.

A problem with using variance is that it is the square of a random variable and thus not easily scalable. This is solved by introducing the standard deviation σ, which is the square root of the variance. In mathematical terms:

$$\sigma = standard\ deviation = \begin{cases} \sqrt{\sum_{all\ k}(k - \mu)^2 * p_X(k)} & \text{if } X \text{ is discrete} \\ \sqrt{\int_{-\infty}^{\infty}(y - \mu)^2 * f_Y(y)dy} & \text{if } Y \text{ is continuous} \end{cases}$$ (Larsen & Marx, 2006).

The formulas described above are the mathematical basis to determine in what format the actual data are needed. This format is described in the next paragraph, where the formulas of the distributions as described are designed in the model.

4.3 The format to gather data is to focus on impact, chance and timing of the risks

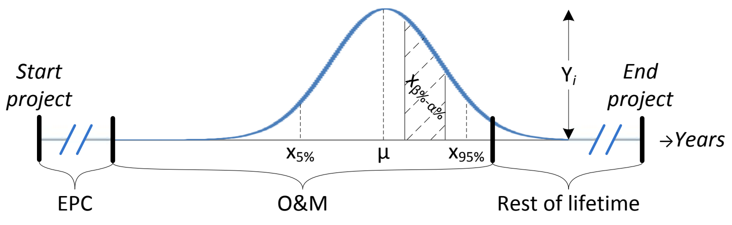
As said in the first paragraph, there are no existing methods or databases in the infrastructure sector to build upon. What we do know is that the parameters impact and chance are frequently used. Since there are no existing databases, the data will be gathered by performing interviews with the SMEs. This means that the SMEs must estimate the variables per risk as defined. Having said that, key criteria in this gathering of the data are that the parameters can be understood and estimated by experts, that the parameters must be able to function as the input of the probabilistic model as chosen in chapter 3 and that the outcome must be realistic. Realistic means that the method of formulating the parameters can influence the outcome of the interviews which must not be the case.

With the criteria as defined above in mind, the impact and chance are also used in the new model. This ensures that the risks can be estimated per parameter and are recognized by the SMEs. The format of the contract is already defined as new infrastructure and setting up a special purpose vehicle (SPV) with the engineering, procurement & construction (EPC) contractor. Although the focus of this research is defined as explicitly the O&M phase, thus without the building of the infrastructure, the desired situation is to work together with the builder. As said before, working together with the EPC contractor can lead to some challenges, which is accounted for in the list of risks as defined in chapter 2. The contract price and duration of the contract (from both the EPC and the O&M side) are different for each (new) contract, the model must thus be able to cope with these differences. Combining this with the fact that the impact and chance must be kept in mind, the impact and chance will be measured in percentages of the total contract price respectively the contract duration.

Another point that is not taken into account in the current situation is the time factor. In the current situation a single number is estimated, but it can be argued that the timing and possibility of occurring of the risks are quite different. For instance, maintenance cost deviation is more likely to deviate later in the lifetime than in the beginning when the road is still new. So you would put more emphasis on the end of the lifetime for this risk than in the beginning. Thus, next to the impact and chance, the time factor must be taken into account when gathering data. This is also a key issue in making the output of the model graphically more comprehensive.

With these percentages, the loss is still not observable. What will be done is to model the impact, chance and timing in terms of the duration and price of the contract. Next to the total chance of a risk occurring, the spread of the chance in relation to the timing will be checked. This will be done by also asking about the percentiles, this means checking what the chance is for different points in time. A (non-)parametric distribution will be assigned per risk, as shown in Figure 13 and Figure 14, to combine all the previously mentioned parameters.

For example, the uniform distribution would have the same chance of occurring in each point in time while a lognormal distribution would tell us that the chance of occurring would be higher in the beginning of the project than at the end of project. The outcome (the PDF) would look, for instance if the risk would have a normal distribution, something like Figure 15.



μ = Expected value of X_i (% of contract duration)
$x_{\beta\%-\alpha\%}$ = Possibility * expected cost of a risk in a given time interval (% of contract price)
X_i = Total possibility of risk *i* occurring (% of contract price)
Y_i = Expected costs if risk *i* occurs (% of contract price)
$x_{5\%}$ = Cumulative 5% chance of the risk occurring (% of contract duration)
$x_{95\%}$ = Cumulative 95% chance of the risk occurring (% of contract duration)

Figure 15 Example outcome of modeling impact, chance and timing of a risk to contract duration and price

The figure represents on the horizontal axis the total lifetime of a new infrastructure project and on the vertical axis the expected costs (i.e., a relative loss) for a certain risk. If the outcome of the risks would have a positive effect, this would result in the function shifting down (since Y is the loss, a line below the axis would represent a profit). Since NedMobiel wants to focus on the negative impact of risks that come with a cash flow, this specific case (i.e., profit) will not be treated in the model.

Vose (2008) states that having the mean, percentiles and standard deviation makes it relatively easy to understand the statistics. Cooke (1991) as cited in Willems et al. (2005) provides a framework in which "experts are asked for quantiles of their uncertainty distributions for observable quantities" in order to find the matching distribution. This method will also be used in this research, the SMEs are asked for the 5%, 50% and 95% quantile (or mathematically correct: 1^{st}, 10^{th} and 19^{th} quintile).

Besides asking the percentages of the impact, chance, timing and quantiles, the graphs of different functions will be shown to the interviewee and (s)he can point out which graph is the most appropriate for a risk. The choice of the graph can later be checked with the numbers and it can then be assessed whether the answers given are consistent. Checking it both mathematically and graphically ensures that the way the SMEs have the risk in their head is correctly formalized.

In the interviews with the SMEs, a standard contract will be used as a reference point. By gathering data about this standard contract, it is made clear for the SMEs what kind of project they have in mind. The standard contract is defined by NedMobiel as a contract in the Netherlands with:

- a duration of 20 years (i.e., excluding 5 years EPC);
- a contract price of 1 billion euro;
- not transferable and no prolongation;
- light maintenance (vs. heavy maintenance);
- frequency based maintenance (vs. performance based maintenance);
- having an availability fee (i.e., no tolling); and
- no readjustments during the lifetime of the contract.

Heavy maintenance is defined as a renovation of the road, e.g., new asphalt or changing the camera's in a tunnel. Heavy maintenance is usually done in intervals of 5 years or longer and puts a high pressure on the availability of the road. Light maintenance is defined as everything else. Light maintenance is usually done in intervals of a year or shorter and puts a low pressure on the availability of the road.

Frequency based maintenance is deciding beforehand how many times you will perform maintenance, e.g., cut the grass four times a year. Performance based maintenance is as good as frequency based maintenance but with potentially less costs, at a greater risk of eventually ending up with higher costs. An example is having sheep eat the grass instead of doing it manually. The effect is the same (i.e., cut grass), but the chance that it is less thorough is in the latter case higher. This could result in still having to cut the grass manually, resulting in higher costs than frequency based maintenance.

A note is that the data gathered will be the 'as if' numbers, specifically based on the standard contract. This means without including the control measures and/or allocation of the risks after they have been identified. In the model there will be an option to deviate from this standard contract if more appropriate. For instance, if a risk ($f(x)$) is *x*% and NedMobiel decides for instance to allocate this risk to another party, it can manually set this risk to zero so that it does not account to NedMobiel. In a formula $f(x) * allocation\ of\ the\ risk\ to\ NedMobiel\ (\%)$ where the allocation is measured in percentage of the risk allocated to NedMobiel. An example, if a risk is 5% of the total contract price (so that $f(x) = 5\%$) and the risk is allocated only for 20% to NedMobiel, the risk accounts for $5\% * 20\% = 1\%$ in the judgment of the O&M contract.

4.4 The data will be gathered by performing interviews

From the previous paragraph it is now clear that the focus lies with the impact, chance, timing and the quantiles in relation to the duration and price of the contract. This format must be converted to specific parameters that can be asked in interviews with the SMEs. An explanation is given in Table 20, for which the parameters has to be gathered *per risk*.

Focus	Parameter	Description	Unit
Impact	Y_i	Total loss *if* the risk occurs	(% of contract price)
Chance	X_i	Total chance of risk occurring during contract duration	(%)
Timing	$x_{5\%}$	When do you have a cumulative 5% chance of the risk occurring	(% of contract duration)
	μ	When do you have the most chance of the risk occurring	(% of contract duration)
	$x_{95\%}$	When do you have a cumulative 95% chance of the risk occurring	(% of contract duration)

Table 20 Description of the focus areas used in the interviews

The focus in the interviews must be the explanation of the parameters and then shift to the assessment of the parameters in respect to the risks. The list of risks as defined in chapter two, including an explanation per risk, is given in Appendix B.

Conducting the interviews gives the data that is needed for the input of the model. The interviews are designed such that the current situation will be sketched by the SMEs. These sessions must done individually to check whether there is any difference in perception or method of working, since the SMEs have a different background. The follow up interviews should also be done individually, in which the actual data as described in Table 20 will be gathered, using an interview scheme with easy-to-understand questions for the SMEs. This interview scheme is designed specifically for NedMobiel and can be viewed in Appendix C. Using these questions, it is made sure that even SMEs without any understanding of statistics could come up with accurate results. Although some values were extracted from already performed interviews, it must be made sure that in a future tender the model is filled in completely.

If there are (large) deviations, a follow up session should be organized to confront the interviewees with their differences and to find out what causes it. If the output is consistent, the values can be added to the model and the results will be automatically aggregated. This will result in a specific dataset for all the risks, for each project. And it can very easily be extended to a dataset which covers all the previous projects, also done automatically by the model. These datasets can then be used in future tenders that NedMobiel will participate in. The next chapter will describe the method of building and using the model.

4.5 Summary of the data sorting

This chapter has given a couple of probability distributions to define the distribution of the risks, which are used in interviews with the SMEs. Furthermore, three focus areas are defined for these interviews: impact, chance and timing. These aforementioned parameters are incorporated in a pre-defined interview scheme. After conducting the interviews with the participants of a tender, a dataset will available to use in the model and be able to assess and quantify the financial risks in an operation and maintenance contract. The method of building and using the model is described in the next chapter.

Chapter 5

This chapter describes the process of building the model. General information about the process to build the model is given (§5.1) after which the building blocks are given (§5.2). An overview of the output and interpreting the results will be stated (§5.3) and the future steps needed to fine-tune the model are given (§5.4). Lastly there is a wrap-up and a conclusion (§5.5).

5. Building and using the statistical model

5.1 General information about the programs used to create the model

Chapter 5 describes the process that led to the model and will not function as a guide to make a model. The choice for the probabilistic model is described in chapter 3. The contents and building of this model are described in this chapter. As was the case with chapter 4, this chapter also relies on some mathematics and programming language (be it implicitly or explicitly). If the reader feels not comfortable with this, the conclusion and wrap up of this chapter is enough to have a basic understanding of the model.

Recall that the outcome of the Analytic Hierarchy Process (AHP) was a probabilistic model. This was the outcome of a (subjective) assessment of various suitable models on various criteria: reporting, usability, feasibility, correlation between risks, awareness and adding data and risks. The probabilistic model scores best on these criteria compared to the other models. The goal of the model is to assess financial risks of an O&M contract and quantify the gut feeling, where the aforementioned criteria are also kept in mind. What should be the outcome of the modeling, according to NedMobiel, is a model that can be operated by everybody familiar with PPP contracts and Excel.

Put in a very simple definition, a probabilistic model is a statistical analysis tool that estimates the probability of an event occurring. The input for this model can be either historical data, user defined data or a combination of these two. As already pointed out in the first chapter, historical data are not available, thus user defined data will be used. In chapter 4 it is described which data need to be gathered. Experts have been consulted to make a first assessment, which need to be extended by future interviews when in the tender phase. This will serve as the input of the model together with the defined distributions.

Excel and Visual Basic for Applications (VBA) are used to build the model. One reason for this is that NedMobiel and the members of the SPV must be able to work with the model. This means that it is more convenient to have the model in widely used programs, which Excel certainly is. Coding the model can be done in numerous programming languages and programs. Using the same argument, the most logic choice is VBA. This program runs user defined code within a host application, which in this case is Excel. There is no need to purchase additional software since it is enough to have Excel to be able to run and adjust the code in VBA. There are of course more (powerful) programs, like Matlab, which have already build-in formula’s and graphically more options. The main reason why these programs are not used is that they are not available to NedMobiel or the members of the SPV and purchasing them for this specific model is in terms of costs and benefits not eligible. These costs could include the training of employees, acquisition price of the specialized programs or time spent with the new programs because of lack of knowledge. Using the model is made as easy as possible for NedMobiel, in the Excel file is a specific description of how to use it.

The technique that is used within Excel and VBA to simulate different scenarios is the Monte Carlo technique. This technique is used in situations where an exact probability is difficult to calculate, as is the case given the fact that there is no data available. Monte Carlo samples “random experiments” of a random variable’s true (but unknown) distribution (Larsen & Marx, 2006). This sampling results in different kind of random ‘scenarios’ which are adjusted to display the uncertainty of the future situation. This uncertainty can be expressed as a risk premium on top of the ‘normal’ contract price. The method was first used by scientist working on the atom bomb, who named the method after the Monaco resort town.

5.2 Aggregating the data to fit the model

The model will be split in two parts, VBA on one hand and Excel on the other, where each of the parts has different subsections (Table 21). Excel will be used for the input and output of the model while the underlying formulas and Monte Carlo procedure will be coded in VBA. The exact VBA and Excel code will be omitted in this report since this is too technical in the description of the process of building the model. For an overview of a small part of the model see Appendix D and Appendix E. Since the model is used in Excel, the VBA code is only visible when the user opens the VBA program.

Program	*Sections*			
Excel	Input contract	Input risks	Output	Multiplication
VBA	Monte Carlo simulation		Probability distributions	

Table 21 The sections of the model divided over Excel and VBA

These sections are all connected and follow a specific order in the whole model. When drawn in a diagram, the process of executing the model is shown in Figure 16. Subsequently the individual sections (**bold**) are described in more detail.

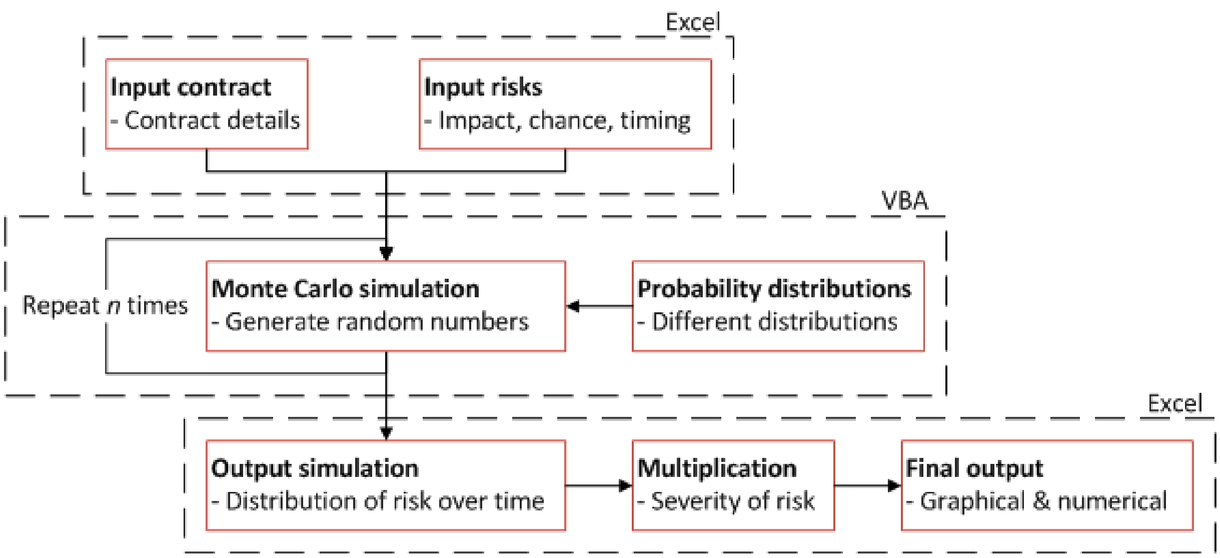


Figure 16 The steps that are taken by the model

Input contract

Since the model should work for different contracts, specific elements of a contract can be added in the model. These include the lifetime of the O&M part, the contract price and the partitioning of the contract value over the lifetime. The lifetime will most of the times be the same, given the framework of this research. It is expected that the contract price will vary from project to project and that the value of the contract varies over the different years of the O&M period, although the *total* value of the contract can stay the same.

Input risks

Using the data that were gathered by interviewing the subject matter experts (SMEs), a standard for the input of risks is established. This input consists of the impact, chance and timing (distribution) per risk, as described in the previous chapter. All three variables can be adjusted in the Excel file. The chance variable is more 'static' over different projects, the impact can be adjusted after each new project because it is directly observable.

To adjust the parameter 'chance', one must have a sample size of *at least* 40 observations without outliers (i.e., extreme values) to say it is statistically significant. In that case you are 90% certain that you are within 15% of the actual chance (StatTrek, 2011). Fewer observations will quickly have a huge impact on the uncertainty of the outcome. With 30 observations you have around 50% chance that you have a statistically significant result (Cohen, 1990), which is the same as flipping a coin and certainly not desirable. On the other hand, raising the sample size will slowly improve your certainty. If you want to be 95% sure that you are within 10% of the actual chance, you must have a sample size of approximately 100 observations (Larsen & Marx, 2006). It is up to NedMobiel to determine the appropriate number of observations (i.e., other projects), it is advised to have *at least* 40 observations before changing the chance parameter. An exception to this number are low probability events, like force majeure. These are once a century events which require at least 2-3 centuries of data (Berg, 2010). However, most defined risk do not fall in this category and it is therefore safe to use 40 observations in general. These observations can be either from past projects or from other experts' judgments. The observations from past projects must be listed in a way that says whether the specific risk has occurred or not. The other expert judgments can be gathered the same way as the data gathering from the internal SMEs. Because of the scope of this research, as stated by NedMobiel, only the SMEs of NedMobiel are consulted to ensure the model is an assessment by NedMobiel. The underlying assumption is that external SMEs are capable of judging the chance quite accurately and judge and interpret the risks the same way as the internal SMEs. The internal (external) accuracy is (will be) increased by interviewing the SMEs separately and, with large deviations, have a group discussion about it. When there are more data available, the chance parameter will no longer be static but will have an expected value and standard deviation. This will automatically be incorporated in the simulation.

For the parameter 'timing', or the distribution of the risk, the same reasoning applies as above. The more observations you have, the more significant your result will be. There are very profound methods to fit data to a distribution, examples are the method of maximum likelihood and the method of moments (Larsen & Marx, 2006). However, the most intuitive way is to plot a histogram of your data along with several distributions. The data are then matched with the distributions and the distribution that best fits the data is selected (Huber, 1999). More profound methods are in place when there is enough data and these profound methods are not applicable for this model given the relatively small sample size. The assumption here is that the distributions are again correctly estimated by the SMEs, using the same interviewing format as with the parameter 'chance'. The same refinement process as with chance can be used here (i.e., looking at past projects and interviewing additional SMEs).

Having to *estimate* the chance and timing from the data, the parameter ‘impact’ is *directly* observable. Per project it can be added to the model, where the impact is taken as a weighted average of projects. The data gathered from the SMEs are taken as the standard. For each new project NedMobiel has, it can add the impact (if a risk occurred) and assign it a weight. This means that NedMobiel can make adjustments and process optimizations such that a scenario analysis is also possible. The impact for a new project is a weighted average of all the impacts. It will be a weighted average because the SMEs based their judgment on multiple past projects, which should have more weight than a single new project. Furthermore, the allocation of the risk can be set here. If NedMobiel chooses to take the risk themselves, the allocation of the risk can be set to 100%. If a risk is fully allocated to another party, then the risk can be set to 0% and it will not be accounted for in the simulation.

Probability distributions
The formulas and data as described in the previous chapter must be conversed before they can be used in Excel and VBA. The formulas of the defined probability distributions are written in VBA code. This process is done such that a user can simply select the probability distribution in Excel and when the simulation is run the program selects the appropriate formula accordingly. Knowledge of Excel is enough to use the model and to add data and risks. Only if the formulas of the probability distributions need to be changed or additional distributions need to be added, VBA has to be used.

Monte Carlo simulation
Monte Carlo simulation is the sampling of random ‘experiments’, as said before. A few consecutive steps are taken in this Monte Carlo method. A domain of possible inputs is created after which the output is created randomly from a certain probability distribution over the domain. Aggregating the results by performing deterministic computations of the output gives the results of the model. So in this simulation process, an equation (in the form of a mathematical model) is calculated thousands of times, each time using random numbers to end with a range of outcomes (Alexander, 2001). This process of simulating with certain assumptions is widely used, for instance in the banking and fusion energy world. In this specific case it means that the simulation uses the input of the contract, the input of the risks and the probability distributions to randomly sample scenarios. Each scenario represents a risk in a certain time period. This is done for all the 30 risks that were identified. The user of the model can set the number of iterations (n) so that the simulation is repeated for n times. The larger the n, the higher the accuracy of the results. By the law of large numbers, the accuracy will converge with $1/\sqrt{n}$ (Alexander, 2001). Practically this meant that quadrupling the number of iterations will halve the error. After testing the model multiple times, it is advised that having an n of 1.000 is the minimum that NedMobiel should use to generate accurate results. The output is a 30 x n matrix and is placed automatically in the Excel file after which Excel handles the rest of the computations.

Output simulation
There is now a 30 x n matrix of raw simulated data in Excel, which has to be further processed. Each of the n scenarios is automatically sorted into bins, where a bin is a small part of the lifetime of the contract (or in other words: a timeframe, for instance $\frac{1}{10}$ of a year). This timeframe can be set

manually to accommodate specific wishes. This creates a list of the amount of scenarios per timeframe. The next step is to correct these scenarios for the severity they have on the cash flow.

In the Excel file the previous mentioned risks and their individual impact, chance and timing is also shown in a list. NedMobiel is more interested in the total overview so that a graphical representation of these risks is omitted.

Multiplication
Having put all the scenarios in bins, each scenario is then multiplied by the impact it would have and the chance that this scenario actually could happen. Subsequently the contract value for a specific timeframe is determined after which the impact is corrected for this. This gives the risk premium per timeframe and per risk.

All these risk premiums are added up which gives the total risk premium per timeframe. Adding up is in this case mathematically allowed because the underlying distributions are based on averages and not on extreme values. Since there are only data that is gathered by interviewing SMEs, a test for correlation between the risks is not possible. Clemen & Winkler (2006) did extensive research at aggregating expert judgments and suggest that simpler aggregation methods perform better than more complex methods. In practice they suggest that if correlation is not possible by extracting it from the data and cannot be 'interpreted' by the experts, assuming independence gives most of the time the best results. This is true when you are looking at 'mean' values, opposed to 'extreme' values. After consulting the SMEs, it became apparent that the correlation will initially be set to zero (i.e., independence between the risks). Since the 'mean' value is used for each risk this correlation of zero is justified. When data are added from future or past projects, correlation between risks can be easily tested in Excel using standard available formulas. The last step is to display the results numerical and graphical.

Final output
After multiplication, there is a list of each timeframe with the according risk premium. Graphically there will be two graphs, one in which a smoothed line is shown by plotting all the timeframes and the according risk premium. The other one will show the risk premium per year, as is convenient for NedMobiel to be able to specify the risk premium during the tender phase and quantify their gut feeling. Numerically there is a table with the risk premium per year and the total risk premium (both in euro and as a percentage of the contract price).

5.3 Overview of the output of the model and using the outcome

The outcome of the model is of course the most important part for NedMobiel and the members of the SPV. An example of the bar chart is shown in Figure 17.

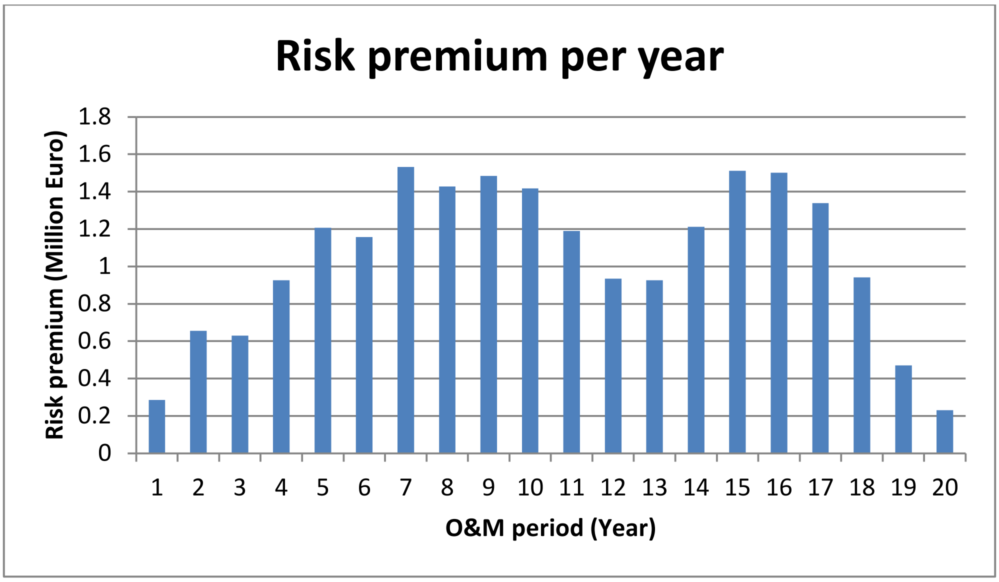


Figure 17 Example output model risk premium per year

This chart tells something about the risk premium that needs to be added to the contract price per year. A detailed chart per timeframe is of course also possible, this is shown in Figure 18. This is especially convenient if the contract has a smaller lifetime and NedMobiel want to check for deviations within a year. For the standard contract which has a lifetime of 20 years, it is less clarifying due to the large number of timeframes. In this example, it is a contract of 20 years divided into bins of $\frac{1}{10}$ of a year. Thus there are 200 data points in the individual graph. It is more useful to use the detailed numerical overview which also shows the risk premium per timeframe, in this case the timeframe is a year.

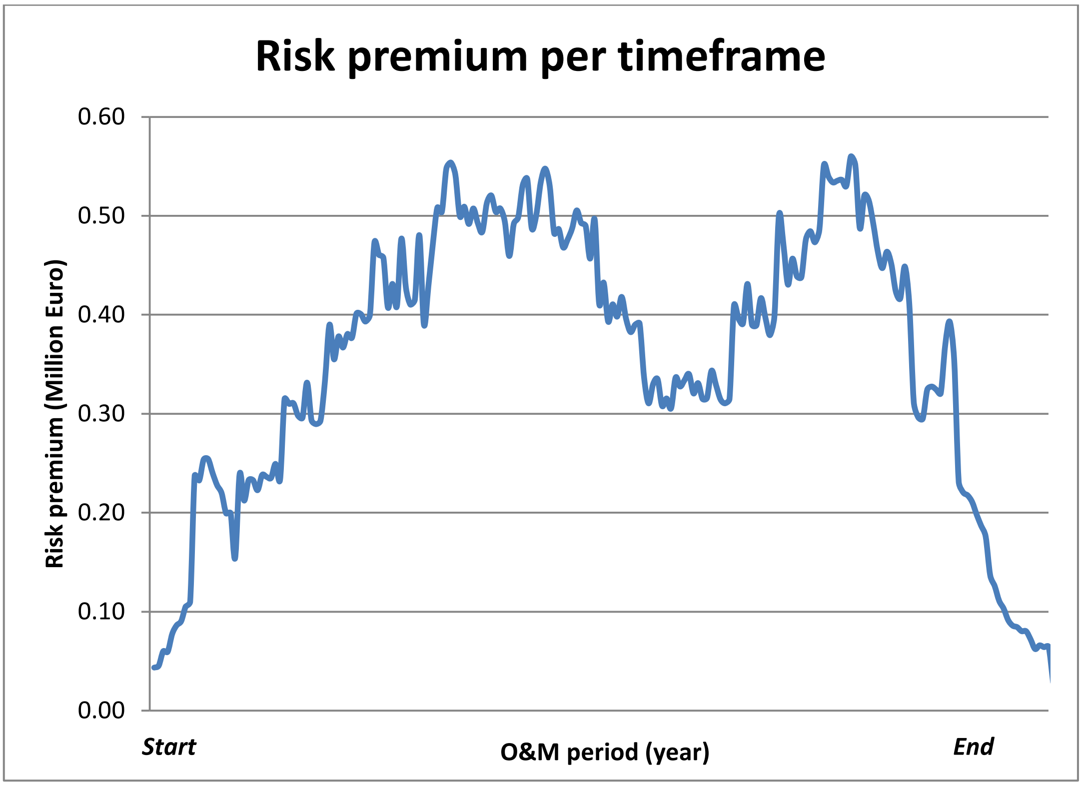


Figure 18 Example output model risk premium per timeframe

The summary of the numerical output is quite straightforward as can be seen in Table 22. This gives the risk premium per year and the total risk premium (both in absolute as in relative numbers).

Total risk premium (in M€)	**M€ 71.47**									
Risk premium in % of contract price	7.15%									
Year	1	2	3	4	(…)	16	17	18	19	20
Risk premium per year (in M€)	0.92	2.22	2.41	3.15	(…)	5.31	4.33	3.24	1.69	0.75

Table 22 Example numerical output risk premium

Recall the current situation, in the tender phase someone will determine a percentage for the risk premium to add to the contract price based on his or her gut feeling. This percentage is estimated on basis of tacit knowledge and is probably a rounded figure and very subjective.

This model will let NedMobiel explicitly calculate the risk premium. The first version is still quite subjective due to the relative small number of estimates by SMEs. When more data will be added to the model, it becomes more and more an objective *estimate* of the risk premium. Using this model allows NedMobiel to explicitly explain which steps are taken in coming up with a price for the risk premium. In the sense of transparency, this is useful to the PPP participants, such as the lenders and investors, the public authority, the special purpose vehicle (SPV), the builder (EPC contractor) and of course for NedMobiel.

Another strong point of the model is that NedMobiel now has the cornerstone of a future database and this database can immediately be used for future tenders without any additional modifications. Furthermore, the risks are broad enough to recognize in various contracts, while they are specific enough to use them in practice. This allows NedMobiel to both consult other SMEs as well as research past projects from (future) partners to fill the database. The model is flexible enough such that risks can be easily adjusted or added if necessary.

This information can either be used to help members of the SPV on new PPP projects with this expert knowledge or in determining the risk within a portfolio. The former to determine the risk premium during the tender phase and subsequently improve the model after each project. The latter case because the model shows the 'amount of risk' per year in which different projects can be aggregated to come up with a companywide risk profile.

5.4 Future steps needed to fine-tune the model

Future steps needed to fine-tune the model can be split into a few categories, shown in Table 23.

Action	Using	Term	Explanation
Additional data	*Chance* Observations	*Short*	To make the model more robust, additional data need to be added. Observations of past projects

	External SMEs		need to be added to the model. The observations for the parameter 'chance' need to be in the form of 'did occur' or 'did not occur'. Future projects can also be used to update the model. Next to these observations, external SMEs can be consulted in which the same interviews can be conducted as was the case with the internal SMEs.
	Impact Observations (Possibly: external SMEs)	*Short*	For the parameter 'impact', past projects can be studied to see whether the impact per risk can be identified. If so, these numbers can be added to the model. When these numbers cannot be deducted, external SMEs can be used and the same interview process can be used. Numbers of the future projects must of course also be added.
Check timing	External SMEs	*Short*	When desirable by NedMobiel, there can be a check whether the timing of the risks is correct. This can be combined with the interviews with external SMEs to add additional data.
Check list of risks	Future observations	*Middle*	To check whether the risks are collectively exhaustive, future projects need to be qualitatively evaluated. This means that the list must be complete according to the users of the model. A comparison between the current list of risks and the risks that have occurred in the project need to be made to see whether there are any deviations.
Correlation between risks	Found data	*Long*	The model currently does not account for correlation between risks. It is unknown whether this under- or overstates the risk premium. If enough data are available, Excel can be used to calculate the correlation and the model needs to be adjusted accordingly to improve the accuracy. Whenever the sample size approaches 100, you can begin testing for correlation with a sufficient certainty level (>90%).
Expand for different countries	Model Observations External SMEs	*Long*	If NedMobiel wants to expand its business outside the Netherlands, the model should be adjusted to match specific values for different countries. The values per risk can deviate from the numbers as defined for the Netherlands.
Evaluate and adjust the model	Experiences of using the model	*Long*	After a few years, when the model has been used in practice, it is advised to thoroughly check the model whether the initial modeling still satisfies the needs of NedMobiel. Preferably this is done by someone with experience in mathematical statistics and who has knowledge of Excel & Visual Basic for Applications to be able to make technical adjustments to the model.

Table 23 Future steps needed to fine-tune the model

5.5 Summary of coding the model

Using the results of chapter four, the model is built in Excel and Visual Basic for Applications. The user of the model can give the input for the specific contract and the model calculates the risk premium using the VBA code and the data that were found by conducting the interviews. The output will be shown in a numerical as well as graphical format to accommodate the desires of NedMobiel. This output can both be used to use in a tender for a specific project or to calculate the overall risk exposure of a portfolio of contracts. Future steps to improve the model include the addition of risks, checking the accuracy of the parameter 'timing' and the list of risks, calculating the correlation between the risks, expanding the model to be used in different countries and the evaluation and adjustment of the model on the long term.

Chapter 6

6. Conclusion and recommendations

6.1 Conclusion

NedMobiel is currently in need of a model that will assist them in tenders for new road infrastructure in which they take on the role of operator. New infrastructure is in this research defined as a standard contract with the following characteristics:

- a duration of 20 years (i.e., excluding 5 years engineering, procurement and construction (EPC));
- a contract price of 1 billion euro;
- not transferable and no prolongation;
- light maintenance (vs. heavy maintenance);
- frequency based maintenance (vs. performance based maintenance);
- having an availability fee (i.e., no tolling); and
- no readjustments during the lifetime of the contract.

There is not yet a formal method to calculate the risk premium that is added to these contracts, this is currently done using tacit knowledge and trusting their gut feeling. Making a model that explicitly calculates the risk premium to quantify the tacit knowledge and gut feeling is the focus of this research. A few steps are taken to design the model: key risks are identified which should be part of the model, an analysis is made to determine what kind of model suits NedMobiel best, the content of the model is defined and the model is built. Key takeaways from the several steps are:

- a list of thirty risks that should be taken into account is made and specifically tailored to the needs of NedMobiel, where risks can easily be in- and excluded in the model;
- from a multi criteria decision analysis it became clear that a probabilistic model will be most suitable to the wishes of NedMobiel;
- the parameters impact, chance and timing are calculated per risk and each risk is assigned a statistical distribution which specifies the three aforementioned parameters;
- everything is modeled in Excel and Visual Basic for Applications, the risks and the associated parameters are admitted in the model;
- NedMobiel can adjust the model to specific needs per project; and
- the model calculates the expected risk premium in becoming an operator thereby quantifying the gut feeling of NedMobiel.

By using different perspectives, a list of ten key risks is composed that will serve as the components of the model. Ten key risks were specified further which resulted in a list of thirty risks that will be used in the model. The model will be flexible enough to easily add or delete risks, such that NedMobiel can tailor the model to its specific needs in each specific project.

Using a multi criteria decision analysis a choice is made which model best suits the needs of NedMobiel. Criteria on which the models are scored: reporting, usability, feasibility, correlation between risks, awareness and adding data and risks. This resulted in a probabilistic simulation model being the most favorable option to be used as a statistical risk model.

For each of the risks, three parameters are defined: impact, chance and timing. Each risk is assigned a probability density function which is combined with the aforementioned criteria to define a detailed expression of the risk premium per timeframe per risk.

The probabilistic model is built in Excel and Visual Basic for Applications. The mathematical functions are programmed which will be automatically used such that NedMobiel does not necessarily need the specific knowledge of the mathematics to operate the model. Input must be done per risk in which the impact, chance and timing are used. Risks can easily be added or in- and excluded if the specific project needs this. The output will be shown in a numerical as well as graphical format to accommodate the desires of NedMobiel.

Future steps to improve the model include the addition of risks, checking the accuracy of the parameter ‘timing’, checking the list of risks, calculating the correlation between the risks, expanding the model to be used in different countries and the evaluation of and adjustments to the model.

The statistical model will serve in assessing financial risks of the Operation & Maintenance phase for future tenders. Not only will the model help NedMobiel determine the risk premium with this model, NedMobiel can also build a database with it and use it to sketch the overall risk exposure for their portfolio.

Although the model is currently working, its first test in practice will be the first tender that NedMobiel will participate in. Unfortunately, there was no tender available in the period that this research was conducted. Since the model is currently based on internal experience, as was requested by NedMobiel, it is good to share and update the model with the EPC contractor in a future tender to check for robustness. It furthermore is a ‘living model’, which will grow over the years.

Reflecting on the six criteria as stated earlier, it becomes clear that the model meets these criteria. According to NedMobiel, the model is simple enough and produces output that is clear. It furthermore is technically feasible to add correlation and to add data and adjust the risks as well as the various parameters of the risks. The question remains whether the model creates awareness outside NedMobiel, but an initial meeting with a large builder showed promising results that there is also interest in the model besides NedMobiel. Furthermore, the mathematical background of the model is sound and NedMobiel values the result that it produces, the risk premium.

So instead of trusting solely on their gut feeling in determining a risk premium, NedMobiel can now use a statistical model which quantifies the risk premium in a clear and unambiguous way.

6.2 Recommendations

Using the model in practice, in a tender were NedMobiel will be the operator, is the first step that NedMobiel must take. In anticipation of a possible construction of a SPV for a future tender, there was already an exploratory conversation with an EPC contractor. This SPV would also cover the ‘gap’ of lack of data for the model. Together with the EPC contractor, data can be added to the model and the model can be put to practice.

Using the model in the tender phase will lead to predicting the risks and its parameters. It is important that NedMobiel will check these predictions in the coming years, when they will actually be the operator. Comparing predictions with the occurred values will prove valuable information. This will not only be useful in future tenders because of the extended knowledge, other companies have shown interest in such specialized experience, which could result in future (consulting) business opportunities for NedMobiel.

It is also recommended to follow the ‘future steps to fine-tune the model’ as described in paragraph 5.4 in the previous chapter. This can be done at the same time that the model is actually used in a tender.

Finally, NedMobiel can further extend the image of an innovative company who is willing to take on the risks that play a role in being an operator. Using this model, the risks are made explicit and are quantified. This should make sure that, as NedMobiel puts is, they can sleep more tranquil at night.

Glossary and list of abbreviations

AHP method	A structured technique for dealing with complex decisions by structuring a decision problem.
CAPEX	Capital expenditures, costs for developing or providing non-consumable parts of the product or system.
Contract price	Price for which the contract is awarded to the private sector by RWS.
DBFMO	Design-build-finance-maintain-operate. The main form of contract in the PFI whereby the service provider is responsible for the design, construction, financing and operation of an asset. Operation refers to the provision of some or all of the services related to the asset's use.
Default	The failure of a party to perform a contractual requirement or obligation, including failures to meet deadlines, to perform to a specified standard, to meet a loan repayment or to meet its obligations in relation to a materialized risk.
Discount rate	The rate used to reduce a future cash flow to a current value.
Discounted cash flow	A general term for analysis which discounts a stream of future cash flows in order to calculate a net present value.
EPC contract	Engineering, procurement, and construction contract, a fixed-price, date-certain, turnkey contract under which the project is designed and engineered, equipment procured or manufactured, and the project constructed and erected.
EPC contractor	The contractor under the EPC contract.
Expected value	The weighted average of possible values of a variable, where the weights are the probabilities of cost estimates.
Financial close	The date on which all project contracts and financing documentation are signed, and conditions precedent to initial drawing of the debt has been fulfilled.
Force majeure	A natural or political event that affects the ability of one party to fulfill its contract, but that is not the fault of, and could not reasonably have been foreseen by, that party.
Input supply contract	A project contract for the supply of fuel or raw materials to the project company.
Joint venture	A contractual agreement joining together two or more parties for the purpose of executing a particular business undertaking. All parties agree to share in the profits and losses of the enterprise.
Mean ($E(X) or\ \mu$)	The expected value or average of a set of numbers.
Monte Carlo method	Computation intensive forecasting technique, used only where the problem has a chance component, and is subject to unpredictable influences.
NPV	Net present value, the discounted present value of a stream of future cash flows.
O&M contract	Operation & Maintenance contract, in this context defined as a DBFMO contract. A project contract to operate and maintain the project on behalf of the project company.
O&M contractor	The contractor under the O&M contract.
O&M operator	*See* O&M contractor.
OPEX	Operating expenditures, ongoing costs for running a project.

Private party	The private sector entity with which the government contracts in a PPP. Traditionally the private party has been a SPV created specifically for the purposes of the project.
Probabilistic (stochastic) model	Statistical analysis tool that estimates, on the basis of past (historical) data, the probability of an event occurring again.
Probability density function (PDF)	A function that describes the relative likelihood for this random variable to occur at a given point.
Project company	The SPV created to construct and operate a project.
Project contract	Contract signed by the project company, which may include a project agreement, EPC contract, input supply contract, O&M contract, government support agreement, and insurance.
Project finance	A method of raising long-term debt financing for major projects through “financial engineering”, based on lending against the cash flow generated by the project alone; it depends on a detailed evaluation of a project’s construction, operating and revenue risks, and their allocation between investors, lenders, and other parties through contractual and other arrangements.
Project Finance Initiative (PFI)	An arrangement whereby a consortium of private sector partners come together to provide an asset-based public service under contract to a public body.
Public Private Partnership (PPP)	A contract under which a private sector party provides a service to or on behalf of the public sector.
Public Sector Comparator (PSC)	A hypothetical constructed benchmark to assess the value for money of conventionally financed procurement in comparison with a privately financed scheme for delivering a publicly funded service.
Random variable	A variable whose value results from a measurement on some type of random process.
Risk	A situation involves risk if the randomness facing an economic entity can be expressed in terms of specific numerical probabilities (objective or subjective).
Risk allocation	The allocation or responsibility for dealing with the consequences of each risk to one of the parties to the contract, or agreeing to deal with the risk through a specified mechanism which may involve sharing the risk.
Sensitivity analysis	Analysis of the effects on an appraisal of varying the projected values of important variables.
SME(s)	Subject matter expert(s).
Special Purpose Vehicle (SPV)	Special purpose vehicle, a separate legal entity with no activity other than those connected with its borrowing.
Standard deviation (σ)	Measure how close the data are clustered around the mean.
Value for money	The optimum combination of costs associated with the ongoing repair and maintenance, risks, completion time and quality in order to meet public requirements and making effective use of public funds.

Table 24 Glossary and list of abbreviations

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Appendices

Appendix A Overview of matrices AHP method

Comparing the criteria to each other

	Ease of use	Building of the model	Awareness	Adding data and risks	Relative priority
Ease of use	1	6	7	2	0.50
Building of the model	1/6	1	1/2	1/6	0.06
Awareness	1/7	2	1	1/3	0.11
Adding data and risks	1/2	6	3	1	0.33
Sum	1 4/5	15	11 1/2	3 1/2	1

n	4
λ_{max}	4.19
CI	0.06
CR	0.07

Comparing the sub criteria of 'ease of use' to each other

	Reporting	Usability	Relative priority
Reporting	1	3	0.75
Usability	1/3	1	0.25
Sum	1 1/3	4	1

Comparing the sub criteria of 'building of the model' to each other

	Feasibility	Correlation	Relative priority
Feasibility	1	4	0.80
Correlation	1/4	1	0.20
Sum	1 1/4	5	1

Comparison of the models for the sub criterion 'reporting'

	VaR/CFaR	ES	Probabilistic	Sensitivity Analysis	Relative priority
VaR/CFaR	1	2	3	6	0.44
ES	1/2	1	2	4	0.28
Probabilistic	1/3	1/2	1	4	0.22
Sensitivity Analysis	1/6	1/4	1/4	1	0.06
Sum	2	3 3/4	6 1/4	15	1

n	4
λ_{max}	4.21
CI	0.07
CR	0.08

Comparison of the models for the sub criterion 'usability'

	VaR/CFaR	ES	Probabilistic	Sensitivity Analysis	Relative priority
VaR/CFaR	1	1	1/6	1/4	0.08
ES	1	1	1/6	1/4	0.08
Probabilistic	6	6	1	3	0.53
Sensitivity Analysis	4	4	1/3	1	0.31
Sum	12	12	1 2/3	4 1/2	1

n	4
λ_{max}	4.20
CI	0.07
CR	0.07

Comparison of the models for the sub criterion 'feasibility'

	VaR/CFaR	ES	Probabilistic	Sensitivity Analysis	Relative priority
VaR/CFaR	1	1/3	1/9	1/4	0.05
ES	3	1	1/4	1	0.16
Probabilistic	9	4	1	5	0.59
Sensitivity Analysis	4	1	1/5	1	0.19
Sum	17	6 1/3	1 5/9	7 1/4	1

n	4
λ_{max}	4.25
CI	0.08
CR	0.09

Comparison of the models for the sub criterion 'correlation between risks'

	VaR/CFaR	ES	Probabilistic	Sensitivity Analysis	Relative priority
VaR/CFaR	1	2	4	7	0.44
ES	1/2	1	3	8	0.39
Probabilistic	1/4	1/3	1	2	0.11
Sensitivity Analysis	1/7	1/8	1/2	1	0.06
Sum	1 8/9	3 1/2	8 1/2	18	1

n	4
λ_{max}	4.14
CI	0.05
CR	0.05

Comparison of the models for the criterion 'awareness'

	VaR/CFaR	ES	Probabilistic	Sensitivity Analysis	Relative priority
VaR/CFaR	1	2	1/2	6	0.31
ES	1/2	1	1/4	3	0.15
Probabilistic	2	4	1	8	0.49
Sensitivity Analysis	1/6	1/3	1/8	1	0.05
Sum	3 2/3	7 1/3	1 7/8	18	1

n	4
λ_{max}	4.11
CI	0.04
CR	0.04

Comparison of the models for the criterion 'adding data and risks'

	VaR/CFaR	ES	Probabilistic	Sensitivity Analysis	Relative priority
VaR/CFaR	1	2	1/7	1/4	0.10
ES	1/2	1	1/8	1/5	0.05
Probabilistic	7	8	1	2	0.53
Sensitivity Analysis	4	5	1/2	1	0.31
Sum	12 1/2	16	1 3/4	3 4/9	1

n	4
λ_{max}	4.14
CI	0.05
CR	0.05

Synthesizing the results (1/2)

	Ease of use 0.50		Building the model 0.06	
	Reporting 0.75	Usability 0.25	Feasibility 0.80	Correlation 0.20
VaR/CFaR	0.44	0.08	0.05	0.44
ES	0.28	0.08	0.16	0.39
Probabilistic	0.22	0.53	0.59	0.11
Sensitivity Analysis	0.06	0.31	0.19	0.06

Synthesizing the results (2/2)

	Awareness 0.11	Adding data and risks 0.33	Overall priority	**Normalized overall priority**
VaR/CFaR	0.31	0.10	0.25	**0.62**
ES	0.15	0.05	0.16	**0.40**
Probabilistic	0.49	0.53	0.41	**1.00**
Sensitivity Analysis	0.05	0.31	0.18	**0.44**

Appendix B Explanation of the 4th level risks

	3rd level risks	*4th level risks*	*Explanation*
Revenue	Inflation rate volatility	Inflation rate volatility	A measure of fluctuations in inflation rate, which can pose difficulties if the fluctuations of revenue and costs do not follow the same path.
	Interest rate volatility	Interest rate volatility	A measure of fluctuations in interest rate, which is an issue when closing a loan with a bank and it is revised before the end of the term of the contract.
	Speed of project approvals and permits	EPC to O&M transfer of property	In the transfer of the infrastructure to the operator from the builder, there lies the risk of deviating quality compared to specifications.
		Communication risk	Expectations about the timing and delivery of deliverables from other parties
		Time to get an approval	If the timing to get an approval deviates from the planning, there could be an adjustment to the planning
	Operational revenues deviation (compared to predictions)	Number of cars on the road	The enforcement risk of gathering the toll and the corresponding costs and possibility of lost revenues.
		Quality of maintenance	If the maintenance does not live up to the desired quality, this can have several implications such as less traffic, more accidents or simply higher costs by having to do the maintenance more often.
		Availability of the road	Due to unforeseen circumstances such as accidents or the weather, the availability of the road can deviate from predictions.
		Measuring availability	Method of measuring availability inadequate such that operator cannot tell how many percent the road was open.
Expenses	Operational costs deviation	Maintenance costs deviation	Maintenance cost deviate from predictions, due to e.g., extra incidents, loan changes, weather conditions, price of materials, electricity prices, extra traffic, etc.
		Maintenance frequency deviation	The number of maintenance rounds deviate from predictions.

	Technological developments	Deviations in the prediction of obsolete techniques cause other reinvestments than scheduled.
	Working hours	The working hours are not as predicted, e.g., night vs. day working hours are other than predicted.
Optimization	Intellectual Property Rights	Either having or buying intellectual property rights can cause a deviation in the costs.
	Taking part in the EPC period	Taking part in the EPC period can change the amount of work the operator later has to do, e.g., choosing better but more expensive asphalt will reduce maintenance costs.
	Costs of optimization higher than savings	Proposed optimizations are more costly to implement than the savings that flow from it.
	Safety issues	Changing safety issues can cause the expected number of accidents to deviate from the predicted rate, e.g., changing the maximum speed.
Operating productivity	Efficiency of organization	The efficiency of the organization is not as predicted, due to e.g., communication, supply routes, physically not enough space to perform maintenance, etc.
	Weather conditions	Conditions that make it impossible to work but cause no damage to the asset, e.g., a blizzard.
	Low level of education	The education level does not meet the requirements to fulfill the job.
Indirect damage to the assets	Weather conditions	Damage to the assets due to weather conditions, e.g., dust, mud, landslides, etc.
	Cause of damage unidentifiable	Damage to the asset due to an unidentifiable cause, such as the situation where the originator of an accident is unidentifiable.
	Overhead costs	Indirect unrecoverable costs of damage to the assets, e.g., office, staffing costs, etc.
Force majeure	Natural disasters	Disasters by the act of nature, e.g., earthquakes, flooding, etc.
	Terrorist attack	Disasters as caused by terrorists.
	Labor disputes and strikes	Direct or indirect damage due to labor disputes and strikes.

Bonus or malus	Availability fee	Credit risk of the public sector entity	The political entity that takes care of the bonus/malus should be creditworthy to live up to the agreements made.
		Measuring method	The risk that a measuring method (in terms of availability) lives up to the expectations of all parties, e.g., how to measure extra performance.
		Costs of measuring higher than bonus	The costs to measure the availability exceed the (potential) benefits that flow out of this measuring.
		Due to culture no motivation to achieve the bonus	The chance that low motivation of employees will result in not making an effort to achieve the bonus.

Table 25 Explanation of the 4th level risks

Appendix C Interview directory – Subject Matter Experts (SMEs)

Standard O&M contract

- a duration of 20 years (i.e., excluding 5 years EPC);
- a contract price of 1 billion euro;
- not transferable and no prolongation;
- light maintenance (vs. heavy maintenance);
- frequency based maintenance (vs. performance based maintenance);
- having an availability fee (i.e., no tolling); and
- no readjustments during the lifetime of the contract.

Questions *per risk*

Impact (Y_i)

What is the impact of the risk *if* it occurs, expressed in a percentage (%) of the total contract price (€)?

Chance (X_i)

What is the chance that the risk will occur, expressed in a percentage (%)?

Timing (x_α) *Note: timing is allowed to be outside the O&M period!*

When do you have the largest chance that the risk will occur, expressed as a percentage (%) of the contract duration (year)?

<Sanity check>
Is the chance of occurring equal for the whole contract duration (year)?

Yes:

Uniform *(minimum (a) & maximum (b))*:
What is the interval in which the risk can occur, expressed as percentages (%) of the contract duration (year) that the risk can occur?

No:
<Show the graphs at the next page>
Which graph represents the timing of the risk best?

Lognormal, Normal *(most likely (μ) = 50%, standard deviation (σ) = filter from the other percentages):*
At what percentage (%) of the contract duration (year) does the risk have a cumulative 0% *(=start project)* / 5% / 50% / 95% / 100% *(=end project)* chance of occurring?

Pareto *(minimum (x_m) = 0%, alfa (α) = filter from the other percentages):*
At what percentage (%) of the contract duration (year) does the risk have a cumulative 0% / 5% / 50% / 95% / 100% chance of occurring?

Hypergeometric *(M = number of simulations, K = answer to the question (whole number), N = 100):*
<take in mind N scenarios>
What percentage (%) of the scenario's will have the specific risk occurring?

Triangular *(minimum (a) & maximum (b) = answer to first question, mode (c) = answer to second question)*:
What is the interval in which the risk can occur, expressed as percentages (%) of the contract duration (year) that the risk can occur?

At what percentage (%) of the contract duration (year) does the risk occur most often?

Cumulative *(depends on the underlying distribution!):*
<only applicable if the risk will most certainly occur>
Can you draw the graph?

Discrete (*value 1, 2, 3)*:
At which (three) values will the risk occur, expressed as percentages (%) of the contract duration (year)?

Overall risk assessment

<Sanity check>
What percentage (%) of the standard contract price would you normally take into account?

--- The values that are gathered need to be filled in the Excel model, check the outcome with the overall risk assessment, this should be more or less the same ---

Graphs – for interviewee

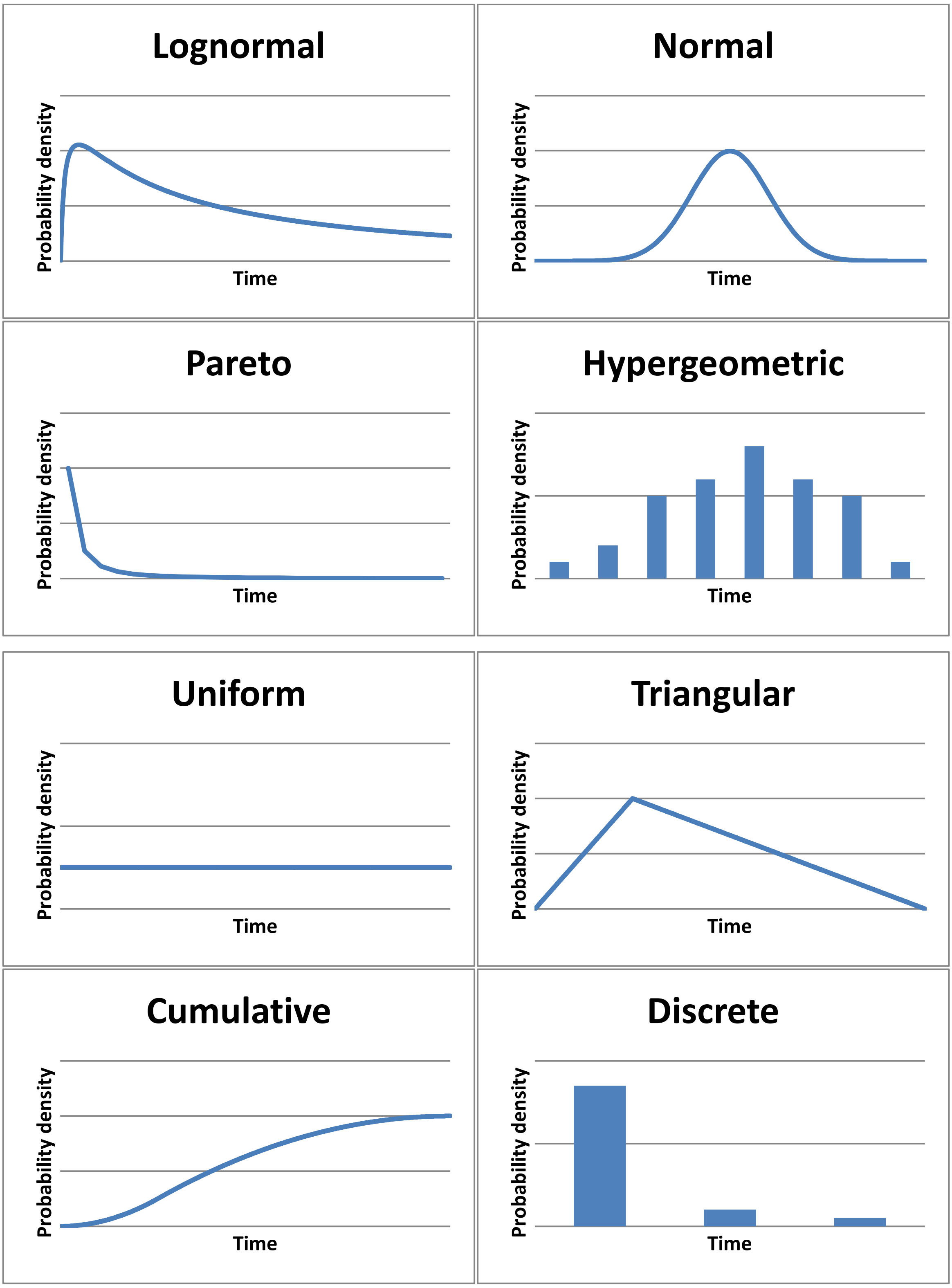

Figure 19 Eight (non-)parametric distributions to choose from

Fill-in form – for interviewer

	4th level risks	*Y (%)*	*X (%)*	*0%*	*5%*	*50%*	*95%*	*100%*	*Distribution*
Revenue	Inflation rate volatility								
	Interest rate volatility								
	EPC to O&M transfer of property								
	Communication risk								
	Time to get an approval								
	Number of cars on the road								
	Quality of maintenance								
	Availability of the road								
	Measuring availability								
Expenses	Maintenance costs deviation								
	Maintenance frequency deviation								
	Technological developments								
	Working hours								
	Intellectual Property Rights								
	Taking part in the EPC period								
	Costs of optimization higher than savings								

	Safety issues								
	Efficiency of organization								
	Weather conditions								
	Low level of education								
	Weather conditions								
	Cause of damage unidentifiable								
	Overhead costs								
	Natural disasters								
	Terrorist attack								
	Labor disputes and strikes								
Bonus or malus	Credit risk of the public sector entity								
	Measuring method								
	Costs of measuring higher than bonus								
	Due to culture no motivation to achieve the bonus								

Table 26 Interview form to be filled in by interviewer

Explanation of the risks – for interviewee

	3rd level risks	4th level risks	Explanation
Revenue	Inflation rate volatility	Inflation rate volatility	A measure of fluctuations in inflation rate, which can pose difficulties if the fluctuations of revenue and costs do not follow the same path.
	Interest rate volatility	Interest rate volatility	A measure of fluctuations in interest rate, which is an issue when closing a loan with a bank and it is revised before the end of the term of the contract.
	Speed of project approvals and permits	EPC to O&M transfer of property	In the transfer of the infrastructure to the operator from the builder, there lies the risks of deviating quality compared to specifications.
		Communication risk	Expectations about the timing and delivery of deliverables from other parties
		Time to get an approval	If the timing to get an approval deviates from the planning, there could be an adjustment to the planning
	Operational revenues deviation (compared to predictions)	Number of cars on the road	The enforcement risk of gathering the toll and the corresponding costs and possibility of lost revenues.
		Quality of maintenance	If the maintenance doesn't live up to the desired quality, this can have several implications such as less traffic, more accidents or simply higher costs by having to do the maintenance more often.
		Availability of the road	Due to unforeseen circumstances such as accidents or the weather, the availability of the road can deviate from predictions.
		Measuring availability	Method of measuring availability inadequate such that operator can't tell how many percent the road was open.
Expenses	Operational costs deviation	Maintenance costs deviation	Maintenance cost deviate from predictions, due to e.g. extra incidents, loan changes, weather conditions, price of materials, electricity prices, extra traffic, etc.
		Maintenance frequency deviation	The number of maintenance rounds deviate from predictions.
		Technological developments	Deviations in the prediction of obsolete techniques cause other reinvestments than scheduled.
		Working hours	The working hours are not as predicted, e.g. night vs. day working hours are other than predicted.
	Optimization	Intellectual Property Rights	Either having or buying intellectual property rights can cause a deviation in the costs.
		Taking part in the EPC period	Taking part in the EPC period can change the amount of work the operator later has to do, e.g. choosing better but more expensive asphalt will reduce maintenance costs.

		Costs of optimization higher than savings	Proposed optimizations are more costly to implement than the savings that flow from it.
		Safety issues	Changing safety issues can cause the expected number of accidents to deviate from the predicted rate, e.g. changing the maximum speed.
	Operating productivity	Efficiency of organization	The efficiency of the organization is not as predicted, due to e.g. communication, supply routes, physically not enough space to perform maintenance, etc.
		Weather conditions	Conditions that make it impossible to work but cause no damage to the asset, e.g. a blizzard.
		Low level of education	The education level does not meet the requirements to fulfill the job.
	Indirect damage to the assets	Weather conditions	Damage to the assets due to weather conditions, e.g. dust, mud, landslides, etc.
		Cause of damage unidentifiable	Damage to the asset due to an unidentifiable cause, such as the situation where the originator of an accident is unidentifiable.
		Overhead costs	Indirect unrecoverable costs of damage to the assets, e.g. office, staffing costs, etc.
	Force majeure	Natural disasters	Disasters by the act of nature, e.g. earthquakes, floodings, etc.
		Terrorist attack	Disasters as caused by terrorists.
		Labor disputes and strikes	Direct or indirect damage due to labor disputes and strikes.
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		Due to culture no motivation to achieve the bonus	The chance that low motivation of employees will result in not making an effort to achieve the bonus.

Table 27 Explanation of the risks – for interviewee

Appendix D Overview of the model – Excel part

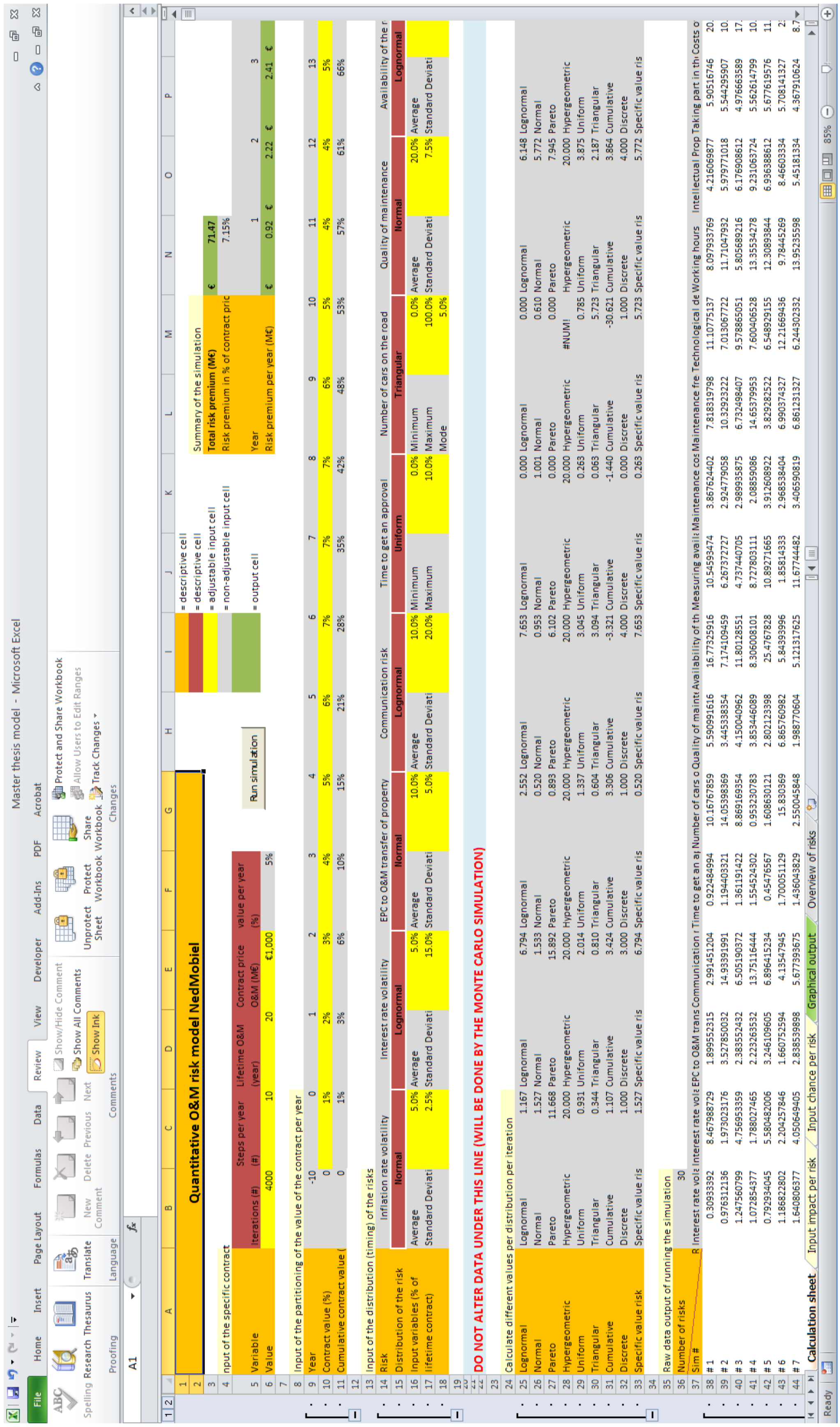

Figure 20 Example of part of the input parameters for the model

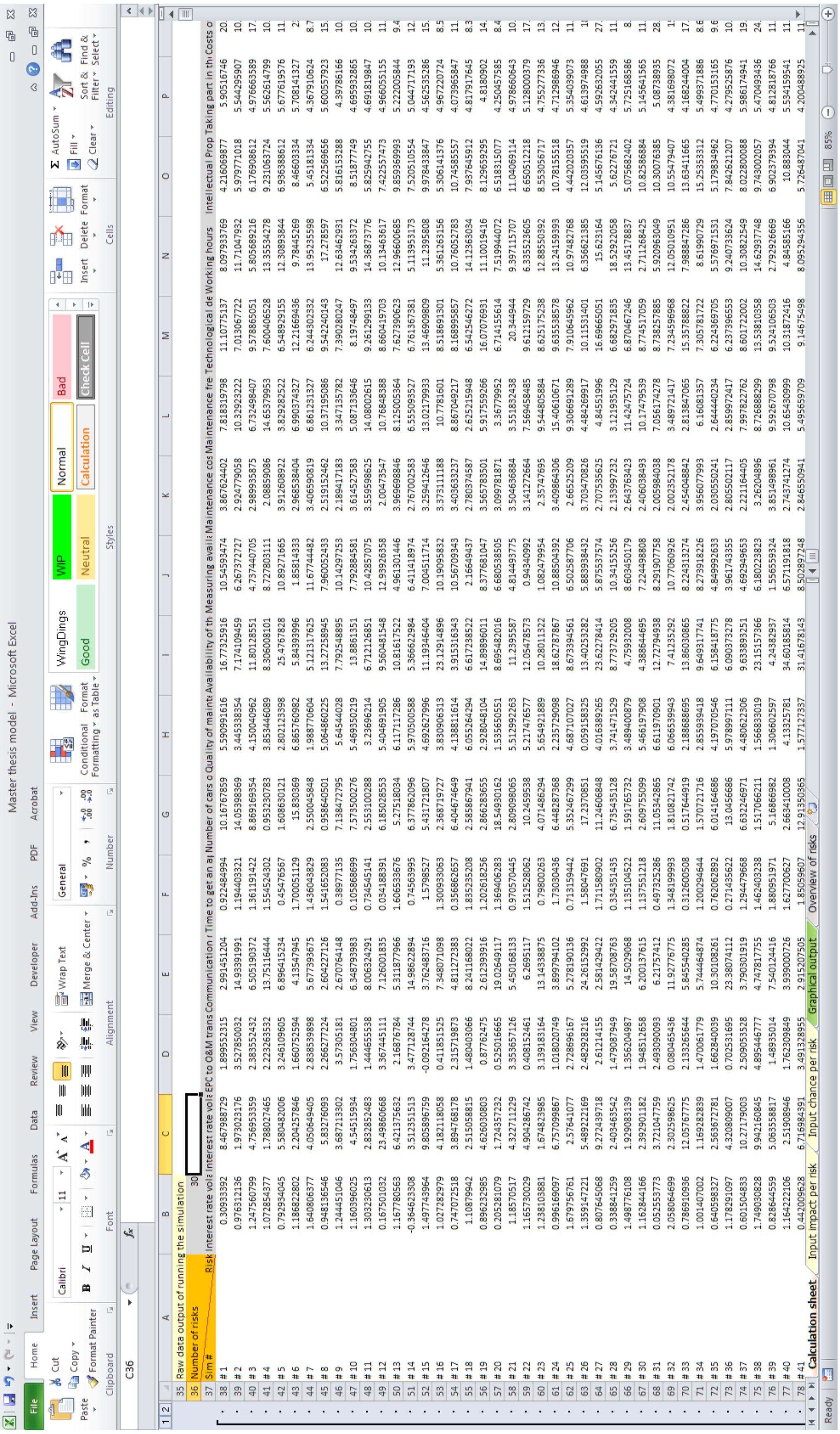

Figure 21 Example of the automated raw data output per risk when running the simulation

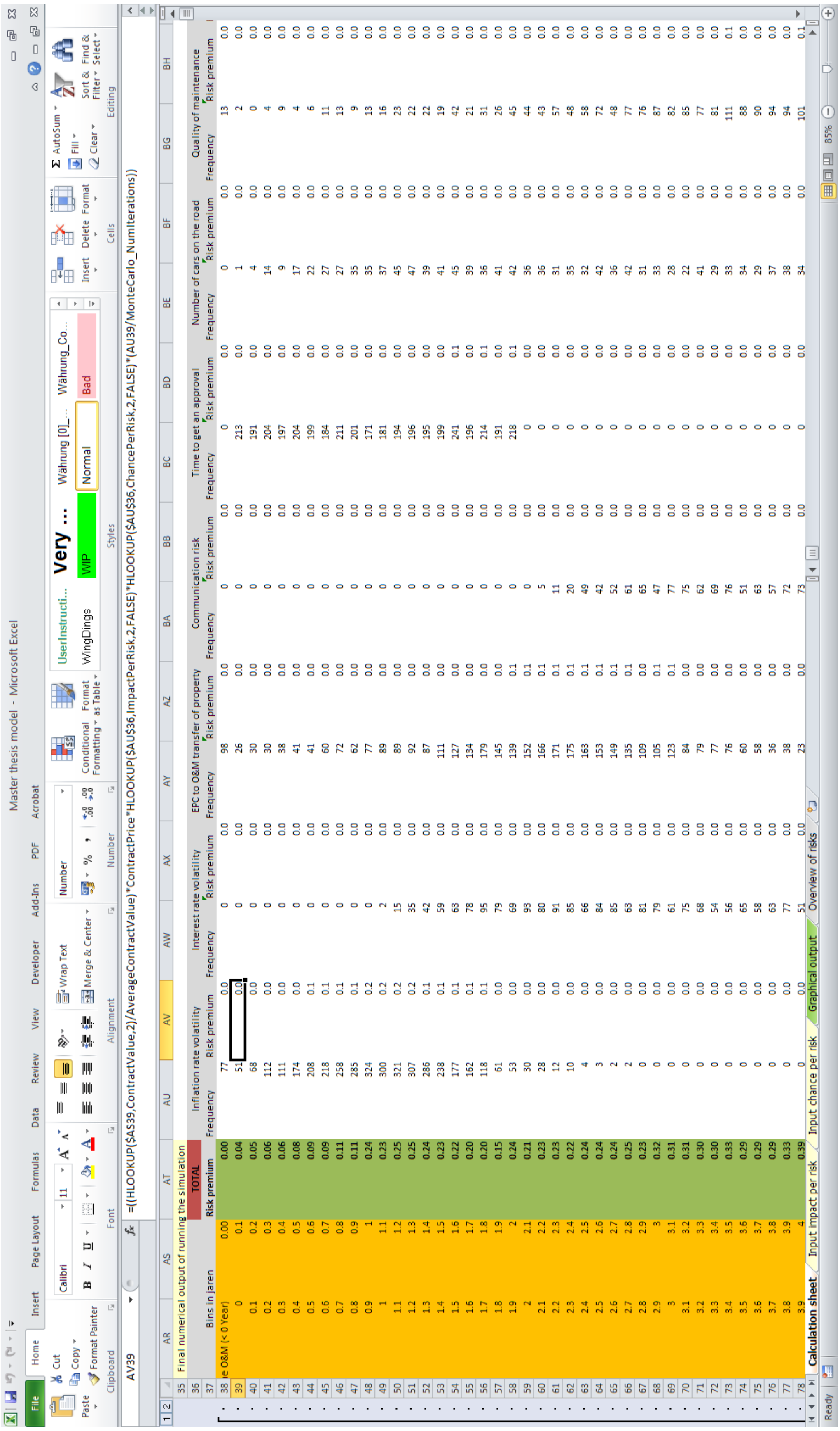

Figure 22 Example of the automated detailed numerical output of running the simulation

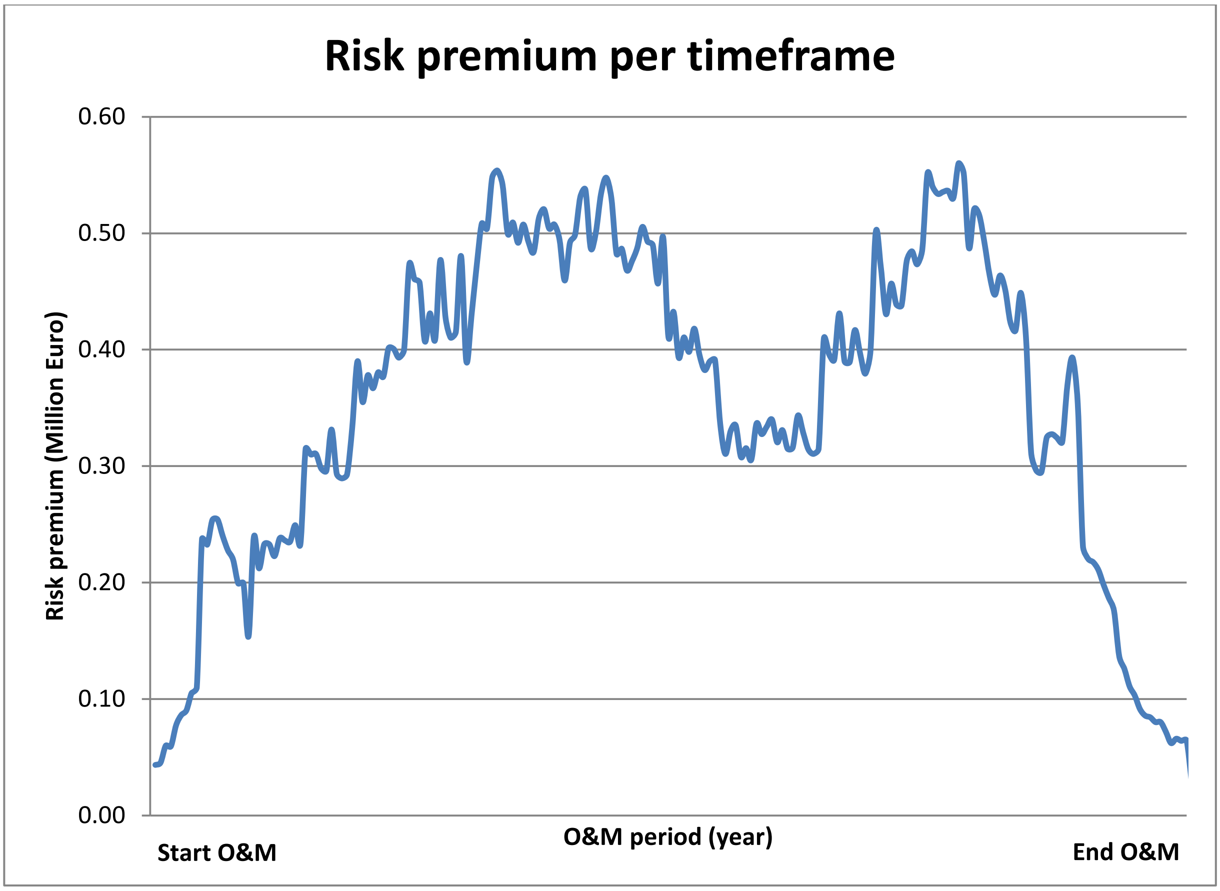

Figure 23 Example of the graphical output - Risk premium per timeframe (steps of 1/10 year)

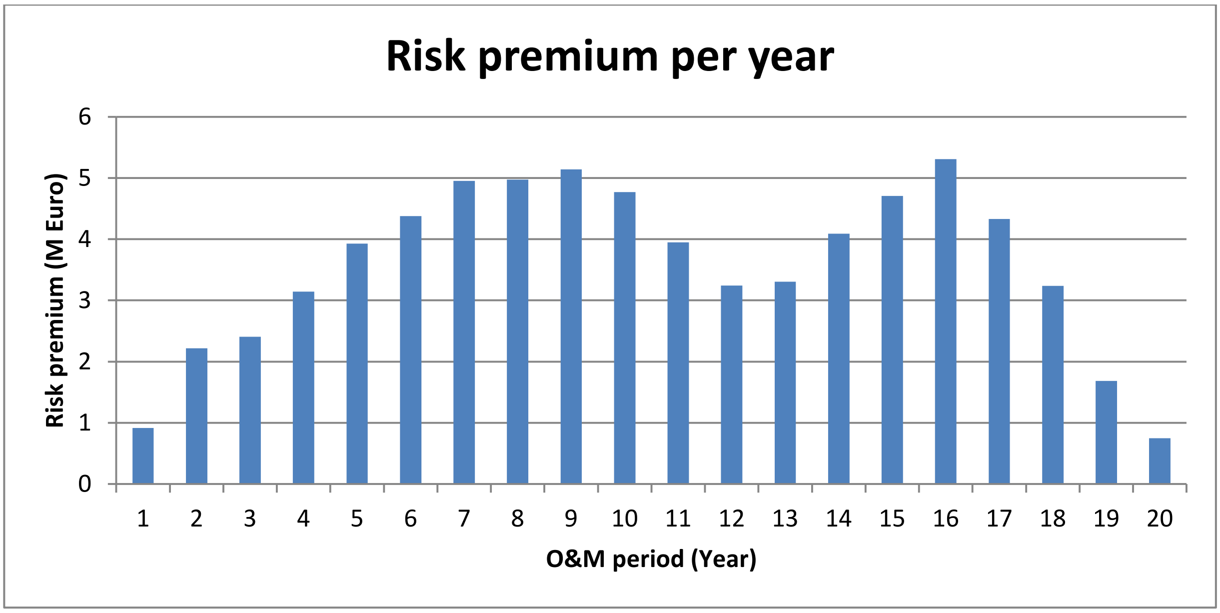

Figure 24 Example of the graphical output - Risk premium per year

Appendix E Overview of the model – VBA part

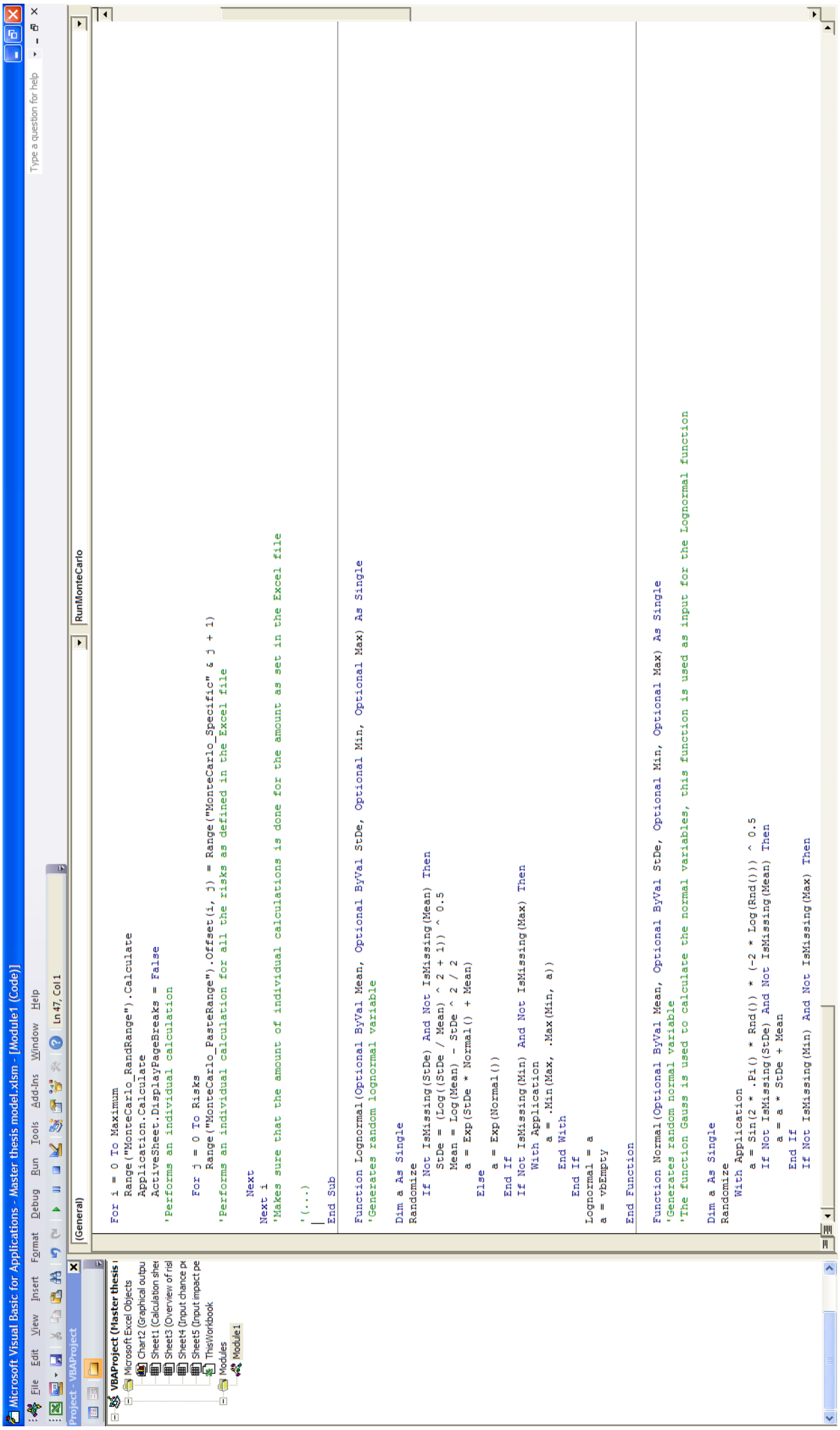

Figure 25 Example of a small part of the VBA code, automatically used by Excel to run the simulation *(certain sections deleted in screenshot)*