ADDED VALUE OF DIFFERENT APPROACHES OF REAL OPTIONS IN TRANSPORTATION INFRASTRUCTURE PROJECTS DECISION-MAKING

CASE STUDIES ON ‘WIDENING OF THE A27’ AND ‘THE REPLACEMENT OF THE KAAGBRUG A44’

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This thesis forms the final part of my master Systems Engineering, Policy Analysis and Management of the faculty Technology, Policy and Management at the Delft University of Technology. Stratelligence offered me the opportunity to conduct this specific project under their guidance during the previous six months. Stratelligence is a consultancy firm that supports effective decision-making and one of the few companies with real options analysis expertise within the Netherlands. They have been involved with previous public studies into real option analysis as for example the recently published study conducted by CPB. Therefore, they were able to provide the most up to date information on the current status of real option analysis and also accommodate me with the useful contacts within Rijkswaterstaat. Conducting a research that aimed to improve current transport infrastructure project decision-making into a real life Dutch context was something that appealed to me. This research gave me the opportunity to apply theoretical knowledge I learned into a real life context. I would not have been able to conduct this thesis without the help of some people, for that reason I would like to devote this section to thank these people.

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Therefore, there is only one last thing for me to say, please enjoy reading this report!

Delft, 2016
Fleur Gijsen
SUMMARY

RESEARCH PROBLEM
The Netherlands has a large transportation infrastructure network that needs maintenance, replacements and construction of new elements to function according to society’s ever changing needs. These days, a contextual transition can be recognised where the need for adaptive policies is growing and the role of flexibility is increasing. Currently, investment decisions about large infrastructure projects are evaluated by means of the Net Present Value (NPV) in a Cost-Benefit Analysis (CBA), according to the recently revised version of the CBA guidelines. This traditional method captures the value of a project’s future cash flow, but excludes the possible value brought by future uncertainties and flexibility. However, uncertainties like climate change, economics and technological development may have a large impact on the future value of a specific decision. For this reason, taking flexibility into account by evaluating infrastructure projects can be valuable for decision-makers.

Real Option Analysis (ROA) is a valuation technique that assumes that flexibility has a value; increasing the flexibility of an investment project may increase its total value substantially. The flexibility is expressed in real options, which can be defined as ‘the right, but not the obligation, to exercise an option that creates flexibility’. Research has demonstrated the potential for real options to enhance the project value by managing uncertainty through investment, structuring and design decisions. Despite this potential, real options theory is not widely used within the discipline of infrastructure development in the Netherlands. This study focuses on increasing the experience regarding the use of ROA in infrastructure projects and on giving advice regarding future applications. This research problem leads to the following research question:

*How and to what extent can real option analysis be a valuable addition to transportation infrastructure project decision-making within the Netherlands?*

RESEARCH APPROACH
The research objective is to investigate to what extent different real options approaches can be an addition to the current decision-making process and to advise on future applications of real options methods. The research consisted of four phases. Firstly, an extensive literature review was conducted to explore the current Dutch decision-making process, ROA in general and the current status regarding the use of real options in the Netherlands. Secondly, insights into two methodologies, the Simplified Decision Tree and the Binomial Option Pricing Method, were gained and selected conducted case studies were analysed. Thirdly, two new case studies were performed to investigate the additional insights and efforts of performing ROA, and additionally to be able to compare both methods according to the approach in the table below. Finally, to research the suitability of ROA into the current decision-making process, people responsible for decision information at Rijkswaterstaat were interviewed.

<table>
<thead>
<tr>
<th>Method</th>
<th>Case 1: Widening of the A27 highway</th>
<th>Case 2: Replacement Kaagbrug A44</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simplified Decision Tree</td>
<td>Conducted in this study</td>
<td>Conducted in this study</td>
</tr>
<tr>
<td>Binomial Option Pricing Method</td>
<td>Conducted in 2010</td>
<td>Conducted in this study</td>
</tr>
</tbody>
</table>

**TABLE 1: CASE STUDY APPROACH**
The literature review showed that although, taking into account the value of flexibility is often mentioned in the project evaluation guidelines, this value is usually ignored or briefly integrated by using common sense. In ROA literature, there are different types of options mentioned, such as the option to defer, the option to expand and the option to phase the investment, which are the most likely within the Netherlands. There are various methodologies for including real options. The Simplified Decision Tree and the Binomial Option Pricing Method are acknowledged as the most appropriate methods in the Netherlands due to their transparency and applicability. However, ROA is not a one-size-fits-all solution for project evaluation and can be used as a way of thinking and as a calculation method. Seven conducted case studies within the Netherlands were analysed and all concluded that ROA could be relevant to optimise the decision-making process, however it is still not explicit what method would be the most appropriate per project and which exact types of projects could benefit from ROA.

**To what extent can ROA be valuable?**

The extent to which ROA can be valuable depends on the characteristics of a project. ROA is only relevant for projects that are characterised by uncertainty, managerial flexibility, irreversibility, asymmetric pay-offs, limited importance of non-monetary costs and no no-regret alternative. For each project a trade-off between the potential added value of ROA and the additional efforts has to be made.

This research demonstrated with two case studies, the additional decision information ROA could have.

- With the case study on ‘widening the A27 highway’ it became clear that deferring the investment was valuable. The Binomial Option Pricing Method showed the most optimal moment to invest based on the uncertainty and the bandwidth of the possible values. The Simplified Decision Tree was mainly relevant to generate insights in the value of flexibility, in this case a phased investment, and consequences of a certain decision.
- In the case study on ‘the Replacement of the Kaagbrug A44’ the Simplified Decision Tree was mainly useful to quantify the consequences of the different decision possibilities by calculating the value of each branch. Based on cost-effectiveness it is recommended to defer the investment till 2028. However, if the bridge had to be replaced before 2028, a bridge is preferred over an aqueduct as this latter eliminates the option to expand. The Binomial Option Pricing Method illustrated that expanding the A44 highway could only be considered after 2018 in case of a high traffic growth.

In general, for these cases ROA led to more valuable alternatives and richer insights in the possible consequences of certain decisions.

**How can ROA be valuable?**

The second part of the main question investigates how ROA can be valuable to transportation infrastructure projects decision-making. In this study, two different methodologies were analysed, applied and compared; The Simplified Decision Tree and the Binomial Option Pricing Method.

- In general, the Simplified Decision Tree is relevant for every project influenced by uncertainties, as the tree can manually be adapted to each project. This is ideal for real-option thinking. Calculating the NPV for each branch is time-consuming and is less reliable as the results highly depend on the chosen scenario probabilities. Especially for the case regarding the ‘replacement of the Kaagbrug’
the Decision Tree was relevant to indicate the possible regret of an early investment and thus the value of deferring the replacement.

- The Binomial Option Pricing Method is helpful to calculate the possible value brought by flexibility and uncertainties accurately for each moment in time. It can determine the optimal investment strategy. For example, it showed that widening the A44 highway could be beneficial from 2018 on. This method is especially applicable for projects that are influenced by one dominant continuous uncertainty that can be captured in the volatility.

To conclude, it is not possible to select one dominant preferred method for all projects, this will depend on the characteristics of a project. In general the Simplified Decision Tree is useful for projects with a yes or no uncertainty while the Binomial Option Pricing method is useful when the uncertainty mainly consists of a continuous dominant uncertainty. Based on transparency it can be recommended to start with using the Simplified Decision Tree as this method also supports real option thinking. If the number of decisions increases, the Binomial Method becomes more appealing as this model can automatically calculate these.

**HOW ROA FITS IN THE DECISION-MAKING PROCESS AND FUTURE IMPLICATIONS**

Although ROA has been noted as having potential in literature, has been mentioned in the project evaluation guidelines since 2000 and is also considered as a valuable asset in this case study, the actual application is still limited. Based on the interviews, it can be concluded that ROA is not considered as something crucial. Currently, practical barriers such as the standardised and time-consuming existing infrastructure project decision-making process hold back the break-through of this method. Decision-making includes plenty of factors other than the investment policy, e.g. the political content.

**RECOMMENDATIONS**

A main recommendation for practice is to investigate, for all future infrastructure projects, to what extent they will meet the characteristics to benefit from ROA. Based on the additional insights in this research a checklist on how to apply ROA could be made. Another recommendation is to produce guidelines for carrying out the methods, nowadays, many people are discouraged by the term ROA, practical guidelines could show that the application does not have to be complicated.

Following from the discussion of this research, the subsequent recommendations for future research are made. Firstly, it could be beneficial to gain insights in the effects of assumptions per methodology. For the Simplified Decision Tree method, it could be interesting to research the effects of using an adjusted discount rate and probabilities to then once more compare with the Binomial Option Pricing Method. The Binomial Option Pricing method could benefit from additional research into the volatility. Secondly, as both included methods are not able to include unlimited types of uncertainties, it would be interesting to make a comparison with a method which is able to, such as the Monte Carlo simulation. Thirdly, this research only tested the methods on the option to defer, option to expand and option to phase. It would be interesting to research the suitability of the methodologies for other types of options. Lastly, it is recommended to investigate the applicability of ROA on all types of projects such as decision-making on construction, maintenance, replacement and procurement.
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1 INTRODUCTION

1.1 CONTEXT

1.1.1 FLEXIBILITY INTO TRANSPORTATION INFRASTRUCTURE DECISION-MAKING

The Netherlands has a large transportation infrastructure network that needs maintenance, replacements and construction of new elements to function according society’s ever changing needs (Ministerie van Infrastructuur en Milieu, Ministerie van Economische Zaken, & Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2014). Currently, investment decisions about large infrastructure projects are evaluated by means of the Net Present Value (NPV) in a Cost-Benefit Analysis (CBA), according to the recently revised version of the OEEI-guidelines (Eijgenraam, Koopmans, Tang, & Verster, 2000; Romijn & Renes, 2013). This traditional method captures the value of a project’s future cash flow, but excludes the possible value brought by future uncertainties and flexibility (Zhao & Tseng, 2003). However, such uncertainties as climate change, economics, technological development may have a large impact on the future value of a specific decision. When uncertainties are likely to have an effect, delaying specific investments may be more effective than an immediate investment, as this allows flexibility to defer the decision to invest until circumstances turn most favourable (Pichatapan, 2003).

These days, a contextual transition can be recognised where the need for adaptive policies is growing and thus the role of flexibility is increasing (Stratelligence, 2012b).

Accordingly, the importance of including flexibility into transportation infrastructure decision-making is acknowledged in the literature (de Neufville & Scholtes, 2011; Zhao & Tseng, 2003). Flexibility can lead to major gains since it enables the system to respond in the most effective way to future circumstances. As flexibility can increase the expected value dramatically, using the NPV without taking into account flexibility may lead to wrong infrastructure decision-making since some alternatives may be undervalued. However, CBA traditionally used to evaluate transportation infrastructure decisions are not required to include the value of flexibility (Eijgenraam et al., 2000). This flexibility could especially be relevant for infrastructure projects, as they contain high uncertainty due to their long life span and their vulnerability for the macroeconomic context (Martins, Marques, & Cruz, 2015).

1.1.2 REAL OPTION ANALYSIS TO INCLUDE FLEXIBILITY

To calculate how flexibility in systems can affect the value of a project, the real option approach was developed (de Neufville, Hodota, Sussman, & Scholtes, 2009). Real Option Analysis (ROA) is a valuation technique derived from the financial world that assumes that flexibility has a value; increasing the flexibility of an investment project may increase its total value substantially (Bos & Zwaneveld, 2014; Trigeorgis, 2005). Hereby flexibility is expressed in real options which can be defined as opportunities to respond to changing circumstances of a project by the management (Yeo & Qiu, 2003). ROA received more attention in the last decade and several studies were conducted to contribute to the understanding of the application of real options in transportation infrastructure management (Garvin & Ford, 2012; Kashani, 2012; van Rhee, Pieters, & Voort, 2008).

Research has demonstrated the potential for real options to enhance project value by managing uncertainty through investment, structuring and design decisions (Stratelligence, 2012c). Despite this,
the real options theory is not widely used within the discipline of infrastructure development within the Netherlands (Herder, Joode, Ligtvoet, Schenk, & Taneja, 2010; Pol, Bos, & Zwaneveld, 2015; Romijn & Renes, 2013; Schenk & Veld, 2008). In the literature, there are several drawbacks mentioned by experts for the practical application of this theory, such as increased complexity, unknown added value by decision-makers and most importantly lack of expertise and guidelines for a proper application (Garvin & Ford, 2012; Lander & Pinches, 1998). Therefore, this study will focus on increasing the experience regarding the use of ROA in infrastructure projects and on giving advice to future applications.

1.2 RESEARCH PROBLEM

As previously mentioned, there is a gap between the recognition and the application of taking into account real options in infrastructure decision-making. This leads to the following problem statement:

*There is not enough experience regarding the application of real options analysis within Dutch transportation infrastructure decision-making.*

In the Netherlands, a few case studies to investigate the potential and application of ROA in infrastructure project evaluation were conducted (van der Pol et al., 2015; Reitsma, 2010). These studies demonstrate the relevance of ROA on those specific cases, but also mention some drawbacks for its application. Furthermore these studies make use of different ROA methods and there is no clear recommended manner as they differ in ease of use, applicability but also on accuracy (Workshop Centraal Planbureau & Rijkswaterstaat, 2015). It is still not clear to what extent; in which situations and in what manner ROA can be relevant and applied on Dutch transportation infrastructure projects.

This question is also relevant for Stratelligence as they have been involved with the application of ROA on infrastructure decision for Ministry of I&M from 2010 on (see Figure 1). Since its mission is to contribute to better decision-making through evidence-based analysis, Stratelligence continuously aims to develop and encourage the use of methods like ROA.

![FIGURE 1: TIMELINE INVOLVEMENT STRATELLIGENCE AND ROA](image)

Although all studies concluded that ROA can be valuable, they resulted into a different practical conclusion. The studies conducted by Stratelligence in 2010 and 2012 concluded that ROA should initially be used as a way of thinking and if the situation requires quantification, the option value can be calculated. The recent study published by CPB concludes that calculations should always be made, but in another way by using the Simplified Decision Tree. Furthermore, these studies first selected the most appropriate method based on literature and desk research, conducted these methods and then compared the results with the regular CBA. For this reason, there is no clear comparison between methods made and for Stratelligence there is no clear answer regarding the most appropriate method.
1.3 RESEARCH OBJECTIVE

Based on this research problem, the following research objective can be derived:

To investigate to what extent different real options approaches can be a valuable addition in transportation infrastructure decision-making in the Netherlands and to advise on future applications of real options methods.

The deliverable of this study is an advice on future dealings with real option applications. In order to formulate this advice, existing case studies will be analysed and two case studies of Dutch infrastructure projects will be executed. A new case is valuable as the existing case studies did not compare different methods in a quantitative way. Furthermore, the performed studies consisted of an ex-post analysis with fixed alternatives and a known CBA. An ex-post analysis restricted the test of the possible added value of real option thinking, as flexible alternatives were usually not included in the known CBA. Performing new case studies that focuses on a future infrastructure decision, offers the opportunity to test the added value of real option thinking and analysis in all phases of the infrastructure decision-making process. In this research, the focus is on the lessons learned from applying ROA instead of delivering a perfect project evaluation.

1.4 RESEARCH QUESTIONS

The main research question resulting from the research problem is:

How and to what extent can real option analysis be a valuable addition to transportation infrastructure projects decision-making within the Netherlands?

In this research ‘valuable’ implies that ROA may lead to better insights without losing transparency for the decision-maker. In order to find a response for this research question, the following sub-questions will need to be answered first. Furthermore, these questions provide the basis for the structure of this research.

1. What is currently known about real option analysis and transportation infrastructure decision-making?
   a. How is infrastructure projects decision-making evaluated within the Netherlands and what role could flexibility play?
   b. What is ROA and how can it be applied to infrastructure decision-making?
      i. What types of real options exist?
      ii. What are the different techniques to value options?
   c. What is the current status of using real options within infrastructure projects decision-making?

2. What can be learned from existing case studies and what data and knowledge are needed before ROA can be applied?

3. What are the effects on project evaluation of taking into account real options?
a. What is the difference between evaluation with and without real options?
b. How do the evaluation outcomes vary between the different real option approaches?

4. Does the real option approach fit in the decision-making process and what do the outcomes and differences between evaluation with and without real options mean for the decision-maker?

5. What advice can be given to infrastructure project decision-makers regarding ROA?
   a. In what circumstances does ROA improve the infrastructure decision-making?
   b. What is the most suitable approach to value real options in infrastructure projects?
   c. What are the lessons learned from applying ROA?
   d. What are the implications for future infrastructure decision-making?

1.5 Research Approach

This section will present the approach used to answer the research questions and argues why these methods were chosen.

Research Method & Data Collections

The objective of this research is to investigate the added value of real options within transportation infrastructure project decision-making in the Netherlands. Besides desk research and interviews, the distinct research method of this study is to conduct case studies of real Dutch infrastructure projects,

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**FIGURE 2: RESEARCH APPROACH OVERVIEW**
which are likely to benefit from including flexibility, and therefore to which ROA can be applied. A case-study method is relevant to find extensive and ‘in depth’ knowledge to answer ‘how’ or ‘why’ questions in situations where the researcher has little control over behavioural events and the focus is a contemporary phenomenon (Yin, 2014). In order to answer the research questions the approach presented in Figure 2 was used. This approach consists of five phases, as discussed in the next section, which were executed sequentially.

**Phase 1: Exploration**
In this first phase, an extensive literature study was performed to gather useful information by using search engines such as Scopus, Google Scholar and Web of Science. Moreover, to find information about the Dutch infrastructure projects, the literature from the Ministry of Infrastructure and the Environment and CPB Netherlands Bureau for Economic Policy Analysis was gathered. Attention was paid to infrastructure decision-making within the Netherlands, backgrounds of ROA and current applications of ROA. The main keywords used were ‘flexibility’, ‘real option analysis’, transportation infrastructure’ in combination with ‘decision-making’, ‘case-study’ and cost-benefit analysis’. The goal of this phase is to explore the available literature and filter the useful knowledge.

**Phase 2: Case study preparation – ROA expertise**
In this section, the case studies were prepared to gain the needed ROA expertise. To start, case studies conducted by both CPB and Stratelligence were analysed. Next, the methodology and input variables needed to conduct ROA were researched and identified. This was only done for the Binomial Option Pricing Method and the Simplified Decision Tree. These methods were chosen as they are acknowledged as the most promising methods to include in Dutch infrastructure decision-making (van der Pol et al., 2015; Reitsma, 2010). This will be explained in section 2.2.3. Next, two cases to apply ROA were selected. There were two main reasons to perform new case studies (van der Pol et al., 2015). Firstly, previous real option applications were conducted on cases with an available CBA, so it was recommended to apply ROA before or while conducting a CBA. Secondly, by applying methods on one specific case a fair comparison in both a qualitative and quantitative manner could be made. As the ROA is expected to be quite detailed and time consuming, it was important that the right cases were selected, so that the findings and conclusions could be generalised. Therefore, criteria and requirements for the selection were identified first. This case selection was done in collaboration with Rijkswaterstaat and ROA experts. Moreover, the different ROA used methods were explored extensively.

**Phase 3: Case studies**
The main focus of this section was to investigate the added value of the two proposed ROA approaches. This was done by conducting two case studies. First, the ‘widening of the A27 highway’ case was analysed, where four alternatives of widening the highway are evaluated. The reason to focus on the A27 case is that in 2010 the Binomial Option Pricing Method was conducted and that those calculations are accessible. In this research, a Simplified Decision Tree was constructed to be able to compare both methods. Secondly, the new selected case study was performed. Before ROA was executed, the required information and data from this case was gathered. First, the different options were identified and the different input variables were defined. After gathering all the input variables, the two proposed
ROA approaches, Binominal Option Pricing method and Simplified Decision Tree analysis, were conducted. Subsequently, the results of this analysis are compared and discussed.

Phase 4: Opinion of the Decision-Maker
Based on the results of applying ROA, this phase focused on how the outcomes may affect the decision-making. This was done by reflecting on ROA in general and discussing the results with people responsible for decision-making information in real life to investigate the added value of ROA. Involving experts was crucial to reflect on the results placed in the context, in this case the decision-making process (Bogner, Littig & Mens, 2009). Five interviews with people responsible for different steps in the decision-making process were conducted. During the interviews, the interviewees were asked to give their opinion on the added value and on the suitability of ROA in the current decision-making process.

Phase 5: Conclusion & Recommendations
In the final phase, conclusions and recommendations were presented. Based on the responses to the sub-questions, the main research question was answered. Furthermore, recommendations for further research and a reflection on the research process is provided.

1.6 Relevance of the Research
The scientific relevance of this research is the need for a more structured way to apply ROA in transportation infrastructure decision-making. As stated before, there is a gap between the recognised value of including real options into transportation infrastructure decision-making and the actual application. The scientific literature argues that more experience with performing ROA has to be gained in order to support future applications. Accordingly, it is scientifically relevant to investigate this by performing ROA on a real life project.

This research is of societal relevance as it contributes to better future decision-making regarding infrastructure projects. The currently required CBA according the OEEI-guidelines does not require to take into account the value of flexibility. For some infrastructure projects, this could lead to wrong decision-making. Since transportation infrastructure is important for society and paid for by the Government, proper infrastructure investment decisions are crucial.

Stratelligence is one of the few parties with expertise on real options within transportation infrastructure decision-making in the Netherlands. This research is relevant for Stratelligence because there is no consensus yet on the most appropriate way to deal with ROA and its mission is to improve decision-making. The research is relevant for Rijkswaterstaat as it is responsible for the transportation infrastructure in the Netherlands. Rijkswaterstaat strives to improve their decision-making and wants to know to what extent ROA could be a useful addition.

Moreover, this research is relevant to the SEPAM programme as transportation infrastructure projects decision-making involves technical and management challenges and takes both public and business values into account. ROA can be seen as a new tool or method to support and optimise the infrastructure decision-making process. The present infrastructure decision-making process is structured
by the current policy regarding infrastructure decision-making and this research strives to improve this process.

Thus, this research is relevant as it could improve current decision-making by including ROA. It combines the scientifically acknowledged ROA and claims to include flexibility within a real life infrastructure project. The relevance of the research is pictured in Figure 3.

FIGURE 3: RELEVANCE OF THE RESEARCH

1.7 REPORT STRUCTURE

The structure of the report will be according the sub-questions.

1. Introduction
2. Infrastructure decision-making & real options: A literature study | sub-question 1
3. Case study preparation – Real Option Expertise | sub-question 2
4. Case study 1: Widening of the A27 Highway | sub-question 3
5. Case study 2: Replacement Kaagbrug A44 | sub-question 4
6. Real Option Analysis in the real decision-making context | sub-question 4
7. Conclusions, Discussion and Recommendations | sub-question 5
2 INFRASTRUCTURE DECISION-MAKING & REAL OPTIONS: A LITERATURE STUDY

As described in the introduction, the aim of this study is to investigate the added value of different real option approaches in transportation infrastructure decision-making in the Netherlands. Before this can be done, it is important to explore the literature available. The research question (1) of this chapter is:

What is currently known about real-option analysis and transportation infrastructure decision-making?

In order to answer this question a literature study was performed. The goal is to present the relevant knowledge found in the extensive amount of available literature. This was done by using search engines such as Scopus, Google Scholar and Web of Science. The main keywords used were ‘flexibility’, ‘real option analysis’, transportation infrastructure’ in combination with ‘decision-making’, ‘case-study’ and cost-benefit analysis’. Moreover, to find information about the Dutch infrastructure projects, the literature from the Ministry of Infrastructure and the Environment and CPB Netherlands Bureau for Economic Policy Analysis was gathered. Besides providing background information and exploring the relevance of this research, this chapter also provides information required for the case studies. This section is structured according to the following sub-questions:

2.1 How is infrastructure projects decision-making evaluated and what role could flexibility play?
2.2 What is real-option analysis and how can it be applied to infrastructure decision-making?
2.3 What is the current status of using real options within infrastructure projects decision-making, in both the Netherlands and abroad?

By providing responses to these questions, research question 1 will be answered.

2.1 INFRASTRUCTURE DECISION-MAKING

This section focuses on the current infrastructure project’s decision-making and the value of including flexibility. The central question of this section is ‘How is infrastructure project decision-making evaluated and what role does flexibility play?’ Firstly, the current infrastructure investment evaluation tool ‘Cost benefit analysis’ is discussed. Secondly, more insights in the decision-making environment are presented. Lastly, the value of flexibility is discussed and to conclude the research question will be answered.

2.1.1 TRADITIONAL INFRASTRUCTURE INVESTMENT EVALUATION - COST BENEFIT ANALYSIS

In the Netherlands large infrastructure project decision-making is performed with a cost-benefit analysis (CBA) according to guidelines. Governmental organisations often have to make investment decisions, also when considering large infrastructure projects. Before an investment is made, it is important to select the most efficient alternative out of different solutions for the problem. Accordingly, all sorted pros and cons must be weighed against each other for each alternatives. A CBA is a well-known tool to do this, whereby the costs and benefits are monetarised to select the alternative from which the benefits outweigh their costs the most (Boardman, Greenberg, Vining, & Weimer, 2013). To standardise the CBA the OEEI guidelines, a widely supported and accepted standard to create CBA for transport infrastructure in the Netherlands, were published in 2000 (Eijgenraam et al., 2000). Additions and
developments to these guidelines are captured and recently published in a more accurate publication (Romijn & Renes, 2013).

When performing a CBA, annual costs and benefits are placed over time and discounted to the base year by means of the net present value (NPV). The NPV is defined as the difference between the present value of the estimated net cash inflows and the present value of the estimated net cash outflows (Yeo & Qiu, 2003). In general, the project with the most positive NPV will be selected, provided that the budget requirements are met. Cash flows are discounted to their present value by the use of the discount rate, which should be adapted to uncertainty. Generally a standard discount rate for infrastructure projects is used for all future cash flows (Romijn & Renes, 2013). This standard discount rate used to be 5.5%, consisting of a risk-free discount rate of 2.5 percent and a risk premium of 3 percent (Werkgroep Discontovoet, 2015). From 2016, a standard discount rate of 4.5 percent is recommended for transport infrastructure. By using a standard discount rate, it is assumed that all projects are equally risky, which is rarely the case (Stratelligence, 2012c). As infrastructure projects have a long time span, many factors can change in that time such as: technical advances, changing stakeholders, political shifts and economic fluctuations (Herder et al., 2010). Hence, it could be argued that a standard discount rate is not always appropriate as the costs and benefits might vary in the future and thus the traditional NPV method is not sufficient for those types of projects. Likewise, de Neufville & Scholtes (2011, p. 5) mention two features of large infrastructure projects which explain why the traditional discounted cash flow analysis NPV does not fit:

- The assumed conditions, such as price and demand, constantly change; and
- The management might – and it generally does- eventually decide to change the system in response to new circumstances.

The current NPV method assumes that a project will be undertaken now and will continuously be operated at a set time scale, until the end of its expected useful life, even though the future is uncertain (Yeo & Qiu, 2003). Also Brandão et al. (2005, p. 70) state: ‘A major criticism is the implicit assumption that the project’s outcome will be unaffected by future decisions of the firm, hereby ignoring any value that comes from managerial flexibility.’ Consequently, this NPV method fails to take into account that uncertainty could also increase the value of a project, by adapting to uncertainty in a smart manner. The OEEI guidelines give additional information about how to deal with uncertainties in theory like sensitivity analysis and scenario analysis (Romijn & Renes, 2013). However, those methods provide insights in the risk of a project and do not directly translate the effect of uncertainty and flexibility in profitability (Lander & Pinches, 1998). Furthermore, the methods to monetise the effects of uncertainty are often associated with risks, while uncertainties can also create new opportunities. These opportunities in the future can be described as flexibility and the importance of flexibility is discussed in section 2.1.3.

2.1.2 THE DECISION-MAKING ENVIRONMENT

The Netherlands has a long-term plan regarding infrastructure projects; Meerjarenprogramma Infrastructuur, Ruimte en Transport (MIRT), which provides a yearly overview of current and planned spatial projects (Ministerie van Infrastructuur en Milieu et al., 2014). This initiative was introduced in 2007 and aims to improve the coherence between the coordination of investments in spatial and
infrastructure projects. To structure the decision-making process of MIRT projects, game rules are established, the so called ‘MIRT spelregels’ (Ministerie van Verkeer en Waterstaat & Ministerie van VROM, 2012). These game rules outline the process that a MIRT project has to pass, from exploration, plan elaboration to realisation, including the associated decision points (Romijn & Renes, 2013). The aim of these rules is to justify the decisions including a substantive description of the decisions and the possible follow-ups. This process includes a couple of stages as shown in Figure 5. The second stage, the preferred decision, is aimed at selecting the best alternative based on a project evaluation. This decision is underpinned by an analysis of the task, problem opportunities and associated CBA to present the financial overview.

Currently, a contextual transition can be recognised where the need for adaptive policies is growing. It always has been the case that a fixed long-term plan for infrastructure decisions was preferred, but nowadays the role of adaptive management is increasing. *Adaptive management, often characterised as ‘learning by doing’, is a formal iterative process of resource management that acknowledges uncertainty and achieves management objectives by increasing system knowledge through a structured feedback process* (Allen, Fontaine, Pope, & Garmestani, 2011, p. 1341). Assuming that adaptive management is getting more and more important, this also has to be taken into account during the project evaluation. ROA could be a solution in this situation, this will be discussed in section 2.2.

![Figure 4: MIRT process](image-url)
The following parties can be seen as the main stakeholders during infrastructure projects (Herder et al., 2010; Ministerie van Verkeer en Waterstaat & Ministerie van VROM, 2012):

- **Initiator:** The initiator of the project has for main interest to complete the project within specified restrictions. In the infrastructure sector, this is usually the Ministry of Infrastructure and Environment or a private party such as a port authority.
- **Financer:** The provider of capital to implement the project. This is usually the Ministry of Finance or a local authority.
- **Financial controlling authority:** This party is responsible for a sound ex-ante evaluation of a project to clarify that the costs weigh up to the benefits. For transportation infrastructure projects this is usually performed by a consultancy company, but also by other parties such as the CPB, the National Bureau of Economic Research and KiM, Netherlands Institute for Transport Policy Analysis are involved.
- **Political level/decision-maker:** Supporting the projects that are in line with their electoral promises and/or success. This is usually discussed during regional governmental meetings.
- **End-users:** The final users of the infrastructure; their main interest is accessing the infrastructure of appropriate quality at bearable costs.

The specific parties that fulfil the role of the stakeholders mentioned above, depends on the project. In MIRT-projects this is always a role for the government and decentralised governments. Usually Rijkswaterstaat provides advice to the Ministry of Infrastructure and Economics (Ministerie van Verkeer en Waterstaat & Ministerie van VROM, 2012). The party responsible for the evaluation with a CBA is thus the party to possibly incorporate flexibility.
2.1.3 The Value of Flexibility

De Neufville & Scholtes (2011, p. 3) state: ‘We should not simply worry about downside risks – We need to keep upside potential in mind’. Their book ‘Flexibility in Engineering Design’ argues that results can be improved by recognising that the future is inevitably uncertain and that by creating flexible designs they can adapt to eventualities. Once we recognise the future is uncertain, the intelligent thing to do is to prepare for its various possibilities. Therefore, design flexibility is needed because standard methods, such as the NPV, are inadequate and passive and do not adapt to an uncertain future.

A flexible system has the feature to adapt to new, different or changing requirements (Schenk & in ‘t Veld, 2008). For example, when constructing a new highway, a decision has to be made about the number of road lanes. Besides comparing the alternatives (i.e. no highway, a 2-lanes highway or a 3-lanes highway), it is also possible to firstly construct a 2-lanes highway and add a third lane in a few years. Keeping this ‘option’ of a third highway open prevents the chance that a future opportunity will be missed but also prevents that unnecessary costs are made. It could be useful to maintain flexibility, especially regarding projects with a long time span and vulnerable for uncertainties, such as infrastructure projects. The costs involved in infrastructure projects are high and nearly irreversible. As a consequence, it is important to plan ahead and identify all possible risks. This indicates the value flexibility could have, as flexibility offers the possibility to adapt to a future situation.

Although flexibility could have an added value, it is not automatically included in the common NPV calculations as mentioned in the previous section. It is usually even the case that only the costs of flexibility are included, for example the costs of the reserved space for a possible third lane. Combined with the fact that the value of flexibility is excluded, this leads to the underestimation of an alternative. Figure 6 shows that flexibility in design increases the expected value (Yeo & Qiu, 2003). In the absence of managerial flexibility, as presented in Figure 6(a) the probability distribution of NPV is reasonably symmetric. Hereby the expected NPV is represented by the mode or most likely estimate. Figure 6(b) demonstrates that the distribution is skewed to the right due to the presence of managerial flexibility. This leads to an enhanced expected value whereby the difference between NPV1 and NPV2 presents the value of flexibility. Although this difference could be relatively small, this could represent a large actual value since infrastructure project involve large investment costs. Nevertheless, it is important to keep in mind that including flexibly could also lead to higher costs, so a trade-off between the value and costs of flexibility should be made.

Because flexibility has a value, a method is needed to take it into account in decision-making. For that reason, a lot of scientific research was conducted to find a manner to include flexibly into project evaluations and ROA is scientifically recognised as a promising approach. For example, a research of Zhao & Tseng (2003) focused on the value of flexibility of an enhanced infrastructure foundation to propose a complete method to value flexibility. Also Yeo & Qiu (2003) researched the value of management flexibility and made the connection towards ROA. Furthermore, Ford, Lander & Voyer (2002) acknowledged ROA as method to valuing strategic flexibility in uncertain construction projects. From these studies, it can be deduced that ROA is seen as a promising method to take flexibility into account. This method will be discussed in section 2.2.
2.1.4 CONCLUSION

The central question in this section was: ‘How is infrastructure projects decision-making evaluated and what role could flexibility play?’. To answer the question, information was provided on the infrastructure project decision-making, decision-making environment and value of flexibility.

Transportation infrastructure decision-making in the Netherlands is a quite detailed process, which includes various stakeholders such as the initiator, the financier, the controlling authority, the decision-maker and the end-user. Currently the NPV is mostly used to evaluate infrastructure projects during the decision-making stage whereby the preferred alternative is chosen. In this CBA there is awareness of the risk and uncertainties which can affect an infrastructure project, but these are usually seen in a negative sense, however uncertainties can also create new opportunities. This can be seen as flexibility. Flexibility has value since a flexible system has the feature to adapt to new, different or changing requirements. Flexibility is especially valuable regarding projects with a long time span, which are irreversible, involve high costs and are vulnerable to uncertainties. Presently, managerial flexibility is often not taken into account in project evaluation. Excluding the opportunities of flexibility could lead to an underestimation of an alternative and subsequently wrong decision-making. Considering these points, research into a method to value flexibility was conducted and the selected option was ROA.

2.2 REAL OPTION APPROACH

As discussed in the previous section, the traditional discounted NPV analysis ignores the potential of flexibility. Flexibility includes the possibility to adapt decision-making to changing circumstances and has value in uncertain situations. ROA is a method to structure and use flexibility and uncertainty (Schenk & Veld, 2008). This chapter provides background information on ROA and focuses on the following question: ‘What is real-option analysis and how can it be applied to infrastructure decision-making?’
2.2.1 ROA BACKGROUNDs

The real option theory is a way to include flexibility in decision-making. This theory is derived from financial options valuation. Financial stock options are contracts that are sold at a certain premium, where the buyer obtains the right, but not the obligation, to buy a stock at a predetermined price (Zhao & Tseng, 2003). The term ‘real option’ was introduced by Myers, a professor of Financial Economics at MIT Sloan School of Management (Myers, 1977). His idea was to apply the option theory on the evaluation of non-financial options (i.e. real options) existing during investment decision-making. He defined a real option as the right, but not an obligation, to exercise an option that creates flexibility.

From the eighties on, the attention towards real options was substantially growing and various approaches to value options were researched. In 1997, a breakthrough happened when Black & Scholes received the Nobel prize in economics for their theory of pricing financial options (Black & Scholes, 1973). Initially, ROA was mainly confined to academia, but from the late nineties the interest increased rapidly in business as for example for oil and gas exploitations and small investments decisions (Lasance, 2010).

Research into real options in infrastructure projects started in 1991, with a theoretical example about the Sydney airport (de Neufville, 1991). Since the start of the 21st century, the research on the application of ROA has increased substantially in the field of infrastructure projects and it currently is still a large study field in literature. Recently, an extensive literature review of real options in infrastructure project was conducted (Martins et al., 2015). This review presents an overview of all different ROA research in the infrastructure field between 2003 and 2013. It also highlights the importance of the real option approach in project design. Despite the scientific ‘hype’ of real options and as previously mentioned its potential and need, the practical application of this approach in infrastructure projects is negligible.

This resulted in growing attention towards the reasons behind this limited real life application in the last five years. For example questions as; ‘Why is it that while real options analysis shows great potential and superior valuation in academic literature, it is not widely implemented in the practice of infrastructure projects valuations?’ and ‘What are the barriers for the implementation of a real option approach?’ have been researched (Herder et al., 2010, p. 2). Also Gavin & Ford investigated real options in infrastructure projects and found six propositions to bridge the dissemination gap (Garvin & Ford, 2012). The master thesis ‘Implementing Real Options in Engineering Projects’ researched the factors influencing real options implementation in project organisations and aimed to develop a conceptual design to adopt real options in projects (Ammerlaan, 2010). The lack of a clear standardised method and difficulty of ROA application are major arguments for this limited real life application of ROA. Essentially, gaining more experience with the application of ROA could help solve these limitations. Currently, ROA needs more examples of applications in order to be accepted in project decision-making.
2.2.2 Basics of ROA

This section will just focus on the principles of ROA. Details are available in the literature in such books as for example: ‘Real Option Analysis: Tools and Techniques for Valuing Strategic investments and Decisions (Mun, 2006). In general real options can be defined as ‘options embedded in real operational processes, activities or investment opportunities that are not financial instruments’ (Trigeorgis, 1996). Put simply, an option is an opportunity to take a beneficial action when the conditions turn favourable. Accordingly, the option theory studies how to price this opportunity. Related to transportation projects, ‘A real option approach shifts the decision-making process from simply choosing whether to invest in a transportation project to a management approach that considers a range of possible decisions, with the potential value of each decision measured in terms of its option creating value’ (Brand, Mehndiratta, & Parody, 2000, p. 57).

Based on the fact flexibility has a value, which can be captured in real options, the new total value of a project would be:

\[ NPV_{active} = NPV_{passive} + f \text{ (value of real options embedded in the project)} \]

In case there are additional costs, since the real option comes with a price this formula will be:

\[ NPV_{active} = NPV_{passive} + \text{value of option} - \text{cost of option} \]

If the value weigh out the costs of an option, the NPV will increase.

Different types of real options

There are various options that may arise in multiple applications and circumstances, and provide the ability to react to a changing environment. It is important to be aware of the different types of real options, as they might all lead to flexibility and could affect the value of options in various ways. The following options presented in Table 1 are all recognised by the different authors (Herder et al., 2010; Martins et al., 2015; van Rhee et al., 2008):

<table>
<thead>
<tr>
<th>Option to:</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defer</td>
<td>Allows the decision-maker to delay taking an action until the circumstances turn favourable.</td>
</tr>
<tr>
<td>Expand</td>
<td>Allows the decision-maker to increase or decrease the system capacity to scale when a trend of higher or lower system demand is formed.</td>
</tr>
<tr>
<td>Abandon</td>
<td>The ability to drop a current operation instead of continuing till the end of the project’s life time</td>
</tr>
<tr>
<td>Grow</td>
<td>This option exists when early investments create the opportunity for future revenue.</td>
</tr>
<tr>
<td>Switch</td>
<td>Allows the system operators to switch different technologies or resources.</td>
</tr>
<tr>
<td>Phase</td>
<td>Some investments can be made in stages in order to create growth and abandonment options.</td>
</tr>
</tbody>
</table>

The options to defer and phase are the most common in infrastructure projects (Eijgenraam et al., 2000).
DIFFERENT WAYS OF USING ROA

ROA can be a valuable addition when there is insufficient information available. In general, there are two ways how ROA is used; as a way of thinking and as a calculation method. Real-option thinking can be valuable as it (Stratelligence, 2012c, p. 13):

1: identifies options and opportunities that were previously not identified;
2: values flexibility that hasn’t been valued in the previous method;
3: combines various scenarios so that it creates unambiguous decision information;
4: provides an optimal investment strategy when a now-or-never decision cannot be made.

Besides the valuable additions mentioned, ROA as a calculation method adds the ability to include differences in risks. The risk premium of 1.5% which is included in the social discount rate can be decreased under the assumption that uncertainty disappeared at the final decision-moment. Stratelligence (2012c) also states the applicability of ROA per type of problem. For MIRT-projects ROA is definitely recommended as way of thinking and can be considered as a calculation method. This is because MIRT-projects usually include a lot of uncertainties and interdependences, which complicates the calculations.

2.2.3 DIFFERENT VALUATION TECHNIQUES

There are different techniques to value options. The applicability of the various approaches depends on the type of project. This section will not explain those methods extensively, but will clarify the reasoning behind the valuation techniques that will be included in this research.

The following techniques to value options can be considered as the main methodologies (Martins et al., 2015; Mun, 2006; van der Pol et al., 2015):

- **Black-Scholes Option Pricing Model**: Value of an option based on a formula with variables like product value, volatility and risk free interest rate.
- **Binominal Option Pricing Model**: Decision Tree over time based on the volatility from the variables where the option value is derived from the tree.
- **(Risk-Adjusted) Decision Trees**: Decision Tree with outcomes and opportunities for some future scenarios where the option value is derived from the tree.

The Monte Carlo Simulation is also considered as a main methodology but it is excluded from this research. The method can be used to include real option by simulating uncertainties based on different probability distributions. The Monte Carlo simulation is excluded in this study as it is recognised as a different type of methodology, a simulation model. Furthermore the workload to conduct a Monte Carlo simulation is considered cumbersome for most situations and is only interesting in situations where insights in the interdependencies are required (Romijn & Renes, 2013).

The following conclusions can be derived from studies conducted into the most practical techniques for valuing infrastructure projects:

- CPB argues that the Decision Tree method is the most favoured method based on arguments concerning transparency, applicability, relation to the CBA, complexity for implementation and
realism (van der Pol et al., 2015). However, this method is not applicable to analyse multiple uncertainties for a large number of alternatives. This conclusion is criticised by experts who argue that this method might be too simple (Workshop Centraal Planbureau & Rijkswaterstaat, 2015). Moreover, this study compared the different methodologies in a qualitative way and recommends to also make a quantitative comparison.

- According to Martins et al. (2015) the Black-Scholes Option Pricing Model and Binomial Option Pricing Model are complex to apply when handling more than one type of uncertainty. Therefore, to apply those methods to infrastructure projects they should not include too many uncertainties, or there should be focused on one dominant uncertainty. When comparing those two methods, the Binomial Option Pricing Model is easier to conduct than the Black-Scholes Option pricing model and thus favoured. The same research also states that the Risk-Adjusted Decision Tree valuation model provides a simpler lay-out and is therefore useful. However, if the number of branches is high, it becomes too complex and unclear.

- Reitsma (2010) applies both the Binomial Option Pricing Model and the Risk-Adjusted Decision and indicates the Binomial Option Pricing Model as the most promising based on the fact that this methodology is the easiest to adapt to the specific conditions of infrastructure projects. She excluded the Black-Scholes Option Pricing Model from her study as this methodology is difficult to understand intuitively and requires some restricting assumptions.

- Block (2007) concludes in his research that the ROA approaches are not mutually exclusive and many were used in combination. In his research, surveys were performed among companies; Binomial Option Pricing Model was thought to be more simplistic than the Risk-Adjusted Decision Tree valuation. It also mentions that the Black-Scholes Option Pricing Model is a preferred method for financial options, but not for real options.

The main question of this project is to investigate if ROA is a valuable addition. In this context ‘valuable’ implies that RO should lead to richer insights without losing transparency for the decision-maker. This explains the importance of transparency and simplicity to apply ROA methodology. This research will use the Binomial Option Pricing Model and Decision Tree methodologies, for the reason that these methodologies are recognised as the most promising in Dutch infrastructure decision-making. Hereby, Decision Tree analysis is considered as an easy to apply but maybe too simple methodology and the Binomial Option Pricing Model as a more complex but more accurate methodology. The Black-Scholes Option Pricing Model is excluded from this research as the Binomial Option Pricing Model is favoured above it in all research. This is due to the fact that Black-Scholes Option Pricing Model is a complex method, the required knowledge for a proper interpretation is especially seen as a disadvantage. There are distinctions between Decision Tree methodologies, in this research the Simplified Decision Tree method recommended by the CPB will be used. This methodology will be explained in section 3.2.1. Although the Decision Tree methodology is not recognised by everyone as a correct method, Brandão et al. (2005, p. 71) state that the application of decision analysis to real-option valuation problems seems natural because Decision Trees are commonly used to model project flexibility. This same article even states that option pricing theory and decision analysis demonstrated yield the same results when applied correctly.
2.2.4 WHEN TO APPLY ROA?

ROA is a methodology to value flexibility and includes this value into project evaluation. However, the value of flexibility depends on the project environment and therefore it is not relevant to include real options in every situation. ROA is a phased and adaptive approach, in which new and relevant information can be acquired and incorporated as the R&D project evolves, recognising that political and economic conditions may change and influence the implementation decision (Concas, Glaesel, Reich, & Yelds, 2003). Bräutigam, Esche & Mehler-Bicher (2003, p. 1) describe that ROA is only appropriate if the following four condition are met:

1. **Uncertainty**: There is uncertainty regarding the outcome.
2. **Managerial flexibility**: Actions can be taken to influence the final outcome.
3. **Irreversibility**: Investments to be made are irreversible and lead to sunk costs.
4. **Asymmetric payoffs**: The final payoffs depend on this uncertainty and can largely fluctuate.

The conditions uncertainty and irreversibility are extremely common in infrastructure investment decisions (Arickx, 2004). The investments are irreversible as the initial costs of the investments exceed the resale value, and the price difference can be considered as sunk costs. Moreover, infrastructures are especially affected by uncertainty, especially due to their long-time span. Figure 7 shows the value of real options in situations with high uncertainty and irreversibility. The other two conditions depend on the project and determine if it is worth it to include ROA. Applying ROA is relevant if future revenues are affected by the future environmental uncertainties and managerial flexibility could influence these effects. When there is the ability to delay a certain action, the so-called flexibility, and a pay-off that depends on these circumstances, it could be interesting to apply ROA. Accordingly, it is important to recognise that the real option approach is not a one-size-fits-all solution for project evaluation.

To decide on when ROA is valuable for infrastructure project decision-making, insights on the effect of uncertainty on future incomes have to be known. It is only when there is a large asymmetric pay-off that the effort of conducting ROA could be exceeded by the additional value. Therefore, the difference between the minimum and maximum cash flows is an important criterion to take into account. The next relevant criterion is the managerial flexibility, which refers to what extent dealing with flexibility could affect the future value. How large those criteria exactly have to be, is undefined and will be taken into account in this research.

The CPB (2015) states that including ROA when evaluating different project alternatives can be valuable when the following conditions are met:

- There is no no-regret alternative; an alternative that is preferred in all future scenarios.
Additional flexibility such as delaying or phasing has clear benefits, but does also include non-negligible additional costs.
- There is a large spreading on the possible outcomes.
- The non-monetary costs and benefits that are not expressed in a value are of limited importance for the outcome of the evaluation, as those non-monetary elements cannot be taken into account as real options.

2.2.5 DISCUSSION OF ROA
ROA is introduced as a promising method to include flexibility. However, ROA also has some limitations. As mentioned in the introduction, in previous years, special attention was paid to the reasons behind this limited application. This section provides a brief overview of the main advantages and disadvantages of the application of ROA mentioned in various research (Ammerlaan, 2010; Block, 2007; Blok et al., 2011; Garvin & Ford, 2012; Herder et al., 2010; Lander & Pinches, 1998; Stratelligence, 2012c).

ADVANTAGES:
- ROA provides an optimal investment strategy when a single now-or-never decision is not optimal; options and opportunities that were previously not included are identified and flexibility is valued.
- ROA reduces the risk of irreversible choices, which can be regretted later.
- ROA provides the ability to optimise a project so that the feasibility of a project becomes larger.
- As ROA does not work with a fixed format, the method can be customised for each project.

DISADVANTAGES:
- The current decision-making framework is already a complex process. The addition of a new extra module causes additional project costs.
- There is no fixed format to conduct ROA, which might result in confusion and a lack of transparency.
- Some input variables, which are needed to make a proper calculation are unknown and have to be determined or estimated.
- There is not enough experience with the application of ROA. More actual case applications and real life implementations are needed to tackle issues and problems.

BARRIERS TO APPLY ROA
In the literature, there are several barriers to apply ROA mentioned. A main barrier is the fact that the application is not a standard procedure and therefore not widely acknowledged (Aazami, 2006; Block, 2007; Bos & Zwaneveld, 2014). Since ROA is relatively new, there are some implementation issues and decision-makers prefer to continue with the current evaluation procedure. Block (2007) surveyed 279 companies and asked for the reasons for not using real options. The main reasons were lack of top management support (42.7%) and the fact that discounted cash flow is a proven method (25.6%). This can be confirmed with the research of Aazami (2006) into the challenges when dealing with uncertainty in the transport infrastructure sector. He mentions that in many cases, simple straight forward policies
are preferred to support prompt decision-making and thus additional evaluation techniques such as ROA are not always desired. Moreover, the standardised required procedure according to the OEEI-guidelines hindered the break-through of a new method. This same research which argued that including options is strongly underused in the transportation infrastructure sector also stated that in many cases there is no awareness of the possibility to incorporate options (Aazami, 2006). A further application barrier mentioned is novelty, this arises when it is generally acknowledged that certain expertise must be applied first. Another barrier to apply ROA is the difficulty to communicate the findings to the decision-maker due to the lack of transparency of the analysis.

Bos & Zwaneveld (2014) present reasons for the limited application of ROA in the current Dutch governmental investment decision-making specific:

- **Fixed alternatives**: Usually the alternatives are determined before the start of the project evaluation.
- **Unknown value**: the possibilities and added value of ROA are unknown.
- **Complex application**: The method is too complex, there is not enough experience and knowledge and the data needed is unavailable.
- **Additional costs**: ROA application is more detailed, which leads to additional research costs.

It is relevant to be aware of the facts mentioned when researching the valuable addition of ROA. The barriers to apply ROA should especially be taken into account when interviewing the decision-makers.

### 2.2.6 Conclusion

The question of focus in this section was: ‘What is real-option analysis and how can it be applied to infrastructure decision-making?’

A real option can be defined as ‘the right, but not the obligation, to exercise an option that creates flexibility’. ROA is a methodology to value real options. ROA can be used in two ways, as a way of thinking and as a calculation method. There are different techniques to value options. For infrastructure projects in the Netherlands, the Binominal Option Pricing Method and the Decision Tree methodology seem to be the most appropriate due to their transparency. However, the ROA approach is not a one-size-fits-all solution for project evaluation. ROA is appropriate if the following fundamentals are incorporated: uncertainty, managerial flexibility, irreversibility of the investment and asymmetric payoffs. Most infrastructure projects are irreversible and vulnerable for uncertainties, but managerial flexibility and asymmetric payoff have to be investigated in order to decide if ROA could be a valuable addition. The major limitations in applying ROA are application barriers such as complexity and missing guidelines as well as the unknown value it could bring to a project.

### 2.3 Current Status of Using Real Options within Infrastructure Projects

After presenting insights in the traditional infrastructure decision-making in section 2.1 and ROA in 2.2, this section focuses on the current application of ROA in transportation decision-making. The central
question of this section is: ‘What is the current status of using real options within infrastructure projects decision-making?’

2.3.1 ROA APPLICATIONS WITHIN THE NETHERLANDS

HISTORY OF ROA IN INFRASTRUCTURE DECISION-MAKING IN THE NETHERLANDS
The previous sections might have given the impression that ROA is barely applied in the current infrastructure decision-making. Although this holds for most (MIRT) project evaluations, which usually just include the required CBA, the idea to include flexibility in infrastructure investment evaluation is not new. In 2000, the OEEI-guidelines mention the value of including flexibility and suggest to use ROA (Eijgenraam et al., 2000). It mentioned that a flexible design and phasing of a project would lead to a better response to future developments and would reduce the risks of inappropriate decisions. Due to uncertainties of future conditions, it would be wise to keep certain ‘options’ open until there is more clarity. ROA would provide a framework for such a strategic decision. In 2004, the risk valuing committee subsequently mentioned that the phasing and timing of projects is essential when investments are irreversible and thus uncertainty leads to option value (Commissie risicowaardering, 2004). Later, a research into flexibility and option value of infrastructure projects was conducted by the commission of the knowledge institution mobility and policy (Schenk & Veld, 2008). It concluded that ROA could be a valuable addition to the - at that time- current Dutch infrastructure decision-making framework. A first recommended step was to apply ROA during example studies. Subsequently, a few case studies into ROA applied to Dutch infrastructure projects were conducted. They mainly consisted of master thesis projects into various non-financial fields like infrastructure projects, engineering projects and real estate (Ammerlaan, 2010; Blokland, 2009; Reedt Dortland, 2013; Reitsma, 2010). Next, Stratelligence published a report about the addition of ROA to the current evaluation methodology of the Ministry of Infrastructure and Environment (Stratelligence, 2012c). Most recently, CPB researched when and how to apply ROA into Dutch infrastructure projects evaluation (Bos & Zwaneveld, 2014; van der Pol et al., 2015).

CURRENT POINT OF VIEW ON ROA IN MIRT PROJECT DECISION-MAKING
Schenk & in ‘t Veld (2008) mention that it would be logical to reserve a spot for the value of flexibility in the MIRT game rules. It is desirable to have an overview of the possible valuable options at an early stage. The most recent study of CPB focuses on gaining insights in the circumstances whereby including real options is valuable for decision-making and the most practical way of applying it (van der Pol et al., 2015). Three case studies on investment projects have been conducted in this methodological study. This study concludes that the Simplified Decision Tree methodology is the most promising method due to its simplicity and broad application possibilities. However, this method is not applicable to analyse multiple uncertainties for a large number of alternatives. The study presented conditions where ROA can be valuable, but it followed up by stating that these conditions are barely met in practice. These CPB study results have been discussed during an expert workshop, which concluded that there are still many uncertainties which require additional research (Workshop Centraal Planbureau & Rijkswaterstaat, 2015). The main recommendations for further studies are firstly applying the Simplified Decision Tree on
a still to be taken investment decision while performing a CBA and secondly to compare different methodologies in a quantitative way. Both recommendations will be further researched in this study.

CURRENT POINT OF VIEW OF DECISION-MAKERS
One of the barriers mentioned for decision-makers to apply ROA is the novelty of this method. Aazami (2006) researched the needs of transport policy advisors to deal with future uncertainties. One of his conclusions is that some expertises were underused, such as taking into account options. However, dealing with uncertainty and including future scenarios received growing attention due to the increasing data about uncertainties. In 2011, a study into the role of climate change and climate uncertainty into CBA’s is conducted (Koetse, Koomen, Koopmans, Rietveld, & Verhagen, 2011). CBA experts at PBL, CPB and KNMI were asked about methodologies to deal with (climate) uncertainty. Figure 8 and Figure 9 are adopted from this study. Figure 8 shows that 17% of the 20 respondents use real options when dealing with uncertainty. Figure 9 demonstrates that the real option method is expected to lead to the most application complications (Koetse et al., 2011)

![Figure 8: Methodologies dealing with uncertainty](image1)

**FIGURE 8: METHODOLOGIES DEALING WITH UNCERTAINTY (KOETSE ET AL., 2011, P. 9)**

![Figure 9: Degree of problems per methodology](image2)

**FIGURE 9: DEGREE OF PROBLEMS PER METHODOLOGY (KOETSE ET AL., 2011, P. 10)**
ROA APPLIED IN DUTCH INFRASTRUCTURE DECISION-MAKING

The research of CPB in 2014 states (Bos & Zwaneveld, 2014, p. 27): ‘While ROA is presented as a method to include flexibility into CBA and infrastructure decision-making, now, more than 13 years later, the practical application of ROA has barely started.’ They state that there are no CBAs of real decision-making in which real option values are completely calculated. However, they provide some real life examples in which flexibility played a role in infrastructure decision-making. For example, in 2011, the cost-effectiveness analysis of renovations and replacements of the Afsluitdijk included a flexible alternative in which it would be renovated first followed by replacements. Another example is the expansion of the Harbour of Rotterdam, Maasvlakte 2, where attention was paid to phased investments (CPB, NEI, & RIVM, 2001). In 2008, the benefits of the ROA method are illustrated with the example of the ‘Zuiderzeelijn’ project, using an option to phase (van Rhee et al., 2008). This example shows that the benefits of this project differ substantially when the NPV and ROA methods are compared. Stratelligence (2012a) actually applied ROA in their study towards improvements of the canal Roode Vaart, where an option to expand the capacity of the Roode Vaart in a later stage was included.

Although real life applications of ROA are limited, there are some case studies conducted in which ROA is applied on real projects in the Netherlands to gain more insights. Table 2 provides an overview of those studies and the main conclusions regarding ROA. Next to these case studies, there are studies performed in other fields than infrastructure. Those studies can, for example, be used to gain insights in the methodology, but are not mentioned in this table. Furthermore, a master thesis project focused on developing a conceptual framework to adopt ROA (Ammerlaan, 2010).

The conclusions of these case studies focus more on recommendations for further research into ROA and its limitations rather than substantive conclusions. This can be explained as the purpose of a case study is to investigate a phenomenon, in this context ROA, within a real life context instead of a study into this specific real life context itself. According to the information presented, it can be determined that there are barely no real life applications of ROA in infrastructure project decision-making besides the few case studies conducted. However, this conclusion could be biased, as specific applications may have not been found during this research. Usually financial evaluations are not available to the public, so it is difficult to gain insights in these studies. It is possible that real option thinking is applied more often than can be derived from this study, but this cannot be seen in the evaluations. Despite this, it can be stated that the actual application in MIRT projects is limited. However, it should be taken into account that the attention towards uncertainty and dealing with this is recently growing extensively, for example when dealing with uncertainties related to climate change.

24
<table>
<thead>
<tr>
<th>Year</th>
<th>Author</th>
<th>Title</th>
<th>Case studies &amp; options</th>
<th>Main conclusion</th>
</tr>
</thead>
</table>
| 2010 | Reitsma | Valuation of real options in infrastructure projects | - Widening the A27 Highway: option to expand, option to phase  
- Deepening the Twente Canals: option to phase, compound option | - The Binominal Option Pricing Method preferred method over de Risk-Adjusted Decision Tree.  
- Including options to traditional CBA is valuable, but requires knowledge. It is crucial that this costly information is required as it also, and perhaps most importantly, helps decision-makers to strategically think about options and how they can increase the feasibility and cost-effectiveness of any infrastructure project |
| 2014 | CPB: Bos & Zwaneveld | Reële opties en de waarde van flexibiliteit bij investeringen in natte infrastructuur | - Extension Volkeraksluices: option to defer  
- Replacement Krammersluices: option to defer | - Identifying the various options for flexibility is usually more important than the estimation of their value  
- Options should be valued in a simple and rough way  
- Further refinement of ROA is needed, but can be counterproductive due to the large number of uncertainties and volatility |
| 2015 | CPB: van der Pol, Bos & Zwaneveld | Vervolg reële opties en infrastructuur: Wanneer en hoe waardering van reële opties bij infrastructuur projecten | Three cases including different types of infrastructure and various types of flexibility:  
- Meppelerdiesluice: option to defer  
- Ramspolbridge: option to defer, expand  
- Highway and Tunnel Amsterdam: option to defer | - Including options can be valuable  
- Including ROA is especially valuable when meeting certain conditions, however, those conditions are not often met in practice  
- Simplified Decision Tree analysis is the preferred method to include flexibility  
- This research only includes projects with options to defer and phase, most commonly in transportation infrastructure projects. |
2.3.2 ROA APPLICATIONS ABROAD

As within the Netherlands, most international studies into ROA in the infrastructure sector are scientific instead of real life applications. Martin et al. (2015) provide an overview of various studies towards applications of ROA in infrastructure projects worldwide. This overview shows that airport and toll roads are the most commonly used fields of application within the infrastructure sector, but also mention examples of bridges, highways or rail transport. Most of these examples are suitable for a real option perspective as they include public private partnerships (PPP). In this type of projects, there usually is a need for contractual flexibility where ROA can be relevant. For example, Bowe and Lee (2004) analysed the Taiwan High-Speed Rail Project which involved the option to defer construction, the option to abandon early in the construction phase, the options to expand, contract or switch use at any time. Zhao, Sundararajan and Tseng (2004) modelled a highway system focusing on real options of expansion. Their research offers a step towards optimal decision-making in highway engineering. Furthermore, in the Melbourne CityLink Project, a toll Road in Australia was analysed, it includes options in contracting between the private and public partnership (Rose, 1998). Also, Lee (2011) provides a summary of studies related to real options and infrastructure investments including case studies related to real options and infrastructure investments. Most studies conclude that including real options has an added value, but do not describe this value extensive nor give recommendations for further research. Furthermore, unfortunately all those mentioned and most familiar case studies are all PPP projects and therefore less relevant to revise exhaustively for this study. This is because these options are related to contractual agreements in the PPP and not in the project itself. However, the studies can still be used to gain insights in the methodology and calculation.

Moreover, the literature found mostly consists of articles and reports instead of a presentation of the calculations. This can be explained by the fact that those calculations are usually used in a private environment and include a lot of assumptions that are not clear-cut presentable for the broader audience. Based on this literature review, it can be concluded that most information on ROA stays limited to the scientific world. It is hard to find insights in the real current evaluation process during infrastructure decision-making as this information is not available to the public. Besides some basic excel sheets for ROA in business investment decision-making, I was not able to find examples of applications, especially not in infrastructure decision-making.

2.3.3 CONCLUSION

The central question of section 2.3 was: **What is the current status of using real options within infrastructure projects decision-making?**

It can be concluded that the current status of using real options within infrastructure projects decision-making is limited within the Netherlands. There are barely any actual applications of ROA in the field of infrastructure decision-making to be found, but just a few case studies conducted to study ROA. The conclusions of those case studies focus more on recommendations for further ROA studies and limitations rather than substantive conclusions. The CPB case-study is the most recent study and concludes that the Simplified Decision Tree is the recommended manner to deal with real options based on transparency. The current status is that more experience with applying ROA should be gained.
Furthermore, it is difficult to get insights in real ROA applications, as the spreadsheets used are not available to the public. Applications abroad mostly focus on real options in PPP projects, which are less relevant for this study. The final conclusion of this section is predictably that the current status of the actual use of real options is limited and that more experience with applying should be gained.

2.4 CONCLUSION

This literature research was performed to answer the following question:

*What is currently known about real-option analysis and transportation infrastructure decision-making?*

Currently the CBA method is mostly used to evaluate infrastructure projects during the decision-making stage where the preferred alternative is chosen. Although, taking into account the value of flexibility is mentioned in the project evaluation guidelines, this is usually not done. This in turn could lead to an underestimation of an alternative and subsequently inadequate decision-making. ROA is a methodology to include the value of flexibility, where flexibility is expressed in real options. A real option can be defined as ‘the right, but not the obligation, to exercise an option that creates flexibility’. ROA can be used as a way of thinking and calculation method. For infrastructure projects, the Binomial Option Pricing Method and Decision Tree methodology are acknowledged as the most appropriate methods within the Netherlands due to their transparency and applicability. However, the real option approach is not a one-size-fits-all solution for project evaluation. ROA is only appropriate if the following fundamentals are incorporated: uncertainty, managerial flexibility, irreversibility of the investment and asymmetric payoffs.

The current status of using real options within infrastructure projects decision-making is limited within the Netherlands, which could be explained by the application barriers such as complexity and missing guidelines and the unknown value it could have. There are barely any actual applications of ROA in the field of Dutch transportation infrastructure decision-making found, merely a few conducted case studies. These case studies focus more on recommendations for further ROA studies and limitations rather than substantive conclusions. The studies abroad mainly focus on options in the contractual agreements and are therefore less relevant to this study. However, this assumption could be biased, as it is difficult to get insights in real ROA applications as the spreadsheets used are not available to the public.

The final conclusion of this literature research is that, scientifically, there is a lot known about ROA, but the application and examples of applications are limited. Although there are barriers mentioned which could clarify the limited application, the potential of ROA is still acknowledged for certain situations. Especially with the currently growing attention towards adaptive management, more insights into the valuable addition of ROA in transportation infrastructure decision-making should be gained. This research will contribute to this knowledge gap by applying the Binomial Option Pricing Method and Decision Tree methodology on Dutch transportation infrastructure projects.
3  CASE STUDY PREPARATION – REAL OPTION EXPERTISE

This chapter provides the main findings from phase 2, the case studies preparation. The goal of this phase is to analyse existing cases, prepare the case studies by gaining the knowledge needed to apply ROA and select appropriate new cases. The central question of this section is: ‘What can be learned from existing case studies and what data and knowledge are needed before ROA can be applied?’. First, selected existing case studies in the Netherlands are analysed. An overview of those case studies, as well as the conclusions and discussions are presented. Next, the two ROA methodologies which will be used during the case studies, are discussed. An important aspect is identifying the input variables needed for a proper application in the third phase. Based on the previous chapter and the analysis in this chapter, the criteria to select new cases are summarised and selected in section 3.3.

3.1  ANALYSIS OF EXISTING CASE STUDIES

Table 3 presents seven case studies applying ROA, which were conducted on Dutch infrastructure decision-making. These cases were performed by three different parties but all focused on studying the value of ROA in transportation infrastructure projects (Bos & Zwaneveld, 2014; van der Pol et al., 2015; Reitsma, 2010). Although there are probably more applications of ROA conducted in the Netherlands, these seven cases are analysed in this study as they were selected especially to learn from applying ROA to projects, which is also a goal in this research. A more extensive overview of the seven cases is presented annex A. The main conclusions of the existing case studies are presented in this section. With the help of this analysis a direction for new case studies can be determined.

### TABLE 3: OVERVIEW OF THE SELECTED CASE STUDIES

<table>
<thead>
<tr>
<th>Type of project</th>
<th>Type of options</th>
<th>Uncertainty</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deepening Twente Canals</td>
<td>wet</td>
<td>Bulk transport volume</td>
<td>BOPM &amp; RADT</td>
</tr>
<tr>
<td>Widening the A27 Highway</td>
<td>dry</td>
<td>Volume of future traffic flows</td>
<td>BOPM &amp; RADT</td>
</tr>
<tr>
<td>Capacity extension Volkerak-sluices</td>
<td>wet</td>
<td>Future shipping volumes</td>
<td>RADT</td>
</tr>
<tr>
<td>Replacement salt-freshwater separation Krammerslides</td>
<td>wet</td>
<td>State of the Lake (fresh or salt water) &amp; knowledge</td>
<td>RADT</td>
</tr>
<tr>
<td>Replacement of the Meppelerdiep sluice</td>
<td>wet</td>
<td>Growth of traffic flows: Shipping &amp; road</td>
<td>SDT</td>
</tr>
<tr>
<td>Replacement of the Meppelerdiep sluice</td>
<td>wet</td>
<td>Growth of traffic flows</td>
<td>SDT</td>
</tr>
<tr>
<td>Replacement of the Meppelerdiep sluice</td>
<td>wet</td>
<td>Growth of traffic flows</td>
<td>SDT</td>
</tr>
<tr>
<td>Expansion of the highw</td>
<td>dry</td>
<td>Expand / defer</td>
<td>SDT</td>
</tr>
</tbody>
</table>

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1 BOPM: Binomial Option Pricing Method, RADT: Risk-Adjusted Decision Tree, SDT: Simplified Decision Tree
Type of Infrastructure Projects
The existing case studies include different types of transportation infrastructure projects, such as sluices, a dam, a canal and a bridge but also two dry infrastructure projects such as highways. All projects focused on public transportation infrastructures. The CPB study cases were selected with support of Rijkswaterstaat and include a variation of projects, which could probably benefit from ROA. There are no Dutch cases focusing on air or rail transport publically available. It is important to realise that infrastructure projects are only relevant for the application of ROA when flexibility can be included.

Type of Options
The projects mentioned mostly included the option to defer the decision-making until a moment when more certainty about the future is available. Based on the fact that an expansion or replacement is expensive, a less expensive temporary solution (‘defeer’) is preferred so the new investment can be perfectly adapted to future situation. The option to defer can also be captured in the option to phase the construction. The options to switch, abandon or grow were not covered in the projects mentioned. This can be explained as literature states that ROA is the most applicable when there are options to defer or stage in infrastructure projects (Romijn & Renes, 2013). Although it could be interesting to research other types of options, these other options might also be less relevant as they are less likely to occur in transportation infrastructure projects.

Type of Uncertainty
Every case included one main, dominant, uncertainty that affected the project value. Usually this was the volume of the traffic or shipping flows and was included with the use of an economic scenario in which the expected traffic growth was estimated. It is important to state that it is difficult to take more than one type of uncertainty into account. For example, for the A27 highway case, it was not possible to distinguish freight and passenger traffic growth, thus they had to be combined into one variable. Only the case of the Krammersluices included two different uncertainties, the state of the lake (fresh or saltwater) and the knowledge available about water separation techniques. However, this case just included a presentation of the Decision Tree but did not present extensive calculations. It was mainly use to structure the decision-making opportunities and thus real option thinking.

Methodology
The methods used in these cases were the Binomial Option Pricing Method, Risk-Adjusted Decision Tree and the Simplified Decision Tree. The Risk-Adjusted Decision Tree is not included in this comparison as this method was already excluded from this research in section 2.2.3. When comparing both remaining methods, it becomes apparent that it is much easier to understand the Simplified Decision Tree than the Binomial Option Pricing Method. The Binomial Option Pricing Method included more extensive excel sheets with more variables and calculations and is in general less transparent for an outsider to understand and interpret than the Simplified Decision Tree. Especially determining an appropriate dividend rate and volatility was clearly a challenge. The Simplified Decision Tree is more suitable to support real-option thinking. The case studies mention a limited number of values for the Simplified Decision Tree, while the Binomial Option Pricing Method consists of large calculations and thus provides many different values. Although both methods provide insights in the preferred alternative, the Binomial
Option Pricing Method could generate more accurate values. More insights in the comparison of the two methods will be discussed in next sections.

**ADDITION TO THE DECISION-MAKING**

All case studies state that taking into account ROA provides new insights, which improve the decision-making. However, the exact added value of applying ROA differs per case and method. Sometimes this is just stating that ROA is an addition and in other situations the flexibility is expressed with a value. In general, the Simplified Decision Tree method mainly supports real-option thinking and structuring while the Binomial Option Pricing Method can provide more accurate calculations of the exact option value.

### 3.2 METHODOLOGY OF THE APPROACHES

The case studies include a comparison between the Simplified Decision Tree and the Binomial Option Pricing Method. This section provides the insights needed in this methodology to perform the case studies.

#### 3.2.1 APPROACH FOR THE SIMPLIFIED DECISION TREE ANALYSES

The Simplified Decision Tree Analysis is the recommended method by CPB to include flexibility in transportation infrastructure decision-making (van der Pol et al., 2015). A Decision Tree represents a sequence of decisions and chance nodes. The decision node is the point where the decision-maker has to make a decision, regarding real options at the node it has to be decided whether or not to exercise the option (Smith & Nau, 1995). The decision node represents the decision the manager could make to maximise the value of a project as uncertainties are resolved over the project’s life (Brandão et al., 2005). Probabilities can be added towards the different scenarios to determine the expected value. According to van der Pol et al. (2015) and Reyck et al. (2008) it is essential that the Decision Tree does not become too complex and does not include a lot of decisions and scenarios. CPB makes, in her study, a difference between a tree with one decision-moment now and different future scenarios and a tree with more decision-moments. The advantages of the Decision Tree are the practicality and the fact that it can easily be combined with CBA. Moreover, the calculations and assumptions are transparent and the implementation and interpretation of the results are relatively simple.

**STEPS**

Five steps have to be taken to perform a Simplified Decision Tree (Eijgenraam et al., 2000; van der Pol et al., 2015). It is assumed in these steps that the alternatives and the corresponding CBA are known.

1. **Construct a Decision Tree based on the CBA**
   a. Determine the decision-moments and possibilities to defer or phase.
   b. Construct a complete Decision Tree with the CBA alternatives
   c. Simplify the Decision Tree to the most relevant decision moments.

2. **Construct a simplified scenario tree with the relevant uncertainties**
   a. Identify the uncertainties and scenarios based on the CBA
   b. Search for combinations of the most relevant uncertainties
   c. Construct a simplified scenario tree
3. Combine the Decision Tree (step 1) and the scenario tree (step 2) into one Simplified Decision Tree.
4. Calculation: calculate results per branch, via a break-even analysis or add probabilities for scenario analysis
5. Select the most optimal alternative

REQUIRED INPUT VARIABLES
To create a Simplified Decision Tree the following input variables are needed:
- Alternatives
- Uncertainties and scenario chances
- CBA (including Costs, Benefits, PV)
- Time horizon: Number of years for the investment
- Decision moments (First, later and timeframe between decision-moments)
- Costs of flexibility

DISCUSSION OF THIS APPROACH
It is argued that the a Decision Tree does not provide a correct valuation of real options (Brandão et al., 2005, p. 72). ‘This is because the optimisation that occurs at the decision nodes changes the expected future cash flows, thereby altering the risk characteristics of the project. Thus, the standard decision of the project cash flows with flexibility is different from that of the project without flexibility.’ Therefore, some say that Decision Tree Analysis is not a valid way to value real options (Workshop Centraal Planbureau & Rijkswaterstaat, 2015).

3.2.2 BINOMIAL OPTION PRICING METHOD
The Binomial Option Pricing Method was developed by Cox, Ross and Rubinstein (1979) and is the most known discrete continent claims model. The model is based upon a formulation for the asset price in which the asset, in any time period, can move to either the price upwards or the price downwards. The price will move up with probability p and down with probability 1-p in any time period. A binomial tree will be used to present those steps and shows how the option value develops. A formula is used to calculate how the value of each step will change. This will be modelled according the Geometric Brownian Motion. The main variables that need to be estimated using this approach are the volatility and the percentage dividends.

![Binomial Model](image1)

**A. Binomial Model** (Pichatapan, 2003, P.4)

![NPV calculation in ROA](image2)

**B. NPV calculation in ROA**
ROA MODEL
The Binomial Opting Pricing method (1979) assumes that the benefit from the project follows a multiplicative binomial process over discrete periods. At each moment in time, the benefit can go either up (up factor u with probability q) or down (down factor d, with probability 1−q) as shown in Figure 10 (derived from Pichatapan, 2003, p. 4).

Hereby the up factor (u) and down factor (d) are derived from the following equations (Cox et al., 1979):

\[ u = e^{\sigma \sqrt{h}} \quad \text{and} \quad d = e^{-\sigma \sqrt{h}} = \frac{1}{u} \]

Require that:

\[ u > (1 + rf) > d \]

Where, 
- \( u \): multiplicative up factor
- \( d \): multiplicative down factor
- \( rf \): risk free rate (= 2.5% in the Netherlands)
- \( \sigma \): volatility parameter (= to be determined input variable)
- \( h \): time length between states (state refers to state of nature d or u)

Using such a value model will always result in that it is optimal to wait with exercising the option until the last period. Building in cash flows expressed in dividends avoids this effect. After including this, the value will be:

\[ V_u = V_0 \times u \times (1 - \delta) \]

Where, 
- \( V \): option value
- \( V_0 \): option value at node 0 (= NPV)
- \( u \): multiplicative up factor
- \( \delta \): dividend share

UNCERTAINTY
Fluctuation in traffic value can be modelled by using the Geometric Brownian Motion (GBM) (Pichatapan, 2003, p. 2):

\[ \Delta Q = \mu Q \Delta t + \sigma Q \varepsilon_t \sqrt{\Delta t} \]

With \( \Delta t = 1 \)

\[ Q_{i+1} = Q_i + \mu Q_i + \sigma Q_i \varepsilon_t \]

Where, 
- \( Q \): uncertainty factor (usually traffic volume)
- \( \mu \): growth rate uncertainty factor (traffic volume growth rate)
- \( \sigma \): variance parameter of uncertainty factor (traffic volume)
- \( \varepsilon_t \): normally distributed random variable with (0,1)
When the uncertainty of two traffic volumes has to be combined (for example, shipping and highway), the volatility of the benefit distribution can be estimated as follows.

\[
\sigma = \frac{\sigma_{benefit}}{\bar{x} \times \sqrt{n}}
\]

Where, \(\sigma\) : volatility parameter

\(\sigma_{benefit}\) : standard deviation of benefit distribution (euro)

\(\bar{x}\) : expected value of benefit distribution (euro)

\(n\) : project life (year)

**CALCULATE THE REAL OPTION VALUE**

The option value can be determined by taking the maximum of the last period values. Hereby, it has to be started with the final nodes in the binomial tree. This results into the following formula (Reitsma, 2010, p. 27)

\[
ROA_t = \max(V_t, V_{tz} - I)
\]

Where, \(ROA_t\) : real option value at end state \(t\)

\(V_t\) : expected real option value at the end state \(t\) when the option is not exercised

\(V_{tz}\) : expected option value at the end state \(t\) when the option is exercised

\(I\) : price of the option

In the last period, it is not possible to wait; so the option is either exercised or not exercised. For the second last period, the formula above does not work anymore, because the ROA value does not just depend on the choice of exercising the option immediately, but also on whether the option is exercised in the future. Therefore \(V_t\) is given by the following equation:

\[
V_t = \frac{ROA_u p + ROA_d (1 - p)}{(1 + r_f)} + CF_t
\]

Where, \(ROA_u\) : real option value at end state \(t\)

\(p\) : risk-neutral probability

\(CF_t\) : cash flow at state \(t\)

\(r_f\) : risk free rate (social discount rate)
**Determine the Risk-Neutral Probability (p)**

To calculate this value, the risk-neutral probability \( p \) has to be determined. This is done with the following equation:

\[
p = \frac{(1 + rf) - d}{u - d}
\]

Where, \( p \): risk-neutral probability (%)

\( rf \): risk free rate

\( \mu \): multiplicative up factor

\( d \): multiplicative down factor

When this is combined into the real option value tree, this leads into the following equation:

\[
ROA_t = \max(V_u, V_u z - I)
\]

\[
ROA_t = \max(ROA_u p + ROA_d(1-p) + CF_0, V_{tz} - I)
\]

\[
ROA_t = \max(V_d, V_d z - I)
\]

Hereby, it should be taken into account that for the final nodes counts: \( ROA_u = V_u \) and \( ROA_d = V_d \) because the option is not exercised.

**Input variables**

This Binomial Option Pricing Approach of Cox, Ross and Rubinstein (1979) can be applied to an existing CBA. The following variables are the key variables to apply the Binomial Option Pricing Method (Reitsma, 2010, p. 30).

**Table 4: Key Variables Binomial Option Pricing Method (Reitsma, 2010, p. 30)**

<table>
<thead>
<tr>
<th>Name</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPV, ( V_t )</td>
<td>Discounting all future benefits, the value can be distracted from the CBA.</td>
</tr>
<tr>
<td>Investment costs, ( I )</td>
<td>Additional investment is given by CBA outcomes or can be determined by the</td>
</tr>
<tr>
<td></td>
<td>difference in investment costs between two alternatives (one more extensive</td>
</tr>
<tr>
<td></td>
<td>than the other). E.g. costs of building additional lane.</td>
</tr>
<tr>
<td>Time to expire, ( t )</td>
<td>Period for which it is possible to expand the project, usually same time</td>
</tr>
<tr>
<td></td>
<td>span as in the CBA.</td>
</tr>
<tr>
<td>Volatility, ( \sigma )</td>
<td>Uncertainty of expected cash flows; a new variable which needs to be</td>
</tr>
<tr>
<td></td>
<td>estimated.</td>
</tr>
<tr>
<td>Risk-free rate, ( rf )</td>
<td>Specified in the CBA guidelines, determined by the interest rate on riskless</td>
</tr>
<tr>
<td></td>
<td>bonds.</td>
</tr>
<tr>
<td>Dividends to determine the</td>
<td>Determined as a steady percentage of the NPV of future benefits. Thus</td>
</tr>
<tr>
<td>annual net benefits, ( \delta )</td>
<td>determined by dividing annual benefits with net present value of benefits</td>
</tr>
<tr>
<td></td>
<td>for the same year. Since infrastructure projects are generally assumed to</td>
</tr>
<tr>
<td></td>
<td>have an infinite lifetime, this seems a realistic assumption.</td>
</tr>
</tbody>
</table>
The main variables that need to be estimated are the volatility and the dividends. To calculate the option value according the Binomial Option Pricing Method, the following variables are needed (Reitsma, 2010, p. 43).

**TABLE 5: INPUT VARIABLES BINOMIAL OPTION PRICING METHOD (REITSMA, 2010, P. 43)**

<table>
<thead>
<tr>
<th>Name</th>
<th>Symbol</th>
<th>Formula, explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volatility</td>
<td>σ</td>
<td>To determine (usually based on historic data)</td>
</tr>
<tr>
<td>Risk-free rate</td>
<td>rf</td>
<td>Specified in the CBA guidelines (2.5% in the Netherlands)</td>
</tr>
<tr>
<td>Dividend share</td>
<td>δ</td>
<td>Average annual dividend share, derived from CBA</td>
</tr>
<tr>
<td>Period concerned</td>
<td>y</td>
<td>The number of years to which volatility and risk-free rate refer</td>
</tr>
<tr>
<td>Number of steps</td>
<td>n</td>
<td>number of steps in 1 year</td>
</tr>
<tr>
<td>Number of years</td>
<td>g</td>
<td>total period, like the CBA</td>
</tr>
<tr>
<td>Up factor</td>
<td>u</td>
<td>(EXP(volatility*y/n^0.5))</td>
</tr>
<tr>
<td>Down factor</td>
<td>d</td>
<td>(1/(EXP(volatility*y/n^0.5)))</td>
</tr>
<tr>
<td>Upward probability</td>
<td>p</td>
<td>((1+rf)-d)/(u-d)</td>
</tr>
<tr>
<td>Risk-free rate per step</td>
<td>rfn</td>
<td>(((1+rf)-d)^y/ng))-1</td>
</tr>
</tbody>
</table>

This section gave an overview of the approach and insights in the data needed. This approach probably has to be adapted to the project and type of options.

### 3.3 CASE SELECTION

The next phase of this research consist of two case studies. This section provides an overview of the requirements and criteria taken into account to select appropriate cases for this research. The requirements have to be fulfilled and the criteria are elements that make a case more appropriate but are not knock-out criteria.

**REQUIREMENTS TO APPLY ROA FROM THE LITERATURE (SEE SECTION 2)**

The following requirements consist of characteristics an infrastructure project should contain to be able to benefit from ROA. For the selection of a case where no CBA has been performed yet, it is not possible to check in advance if all the criteria are met. In that case, the criteria should be taken into account based on expectations.

- **Uncertainty:** There is uncertainty regarding the outcomes with a large bandwidth.
- **Managerial flexibility:** Actions can be taken to influence the final outcome.
- **Irreversibility:** Investments to be made are irreversible and lead to sunk costs.
- **Asymmetric payoffs:** The final payoffs depend on this uncertainty and can largely fluctuate, so there is a large spreading in the possible outcomes.
- **No no-regret alternative:** There is no alternative that is preferred in all future scenarios.
- **Limited importance non-monetary costs:** The non-monetary costs and benefits are of limited importance for the outcome of the evaluation as non-monetary elements cannot be taken into account as real options.
OTHER SELECTION CRITERIA

The following points are criteria that make a case more appropriate to select during this research, thus these are not knock-out criteria:

- **Relevance**: The selected case should be a real-life Dutch transportation infrastructure-project that includes flexibility and is expected to gain from applying ROA. Especially applying ROA while creating CBA for a new infrastructure decision would be relevant (van der Pol et al., 2015).

- **Newness**: The selected case should contain a special or new under-researched element so that practice could benefit from the case. Elements to check are: type of options, type of infrastructure project and type of uncertainty and number of decision moments.

- **Generalisability**: It is important that the findings can be generalised to a certain extent. Note that this is at odds with the criteria ‘newness’.

- **Applicability**: The selected case should be applicable for ROA.
  - **Data availability**: Required data should be available or possible to determine
  - **Limited amount of decisions and scenarios**: To be able to apply ROA, the case cannot include too many elements.

- **Political sensitivity**: As this is a study investigation project which has to be conducted in a limited time, the study should not be politically sensitive, as this could hinder the data collection and thus cause delay. Furthermore, as the selected project is a case to test a method, this is more important than a political project high on the agenda.

SELECTING THE CASES

The first case taken into account will be the ‘Widening of the A27 highway’ case. The reason to focus on this case is that in 2010 the Binomial Option Pricing Method was already conducted and these calculations are accessible. By conducting a Simplified Decision Tree in this research, a comparison of both methods could be undertaken.

To select an appropriate new case the mentioned requirements and criteria have been taken into account. Hereby, it was important to strive for a project that fulfils all these criteria, but this was not a must. It was preferred to select a project which could actually benefit from additional decision-making information, so a real-life planned decision would be the most relevant. In consultation with Rijkswaterstaat the case ‘replacement Kaagbrug A44’ was selected. This movable bridge, part of the A44 highway has to be opened regularly for shipping traffic, which stagnates the road traffic. There is uncertainty about the future road and shipping traffic flows. It is questioned if and when the bridge should be heightened, widened or could even be replaced by an aqueduct. This case is relevant as it is planned to be replaced in the near future, but this is not politically sensitive yet.

There are some evaluation studies conducted on widening the A44 highway which includes the Kaagbrug, so there is data available. Despite this, there is no CBA available, thus CBA calculations have to be done in this research as well. However, due to the fact that the alternatives are not fixed, this gives the opportunity to test real option thinking as the case can be approached in the most relevant way. This latter argument is very important for selecting this case as this is a main recommendation of the recently published CPB study (van der Pol et al., 2015, p. 11)
Table 6 provides an overview of the case study approach that is used in this study.

<table>
<thead>
<tr>
<th>Method</th>
<th>Case 1: Widening of the A27 highway</th>
<th>Case 2: Replacement Kaagbrug A44</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simplified Decision Tree</td>
<td>Conducted in this study (see 4.3)</td>
<td>Conducted in this study (see 5.3)</td>
</tr>
<tr>
<td>Binomial Option Pricing</td>
<td>Conducted in 2010 (Reitsma, 2010)</td>
<td>Conducted in this study on the decision regarding widening of the A44 highway itself (see 5.4)</td>
</tr>
</tbody>
</table>

3.4 CONCLUSION

The goal of this section was to make a first comparison between methods based on the existing cases, give an overview of the knowledge needed before ROA can be applied and select an appropriate new case. The central question of this section was: ‘What can be learned from existing case studies and what data and knowledge are needed before ROA can be applied?’

Every infrastructure project that meets the following requirements: affected by uncertainty, managerial flexibility, irreversibility, asymmetric pay-offs could in theory benefit from applying ROA. The conducted case studies analysed show a variation on projects that met those requirements and on which ROA was applied. Every case concludes that there is a valuable addition of applying ROA, although this value varies. When infrastructure projects prone to uncertainties include the options to defer or phase, they are usually relevant to apply ROA. However, a trade-off between the added value and the effort to apply ROA has to be made. The case studies mainly mention the benefits conducting ROA could have, but do not reflect on the process to gather those results. To investigate this, two case studies will be performed in the next section. These cases will be ‘Widening of the A27 highway’ and the ‘Replacement of the Kaagbrug A44’.

The data and information needed to perform ROA were investigated. For the Simplified Decision Tree this will also be the information needed for the CBA and additional information on the decision moments, uncertainties, scenario chances and costs of flexibility. For the Binomial Option Pricing Method the costs and benefits over time are needed, which can be derived from the CBA. Also the additional costs of the flexibility are required. In addition, (historic) data on the main uncertainty is required to determine the volatility.
4 Case study: ‘Widening of the highway A27’

The goal of this section is to compare both methodologies on the ‘Widening of the highway A27’ case. For this case, the Binomial Option Pricing Method was performed in 2010 (Reitsma, 2010). Now, the CPB Simplified Decision Tree method will also be conducted on this case in order to identify the differences between these methods. The reason why this case is chosen is simply the fact that the calculations of the Binomial Option Pricing method are available. Furthermore, it has recently been decided that the A27 will be widened in 2019 (Rijkswaterstaat, 2015a). It would be interesting to investigate if the real life decision matches with the conclusions of the ROA application.

4.1 Case introduction - Widening Highway A27

This case is about widening the A27 highway to support the large traffic flows between Lunetten & Hooipolder. As the total investment costs did not compensate for the travel time benefits, a phased investment was researched (see Table 7). This could be relevant because the future traffic flows are uncertain. The future traffic flows determine the travel time benefits, so delaying an investment could lead to benefits. The CBA included four alternatives that varied on the number of tracks to widen as presented in Figure 11.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Widening</th>
<th>Colour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
<td>0 tracks</td>
<td></td>
</tr>
<tr>
<td>B3</td>
<td>1 track</td>
<td>orange</td>
</tr>
<tr>
<td>B2</td>
<td>2 tracks</td>
<td>orange + purple</td>
</tr>
<tr>
<td>B1</td>
<td>3 tracks</td>
<td>orange + purple + blue</td>
</tr>
<tr>
<td>B</td>
<td>4 tracks</td>
<td>orange + purple + blue + green = red</td>
</tr>
</tbody>
</table>

Table 7 includes the CBA results for the different alternatives. For the calculations of this NPV a discount rate of 5.5% was used. The travel benefits are based on both passenger and freight transport. For more insights into the assumptions and variables used, see the CBA (Decisio, 2010). It can be concluded from this CBA that B3 is the least negative and thus the preferred alternative. Furthermore, the B/C ratio of all alternatives are quite close to each other. As the travel time benefits mainly determine the total benefits, it is interesting to investigate the impact of the traffic growth uncertainty with the ROA methods.
TABLE 7: CBA (NPV 2013, PP 2009, IN € MLN) ADAPTED FROM (DECISIO, 2010)

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Alt. B</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>-1,165</td>
<td>-991</td>
<td>-832</td>
<td>-458</td>
</tr>
<tr>
<td>Investment costs</td>
<td>-1,002</td>
<td>-849</td>
<td>-712</td>
<td>-391</td>
</tr>
<tr>
<td>Maintenance costs</td>
<td>-163</td>
<td>-142</td>
<td>-119</td>
<td>-67</td>
</tr>
<tr>
<td>Direct benefits</td>
<td>1,034</td>
<td>911</td>
<td>671</td>
<td>302</td>
</tr>
<tr>
<td>Travel time benefits</td>
<td>805</td>
<td>729</td>
<td>537</td>
<td>248</td>
</tr>
<tr>
<td>Reliability</td>
<td>201</td>
<td>182</td>
<td>134</td>
<td>62</td>
</tr>
<tr>
<td>Travel distance benefits</td>
<td>28</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>External effects</td>
<td>-99</td>
<td>-110</td>
<td>-44</td>
<td>57</td>
</tr>
<tr>
<td>Air quality</td>
<td>-6</td>
<td>-12</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>Noise</td>
<td>8</td>
<td>8</td>
<td>11</td>
<td>17</td>
</tr>
<tr>
<td>Safety</td>
<td>-65</td>
<td>-67</td>
<td>-31</td>
<td>33</td>
</tr>
<tr>
<td>Climate</td>
<td>-36</td>
<td>-39</td>
<td>-25</td>
<td>-5</td>
</tr>
<tr>
<td>Total</td>
<td>-230</td>
<td>-190</td>
<td>-204</td>
<td>-91</td>
</tr>
<tr>
<td>B/C-ratio</td>
<td>0.80</td>
<td>0.81</td>
<td>0.75</td>
<td>0.80</td>
</tr>
</tbody>
</table>

4.2 BINOMIAL OPTION PRICING METHOD – WIDENING HIGHWAY A27 (REITSMA, 2010)

In 2010, the Binomial Option Pricing Method was conducted on this case by Reitsma (2010). The main findings, as well as the added value to the decision-making and discussions will be presented in this section.

MAIN FINDINGS
- The regular CBA concluded that it is not beneficial to widen the A27, due to its negative NPV. However, the ROA demonstrated that it would be relevant to invest in the highway at a future moment. This depends on the development of future road traffic. With the expected transport volume growth, it could be worthwhile to start widening the highway in 2016 or later. To avoid wrong decision-making it was recommended to investigate the traffic developments again before the actual widening in 2016.

- The ROA also pointed out that when the transport volume growth is high enough and the first investments are made, one would immediately consider widening the complete highway, alternative B. This can be explained as the first track, B3, includes by far the highest investment costs, if these are made, expansion of the other tracks is recommended. Once the investment for alternative B3 is made, which will be made in 2016 or later, it is only a small additional investment with a large additional benefit to expand even further. This conclusion was not drawn from the regular CBA (see Figure 12).
The calculations showed that the alternatives are less negative due to the option value. The reference alternative as option to wait is worth €80 million with optimal timing, which refers to the option value (see Table 8). This means that waiting with the investment to the moment that the traffic volumes are sufficient to support the additional investment could have a value of €80 million. In this case it assumed that alternative B has no value of flexibility, as this alternative includes widening the complete highway and there is thus no flexibility to defer left.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>PV Benefits ROA</th>
<th>PV Investment</th>
<th>Real Option Value</th>
<th>Net Present Value (CBA)</th>
<th>Difference (ROA-CBA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ref</td>
<td>80</td>
<td>0</td>
<td>80*</td>
<td>0</td>
<td>80</td>
</tr>
<tr>
<td>B3</td>
<td>420</td>
<td>458</td>
<td>-38</td>
<td>-90</td>
<td>52</td>
</tr>
<tr>
<td>B2</td>
<td>675</td>
<td>831</td>
<td>-156</td>
<td>-204</td>
<td>47</td>
</tr>
<tr>
<td>B1</td>
<td>820</td>
<td>990</td>
<td>-169</td>
<td>-189</td>
<td>20</td>
</tr>
<tr>
<td>B</td>
<td>935</td>
<td>1,165</td>
<td>-229</td>
<td>-229</td>
<td>0</td>
</tr>
</tbody>
</table>

*For the CBA it is uncommon that the reference-alternative has a value. In the ROA methods this presents the existing value brought by uncertainty or flexibility as all possibilities are still open in this alternative.

**ADDED VALUE OF ROA TO DECISION-MAKING**

This study by Reitsma (2010) demonstrated the value of the option to defer and phase the construction. In the CBA the most promising alternatives were compared, followed up by choosing the most promising one. With the Binomial Option Pricing Method it was possible to find additional decision-making information on the most optimal moment to widen the highway. Performing ROA demonstrated the value of deferring the investment to the moment when the traffic flows are high enough to be beneficial. During the time of deferral, the investment value can be used to make return on investment. In this case the ROA showed that it would be beneficial to invest in the future, while it could also be possible that no investment was made at all as it turned out widening the highway was not required. Moreover, the Binomial Option Pricing method calculated the option value, it shows that the option to expand further is worth at least €20 million.

**DISCUSSION**

Although the application of ROA gave some interesting insights, there are some points of discussion on the Binomial Option Pricing Method conducted. A first limitation of the research to mention was that the order of the phased investment was fixed, for that reason the ROA was not used to gain insights in the most optimal order of the investments. However, it can be questioned if it would have been possible to research the most optimal order of the investments, as performing ROA would get very complex due to many possible orders. Secondly, the travel time benefits are based on both freight and passenger transport flows. The Binomial Option Pricing Method can include just one volatility parameter that captures the uncertainty of both travel time benefits. However, the developments of those different transport flows vary as well as the hourly travel time benefits, so it would be better to take them both into account separately. A weighted average is used to combine both travel volume uncertainties in one variable, which might decrease the reliability. Determining the volatility was complicated and might be unreliable. In this case the volatility was based on historical data, however historic data is not necessarily
a forecast of the future. Lastly, there were no direct costs of the option to defer taken into account. The indirect option costs, the losses of the deferral in terms of travel time losses, are calculated within the model, but there are no costs of the deferral itself taken into account.

4.3 SIMPLIFIED DECISION TREE - WIDENING HIGHWAY A27 (NEW IN THIS STUDY)

To compare both ROA methods in this research, the Simplified Decision Tree approach is performed in this study. The steps of this approach are described in section 3.2 and were conducted accordingly. In order to make the comparison as reliable as possible, it is important to strive to use the same assumptions and variables as used in the Binomial Option Pricing Method.

INPUT VARIABLES

To start, the input variables mentioned in Table 9 were needed and are based on the information of this project (Decisio, 2010; Ministerie van Verkeer en Waterstaat, 2010; Reitsma, 2010).

<table>
<thead>
<tr>
<th>Input variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>First decision-making moment</td>
<td>2013</td>
</tr>
<tr>
<td>Timeframe between decision-making moments</td>
<td>5 years</td>
</tr>
<tr>
<td>Possibilities to extend, future decision moments</td>
<td>2018, 2023</td>
</tr>
<tr>
<td>Uncertainty, information gained of time</td>
<td>Transport volume flows in scenario</td>
</tr>
<tr>
<td>Time span</td>
<td>2013 - 2100</td>
</tr>
<tr>
<td>Cost of the flexibility option</td>
<td>No costs</td>
</tr>
</tbody>
</table>

EXPLANATION OF INPUT VARIABLES

Similar to the Binomial Option Pricing analysis performed, the first decision-moment is 2013, which also represents the moment the construction started. Although, this is not the case in real situations, this is done to make a proper comparison. The NPV price level is set on the year 2009. The time between the decision-making moments is 5 years. This choice is made as it is recommended to test the option to defer usually for 5 or 10 years (Bos & Zwaneveld, 2014). Furthermore, the research conducted showed that a small deferral of a few years was optimal due to the expected traffic growth especially until 2020. This is captured by including nearby future decision-making moments in 2018 and 2023. The dominant uncertainty is the development of transport volume flows, which influences the travel time benefits. Both a low and high scenario are used to take this into account. The timespan used for this calculation is 87 years. Although, 100 years is usually standard to evaluate transport infrastructure projects it was decided to conduct this evaluation until 2100. The values after 2100 are supposed to be very small and, thus, can be ignored. However, as the CBA by Decisio (2010) included an infinite time span, the values change a little, which has also been estimated by using the Binomial Option Pricing Method. Likewise, for the Binomial Option Pricing Method, it is supposed that no direct additional costs involved with deferring the construction of an alternative are present. This means that there are no costs included for road reservation, but note that the methods does involve the losses in terms of travel time benefits.
CONSTRUCTION AND SIMPLIFYING THE DECISION TREE

To start, a Decision Tree with the decisions and decision moments as well as a scenario tree with the uncertainties were constructed (See appendix B). To create the Simplified Decision Tree those trees had to be simplified and combined into one tree. An important step of the Simplified Decision Tree is to limit the tree towards the most relevant alternatives and scenarios. In order to do this the following assumptions were made:

- There is a decision moment every 5 years and the tree includes decision rounds in 2013, 2018 and 2023.
- The possible alternatives are limited to three decision possibilities:
  - R: Do not widen the highway
  - B: Widen the complete highway (4 tracks)
  - B3: Widen the first most complicated track (1 track)

  This means that the alternatives B1 and B2 are not taken into account separately. As it is clear from previous studies, the track B3 is the most expensive track to widen and after constructing this one, it could be the most relevant to widen the complete highway instead of 2 or 3 tracks more.
- It is chosen to translate the traffic volume growth uncertainty into two scenarios: a high scenario which represent a high traffic volume growth and a low scenario which represents a low traffic volume growth (Rienstra, 2012). The two scenarios are the commonly used scenarios: Regional communities (RC) and Global economy (GE).

CALCULATION OF THE NPV

After creating the Decision Tree, the NPV of the different end nodes had to be determined. This was done by adjusting the calculations of the known CBA to a deferred investment. Due to a traffic volume growth factor this would lead to a larger decrease of the costs than the benefits, which could make an alternative more attractive. This NPV is based on a base scenario consisting of a traffic growth of 1% until 2010 and of 0.5% from 2010 until 2040. More details are presented in Annex B. Although this calculation uses a discount rate of 5.5%, it would have been possible to decrease the discount rate to a lower percentage due to a decreased risk premium as the situation is less uncertain.

Table 10 presents the NPV calculated for the nine alternatives compared with the 0-alternative of not widening. There are three alternatives B, B3 or first B3 and later expand to B, which vary on the year of investment. The numbers behind the alternatives refer to the construction year. For example, #2 refers to a deferral of 5 years where after B is constructed in 2018 and alternative #7 means, constructing B3 in 2013 and extend to B in 2018. Again, it is important to note that there are no costs of the deferral involved to make a fair comparison with the Binomial Option Pricing method.

For all alternatives the NPV is determined and usually the alternative with the highest NPV or highest B/C ratio will be selected (Boardman et al., 2013). Table 10 demonstrates that the alternative with the most positive NPV is alternative 6, construct B3 in 2018. Based on the B/C ratio, alternative 2, construct B in 2018 is equally beneficial. Note: The benefits of B3 2013 vary a little with the benefits of the known CBA in Table 7 as they had to be reproduced.
TABLE 10: NPV AVERAGE SCENARIO - SDT A27 (NPV 2013, PRICELEVEL 2009, IN € MLN) (AUTHOR’S ANALYSIS)

<table>
<thead>
<tr>
<th>#</th>
<th>Alternative</th>
<th>Benefits</th>
<th>Costs</th>
<th>NPV</th>
<th>B/C ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>B 2013</td>
<td>935</td>
<td>-1165</td>
<td>-231</td>
<td>0.80</td>
</tr>
<tr>
<td>2</td>
<td>B 2018</td>
<td>743</td>
<td>-836</td>
<td>-93</td>
<td>0.89</td>
</tr>
<tr>
<td>3</td>
<td>B 2023</td>
<td>590</td>
<td>-681</td>
<td>-91</td>
<td>0.87</td>
</tr>
<tr>
<td>4</td>
<td>B3 2013</td>
<td>359</td>
<td>-457</td>
<td>-99</td>
<td>0.78</td>
</tr>
<tr>
<td>5</td>
<td>B3 2018</td>
<td>287</td>
<td>-335</td>
<td>-48</td>
<td>0.86</td>
</tr>
<tr>
<td>6</td>
<td>B3 2023</td>
<td>229</td>
<td>-256</td>
<td>-27</td>
<td>0.89</td>
</tr>
<tr>
<td>7</td>
<td>B3 2013 --&gt; B2018</td>
<td>827</td>
<td>-961</td>
<td>-134</td>
<td>0.86</td>
</tr>
<tr>
<td>8</td>
<td>B3 2013 --&gt; B2023</td>
<td>730</td>
<td>-885</td>
<td>-155</td>
<td>0.82</td>
</tr>
<tr>
<td>9</td>
<td>B3 2018 --&gt; B2023</td>
<td>658</td>
<td>-762</td>
<td>-105</td>
<td>0.86</td>
</tr>
</tbody>
</table>

ADDING THE SCENARIOS

After calculating the NPV of the different alternatives, the effects of uncertainty of the traffic volumes on the travel time benefits were calculated by performing a scenario analysis. For the RC scenario a yearly growth of 0.8% for road traffic is expected until 2020, followed by a decrease of -0.18% per year in the years after 2020. The GE scenario includes a yearly growth of 1.7% for road traffic until 2020, followed by an increase of 0.095% per year from 2020 until 2040. After 2040 stabilisation is assumed in both scenarios. In this calculation the growth percentages are adjusted to the percentages used in the Binomial Option Pricing Method which consist of a growth of 1.5% until 2020 followed by an increase of 0.85% in the GE scenario.

After calculating the NPV in both the low (RC) and high (GE) scenario, probabilities are added. These probabilities are 50/50 which refers to an equal chance on both scenarios. Likewise 80/20 refers to 80% probability on low scenario and 20% probability on high scenario and the other way around with 20/80. The results are presented in Table 11.

TABLE 11: NPV INCLUSIVE SCENARIOS - SDT A27 (NCW 2013, PRICELEVEL 2009, IN € MLN) (AUTHOR’S ANALYSIS)

<table>
<thead>
<tr>
<th>#</th>
<th>Alternative</th>
<th>NPV without scenarios (Table 10)</th>
<th>NPV Low (RC)</th>
<th>NPV High (GE)</th>
<th>NPV P: 50/50</th>
<th>NPV P: 80/20</th>
<th>NPV P: 20/80</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>B 2013</td>
<td>-231</td>
<td>-287</td>
<td>-67</td>
<td>-177</td>
<td>-243</td>
<td>-111</td>
</tr>
<tr>
<td>2</td>
<td>B 2018</td>
<td>-93</td>
<td>-138</td>
<td>38</td>
<td>-50</td>
<td>-103</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>B 2023</td>
<td>-91</td>
<td>-128</td>
<td>13</td>
<td>-57</td>
<td>-99</td>
<td>-15</td>
</tr>
<tr>
<td>4</td>
<td>B3 2013</td>
<td>-99</td>
<td>-116</td>
<td>-49</td>
<td>-82</td>
<td>-102</td>
<td>-63</td>
</tr>
<tr>
<td>5</td>
<td>B3 2018</td>
<td>-48</td>
<td>-62</td>
<td>-9</td>
<td>-35</td>
<td>-51</td>
<td>-19</td>
</tr>
<tr>
<td>6</td>
<td>B3 2023</td>
<td>-27</td>
<td>-38</td>
<td>5</td>
<td>-17</td>
<td>-29</td>
<td>-4</td>
</tr>
<tr>
<td>7</td>
<td>B3 2013 --&gt; B2018</td>
<td>-134</td>
<td>-183</td>
<td>9</td>
<td>-87</td>
<td>-144</td>
<td>-29</td>
</tr>
<tr>
<td>8</td>
<td>B3 2013 --&gt; B2023</td>
<td>-155</td>
<td>-198</td>
<td>-31</td>
<td>-114</td>
<td>-164</td>
<td>-64</td>
</tr>
<tr>
<td>9</td>
<td>B3 2018 --&gt; B2023</td>
<td>-105</td>
<td>-144</td>
<td>10</td>
<td>-67</td>
<td>-113</td>
<td>-21</td>
</tr>
</tbody>
</table>
INTERPRETATION OF THE RESULTS

When the scenarios are included as presented in Table 11 and using a 50/50 probability, alternative 6, construct B3 in 2023 is the most optimal. However, the differences between the alternatives are relatively small, so there is no strong preference. #8 and #9 which both include a phased construction whereby B will be constructed in 2023, after 2018, are overruled by constructing B in 2018. Table 12 presents the value to defer the investment for both alternatives B3 and B.

TABLE 12: VALUE TO DEFER B OR B3, IN € MLN (AUTHOR’S ANALYSIS)

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Original Deferral to</th>
<th>Value Low (RC)</th>
<th>Value High (GE)</th>
<th>Value 50/50</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>2013 2018</td>
<td>149</td>
<td>105</td>
<td>127</td>
</tr>
<tr>
<td>B3</td>
<td>2013 2018</td>
<td>54</td>
<td>41</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>2013 2023</td>
<td>160</td>
<td>36</td>
<td>98</td>
</tr>
</tbody>
</table>

The value to defer the construction of the total highway, B, from 2013 to 2018 is worth €127 million (the difference between #1 -177 and #2 -50 in Table 11). So the value of flexibility could be worth this €127. For B3 it is always preferred to defer the investment even further, deferring from 2013 until 2023 has a value of €98 million. Deferring in a low scenario is always valued more than in a high scenario.

DISCUSSION OF THE RESULTS

It can be discussed how plausible the results are; the deferral of 5 years for alternative B in an average scenario has a value of €127million. This seems very large, but can be explained by a decrease in costs due to the deferral in combination with the discount rate of 5.5% (1/1.055^5=0.76). The benefits decrease less due to the expected traffic growth. Using a decreased discount rate of 4.5% or even 3.5% could have caused a smaller decrease of the costs with substantially 0.80 or 0.84. As mentioned before, an adjusted discount rate is not used. Furthermore, as this calculation is done for all alternatives, they are equally treated. Despite the fact that the exact value might be incorrect, the alternatives can be compared mutually and alternative B will be selected.

Another important point of discussion is that the costs of the option to defer are excluded in this case as in the performed Binomial Option Pricing Method, while it can be expected that a deferral would have costs, for example, additional maintenance costs or travel time losses due to increased traffic intensity on a still not widened road.

INSIGHTS IN THE DECISION-MAKING OPPORTUNITIES

An added value of the Simplified Decision Tree is the insights it could give in the value of waiting due to a large difference in the NPV between a high or low scenario. Although the NPV of alternative B 2013 seems the most positive, pre-selecting this alternative might be risky as the results depends on the scenario.

Figure 14 presents a part of the Simplified Decision Tree and provides insights into the value it could have to defer an investment. These values are also included in Table 13. In this figure the NPVs presented in Table 11 are included. It is assumed that the first investment will be made in 2018. A choice between alternative B and B3 must be made. If B is chosen, the NPV could vary between €-138 million in
the low scenario to €38 million in the high scenario. Therefore, it might be worth to first just widen part B3 in 2018 and defer the investment decision to 2023. If it turns out that the traffic growth is high, all tracks will be widened (alternative B) which leads to a positive NPV of €10 million. If the traffic growth is low it would be chosen to do nothing which leads to a negative NPV of €-62 million.

Waiting with the investment until more insights in the scenario could save €76 million in the low scenario (difference -138 and -62). But could lead to a loss of €-28 million in the high scenario (difference 38 and 10). Also investing in phases instead of one direct investment (first B3 and later possibly B) decreases the bandwidth from €38 million to €-138 million to €10 million to €-62 million. This is also presented in Table 13. So it is up to the decision-maker to decide on how adverse the risk is. Naturally, it also might be the case that other criteria are important for the decision-maker.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Scenario</th>
<th>Benefits</th>
<th>Costs</th>
<th>NPV</th>
<th>Regret choosing B or B3</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Low</td>
<td>698</td>
<td>836</td>
<td>-138</td>
<td>76</td>
</tr>
<tr>
<td>B</td>
<td>High</td>
<td>874</td>
<td>836</td>
<td>38</td>
<td>0</td>
</tr>
<tr>
<td>B3</td>
<td>Low</td>
<td>273</td>
<td>335</td>
<td>-62</td>
<td>0</td>
</tr>
<tr>
<td>B3 → B</td>
<td>Low</td>
<td>687</td>
<td>762</td>
<td>-75</td>
<td>n/a</td>
</tr>
<tr>
<td>B3</td>
<td>High</td>
<td>326</td>
<td>335</td>
<td>-9</td>
<td>47</td>
</tr>
<tr>
<td>B3 → B</td>
<td>High</td>
<td>772</td>
<td>762</td>
<td>10</td>
<td>28</td>
</tr>
</tbody>
</table>

FIGURE 14: SIMPLIFIED DECISION TREE WITH VALUES
**Main Conclusion**

Compared to the standard CBA a few additional insights are gained. Firstly, the Simplified Decision Tree shows that it is valuable to delay the construction, especially if the traffic growth turns out to be low. The CBA did not even consider a delayed investment. Secondly, the method demonstrates that a phased investment decreases the risk, as it decreases the bandwidth of the possible values significantly and for that reason lowers the risk of sunk costs. Thirdly, conducting the Simplified Decision Tree demonstrates insights in the consequences of an early investment. Especially the construction of alternative B in an early phase could have larger consequences than the smaller investment in in alternative B3. While the CBA resulted in more or less equal NPV. In general, the Simplified Decision Tree demonstrates the consequences and regret decisions could have under certain uncertainties, while the CBA just shows the final value.

**Discussion of the Simplified Decision Tree Method**

- It was impossible to include all the information in the Simplified Decision Tree. The tree can only deal with the most relevant decision moments and uncertainty. As a consequence, a large simplification had to be made. Thinking about the most relevant decisions and uncertainties to include, was maybe even more valuable than the calculations. The calculation itself consisted essentially of a scenario analysis with a few alternatives.

- A major disadvantage of the Simplified Decision is the fact that the decision-moments had to be limited to a few and for that reason had to be selected. Consequently, it was impossible to deliver a detailed study on the right moments to invest, for that reason a comparison of a deferral every 5 years was made. As the traffic growth was expected to be less after 2020 in both scenarios, it could have been expected that this would be in favour of a first investment in 2018.

- Due to the fact that the expansion order of widening the A27 was already fixed, applying the Simplified Decision Tree was not the most relevant. The added value of real-option thinking was therefore less valuable. Furthermore, the uncertainty influencing the outcomes consisted of the traffic volumes and was included by using the RC and GE scenarios. As these scenarios are also commonly used in a general scenario analysis, this calculation did not add that many new insights. However, insights in the possible regret are valuable.

- An adjusted discount rate while deferring the alternatives was not used. Decreasing the discount rate would have led to a different NPV for the deferred alternatives. Therefore, the results should not be taken for a fact, but it is important to note that using an adjusted discount rate with less or no risk-premium included could change the results.

**4.4 Comparison of the Methods based on the ‘Widening of the A27 Highway’ case**

In this section the two methods, Binomial Option Pricing Method and Simplified Decision Tree, which both were applied on the widening of the A27 highway case will be compared. Attention will be paid to a comparison between findings, methods and added value to the decision-making. It is important to emphasise once more that the Binomial Option Pricing Method was conducted by Reitsma (2010) and that the Simplified Decision Tree was carried out in this study.
MAIN FINDINGS
The Binomial Option Pricing Method concluded on two main points; when widening the highway it would be the most optimal to do this in 2016 or later (1) and in once, thus alternative B(2).

The Simplified Decision Tree also showed that it is better to defer the widening of the highway until 2018. This is mainly due to the fact that the investment costs decreased considerably due to the discount rate and the growth of the traffic volume. Furthermore, constructing the complete highway at once, alternative B, is also more valued than a phased construction when assuming a 50/50 chance on both scenarios. However, the Simplified Decision Tree also demonstrated that a phased investment would decrease the bandwidth of the expected NPV and thus decrease the risk. This is a value of flexibility.

A major difference between both outcomes is that the Simplified Decision Tree leads to a significant higher value of flexibility than the Binomial Option Pricing Method. The Simplified Decision Tree method is a simplification of the real situation, so the assumptions have a large influence and could be wrong. It could be that the traffic growth was taken into account too optimistically and the benefits are too high. The Simplified Decision Tree shows that flexibility could have a value of €127 million when the widening is deferred to 2018. However, this value could vary between 149 (low scenario) and 105 (high scenario) as it depends on the scenario chances (see Table 12). The option value of the Binomial Option Pricing Method is €80 million (see Table 14). Although the values are not fully comparable by nature, it is remarkable that the differences between the alternative B3 and B are for both methods more or less the same.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Binomial Option Pricing Method</th>
<th>Simplified Decision Tree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defer B</td>
<td>80</td>
<td>127</td>
</tr>
<tr>
<td>Defer B3</td>
<td>52</td>
<td>98</td>
</tr>
</tbody>
</table>

Both methods demonstrate that it could be profitable to widen the highway at a later stage, while the NPV of the original CBA was negative. When comparing the methods, both approximately lead to the same decision to defer the first investment to a moment after 2016.

COMPARISON METHODS
Although both methods are based on a tree structure, there are differences between the methods:

- The Simplified Decision Tree analysis is considerably easier to conduct and more transparent. The main challenge is how to simplify the decisions and uncertainties into one tree. This simplification forces the analyst to think about the most relevant decisions and uncertainties and, therefore, it stimulates real option thinking.

- The Binomial Option Pricing Method provides an exact calculation of the optimal moment to invest as the decision-moments do not have to be set beforehand. However, because there is a decision-moment at least every year, a large spreadsheet has to be created. To determine the value of each node input variables are required. These input variables are more difficult to understand as they are derived from the financial calculations. Therefore, this analysis is more complex and less transparent for an outsider.
Contents wise, the methods especially differ on including the uncertainty and the effects this uncertainty has on the benefits. Whereby the Simplified Decision Tree Method recommends to include just two scenarios, the Binomial Option Pricing Method requires determining the volatility that presents the expected growth of, for example, road traffic for each moment in time. For that reason, this latter method is more appropriate to include decisions based on a continuous uncertainty.

To conclude on both methods related to this case, the Binomial Option Pricing Method required more input variables and effort, while the Simplified Decision Tree needed less. In the latter method it was more of a challenge to simplify, whereas in the Binomial Option Pricing Method it is more a challenge to determine the right input variables and include these in the model. As they both lead to approximately the same decision to defer the investment till 2018, the simple method is preferred for this case. However, the results of the Simplified Decision Tree are dependent on the scenario chances. Therefore, it was researched how the probability chances chosen refer to the distribution of the Binomial Option Pricing Method. This research argued that the RC and GE scenario are in the middle of the distribution of the Binomial Option Pricing Method and thus the results of the 50/50 scenario can be used to compare the value of flexibility.

**Added value of ROA to Decision-making**

The main purpose of this research is to investigate the valuable addition of ROA and to research if this varies per method.

In addition to the standard conducted CBA, both methods led to additional decision information. They both demonstrated that it could be profitable to invest at a later stage in the highway, while the NPV showed that it was in no way cost-effective. Also both methods show that constructing the complete alternative B is more beneficial than a phased construction. Although constructing B in once could be more beneficial, the Simplified Decision Tree also generated insights in the possible values a phased construction could have. This is especially valuable to see the possible consequences and risks of a non-phased investment. Even if this is less beneficial, it could be worth to consider the phased investment in a very uncertain situation. These insights are helpful and lead to the same recommendations as the Binomial Option Pricing Method to defer the investment until at least 2018 and perform a new cost evaluation in the future when more accurate information on the uncertainty is known.

As both methods provide approximately the same decision-making recommendations, it could be argued that the Simplified Decision Tree should be used, as it is less complicated to conduct and can give more insights due to its more transparent presentation. However, this is not known in advance and also when the decision-maker wants to know the exact most optimal moment to invest out of all possible moments, the Binomial Option Pricing Method would be preferred. Moreover, the Binomial Option Pricing Method could also be used to determine the value per alternative without the CBA, while the Simplified Decision Tree needs the NPV calculated in the CBA.
DISCUSSION
Firstly, as the results of the Binomial Option Pricing Method were available beforehand, it was difficult to have a complete reliable comparison between methods. It is possible that the Simplified Decision Tree approach and simplification were influenced by the information known from analysing the other case. For example, it was known that the most ideal decision-making moment was in the near future, so the decision moments were chosen in the near future. Moreover, only the relevant phased investments were analysed, based on the recommendations of the Binomial Option Pricing Method. To compensate for this, it is recommended to perform the Simplified Decision Tree first in the next case study.

Secondly, it can be questioned if the Simplified Decision Tree can be seen as a ROA. Actually the Binomial Option Pricing Method is an extensive version of a Decision Tree. As the results of both methods present a different value based on other assumptions, they cannot be compared by nature. However, they are both useful to detect the value of flexibility. Because the main question of this research is about the addition of real options, the translation from the results to added value for the decision-maker is especially important.

Thirdly, this analysis did not include the costs of road reservation. This could explain that it is in general valued higher to defer the investment, as this leads to limited additional costs. Note that the losses of travel time benefits in case of deferral are included in the method.

A final point of discussion is that the case only included the option to defer with fixed alternatives. Therefore, the possibility to integrate flexibility in the alternatives was quite limited and the conclusions of this case study are not that ‘breath-taking’.

CONNECTION TO THE REAL LIFE STATUS OF WIDENING THE A27
In real life the A27 will be widened in 2019 (Rijkswaterstaat, 2015a). It has been chosen to widen all tracks (alternative B), with usually a regular road lane or peak hour lanes. In a second opinion by KiM, the final CBA of this project is criticised on the fact that the way how the partial tracks are combined in one project is not transparent (Donselaar & Rienstra, 2014). The final CBA on its own not being publically available leads me to think that merely prioritising the different tracks was considered and a phased investment was not examined. The upper part of track 1 is abandoned from this project to the project ‘Ring Utrecht’. Based on the second opinion of the CBA of this other project, the following message was published (Centraal Plan Bureau, 2014, p. 2): ‘An analysis of the social costs and benefits shows that the project pays off only if the traffic jams around Utrecht worsen significantly compared to the current situation’. It mentions that there is a large bandwidth and thus uncertainty about the efficiency of the project which asks for a deferral to ‘a moment’ when there is more certainty about the scenarios. Next, it states that deferring the investment offers the opportunity to investigate less expensive alternatives and that phased investment should be researched. This points out the importance ROA could have.
4.5 CONCLUSION

The main question of this section was: What are the effects on project evaluation of taking into account real options? Based on this case it can be concluded that including real options is a valuable addition as it provides additional information for the decision-maker. The main conclusion from this case study was that both methods led to approximately the same conclusion to defer the investment for a few years, but provide different decision information.

The Binomial Option Pricing Method is mainly relevant to gain more insights in the exact most optimal moment to invest, while the Simplified Decision Tree method supports real option thinking and generates insights in the value flexibility, in this case, a phased construction could have. The effort to perform the Simplified Decision Tree was relatively low, as all the information was already known. However, assumptions were made to make this project suitable to conduct this analysis. It is recommended to gain more insights in the possibilities of the Simplified Decision Tree by varying with the decision moments and scenario chances. In this case this could have been done by varying with different tracks and decision-moments. The Binomial Option Pricing Method resulted in the recommendation to defer the investment until at least 2016 and the Simplified Decision Tree shows the consequences an early investment could have.

Although this A27 case study gained insights into the application of ROA, there are some elements that make the case less interesting. The order of the phased option was fixed and the uncertainty existed regarding road traffic volume growth. In addition, there was limited space to test the value of real-option thinking, as the alternatives were fixed. Also, there were no direct option costs involved, merely the additional losses in terms of travel time benefits.

When considering the applicability of the methods it became clear that the Simplified Decision Tree is considerably easier to conduct and more transparent. Due to the forced simplification, real option thinking is stimulated. The Binomial Option Pricing Method is more accurate as it includes each node in time. However, this leads to a large spreadsheet and thus the disadvantage of less transparency for an outsider.

In general, it can be concluded that including real options are useful for evaluation questions like these as it quantifies the value brought by uncertainty and provides additional information for the decision-maker. ROA implied a reflection on flexibility and thus real option thinking and makes the decision-maker aware of the fact that a phased investment could be a possibility. For this case both ROA methods were useful to recommend deferring the investment for a few years.
5 CASE STUDY: ‘REPLACEMENT KAAGBRUG A44’

5.1 CASE INTRODUCTION - REPLACEMENT KAAGBRUG A44

BACKGROUND BRIDGE
The ‘Kaagbrug’ is a movable bridge, part of the A44 highway on the border of the provinces South and North Holland. The bridge spans over the Ringvaart Haarlemmermeer, a canal used for recreational boating traffic and shipping. The bridge build in 1939 is a bascule bridge with two separate parallel roads. The A44 that runs over the bridge has 2x2 lanes without emergency lanes. The bridge has a total length of 140 meters and is quite narrow which limits the maximum speed to 100 km/h instead of 120 km/h on this section of the A44. In 2008, large maintenance was conducted due to increasing technical interruptions. The official technical end-of-life of the bridge is 2020, but could be deferred with additional maintenance.

CURRENT PROBLEMS
Currently the bridge and A44 causes some problems. Due to the canal the bridge regularly has to be opened for shipping traffic, which stagnates the traffic on the A44 highway. Furthermore, due to the narrowness and the lack of emergency lanes the road safety is endangered. Moreover, widening the A44 highway was researched, which also includes widening this bridge (Arcadis, 2014; Stratelligence, 2015). Alternatives taken into account in that study were downgrading the A44, adding an emergency lane or even an additional road and an emergency lane. The bridge has to be adjusted to the plans of the A44, which could possibly mean widening the bridge. In order to do this, the bridge has to be replaced by a new bridge or could be replaced by an aqueduct. Creating an aqueduct involves higher investment costs but will lead to better traffic and shipping flows and probably lower maintenance cost. Currently, the question is what the best alternative would be, but this depends on the uncertainties in the future.

The main uncertainty is the development of traffic flows, both shipping and road traffic, which will largely influence the benefits and thereby the appropriateness of the alternatives. Furthermore, a decision on the width of A44 will be made in the future which determines the number of road lanes the bridge should contain. The decision regarding the A44 will probably be made after 2028, while the end-of-life of the bridge will be reached in 2020. Therefore, this study will focus on how and when to replace the bridge.

RELEVANCE OF THIS CASE
In the previous section the requirements for applying ROA are mentioned. Hereby, it is demonstrated that those requirements are met in this case:
- **Uncertainty**: These are traffic flows (both shipping and road traffic) and the decision of the A44.
- **Managerial flexibility**: These are variation between small maintenance, replacement until a possibly new higher bridge or an aqueduct.
- **Irreversibility**: A replacement of a bridge cannot be reversed and will lead to sunk costs.
- **Asymmetric pay offs**: Travel time benefits largely depend on the development of the traffic & shipping flows. Previous research also pointed out that in a high scenario a different alternative is favoured than in the case of a low scenario (Stratelligence, 2015).
- **No no-regret alternative**: Unfortunately, this is currently unknown as there is no CBA conducted yet. However, the studies on the entire A44 demonstrate that different alternatives could be recommended, so it is assumed that this is also applicable to the Kaagbrug. A CBA will also be conducted first to check whether this case meets this requirement.
- **Limited importance of non-monetary benefits**: The A44 study investigated the non-monetary external impacts. This study demonstrates that those are indeed of limited importance (see appendix C1).

Furthermore these other selection criteria are mentioned and linked to this case.
- **Relevance**: The decision regarding the Kaagbrug and the A44 is a real life decision that is expected to be influenced by uncertainty and offers the possibility to include flexibility. Therefore, additional decision information was expected to be relevant to support the real life decision.
- **Newness**: A new element in this case is that no CBA has been performed yet and it includes two different types of uncertainty.
- **Generalisability**: The findings could be relevant for other replacement projects as well.
- **Applicability**:
  - **Data availability**: A lot of information is known due to existing studies performed into the A44 or was expected to be possible to obtain with the help of Rijkswaterstaat.
  - **Limited amount of decisions and scenarios**: The scope of the project seemed appropriate for the application of ROA in this project.
- **Political sensitivity**: The case was not expected to be political sensitive as it involves merely a part of the A44 and has not often been politically discussed.

**Replacement variants**

There are several variants for the replacement of the bridge. The previous research focused on three alternatives (Arcadis, 2014):

- MIN: replace by a bridge with 2x2 road lanes + storage area
- BASIC: replace by a bridge with 2x2 road lanes + road shoulder
- PLUS: replace by a bridge with 2x3 road lanes + road shoulder

These alternatives are depicted in annex C2. Besides these alternatives Arcadis (2014) also recommended to research the possibility of creating an aqueduct. For this research it was considered to heighten the bridge to decrease the amount of bridge openings. However, after some research it was discovered that heightening is not relevant as most of the shipping consist of sailboats which do not benefit from a heightened bridge as they have a tall hull. Therefore, the option to heighten the bridge
was not relevant to include in this study. Next, it is possible to extend the end-of-life of the bridge. While conducting this research it became clear that the end-of-life of the bridge could be extended to 2028 and that it is even possible that the bridge could reach the 2039 (Leidsch dagblad, 2015).

**Type of Options**

In this case two types of options are relevant:

- **Option to defer**: The replacement of the bridge could be deferred to a moment in time where more information about the uncertainties is known. For example, the moment when the future of the A44 is decided.

- **Option to expand**: This option means that the capacity can be expanded when the demand changes. In this project this means first constructing a 2x2 bridge and widen this bridge in a later phase to 2x3 road lanes. It is important to realise that this option is only available when a certain first investment is made (in this case merely the bridge is chosen instead of an aqueduct). Furthermore, as this is about infrastructure investments it is not possible to scale the capacity down without sunk costs. As mentioned before, the option to expand the height of the bridge is not relevant as most of the shipping consist of sail ships.

**Scope**

Although the Kaagbrug and the neighbouring railway bridge form together a nautical unit, only the replacement of the Kaagbrug is taken into account. This was done as the uncertainty of the A44 does not impact the railway bridge. The benefits for a replacement of the railway bridge can be ignored, as the railway has a low train intensity according to a fixed time schedule. The demarcation of the Kaagbrug consists of all ships passing the Kaagbrug and all road traffic over the A44 between exists 2-3. Biking and walking is thus not included.

**5.2 Cost Benefit Analysis**

Before ROA can be applied the general input variables required have to be known: alternatives, uncertainties and the CBA inclusive costs, benefits and NPV.

**5.2.1 Input variables for the CBA**

Based on the previous studies and recommendations the alternatives presented in Table 15 were identified (Arcadis, 2014; Stratelligence, 2015). The 0-alternative represents preserving the current bridge including the required maintenance to expand the end-of-life. From there on, a choice to replace the current bridge by a new bridge or an aqueduct can be made. The replacement includes the variations Basic and Plus, as taken into account in the previous studies of the A44.

**Table 15: Alternatives Kaagbrug**

<table>
<thead>
<tr>
<th>#</th>
<th>Alternative</th>
<th>Explanation</th>
<th>Height bridge (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>R: 0-alternative</td>
<td>Life expiration of the current bridge</td>
<td>4.55</td>
</tr>
<tr>
<td>1</td>
<td>Bridge Basic</td>
<td>2 x 3.5 + road shoulder 3.15m</td>
<td>6.8</td>
</tr>
<tr>
<td>2</td>
<td>Bridge Plus</td>
<td>3 x 3.5 + road shoulder 3.15m</td>
<td>6.8</td>
</tr>
<tr>
<td>3</td>
<td>Aqueduct Basic</td>
<td>2 x 3.5 + road shoulder 3.15m</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Aqueduct Plus</td>
<td>3 x 3.5 + road shoulder 3.15m</td>
<td></td>
</tr>
</tbody>
</table>
Table 16 presents the starting points taken into account to calculate the NPV. These are mainly based on the A44 study, so the data could be derived from that study. The Kaagbrug is located between the exits 2 and 3 of the A44 and all road traffic in between these exits is taken into account. Furthermore, all ships that travel under the bridge are included. Thus the effect that the replacement might have on other traffic, for example by attracting more traffic due to better traffic flows is not taken into account in this study. The standard discount rate used is 4.5% according to the new 2016 standard (Ministerie van Financiën, 2015; Werkgroep Discontovoet, 2015).

**TABLE 16: STARTINGPOINTS CBA**

<table>
<thead>
<tr>
<th>Theme</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demarcation</td>
<td>Exits 2 - 3 A44 + passing ships</td>
</tr>
<tr>
<td>Time horizon</td>
<td>2015 - 2100</td>
</tr>
<tr>
<td>Base year</td>
<td>2015</td>
</tr>
<tr>
<td>End year</td>
<td>2100</td>
</tr>
<tr>
<td>Price level</td>
<td>2014</td>
</tr>
<tr>
<td>Discount rate</td>
<td>4.5% (new standards 2016)</td>
</tr>
<tr>
<td>End traffic growth</td>
<td>2040</td>
</tr>
</tbody>
</table>

Table 17 and Table 18 provide an overview of the costs and benefits taken into account. For the costs, investment and maintenance costs are distinguished. There are no additional costs included such as the A44 spatial costs. It is assumed that these costs can be ignored in this case as they are limited since the replacement of the bridge just includes a small space.

The benefits mainly consist of the travel time benefits. The A44 study included these, based on the travel time losses for road traffic. In this case the travel time benefits for shipping due to the number of bridge openings are also taken into account. Next, the safety benefits are included as in the current situation safety is quite an issue.

**TABLE 17: COSTS - KAAGBRUG**

<table>
<thead>
<tr>
<th>Costs</th>
<th>Unit</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment costs</td>
<td>€</td>
<td>Initial construction costs</td>
</tr>
<tr>
<td>Maintenance costs</td>
<td>€ per year</td>
<td>Additional maintenance costs towards the current costs</td>
</tr>
<tr>
<td>Additional costs</td>
<td>€</td>
<td>Excluded (Environmental costs for the needed space to create a new infrastructure as mentioned in the A44 study)</td>
</tr>
<tr>
<td>environment</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TABLE 18: BENEFITS - KAAGBRUG**

<table>
<thead>
<tr>
<th>Benefit</th>
<th>Unit</th>
<th>How?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel time benefits</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road traffic</td>
<td>€ per year</td>
<td>Both road &amp; shipping</td>
</tr>
<tr>
<td>Shipping</td>
<td>€ per year</td>
<td>Travel time hour losses between exits 2-3</td>
</tr>
<tr>
<td>Less bridge openings</td>
<td>€ per year</td>
<td>Based on travel time costs of all passing shipping</td>
</tr>
<tr>
<td>Safety</td>
<td>€ per year</td>
<td>Based on bridge openings &amp; traffic intensity</td>
</tr>
<tr>
<td>External</td>
<td>€ per year</td>
<td>Estimation based on historical data</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(excluded due to limited importance)</td>
</tr>
</tbody>
</table>
5.2.2 Data Collection
This section describes how the data needed is collected. First the data available used for the A44 was analysed to investigate what data was missing and had to be collected.

Available Data
The replacement of the Kaagbrug by itself was never studied before. However, the two studies on widening the A44 highway included widening the Kaagbrug as well (Arcadis, 2014; Stratelligence, 2015). The Arcadis study is a quick-scan towards the costs of the replacement of the different elements of the A44. The Stratelligence research focused on the theoretical advantages of an adaptive approach for the plans of Rijkswaterstaat, whereby the A44 was the case. Currently, there is information about the replacement of the Kaagbrug, but there is no CBA and there are no strict alternatives planned.

Collected Data
The following paragraphs describe the way the data was collected and calculated. As the replacement of the Kaagbrug is used as a case, the purpose of this study is not to perform a perfect CBA, but to produce decent data that can be used to test the addition of ROA.

Costs
Table 19 presents the resources of the costs. In appendix C the costs can be found.

<table>
<thead>
<tr>
<th>Costs</th>
<th>Resource</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment costs</td>
<td>Bridge</td>
</tr>
<tr>
<td></td>
<td>Arcadis study (Arcadis, 2014)</td>
</tr>
<tr>
<td></td>
<td>Aqueduct</td>
</tr>
<tr>
<td></td>
<td>Cost expert Rijkswaterstaat²</td>
</tr>
<tr>
<td></td>
<td>Road</td>
</tr>
<tr>
<td></td>
<td>A44 study (Stratelligence, 2015)</td>
</tr>
<tr>
<td>Maintenance costs</td>
<td>Bridge</td>
</tr>
<tr>
<td></td>
<td>A44 study (Stratelligence, 2015)</td>
</tr>
<tr>
<td></td>
<td>Aqueduct</td>
</tr>
<tr>
<td></td>
<td>Cost expert Rijkswaterstaat</td>
</tr>
<tr>
<td></td>
<td>Road</td>
</tr>
<tr>
<td></td>
<td>A44 study (Stratelligence, 2015)</td>
</tr>
</tbody>
</table>

Benefits

Travel Time Benefits — Road Traffic
To calculate the travel time benefits, information on the traffic intensity, type of traffic (passenger or freight) and hourly travel time value has to be determined. These values were derived from the data collected for the A44 study (Stratelligence, 2015). 20.4% of all traffic on the A44 consists of freight transport and thus 79.6% of passenger transport. The hourly average travel time value is based on the travel time value of freight transport, passenger transport and the passenger freight ratio.

For the A44 study the hourly travel time losses (VVU) per day per track are determined in both the general, RC and GE scenario (Stratelligence, 2015). These hourly travel time losses are based on the Dutch Regional Model-west (NRM-West). Hereby, both directions are taken into account and the losses are determined on 260 workdays per year (52*5).

² Kees van der Werff, cost advisor Rijkswaterstaat, meeting 9th of December 2015
The travel time benefits of shipping were not included in the A44 study, so all the data needed had to be collected. Data on the number of bridge openings, duration of the bridge opening, type of shipping was gathered and presented in the Appendix C3. It is important to notice that there are on average only 900 bridge openings per year and most of the shipping consists of recreational shipping. The number of ships passing the bridge is larger, as the bridge is not opened for every ship, but there are no data regarding the total number of passing shipping traffic. It can be discussed if the travel time benefits of recreational shipping can be expressed as a value, however, as this is an example, the assumptions made in the Ramspolbridge example are used. Replacement by a new bridge leads to travel time benefits for commercial shipping as the bridge will be a bit heightened and replacement by an aqueduct leads to benefits for recreational shipping as well.

A main difference between the aqueduct and a bridge is the travel time hinder due to bridge openings. Constructing an aqueduct will result in the bridge not having to be opened which will lead to travel time benefits for the passing road traffic. For every bridge opening a car is delayed for 6 minutes. This is based on the average waiting time of 3.50 minutes and the delay due to traffic jams. Based on the road intensity, number and time of bridge openings the chance to be hindered by a bridge opening per car is determined. Based on the hourly travel time value per vehicle, expected yearly road intensity and expected number of bridge openings the travel time delay to bridge openings can be determined. This value is translated as a benefit for the aqueduct alternatives.

Although the safety was not included in the A44 study, it was taken into account in this CBA as safety is mentioned as a major issue for the current situation. For example, the Arcadis report mentions (Arcadis, 2014, p. 32) ‘On the Kaagbrug there are relatively more accidents, this is probably due to bridge openings which cause motorised road traffic to come to a stop, this increases the chances of rear-end collisions.’ In addition, several old news items on accidents around the Kaagbrug were found. Although it is mentioned various times that safety is a large issue around the Kaagbrug, no data on the amount of traffic accidents occurred on this bridge was found. To monetise safety, the different factors were scored in comparison with each other. This scores were used to take an percentage of the known costs per traffic incident (SWOV, 2014).

The NPV was calculated for all factors described in 5.2.2 and is presented in Table 20. The starting points mentioned are used; a discount rate of 4.5% is used and a time horizon until 2100 is assumed. These are calculated towards the 0-alternative of no replacement and maintaining the current bridge. For the travel time benefits an average of the low (RC) and high (GE) scenario of traffic growth is used. The hourly travel time losses per scenario and alternative were determined for the A44 study and are taken over. In addition, the travel time benefits due to the number of bridge openings were calculated based on the road intensity in both scenarios. The low RC scenario presents a growth of 0.8% until 2020 and -0.18% from 2020 until 2040. The GE scenario presents a growth from 1.7% until 2020 and a growth of...
0.95% between 2020 and 2040. For each alternative the NPV per scenario is presented in Table 21 expressed in € millions. It is important to mention that the alternatives represent the whole track between exits 2 and 3 and thus also the type of widening.

**TABLE 20: CBA - KAAGBRUG (IN € MLN UNTIL 2100) (AUTHOR’S ANALYSIS)**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs</td>
<td>-38</td>
<td>-70</td>
<td>-65</td>
<td>-103</td>
</tr>
<tr>
<td>Investment costs</td>
<td>-37</td>
<td>-68</td>
<td>-64</td>
<td>-100</td>
</tr>
<tr>
<td>Maintenance costs</td>
<td>-1</td>
<td>-2</td>
<td>-2</td>
<td>-3</td>
</tr>
<tr>
<td>Benefits</td>
<td>1</td>
<td>40</td>
<td>23</td>
<td>62</td>
</tr>
<tr>
<td>Travel time benefits</td>
<td>0</td>
<td>38</td>
<td>18</td>
<td>55</td>
</tr>
<tr>
<td>Road traffic</td>
<td>0</td>
<td>38</td>
<td>0</td>
<td>38</td>
</tr>
<tr>
<td>Shipping*</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Less bridge openings</td>
<td>0</td>
<td>0</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Safety</td>
<td>1</td>
<td>2</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td>-37</td>
<td>-30</td>
<td>-42</td>
<td>-40</td>
</tr>
<tr>
<td>B/C ratio</td>
<td>0.04</td>
<td>0.57</td>
<td>0.36</td>
<td>0.61</td>
</tr>
</tbody>
</table>

*The shipping benefits are not equal to zero, but less than 1,000,000.

**TABLE 21: NPV IN € MLN TOWARDS 0-ALTERNATIVE (AUTHOR’S ANALYSIS)**

<table>
<thead>
<tr>
<th>#</th>
<th>Alternative</th>
<th>Benefits</th>
<th>Costs</th>
<th>NPV</th>
<th>B/C ratio</th>
<th>NPV (RC)</th>
<th>NPV (GE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bridge Basic</td>
<td>1</td>
<td>-38</td>
<td>-37</td>
<td>0.04</td>
<td>-5</td>
<td>-68</td>
</tr>
<tr>
<td>2</td>
<td>Bridge Plus</td>
<td>40</td>
<td>-70</td>
<td>-30</td>
<td>0.57</td>
<td>-23</td>
<td>-36</td>
</tr>
<tr>
<td>3</td>
<td>Aqueduct Basic</td>
<td>23</td>
<td>-65</td>
<td>-42</td>
<td>0.36</td>
<td>-12</td>
<td>-72</td>
</tr>
<tr>
<td>4</td>
<td>Aqueduct Plus</td>
<td>62</td>
<td>-103</td>
<td>-40</td>
<td>0.61</td>
<td>-36</td>
<td>-45</td>
</tr>
</tbody>
</table>

**INTERPRETATION OF THE RESULTS**

When looking at the results it can be concluded that the Bridge Plus alternative leads to the most optimal NPV. However, the difference between the alternatives is not significant. When considering the B/C ratio, #4 Plus Aqueduct has the largest ratio. This can be explained as this more expensive alternative leads to benefits due to no bridge openings.

When taking into account the scenarios, unsurprisingly, the Basic variants are favoured in the low RC scenario and the Plus variants in the high GE scenario. In the average scenario the Plus alternative is favoured with a NPV of -30, although it is just with a minor preference. As the results per alternative between the scenarios differ a lot, it could lead to major benefits to wait with the investment until more certainty about the traffic growth is known.

**DISCUSSION OF THE RESULTS**

Although the results seem logical, it is important to realise that this CBA may not be the most reliable. As the purpose of the case is to investigate the addition of applying ROA and not the deliver a CBA, some assumptions and estimations were made. When comparing these results with the findings of the A44 study for the track between exits 2 and 3, the results could be verified. The differences between the alternatives and scenarios are more or less the same. However, this study also included the benefits for
shipping and safety which leads to more positive NPVs, especially for the aqueduct alternatives. To conclude, as the results between the scenarios differ and the requirement that there is no no-regret alternative is met, it is worth to investigate the addition of ROA.

5.3 **SIMPLIFIED DECISION TREE – REPLACEMENT KAAGBRUG A44**

As the CBA demonstrates that in a different scenario another alternative will be favoured, applying the Simplified Decision Tree on this case could gain new insights. Furthermore, the uncertainty of future plans of the A44 was not included in the CBA. Therefore, the Simplified Decision Tree is expected to lead to more decision-making information as the option to defer and the option to expand from Basic to Plus can be taken into account.

**INPUT VARIABLES**

<table>
<thead>
<tr>
<th>Input variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>First decision-making moment</td>
<td>2015</td>
</tr>
<tr>
<td>Future decision moments</td>
<td>2028, 2039</td>
</tr>
<tr>
<td>Uncertainty, information gained over time</td>
<td>Traffic growth and decision regarding the A44</td>
</tr>
<tr>
<td>Timespan</td>
<td>2015-2100</td>
</tr>
<tr>
<td>Cost of the flexibility option</td>
<td>- Additional maintenance when deferring the replacement&lt;br&gt;- Cost to expand from Basic to Plus</td>
</tr>
</tbody>
</table>

As the replacement of the Kaagbrug is a real life case the *first decision-making moment* is right now, thus 2015. Although 2016 might have been more accurate, it was chosen to use 2015 as base year, as this year was also used in the previous studies and thus the values could be directly derived. The *future decision-moments* are 2028 and 2039, as recently published in the Leidsch Dagblad the replacement can be deferred to 2028 and in 2028 a decision on the A44 will be made (Leidsch dagblad, 2015). Next, research on the current state of the bridge noted that it would probably be possible to extend the end-of-life once more until 2039. Although more decision-moments could occur in real life, with this method the number of decision-moments has to be limited to the most critical. The *uncertainties* included in the Simplified Decision Tree are traffic growth and the decision regarding the A44. The *timespan* is from 2015 until 2100, similarly to the previous A44 studies. Next, the *costs of the flexibility option* are the additional maintenance costs when deferring the replacement for the option to defer. For the option to expand the costs of flexibility are the additional investment costs to expand from the basic to the plus variant. Note that the costs in terms of travel time losses are involved in the calculation of the method.

5.3.1 **CONSTRUCTING AND SIMPLIFYING THE DECISION TREE**

The steps of the Simplified Decision Tree approach are described in section 3.2 and will be conducted accordingly. To start, a Decision Tree with the decisions and decision moments as well as a scenario tree with the uncertainties were constructed (See appendix C4).
DECISION TREE
The Simplified Decision Tree will include five alternatives, according to the different investment moments as presented in Table 23.

TABLE 23: ALTERNATIVES SDT - KAAGBRUG

<table>
<thead>
<tr>
<th>#</th>
<th>Alternative</th>
<th>Investment moments</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0 - Alternative: Maintain current bridge</td>
<td>2015, 2028, 2039</td>
</tr>
<tr>
<td>1</td>
<td>Replacement Basic</td>
<td>2015, 2028, 2039</td>
</tr>
<tr>
<td>2</td>
<td>Aqueduct Basic</td>
<td>2015, 2028, 2039</td>
</tr>
<tr>
<td>3</td>
<td>Replacement Plus</td>
<td>2015, 2028, 2039</td>
</tr>
<tr>
<td>4</td>
<td>Aqueduct Plus</td>
<td>2015, 2028, 2039</td>
</tr>
<tr>
<td>5</td>
<td>Replacement Basic → Replacement Plus</td>
<td>2015 and 2028, 2039</td>
</tr>
</tbody>
</table>

*For alternatives #3, 4 and 5 the investment moment 2039 is not included in this study due to practical reasons.

This means that the Replacement Basic can be done in 2015 or deferred to 2028 or 2039. In total this leads to 11 alternatives The Min alternative mentioned in the CBA conducted is not taken into account, as the previous CBA and studies showed that this alternative is overruled by all other alternatives.

When relating the decision to the different options, the following two options are included:
- **Option to defer:** Defer the investment and thus replacement by maintaining the current bridge (towards 2015, 2028 or 2039)
- **Option to expand:** Expand the bridge from Basic to Plus. This is only possible for the bridge alternative and not the aqueduct. This will lead to an additional 5th alternative. The costs of this expansion was also calculated in the Arcadis study. The Basic bridge will be constructed in a way that it is easily expandable and enough space for this will be available (Arcadis, 2014, p. 17). The additional costs to expand the bridge from Basic to Plus are relatively low, due to the relative simple construction and no additional spatial cost.

SCENARIO TREE
As mentioned before there are two main uncertainties which will be translated into scenario situations:
- **Traffic growth:** For the traffic growth both a high and a low scenario is assumed. These consist of both the growth of road traffic and the growth of shipping traffic.
- **Decision regarding the A44:** The plans of the A44 are the main uncertainty affecting the needed bridge alternative. The options are downgrading the A44 to a N-road, keeping 2x2 or widening the highway to 2x3.

The scenarios can be found in the appendix. To simplify to the most relevant scenarios a few simplifications are made. Firstly, the decision to downgrade the A44 to an N-way is not individually included in the Simplified Decision Tree. This scenario is implied in the ‘keep 2x2’ scenario tree as in terms of road lanes this has the same consequences for the bridge to be constructed. Secondly, there are just a low and a high traffic growth scenario taken into account for the road traffic. As the shipping is of minimal influence on the NPV, the scenarios refer to the traffic growth of road traffic. Moreover, it is important to realise that the traffic growth will affect the decision regarding the A44. For that reason,
they are placed behind each other. This results, in total, in four different situations as pictured in Figure 16. 

*Note: to avoid confusion, the combined scenarios will be called ‘situations’ in this report from now on.*

![Decision Tree Diagram](image)

**FIGURE 16: SCENARIOS A44**

**SIMPLIFIED DECISION TREE**
To create the Simplified Decision Tree, the decision and scenario tree both had to be simplified and combined into one tree. An important step in constructing the Simplified Decision Tree is limiting the tree to the most relevant alternatives and situations. It is important to realise that those simplifications are results of real option thinking. While thinking about the most relevant decisions and scenarios it becomes clear that some combinations will never happen and thus are irrelevant to consider. This provides insights in the decisions were flexibility could be valuable.

An important assumption made to simplify this case is that the decision regarding the A44 will be made in 2028. This means that from 2028 on there is 100% certainty about the plans of the A44. Therefore, no decision on expanding to the Plus-variant in 2039 can be made. Moreover, it is assumed that the A44 decision will be made based on the traffic growth, thus the traffic growth uncertainty is placed before the decision regarding the A44 uncertainty. However, it is still possible that the A44 will be widened in a low scenario as there are more factors influencing this decision.

The Simplified Decision Tree is pictured in annex C4. Although it was chosen to include all possible paths, some branches are less relevant.

5.3.2 THE RESULTS OF THE SIMPLIFIED DECISION TREE
Based on the Simplified Decision Tree the NPV of the different end nodes was determined. This was done by adjusting the calculations of the CBA in the previous section to a deferred investment. A discount rate of 4.5% was used for all calculations. However, it would have been possible to use a decreased risk-adjusted discount rate under the assumption that the risk will decrease over time.
Although this is often recommended in literature, it is unusual when evaluating infrastructure-projects and for that reason not included.

The cost to defer the replacement are also included. These consist of additional maintenance costs to maintain the current bridge, which are taken into account under the investment costs. These additional investments will be done in 2015, 2020 and 2024 and when they will be deferred from 2028 to 2039 also in 2028 and 2034. In case of a deferral, this leads to additional travel time and for that reason lower travel time benefits. For the scenarios the same low RC and high GE scenarios are used as for the CBA.

Table 24 presents the NPV for the various alternatives in the different situations. The n/a refers to the decisions which are irrelevant. For example, alternative #1b Replacement Basic 2028 will never happen in a situation whereby the A44 will be widened to 2x3. In total this results in 28 different alternatives also depicted in the Decision Tree in the appendix. In this table three different variables can be found which represent the following:

- Number: the NPV of the alternative per situation in million €
- n/a: not applicable, in this situation this alternative will never be chosen as it is overruled by another alternative
- →#5: This represents the fact that in this situation, the alternative 1a will be expanded to alternative #5, thus from the Basic to the Plus variant.

**TABLE 24: NPV - SIMPLIFIED DECISION TREE KAAGBRUG, IN € MLN (AUTHOR’S ANALYSIS)**

<table>
<thead>
<tr>
<th>#</th>
<th>Alternative</th>
<th>Year of investment</th>
<th>Situation 1</th>
<th>Situation 2</th>
<th>Situation 3</th>
<th>Situation 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>GE - 2x3</td>
<td>GE - 2x2</td>
<td>RC - 2x3</td>
<td>RC - 2x2</td>
</tr>
<tr>
<td>1a</td>
<td>Replacement Basic</td>
<td>a. 2015</td>
<td>→ #5</td>
<td>-68</td>
<td>→ #5</td>
<td>-5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b. 2028</td>
<td>n/a</td>
<td>-52</td>
<td>n/a</td>
<td>11</td>
</tr>
<tr>
<td>1c</td>
<td>Replacement Basic</td>
<td>c. 2039</td>
<td>n/a</td>
<td>-44</td>
<td>n/a</td>
<td>19</td>
</tr>
<tr>
<td>2a</td>
<td>Aqueduct Basic</td>
<td>a. 2015</td>
<td>-136</td>
<td>-72</td>
<td>-26</td>
<td>-12</td>
</tr>
<tr>
<td>2b</td>
<td>Aqueduct Basic</td>
<td>b. 2028</td>
<td>n/a</td>
<td>-47</td>
<td>n/a</td>
<td>10</td>
</tr>
<tr>
<td>2c</td>
<td>Aqueduct Basic</td>
<td>c. 2039</td>
<td>n/a</td>
<td>-34</td>
<td>n/a</td>
<td>24</td>
</tr>
<tr>
<td>3a</td>
<td>Replacement Plus</td>
<td>a. 2015</td>
<td>-42</td>
<td>-70</td>
<td>-16</td>
<td>-7</td>
</tr>
<tr>
<td>3b</td>
<td>Replacement Plus</td>
<td>b. 2028</td>
<td>-25</td>
<td>n/a</td>
<td>1</td>
<td>n/a</td>
</tr>
<tr>
<td>4a</td>
<td>Aqueduct Plus</td>
<td>a. 2015</td>
<td>-51</td>
<td>-79</td>
<td>-29</td>
<td>-19</td>
</tr>
<tr>
<td>4b</td>
<td>Aqueduct Plus</td>
<td>b. 2028</td>
<td>-27</td>
<td>n/a</td>
<td>-4</td>
<td>n/a</td>
</tr>
<tr>
<td>5</td>
<td>Replacement Basic - Plus</td>
<td>2015 → 2028</td>
<td>-42</td>
<td>n/a</td>
<td>-16</td>
<td>n/a</td>
</tr>
</tbody>
</table>

**INTERPRETATION OF THE RESULTS**

A first result is that different alternatives are favoured per situation, thus keeping managerial flexibility is valuable. Secondly, when looking to the individual alternatives, for each alternative a large bandwidth can be noticed. In all situations, it is more beneficial to defer the investment as the replacement of the bridge mainly involves costs and the benefits are relatively low. In general, it can be concluded that deferring the investment till at least 2028 is recommended. This can also be explained by the fact that the current bridge is in a relative good state for its age and the additional maintenance costs to preserve this bridge are limited.
It is interesting to see that after a larger deferral the aqueduct becomes more beneficial than a bridge. It is remarkable that the NPVs for the alternatives 3a and 5 are almost the same. This can be explained by the fact that the additional costs of a phased construction compared to the immediate construction of a Plus variant are very small (less than 1 million). In the period between 2015 and 2028 this will save maintenance costs, for that reason they finally end up with more or less the same NPV.

The option to expand the replaced bridge Basic towards the bridge Plus seems expensive (#5). However, in the high GE scenario this could save €26 million as a 2x3 A44 (#1a minus #5: -68 - -42) will be chosen. In the low scenario this will lead to sunk costs, therefore, it is only beneficial to expand the bridge and thus the A44 in a higher scenario. This demonstrates again the value the option to defer has on the decision.

**Adding Scenario Chances When Early Decision-Making is Required**

The previous section presented the NPVs in the different situations. However, some scenarios are more probable than others, for that reason chances are assigned to the scenarios to gain more insights in the alternatives that score best in most scenarios. From the NPV calculated in the scenario tree it can be derived that widening the A44 in a high scenario is always preferred over none widening. In a low scenario keeping the 2x2 highway is preferred. This is translated into a likely situation as presented in Figure 17; if a high traffic growth occurs, the probability of widening the highway to 2x3 is 80% while with a low scenario it is only 20%.

**FIGURE 17: SCENARIO CHANCES KAAGBRUG**

This analysis would have been especially relevant if the bridge had to be replaced before 2028, like it was originally intended. During the execution of this research it became clear that the end-of-life of the bridge is expired until 2028. Despite this fact, it is interesting to investigate the potential losses when an early decision has to be made as this could lead to sunk costs or a regret value. Also when it turns out that the bridge suddenly has to be replaced, it is interesting to know what the most optimal solution would be.

---

3 Kingson Wu, Projectmanager A44 Rijkswaterstaat, November 2015
The alternative 2a, 3a, 4a and 5 are taken into account as those present the alternatives with an investment made before 2028. The following three tables demonstrates the value when the chances of each scenario are included. Table 25 presents the NPV based on the scenario as presented in the figure above. Table 26 shows the situation when the highway will not be widened and Table 27 includes the situation where the A44 is widened. The final column presents the weighted average NPV based on the assigned values of P. P represents the probabilities of the situations based on the combined chances per scenario as depicted in the tables (for example 50% x 80% =0.4).

For the interpretation of the results it is important to keep in mind that alternative #5, represents the Replacement Basic in 2015 with the option to expand to a Plus variant in 2028. In Table 26, alternative 1 represents the scenario with no widening of the highway, as it will not be expanded to a Plus variant.

**TABLE 25: NPV KAAGBRUG IN € MLN - BASED ON SCENARIO IN FIGURE 17 (AUTHOR’S ANALYSIS)**

<table>
<thead>
<tr>
<th>#</th>
<th>Alternative</th>
<th>Situation 1</th>
<th>Situation 2</th>
<th>Situation 3</th>
<th>Situation 4</th>
<th>NPV (weighted average)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>GE – 2x3</td>
<td>GE – 2x2</td>
<td>RC – 2x3</td>
<td>RC – 2x2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>P=0.4</td>
<td>P=0.1</td>
<td>P=0.1</td>
<td>P=0.4</td>
<td></td>
</tr>
<tr>
<td>2a</td>
<td>Aqueduct Basic 2015</td>
<td>-136</td>
<td>-72</td>
<td>-26</td>
<td>-12</td>
<td>-69.2</td>
</tr>
<tr>
<td>3a</td>
<td>Replacement Plus 2015</td>
<td>-42</td>
<td>-70</td>
<td>-16</td>
<td>-7</td>
<td>-28.2</td>
</tr>
<tr>
<td>4a</td>
<td>Aqueduct Plus 2015</td>
<td>-51</td>
<td>-79</td>
<td>-29</td>
<td>-19</td>
<td>-39.0</td>
</tr>
<tr>
<td>5</td>
<td>Replacement Basic 2015 - Plus 2028</td>
<td>-42</td>
<td>-68</td>
<td>-16</td>
<td>-5</td>
<td>-27.2</td>
</tr>
</tbody>
</table>

**TABLE 26: NPV KAAGBRUG IN € MLN - BASED ON SCENARIO NO WIDENING (AUTHOR'S ANALYSIS)**

<table>
<thead>
<tr>
<th>#</th>
<th>Alternative</th>
<th>Situation 1</th>
<th>Situation 2</th>
<th>Situation 3</th>
<th>Situation 4</th>
<th>NPV (weighted average)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>GE – 2x3</td>
<td>GE – 2x2</td>
<td>RC – 2x3</td>
<td>RC – 2x2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>P=0</td>
<td>P=0.5</td>
<td>P=0</td>
<td>P=0.5</td>
<td></td>
</tr>
<tr>
<td>2a</td>
<td>Aqueduct Basic 2015</td>
<td>-136</td>
<td>-72</td>
<td>-26</td>
<td>-12</td>
<td>-42.0</td>
</tr>
<tr>
<td>3a</td>
<td>Replacement Plus 2015</td>
<td>-42</td>
<td>-70</td>
<td>-16</td>
<td>-7</td>
<td>-38.4</td>
</tr>
<tr>
<td>4a</td>
<td>Aqueduct Plus 2015</td>
<td>-51</td>
<td>-79</td>
<td>-29</td>
<td>-19</td>
<td>-49.1</td>
</tr>
<tr>
<td>5</td>
<td>Replacement Basic 2015 - Plus 2028</td>
<td>n/a</td>
<td>-68</td>
<td>n/a</td>
<td>-5</td>
<td>-36.6</td>
</tr>
</tbody>
</table>

**TABLE 27: NPV KAAGBRUG IN € MLN - BASED ON SCENARIO WIDENING THE A44 (AUTHOR’S ANALYSIS)**

<table>
<thead>
<tr>
<th>#</th>
<th>Alternative</th>
<th>Situation 1</th>
<th>Situation 2</th>
<th>Situation 3</th>
<th>Situation 4</th>
<th>NPV (weighted average)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>GE – 2x3</td>
<td>GE – 2x2</td>
<td>RC – 2x3</td>
<td>RC – 2x2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>P=0.5</td>
<td>P=0</td>
<td>P=0.5</td>
<td>P=0</td>
<td></td>
</tr>
<tr>
<td>2a</td>
<td>Aqueduct Basic 2015</td>
<td>-136</td>
<td>-72</td>
<td>-26</td>
<td>-12</td>
<td>-81.2</td>
</tr>
<tr>
<td>3a</td>
<td>Replacement Plus 2015</td>
<td>-42</td>
<td>-70</td>
<td>-16</td>
<td>-7</td>
<td>-29.3</td>
</tr>
<tr>
<td>4a</td>
<td>Aqueduct Plus 2015</td>
<td>-51</td>
<td>-79</td>
<td>-29</td>
<td>-19</td>
<td>-40.1</td>
</tr>
<tr>
<td>5</td>
<td>Replacement Basic 2015 - Plus 2028</td>
<td>-42</td>
<td>-68</td>
<td>-16</td>
<td>-5</td>
<td>-29.0</td>
</tr>
</tbody>
</table>

*#5 is favoured over #3 as the additional costs to maintain the bridge between 2015 are larger than the additional costs to expand the bridge in 2028 from Basic to Plus.*
INTERPRETATION OF THE RESULTS
Looking at the tables above, in general #5 Replacement Basic 2015 with the option to expand towards Plus in 2028 is the most beneficial alternative. There is a small difference with alternative #3a, the Plus variant. In this case there is no need to invest to a Plus variant, as the additional option costs to expand to a Plus variant are very small. However, these costs only include the direct investment costs and not the additional costs for traffic delay for example. So if taken other aspects then the direct investment costs into account, it would be recommended to directly invest in the Plus variant of the bridge, if there is decent chance that the A44 will be widened to 2x3. As presented in the cost calculations, widening the bridge from Basic to Plus in a later stage involves just 0.9 million extra direct costs. In case the traffic growth will be limited, the Replacement Basic 2015 is favoured.

Moreover, it can be concluded that a bridge replacement is always more cost-effective than realising an aqueduct. This can be explained by the investment costs being almost twice as high and the limited additional benefits due to the low shipping intensity. However, if it would was decided to invest in an aqueduct, the favoured option would be to invest in the Aqueduct Plus instead of the Aqueduct Basic. Despite the fact that the investment costs of this larger aqueduct are higher, investing in the Aqueduct basic in 2015 instead of the Aqueduct Plus could lead to major losses when, at a later stage, it is decided to widen the A44 (136-51 = €85 million).

5.3.3 CONCLUSION & DISCUSSION OF THE SIMPLIFIED DECISION TREE – KAAGBRUG
This section provides the conclusions and discussion regarding the case conducted. Furthermore, the addition of the Simplified Decision Tree will be discussed.

CONCLUSION
Several major conclusions can be drawn from this study for the decision regarding the Kaagbrug:

- In general it is recommended to defer the replacement as long as possible, because during this deferral more insights in the uncertainties can be generated and thus decrease the risk and bandwidth of the results.
- If the current bridge has to be replaced before 2028, the replacement by a bridge is always preferred over an aqueduct. This can be explained by the fact that the shipping is limited thus the benefits are not much higher but also because an aqueduct eliminates the option to expand. However, if other criteria besides cost-effectiveness would play a larger role, the aqueduct could be favoured.
- If it is likely that the A44 will be widened and the current bridge will be replaced by a new bridge, it does not matter if a Basic or Plus variant will be chosen based on the costs and benefits. If an aqueduct is chosen, it is worth to invest in a Plus variant when there is a decent chance of the A44 being widened.

**DISCUSSION**

There are some points of discussion that could influence the reliability of this study:

- The scenarios assumed that the traffic growth scenario before 2028 will continue with the same scenario after 2028. As after 2040 the traffic growth stagnates in both scenarios the effect of this on the results is expected to be limited.

- Next, it was assumed that the decision regarding the A44 had to be made in 2028. However, it could be the case that in 2028 it will be decided to defer this decision again. For that reason there should actually also be scenarios which represent the situation when the A44 is widened somewhere after 2028. Unfortunately, the Simplified Decision Tree just allows one or two decision-making moments, so a new tree should be created in order to test this.

- When the case was selected, it was expected that shipping would have more impact on the results. After research was discovered that the shipping under the Kaagbrug is limited and mainly consist of recreational traffic. Therefore, the uncertainty of shipping growth was not taken into account separately. However, it could be the case that shipping will suddenly increase considerably and thus the need for an aqueduct will grow.

- The costs of the option to expand (from Bridge Basic to Bridge Plus) are limited, therefore, the risk of choosing Basic instead of Plus is small. The cost estimations used are not complete, so it is expected that the actual difference between the Basic and Plus alternatives is larger in real life as there is not fully compensated for the inefficiency of a phased investment.

- A limitation of this study is that it was focused on the track between the A44 exits 2 and 3. In real life it will never be the case that just this part of the A44 will be widened.

- This study assumed that the decision regarding the A44 is an uncertainty, however, this uncertainty could actually be influenced.

Furthermore, not all possible scenarios or decisions were investigated in this study. It is recommended to gain more insights in the situation by conducting this method based on other assumptions, possibilities and scenarios.

**CONTRIBUTION OF THE SIMPLIFIED DECISION TREE TO DECISION-MAKING**

The CBA demonstrated that all different alternatives resulted in a negative NPV and marked the replacement Plus as favoured in an average scenario. However, the low scenario favoured the Basic Bridge and the high scenario the Plus Bridge. This Simplified Decision Tree gained more insights in the scenario possibilities. The Simplified Decision Tree concluded that it was valuable to defer the investment until more information on the uncertainties is known. Deferring the investment to 2039 could even lead to a positive NPV in the fourth scenario. A second conclusion is that investing in a more flexible option is preferred over the replacement of the fixed aqueduct as long as the uncertainty is high.

A major contribution of the Simplified Decision Tree is that it forces one to think about the uncertainties at an early phase. From then on, it could be envisaged to create alternatives that could adapt to these
uncertainties and identifying the possible decisions that could be made. From then on, the decision-maker can include flexibility and react in an adaptive way. For example, the decision-maker would find out that in a case the bridge and aqueduct both have the exact same NPV, the bridge would be favoured as this keeps the options to expand open and thus this flexibility is valued. Due to the fact that it was known beforehand that the Simplified Decision Tree would be performed, the alternatives were selected so that widening was possible.

5.3.4 DISCUSSION OF THE SIMPLIFIED DECISION TREE METHOD
After performing the Simplified Decision Tree method on the widening of the Kaagbrug A44 case, this method will be evaluated.

GENERAL LESSONS LEARNED FROM THIS CASE STUDY
The Decision Tree analysis generated insights in what alternative will be favoured per scenario and in the value of deferral or expansion. This case study showed that with relatively few information a lot of insights can be generated by analysing different scenarios and alternatives with the Simplified Decision Tree. It is a good example of real option thinking as a support structuring the situation and the possible decision moments in time.

Two general conclusions that can be derived from this case study for infrastructure decision-making projects are:
- In a situation when the investment costs of a more flexible alternative are not much higher and there is a chance that the uncertainty will occur, it is worth to invest in this alternative immediately (in this case study, when comparing the Plus & Basic alternative and there is a large chance that the A44 will be widened, investing in the more expensive Plus alternative is favoured).
- If the costs of the option to expand at a later stage are relatively low, it could be worth to wait with the investment, especially when the chance that this expansion will be needed is low (in this case it is worth to just replace the bridge by the Basic variant in the low scenario, as the cost of the expansion to Plus are relatively low and enough space is available).

If there are more uncertainties that are expected to influence each other, it is possible to investigate this with combined chances. For example, in this case the traffic growth is expected to influence the decision regarding the A44. The Simplified Decision Tree also helps to structure the uncertainty.

ADVANTAGES
The following advantages of the Simplified Decision Tree were discovered by applying this method:
- **Compelled to think about flexibility:** The Simplified Decision Tree forces the decision-maker to consider alternatives which include flexibility. As mentioned in the literature review, a criticism of the current NPV method was that the project’s outcome will be unaffected by future decisions (Brandão et al., 2005). Conducting the Simplified Decision Tree investigates the value this could have and can take those insights into account during the decision-making process.
- **Easy to perform:** In terms of applicability, after conducting the CBA it was relatively easy to perform the Simplified Decision Tree, as the options of flexibility were included in the
alternatives. If it is expected that flexibility will play a role, it is important to think about this while performing a CBA. The calculations are relatively simple but they generates a large awareness of possibilities.

- **Always valuable**: Even when no calculations are performed, the Simplified Decision Tree generates insights in the decision-making opportunities and uncertainty. Thus, this real option thinking leads to insights that can support adaptive decision-making.

- **Applicability**: The applicability of the method is large (for explanation, see below).

**Disadvantages**

The following disadvantages of the Simplified Decision Tree were discovered be applying this method:

- **Simplification**: The major disadvantage of the Simplified Decision Tree is the simplification required regarding the decision and scenario possibilities. This means that the uncertainty has to be captured in a limited amount of scenarios and for that reason the method is not very accurate in dealing with continuous uncertainties. This could be a disadvantage for some transportation infrastructure projects, however, in this case it was not a problem, as this forced the prioritisation of the most relevant decisions and uncertainties.

- **Additional time and effort**: Although this method is not very complicated, it takes time to think about the options and conduct the different analysis. For this reason the Simplified Decision Tree can be seen as an addition to the CBA. As the chances or decision have to be changed manually, it is time consuming to investigate all possibilities.

- **Results vulnerable for assumptions**: Another disadvantage is the vulnerability for assumptions, as the chances have to be determined manually. This can be difficult due to the extensive excel sheet. As the environment of the project and the uncertainty changes over time, the analysis is temporary usable. This disadvantage can be solved by updating the analysis at a later stage.

- **No official real option value**: A major point of discussion is that the Simplified Decision Tree does not provide a real option value. The method generates insights in structuring the decision-making and also leads to values flexibility could have, but it is not clear on the value that can be assigned as the real option value.

**Applicability of the Simplified Decision Tree**

The CPB study mentioned four criteria that are important in investigating the addition ROA could have on a project (van der Pol et al., 2015). These criteria are tested for this case:

- **Relation with the CBA**: This case study demonstrated that conducting the Simplified Decision Tree gives the impression of adding an extra step to conducting the CBA. Especially as it was known beforehand, the CBA was conducted in a way so that it was relatively easy to perform the Simplified Decision Tree. The relation with the CBA is high, which is an advantage of this method.

- **Transparency and accessibility**: It can be concluded that the Simplified Decision Tree is accessible for the broader audience and that the conclusions are transparent for the decision-maker. The calculations are relatively easy and therefore understandable for the decision-maker as the assumptions are also clear due to the graphical presentation of the tree.

- **Simplicity of the application**: There are no difficult programs or calculations required and it can just be performed with spreadsheet as the general CBA.
- **Realism**: Although the results seem plausible, it can be discussed how reliable and useful these are, as they are influenced by the assumptions made.

## 5.4 Binomial Option Pricing Method – Widening A44 Highway

The original intention of this case study was to compare the Binomial Option Pricing Method and the Simplified Decision Tree on the same investment decision. However, after conducting the Simplified Decision Tree, it became clear that the replacement of the Kaagbrug was not a suitable case on which to apply the Binomial Option Pricing Method. As the goal is to gain insights into the method and added value of this method, the approach of this case was changed a bit, to be able to apply the method.

### 5.4.1 Approach

The Binomial Option Pricing Model can be relevant to determine the most optimal investment strategy based on the dominant uncertainty and the value a deferral could have. The dominant uncertainty has to be captured in the volatility, a variable that presents the possible growth or decrease per time step of the uncertainty. In most transport investment cases, this includes the uncertainty of traffic growth. However, for the replacement of the Kaagbrug, there are two main uncertainties, where the decision regarding the A44 is the dominant uncertainty that determines the moment of investment. As this is not a continuous uncertainty that can be captured in the volatility, the decision regarding the replacement of the Kaagbrug cannot benefit from the Binomial Option Pricing Method.

For this reason, it was chosen to test this method on the widening of the A44 highway and not just the replacement of the Kaagbrug itself. While selecting this case, it was expected that the traffic growth would be the dominant uncertainty. This would have made the case more interesting to conduct the Binomial Option Pricing Method, as then the volatility could be based on both the shipping and road traffic growths. Moreover, it was expected that the additional costs of an expansion from a Basic to Plus variant in a later stage would be higher. As both expectations were not true, it is less relevant to determine the most cost-effective moment to replace the bridge, as this moment is always going to be later on. For this reason, the scope of this case changed to the widening of the A44 highway instead of the replacement of the Kaagbrug. Conducting ROA is expected to generate insights into the most optimal moment to broaden the highway to a 2x3 highway and the values of this deferral.

### 5.4.2 Conduction of the Method

After mentioning the alternatives, the new input variables had to determined. The main new variable is the volatility, which had to be determined first. The method was conducted based on the variables and the methodology described in section 3.2.2.

### Alternatives

<table>
<thead>
<tr>
<th>#</th>
<th>Alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>REFERENCE: Doing nothing: Maintain current highway</td>
</tr>
<tr>
<td>1</td>
<td>BASIC: Improve current highway to: 2 x 3.5 + road shoulder 3.15m</td>
</tr>
<tr>
<td>2</td>
<td>PLUS: Improve and widen current highway to: 3 x 3.5 + road shoulder 3.15</td>
</tr>
</tbody>
</table>
**Volatility**

The volatility presents the uncertainty of the future cash flows. As the benefits are directly related to the traffic intensity, the volatility can be determined based on the historic traffic growth. Based on the known historic data of the traffic intensity growth from the A44 between exits 2 and 3 the volatility was calculated (Rijkswaterstaat, 2015c).

**TABLE 29: HISTORIC TRAFFIC INTENSITY A44 BETWEEN EXITS 2-3 (RIJKSWATERSTAAT, 2015C)**

<table>
<thead>
<tr>
<th>Year</th>
<th>Traffic intensity</th>
<th>Growth (%)</th>
<th>Year</th>
<th>Traffic intensity</th>
<th>Growth (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986</td>
<td>35.582</td>
<td></td>
<td>2000</td>
<td>57.998</td>
<td>2%</td>
</tr>
<tr>
<td>1987</td>
<td>37.315</td>
<td>5%</td>
<td>2001</td>
<td>58.653</td>
<td>1%</td>
</tr>
<tr>
<td>1988</td>
<td>39.974</td>
<td>7%</td>
<td>2002</td>
<td>59.093</td>
<td>1%</td>
</tr>
<tr>
<td>1989</td>
<td>46.515</td>
<td>16%</td>
<td>2003</td>
<td>60.528</td>
<td>2%</td>
</tr>
<tr>
<td>1990</td>
<td>45.000</td>
<td>-3%</td>
<td>2004</td>
<td>62.846</td>
<td>4%</td>
</tr>
<tr>
<td>1991</td>
<td>45.356</td>
<td>1%</td>
<td>2005</td>
<td>62.128</td>
<td>-1%</td>
</tr>
<tr>
<td>1992</td>
<td>47.663</td>
<td>5%</td>
<td>2006</td>
<td>62.398</td>
<td>0%</td>
</tr>
<tr>
<td>1993</td>
<td>47.484</td>
<td>0%</td>
<td>2007</td>
<td>67.729</td>
<td>9%</td>
</tr>
<tr>
<td>1994</td>
<td>49.988</td>
<td>5%</td>
<td>2008</td>
<td>65.914</td>
<td>-3%</td>
</tr>
<tr>
<td>1995</td>
<td>51.221</td>
<td>2%</td>
<td>2009</td>
<td>67.533</td>
<td>2%</td>
</tr>
<tr>
<td>1996</td>
<td>51.621</td>
<td>1%</td>
<td>2010</td>
<td>73.648</td>
<td>9%</td>
</tr>
<tr>
<td>1997</td>
<td>55.441</td>
<td>7%</td>
<td>2011</td>
<td>72.893</td>
<td>-1%</td>
</tr>
<tr>
<td>1998</td>
<td>55.724</td>
<td>1%</td>
<td>2012</td>
<td>67.900</td>
<td>-7%</td>
</tr>
<tr>
<td>1999</td>
<td>56.777</td>
<td>2%</td>
<td>2013</td>
<td>66.000</td>
<td>-3%</td>
</tr>
</tbody>
</table>

**TABLE 30: DETERMINE THE VOLATILITY BASED ON HISTORIC DATA A44 (AUTHOR’S ANALYSIS)**

- Average traffic intensity: 56.104
- Average growth: 2%
- Standard deviation: 10.438
- % of average = volatility: 18.65%

**INPUT VARIABLES**

Based on the volatility and the assumptions of the CBA, the following input variables were determined.

**TABLE 31: REAL OPTION INPUT VALUES A44 – BOPM (AUTHOR’S ANALYSIS)**

<table>
<thead>
<tr>
<th>Name</th>
<th>Symbol</th>
<th>Value</th>
<th>Formula, explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volatility</td>
<td>$\sigma$</td>
<td>18.65%</td>
<td>To determine with historic data</td>
</tr>
<tr>
<td>Risk-free rate</td>
<td>$r_f$</td>
<td>2.5%</td>
<td>Given by CBA guidelines</td>
</tr>
<tr>
<td>Dividend share</td>
<td>$\delta$</td>
<td>0.035</td>
<td>Average annual dividend share, derived from CBA</td>
</tr>
<tr>
<td>Time step</td>
<td>$t$</td>
<td>1</td>
<td>Number of steps per period (1 step per year)</td>
</tr>
<tr>
<td>Up factor</td>
<td>$u$</td>
<td>1.20</td>
<td>$(\text{EXP}(\text{volatility}*1/t^{0.5}))$</td>
</tr>
<tr>
<td>Down factor</td>
<td>$d$</td>
<td>0.830</td>
<td>$(1/(\text{EXP}(\text{volatility}*1/t^{0.5})))$</td>
</tr>
<tr>
<td>Upward probability</td>
<td>$p$</td>
<td>0.520</td>
<td>$((1+r_f)-d)/(u-d)$</td>
</tr>
<tr>
<td>Downward probability</td>
<td>$(1-p)$</td>
<td>0.479</td>
<td>1-p</td>
</tr>
</tbody>
</table>
As the method focuses on the most optimal moment to expand the highway with a third lane, the variables presented in Table 32 are used. These numbers are derived from the CBA and present the costs and benefits for the track between exits 2 and 3 with a length of approximately two km.

### TABLE 32: COSTS AND BENEFITS A44 – BOPM (IN €, BASED ON TIMEPERIOD 2015 - 2100) (AUTHOR’S ANALYSIS)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>REFERENCE</td>
<td>-1,057,550</td>
<td>-47,150,722</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>BASIC</td>
<td>-990,248</td>
<td>67,302</td>
<td>-45,684,043</td>
<td>1,466,678</td>
<td>38,800,000</td>
<td>-37,333,322</td>
</tr>
<tr>
<td>2</td>
<td>PLUS</td>
<td>-111,708</td>
<td>945,842</td>
<td>-7,257,637</td>
<td>39,893,084</td>
<td>70,600,000</td>
<td>-30,706,916</td>
</tr>
</tbody>
</table>

Based on the CBA, it is never recommended to invest in a BASIC or PLUS alternative as both NPVs are negative.

**The Calculation**

In order to perform ROA, the following trees were modelled in a spread sheet based on the input variables for each alternative:

- Cash flow trees that show the cash-flow per node, with 2015 as base year.
- ROA trees based on the formula: $ROA_t = \max \left( \frac{ROA_u p + ROA_d (1-p)}{1+ rf} + CF_0, V_t - I \right)$.
- Comparison trees that show per node: ‘Expand’ or ‘not expand’.

#### 5.4.3 Results

Table 33 presents the ROA values of the Basic and Plus alternatives towards the reference alternative.

### TABLE 33: ROA VALUE A44 – BOPM (IN €, BASED ON TIMEPERIOD 2015 - 2100) (AUTHOR’S ANALYSIS)

<table>
<thead>
<tr>
<th>#</th>
<th>Alternative</th>
<th>PV Benefits ROA</th>
<th>PV Investment</th>
<th>Real Option Value</th>
<th>Net Present Value (CBA)</th>
<th>Difference (CBA – ROA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BASIC</td>
<td>2,960,616</td>
<td>-38,800,000</td>
<td>-35,839,384</td>
<td>-37,333,322</td>
<td>1,493,938</td>
</tr>
<tr>
<td>2</td>
<td>PLUS</td>
<td>41,607,551</td>
<td>-70,600,000</td>
<td>-28,992,449</td>
<td>-30,706,916</td>
<td>1,714,466</td>
</tr>
</tbody>
</table>

This study demonstrates the additional value of including real options and shows that the alternatives become less negative. Figure 18 presents the binomial choice tree over time. The figures show that it is not recommended to invest in Plus before 2018. One could consider to expand the highway to Plus from 2018 onwards, although this is only recommended in a very high scenario. Looking at the complete bandwidth in 2100, for the upper 36% an expansion to Plus can be considered.

**FIGURE 18: BINOMIAL CHOICE TREE OVER TIME - A44**
5.4.4 CONCLUSION AND DISCUSSION OF THIS CASE

CONCLUSION
Based on the results it can be concluded that:
- Uncertainty has a value and leads to less negative alternatives. This value is respectively €1.5 million for the Basic and €1.7 million for the Plus Alternative.
- Expanding to Plus is not recommended, but could be considered after 2018 if a high traffic growth is observed.

DISCUSSION
- In the Binomial Model, the uncertainty is assumed constantly. This is based on the average growth of the historical data. This means that it is assumed that the development of the traffic growth will be similar to the average of the last decades. However, the traffic growth also shows a decrease in the previous three years. For this reason, it should be questioned how reliable the volatility is. Table 34 and Figure 19 present a sensitivity analysis on the volatility, this demonstrates that the larger the volatility the more valuable the alternative.

TABLE 34: PV ROA ALTERNATIVES BY ADJUSTING THE VOLATILITY IN € (AUTHOR’S ANALYSIS)

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Volatility in %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5%</td>
</tr>
<tr>
<td>PLUS</td>
<td>-51,557,883</td>
</tr>
</tbody>
</table>

FIGURE 19: SENSITIVITY TO CHANGES IN VOLATILITY

- Moreover, in real life there are many other factors influencing the benefits, not only the traffic growth.
- Another point of discussion is that the option costs of the expansion are assumed as constant, although they might change over the years. This can easily be adjusted in the spreadsheet, but was not included in this specific analysis.
CONTRIBUTION OF THE METHOD TO DECISION-MAKING
The main purpose of this application was to investigate the addition of the method to the decision information. The following valuable additions are acknowledged:

- The Binomial Option Pricing Method calculates a more complete NPV per alternative, as it also includes the value brought by uncertainty and flexibility.
- The option value of a deferral of the investment. In this case it could be considered to expand to Plus from 2018, but only in a really high scenario.
- Insights in the behaviour under uncertainty. The input variables of the model can easily be adapted, for example, the probabilities or volatility can be adjusted to gain insights in the behaviour of the uncertainty.

5.4.5 DISCUSSION OF THE BINOMIAL OPTION PRICING METHOD
This section will evaluate the Binomial Option Pricing Method.

ADVANTAGES
The following advantages of the Binomial Model were discovered by applying this method:

- For every node, the value can precisely be determined.
- It is easy to adjust the input variables and analyse the results. Although determining valid input variables might be difficult, sensitivity analysis can be conducted to test this.

DISADVANTAGES
The following disadvantages of the Binomial Model were discovered by applying this method:

- A major disadvantage of the method is that it only functions with projects that are influenced by one dominant uncertainty that can be captured in the volatility.
- The model based on the volatility assumed a continuous growth, however, in real life it could be that other events or measures suddenly influence the traffic growth, for example the construction of another highway.
- Determining the volatility is difficult. In this application, it was based on historical data, however, this is not necessarily a forecast of the future.
- The transparency of the method is low due to the extensive excel sheet. It is hard for the decision-maker to understand the backgrounds of the calculations and even harder to verify the results of the applications.

APPLICABILITY
Although the applicability of the method at the first glance seemed low, after conducting the method it was not that inadequate. It takes some effort to understand how the method is composed, but once this barrier is passed, it is easy to conduct the method and repeat it for other alternatives or even projects.

A disadvantage of the applicability is that every node in a tree requires an individual cell and several trees are needed. This leads to extensive spreadsheets at the expense of transparency.

The main point of the applicability is that there are probably not many projects for which applying the method is appropriate. However, if this is the case, this method can be useful.
5.5 **Comparison of the Two Methods – Case 2**

In this case study both the Simplified Decision Tree and the Binomial Option Pricing method were applied to be able to compare the methods. However, it was not possible to conduct both methods on exactly the same investment decision and for this reason it is not possible to make a fair comparison. As the methods were compared already in the previous case study in section 4.4, this section will mention the additions this second case brings.

**Main Findings**

Despite not being able to compare the results quantitatively as the values present a different decision, the approaches are related and thus some points can be made. The Simplified Decision Tree showed that it is in general preferred to defer the replacement as long as possible, because during this deferral more insights in the uncertainties can be obtained and thus decrease the risk and bandwidth of the results. The Binomial Option Pricing Method showed that only with high traffic growth the expansion to Plus can be beneficial, thus a deferral is also preferred. When both cases are combined, it can be recommended to defer all investments and thus try to maintain the current highway including the Kaagbrug as long as possible in current state.

**Comparison Methods**

A comparison was made in the first case study. However, in this case study both methods were applied during this research, thus the applicability can be reflected upon. The major difference is that the Simplified Decision Tree is easier to understand and can be conducted directly. The Binomial Option Pricing Method needs a bit more time to be understood. However, when both methods are applied, it much easier to make adjustments in the Binomial model than in the Simplified Decision Tree. This is because the Simplified Decision Tree needs more manual adjustments and in the Binomial Option Pricing Method the input variables can easily be changed. In terms of transparency the Simplified Decision Tree seems more transparent due to the graphic presentation, however, both methods use extensive sheets and are prone to errors. An overview of the comparison of the two methods can be found in Table 35 in the following section.

**Added Value to Decision-Making**

If looking at the added value to decision-making, it is difficult to compare the findings of both methods precisely as they lead to another addition. The Simplified Decision Tree can support projects to gain insights in the consequences of an uncertain event if there is no optimal alternative based on the CBA, while the Binomial Option Pricing method is especially relevant to investigate the effect of a continuous uncertainty.
5.6 CONCLUSION

The main question of this section was:

*What are the effects on project evaluation of taking into account real options?*

In this case, the CBA did not lead to a no-regret alternative and no clear choice between the alternatives could be made, as this depended on the uncertainty. With help of ROA the decision information was enriched. An important result of this case is that deferring the investment has a value, as more information on the uncertainty becomes clear.

When answering the questions: ‘*What is the difference between evaluation with and without real options?*’ the Simplified Decision Tree leads to insights in what to do under uncertain circumstances and the possible regret of losses. In this case regarding the replacement of the Kaagbrug, it is preferred to defer the replacement as long as possible, because during this deferral more insights in the uncertainties can be generated which decrease the risk and bandwidth of the results. If the current bridge has to be replaced before 2028, it is preferred to go for the more flexible Bridge alternative because an aqueduct eliminates the option to expand and does not involve high benefits.

As the traffic growth uncertainty did not dominate the decision regarding the replacement of the Kaagbrug, the Binomial Option Pricing Method was applied on the question when to widen to A44 Highway. This resulted in the value the deferred investment could have and noted that based on the traffic growth a widening should not be considered before 2018 based on the continuous traffic growth. Only with very high traffic growth widening to Plus could be beneficial.

The second sub-question into the different real option approaches will be answered by the help of Table 35 on the next page.

To conclude, ROA adds the following advantages to current decision-making:

- **Optimised decision-making:** By including the possible value of flexibility and uncertainty, the evaluation is closer to reality.
- **Additional strategic insights:** New and possibly better flexible alternatives become feasible.
- **Supports adaptive decision-making:** Performing ROA could lead to decisions that are better adapted to the future and creates risk-awareness.
OVERVIEW OF COMPARISON METHODS – ANSWERING SUB-QUESTION 3B

In this research the Simplified Decision Tree and the Binomial Option Pricing Method were evaluated to answer the sub-question: How do the evaluation outcomes vary between the different real option approaches? Based on both case studies the following table was constructed:

<table>
<thead>
<tr>
<th>Method</th>
<th>Simplified Decision Tree</th>
<th>Binomial Option Pricing Method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>By using a graphical tree, decision-moments and uncertainties are identified and structured. Per branch the NPV is calculated to get insights in the consequences of decisions under a certain scenario.</td>
<td>A continuous Decision Tree that determines the value of an alternative based at each moment in time while taking into account the volatility, where the option value is derived from the tree.</td>
</tr>
</tbody>
</table>
| Advantages              | - Supports structuring the uncertainty and possibilities of flexibility and thus real option thinking.  
                         | - Generates insights in the regret, choosing the wrong alternative, by calculating the regret value in a relatively simple manner.  
                         | - Method is transparent, intelligible and easily conductible after performing a CBA. | - Generate insights in optimal investment strategy and the value of flexibility.  
                         | - Accurate: determines the value for each moment in time.  
                         | - Input variables can easily be adjusted to calculate the value of a different decision situation. |
| Disadvantages           | - Only able to include a limited amount of uncertainties or flexibility into one tree.  
                         | Continuous uncertainties have to be captured in yes or no scenarios.  
                         | - The results strongly depend on the simplifications made and probabilities chosen during the analysis.  
                         | - The tree has to be constructed manually, for each new decision or project this requires a new effort. | - Includes uncertainty and yearly benefits in a continuous way. If this does not match with the real life situation, manually adjustment is required.  
                         |                         | - Calculations are less transparent due to extensive spreadsheet.  
                         |                         | - Determining a correct volatility is a challenge while this variable dominates the results of the tree. |
| Results                 | - Structure of the decisions and uncertainty  
                         | - Value per branch  
                         | - Regret value per alternative under certain scenario | - Optimal investment strategy  
                         |                         | - Real option value, value of flexibility |

In general, it can be concluded that the Simplified Decision Tree can be relevant for structuring the decision and uncertain situation of every project, as the tree can manually be adapted to each project specific. This is ideal for real-option thinking and decisions influenced by a yes or no uncertainty, although calculating the NPV for each branch takes quite some time and is less reliable, as the results highly depend on the assumptions on the scenario probability. The Binomial Option Pricing Method is helpful to calculate the possible value brought by flexibility and uncertainties and can determine the optimal investment moment in time. However, this method is especially relevant for projects that are influenced by a continuous dominant uncertainty that can be captured in the volatility.
6  REAL OPTION ANALYSIS IN THE REAL DECISION-MAKING CONTEXT

In the research so far, the effects of including ROA were examined. After a literature study, selected case studies applying ROA were performed and analysed and two new case studies were performed. These different studies presented the additional information that results from conducting ROA. However, it is not surprising that conducting ROA will deliver some new insights. To investigate the value and usefulness of this additional information, interviews with the people responsible for decision information were held. The way how ROA fits in the current decision-making process was also investigated.

This section will answer the following sub-question: Does the real option approach fit in the decision-making process and what do the outcomes and differences between evaluation with and without real options mean for the decision-maker?

The introduction in 6.1 describes the plan of the interviews. In the second section the results from the interviews are discussed and presented per topic. Finally, the conclusions can be found in section 6.3.

6.1  INTRODUCTION

The goal of the interviews was to gain insights in the possible value broach of conducting ROA and see how this additional information fits in the overall decision-making process. In the Netherlands Rijkswaterstaat is the executive organisation of the Ministry of Infrastructure and Environment and responsible to deliver decision information. In consultation with Rijkswaterstaat five persons which are responsible daily for decision information were interviewed. This was done asking the following questions, these answers can be found in the sections mentioned below:

-  6.2.1 Is there a contextual need to include the value of flexibility in the decision-making process?
-  6.2.2 Does ROA provide relevant decision information?
-  6.2.3 For what type of infrastructure projects and situations can ROA be valuable?
-  6.2.4 How are the two methods evaluated?
-  6.2.5 Does ROA fit in the current decision-making process? What criticism is given?

The complete interview can be found in appendix D. This section includes the main findings based on the interviews. In order to preserve the interviewees’ anonymity, there is no reference to specific quotes or persons in this section. However, it is important to note that the people interviewed are all responsible for infrastructure decision-making information at the Rijkswaterstaat Ministry of Infrastructure and Environment at a high-level. They are not in charge for the decision-making itself, but advise the Ministry by collecting useful decision information. Furthermore, it is has to be noted that the results can be influenced by the fact that all interviewees are operating in the same organisation.

6.2  RESULTS FROM THE INTERVIEWS

This section provides a general conclusion per heading based on all the interviews.

6.2.1  CONTEXTUAL SITUATION

To investigate if there is a contextual need to include the value of flexibility into the decision-making process, some more information about the contextual situation is provided in this section.
THE DECISION-MAKING PROCESS STRIVES TO EFFECTIVENESS AND LESS WORKLOAD
The current decision-making process within the Netherlands consist of four stages, where after each stage a decision is made, as presented in the Figure 4 and Figure 5 in section 2.1.2. At each stage, the relevant decision information has to be gathered to support proper decision-making to continue to the next stage. In previous years, this decision-making process has changed; to limit the amount of possibilities and thus accessory research, a preferred alternative is chosen first. Based on this preferred alternative various variants are researched extensively. In the interviews it was mentioned that this process is effective as it diminishes the workload and the information required and it also preserves transparency. Therefore, an important first point to make is that it could be relevant to include the value of flexibility, however this should not result in an overload of information.

CHANGING DECISION-MAKING CONTEXT
The current infrastructure decision-making context is changing. The transportation infrastructure in the Netherlands has reached a point where the focus is no longer on creating new infrastructure, but on maintaining the outdated infrastructure with renovations or replacements. Furthermore, the awareness of being adaptive by taking into account future uncertainties is increasing. Therefore, ROA, a method that includes the possible value brought by future uncertainties and flexibility into the decision-making process could be relevant. Another contextual change is that the golden years are over and the budget available to preserve our transportation infrastructure network is limited. For this reason, we have to be smarter with the funds available, including options to be flexible could be a way to do this. To conclude, as the context of transportation infrastructure decision-making changes, it is important that our methodology adapts to this changing situation.

THERE ARE OTHER WAYS TO INCLUDE FLEXIBILITY
Today, to take into account uncertainty and flexibility, the future-certainty ('toekomstvastheid') for each alternative is evaluated. This is usually done in a qualitative way, ROA could add the possibility to include the value of flexibility in a quantitative way as well. In the decision-making process, quantitative decision-making information can be useful to conclude a discussion, as it can objectively underpin certain decisions. Currently, the CBA is used to give an overview of the costs and benefits per alternative, but there are different variants with different purposes. For example, Life-Cycle Costing to investigate the optimal investment moment based on the uncertainties in the future.

COSTS AND BENEFITS ARE JUST ONE ELEMENT OF ALL THE DECISION INFORMATION
Moreover, it is important that the costs and benefits are just one element of all the decision information gathered in the decision-making process. The infrastructure decision-making process is a complex and large process that includes all facets that could be affected by or affect a certain decision. There are many other non-monetary aspects taken into account during decision-making, for example, environmental aspects and the interests of stakeholders. Especially in current times, where an integral approach is becoming increasingly important, environmental arguments are usually at least as important as information about the costs. On top of that, although the basics of the decision-making consists of analysing and researching, there is also a large impact of the political environment. Ultimately, it is the
politicians who decide, however, it is important to feed politicians with the right decision information in an objective way.

In conclusion, the current contextual situation is changing and being adaptive by taking into account possible impacts of future uncertainties and flexibility is important. For that reason, it can be relevant to include the value of flexibility in the decision-making process. Currently, the notion of flexibility in infrastructure project is being considered, but there is no uniform method to include the value of flexibility to do this. It is questioned if there is the need for a new method to do this or if this can be easily integrated in the current methods. The current decision-making process is already complex and extensive and includes many other effects than quantifying the costs and benefits. ROA could be a small addition to all the existing and current decision information required. It is important to understand the situations where ROA could bring added value.

6.2.2 Reflection on the additional decision information

Although it is not sure whether there is always a contextual need for a new method that values flexibility, it is important to investigate the value of additional decision information resulting from ROA. The interviewees were asked to reflect on the relevance and usefulness of the results and additional decision information.

To start, the interviewees were asked to give a definition of useful decision information, the following characteristics were mentioned by most of them and define ‘good’ decision information:
- **Added insights**: The decision information simplified and supports the decision-making and leads to new insights compared to the known decision information.
- **Transparency**: The decision information is transparent and understandable by everyone.
- **Relevance**: The decision information is filtered towards the most relevant information. (Prevents an overload of information).
- **Completeness**: The decision information is complete and does not ignore relevant information.

Next, it was investigated whether ROA results in useful decision information. Based on all interviews, it can be concluded that the addition of ROA strongly depends on the type of infrastructure project. As the aim is to do away with the political game and make objective considerations based on clear decision information, ROA could be a step in the right direction. Both real option thinking and real options as a calculation method were considered useful, but the value varies per project. All interviewees responded that real option thinking can be relevant in all situation and is something that is also done already. However, there is currently no uniform method to do this, so ROA can be valuable as a first step to structure and standardise the inclusion of flexibility. Although qualitatively including the value of flexibility is always relevant, the added value of quantifying flexibility depends on the issue. Especially with the growing awareness of an integral approach, qualitative arguments are usually at least as important as quantitative decision information. But within an evaluation framework, quantified information is relevant to simplify decision-making, as numbers are easy to compare and not debatable. Likewise, the real option value can be useful if there is additional substantiation to underpin a certain decision required.
One of the results that can be derived from conducting ROA is gaining insights into the ideal investment or decision-making moment based on the growth of the uncertainty. However, three interviewees mentioned that this is usually irrelevant information, as in practice most projects respond to problems where the most ideal investment moment will follow as soon as possible. For that reason, ROA is only relevant for a small fraction of all infrastructure projects, where there is no clarity about the preferred alternative.

When reflecting on the added value of the case studies performed in this research, all interviewees saw the usefulness of applying ROA on the replacement of the Kaagbrug. Especially, structuring the situation with the Simplified Decision Tree was found useful. Some also said that the same insights could have been reached with logical thinking, by applying other methods or by simply changing the start value of the CBA. For the case study of the Kaagbrug, structuring the uncertainty and the decision possibilities was seen as one of the main values of applying ROA. The ROA results of widening the A27 highway case were not been found to be that surprising. Based on the traffic information and logical thinking the same conclusion could have been derived. Despite this, it was found valuable that the method confirmed this conclusion.

To conclude, in general the interviewees reflected positively to ROA, especially as there is currently no clear method to deal with the value of flexibility. ROA could help to standardise and structure this in a uniform method. Moreover, ROA can be useful to gain insights in the (financial) consequences of certain non-flexible alternatives. However, although ROA seems elegant in theory in practice it is usually complex as every situation is different.

6.2.3 CONDITIONS FOR APPLYING ROA

Although all interviewees generally reacted positively to ROA, they noted that it has to be very clear when and in under which circumstances it is necessary to conduct this additional analysis. From the literature infrastructure projects that are characterised by uncertainty, managerial flexibility, irreversibility, asymmetric pay-offs, limited importance of non-monetary costs and no no-regret alternative could benefit from ROA (Bräutigam et al., 2003; van der Pol et al., 2015). Despite the interviewees agreeing with these criteria, it was also mentioned that the first four criteria are usually present in every infrastructure project. Next, the limited importance of non-monetary costs is barely met in practice. For that reason, it is important to state how essential the characteristics are, in order to clarify in what situations ROA could be a valuable addition.

The interviewees could not give a precise answer on the criteria a project should meet in order to benefit from ROA. Furthermore, they were not able to mention many examples of real life projects that would have needed ROA. However, the following criteria were mentioned during the interviews to define the relevant situations to apply ROA. Note that these criteria are not all on the same level of detail and are usually more general instead of project specific:

- **Transparent decision situation:** As ROA is a model that needs quantitative input information, it is important that the situation is transparent. If a project is too complex as there are, for example, many network effects, it is not possible to fit this situation into the ROA calculation.
- **Need for a result:** The results of ROA should provide new information that provides answers to crucial questions. Thus, the information should be relevant and provide additional data when needed, which could not be derived from the current methods.

- **Difference with not conducting the method:** It is important to investigate what would happen if the method was not conducted. What is the additional decision information ROA adds and could this also be derived from another easier method.

- **Information required to deliver reliable decision information:** The additional decision information should be reliable and deliver clear decision information. In order to do this the input information must also be reliable.

- **Project with large investment costs:** The larger a project, the more research can be justified. Thus large projects with large investment costs should allow to research additional elements, in this case for example, the value brought by flexibility and uncertainty.

- **Major uncertainties or value of flexibility:** The uncertainties or value of flexibility have to be potent. Although this criterion is also captured in the characteristics mentioned in the literature, this is a crucial criterion. ROA can be valuable in situations where the flexibility and uncertainty are so large, that it will be distinctive in the outcomes.

It would be the best to create a checklist with quantitative criteria and requirements that a project needs to meet to benefit from applying ROA.

**When in the decision-making process to integrate ROA**

Although the ‘spelregels of MIRT project’ state what decision information has to be gathered in each phase of the decision-making process, there is no standard procedure to determine what methods should be used to gather this decision-making information (Ministerie van Verkeer en Waterstaat & Ministerie van VROM, 2012). The interviewees mentioned that currently it is decided during project meetings what methods which will be used to gather the information. As there are no guidelines to determine what methods to use, this is project specific and done on a case by case basis. For each method, a trade-off between the effort of the application and the added value has to be made. If a method can easily be added or performed in parallel to another research, it is usually considered. It is always important to keep the deadlines in mind and try to gather appropriate decision information without delaying the decision-making. In general, the interviewees said that if it is decided to apply ROA, it is the best to start simple. First, perform the Simplified Decision Tree and then research whether the Binomial Model could add something to those results.

According to the interviewees, ROA is found to be most relevant in the exploration phase of the decision-making process. In this case, the extent to which the value of flexibility could play a role should be investigated. It can be argued that including flexibility too early in the decision-making process will result in an overload of research and including flexibility too late in the process will lead to adjusting the research conducted on non-flexible alternatives. At the beginning of a project it should be investigated whether flexibility could play a large role, and if so the ROA balanced against the added value should also be evaluated. This contradicts the statement in the CPB report, which said that ROA can be valuable in every phase of the decision-making process. To properly take flexibility into account in an adaptive approach, fundamental changes in the decision-making process are implied. This can clarify the
contradiction with the opinion of the interviewees, as their thinking is based on the current decision-making process.

6.2.4 EVALUATION OF THE TWO METHODS

One of the goals of the interviews was to gain insights in the preferred method; the Binomial Option Pricing Method or the Simplified Decision Tree. In general, it has to be noted that the people interviewed were not directly responsible for the economic evaluation of project alternatives. For that reason, they were not able to reflect on the two different methods in detail. However, as they are responsible on a daily basis for delivering relevant decision information, they definitely could reflect on the value of the results of the different methods.

All interviewees had a preference for the Simplified Decision Tree. This is mainly as transparency is accepted as the main criterion for decision information and the Simplified Decision Tree seems more transparent. It is important that the decision-maker understands the decision information himself and is also able to explain the interpretation to the people who have to live with the consequences of a certain decision. According the interviewees the strength of the Simplified Decision Tree is that it shows what is behind the final value, while the Binominal Method combines everything in one value. Intelligibility and transparency are mentioned as important criteria for using a certain method.

It was also mentioned by one of the interviewees that the two methods seem similar as they are both based on a tree structure with different decision or uncertainty moments in the future. According to all interviewees, the applicability of the methods depends on the type of problem and uncertainties available. Thus, in one situation the Simplified Decision Tree will be favoured and in another situation the Binomial Option Pricing Model is preferred. It is important to know for what type of project what method is the most appropriate. Two of the interviewees said that they would first conduct the Simplified Decision Tree, and in case it would be worth to gain additional insights, for example the exact optimal moment of investment, the Binomial Option Pricing Method could then also be applied. After all, the determining factor is always the consideration of whether the additional decision information outweighs the extra burden of applying a method.

In general, the Binomial Option Pricing Model is acknowledged by the interviewees as relevant in situations where the traffic growth is substantial and thus, it is applicable mainly for projects that include one dominant uncertainty. However, for projects that mainly depend on the traffic growth, there are currently appropriate calculations available based on the traffic growth expectations.

To conclude, both methods are seen as relevant by the interviewees, but it is especially important to know for what type of project what method is favoured. Transparency is an important factor which favours the Simplified Decision Tree. Furthermore, constructing a Decision Tree can be helpful to unravel the decision situation. A disadvantage of both methods is that they are just limited to possible uncertainties that can be included. Again, it is always a trade-off between the effort and the additional decision information, and this will depend on each project.
6.2.5 Criticism on ROA

Although ROA could theoretically have additional value, there is criticism given during the interviews that could hinder the practical application of ROA. This criticism is classified in three categories in this research.

1. Complexity and transparency of conducting ROA

One of the main criticisms regarding ROA is the complexity to conduct this method and the transparency of the background of the results. ROA is a new method that includes calculations. Additional calculations always imply time, money and manpower. A compromise between the effort and the added value has to be made. Moreover, a possible pitfall for ROA is that expressing flexibility in one real option value might lead to nobody really knowing what is included in the calculation. With quantifying it is important to make sure the decision-maker knows what is behind the value. Furthermore, it was mentioned that including flexibility by logical thinking could be enough in most situations.

2. Suitability in the current decision-making process

Some criticism was given in the way ROA fits in the current decision-making process. Firstly, flexibility might interfere with uncontrollability. In the current decision-making process all decision information is nicely funnelled into a preferred alternative and variants on which the Minister can decide. Keeping options open could cause the risk of widespread possibilities that lead to an increase in the research workload. If there are too many flexible alternatives involved, questions as to who will decide what at which moment arise. It is therefore important to find a balance between acting rigid and being flexible. Being too rigid excludes flexibility, but being too flexible will lose the focus.

Secondly, decisions will usually be made on other criteria than quantitative information. Most large infrastructure decisions are that large and complex that there are always non-monetary factors playing a role and monetising these is complex. ROA can better deal with situations with one dominant uncertainty, however most projects include more than one dominant uncertainty. Many projects consist of a network, whereby the network’s effects are decisive and not the dominant uncertainty. To base decisions on the traffic growth fits with the traditional decision-making, where only the traffic growth was substantial. Current infrastructure decision-making pays increasingly more attention towards other factors.

3. Limited added value of the results

Some other criticism was given on the limited effect the results could have for the society. Firstly, it can be questioned whether the additional decision information is significant for the decision-making, as future uncertainties stay uncertainties and to what extend is it possible to make a decision based on an uncertainty. Secondly, a common result of ROA is a deferral. It can be questioned if a Minister is willing to postpone the implementation of a project to moment in time when he is no longer in government. The delivery of a project is often important for a Minister. However, ROA could be a manner to gain additional decision information, so this could also be desired by the Minister. Thirdly, it can be questioned if the value of flexibility is something crucial to invest in. After all, there is just one total budget, so are decision-maker willing to invest in the expected future value of flexibility. Lastly, it is
important to realise that flexibility is not always better, after all, you make a decision based on an uncertain future, so this is not always true.

**SUMMING UP THE PRACTICAL APPLICATION BARRIERS FOR ROA**

As discussed in the literature review in section 2.2.5, there are some applications barriers for applying ROA. To test if these barriers truly exist in the Dutch Infrastructure Project decision-making, questions on this topic were raised during these interviews. The following barriers were mentioned:

- **Additional time and effort:** The main application barrier for conducting ROA is the additional time it will cost to apply this method. After all, there is only a certain time and manpower available to deliver the decision information.

- **Prompt decision-making:** The current decision-making process is already time-consuming. Conducting an additional method could imply additional time and the current aim is to avoid delaying the decision-making process.

- **Rigid decision-making process:** Gathering the required decision information is already cumbersome. This can be a reason why people are not open for trying and using new or additional analysis as ROA, especially when the current method is effective and methods exist to research the impact of future uncertainties.

- **Political will:** Although you can continue analysing to be able to deliver the best decision information, in the end, it is the decision-makers that make the final decision. Analysis is a tool to streamline a discussion, but the decision is usually based on political reasons. Although all the decision information required is gathered, the decision-maker is in charge of the way this information is used and will select the information that underpins his preferred alternative.

- **Political pressure to deliver:** Usually a result of ROA is a deferral. It can be questioned if a Minister is willing to postpone the implementation of a project to moment in time when he is no longer in government. The delivery of a project is often important for a Minister. When finally an agreement about the most optimal alternative has been reached, one likes to get the project started as quickly as possible.

- **Complexity:** ROA is seen as a complex method that requires additional input information. To value flexibility, on needs to be known how to do this and what factors to take into account. Every calculation and model is based on assumptions.

- **Novelty and ignorance:** The novelty of ROA method can be an application barrier. However, this was remarked as a barrier relatively easy to overcome. It is important to make people curious about the results of conducting a method, and then the applications will follow.

- **The commissioning company decides:** Often the person in charge for delivering the decision-making information is not the one who decides what decision information is used. Essentially, the civil servants just deliver the decision information they are asked for.

**LINK WITH THE APPLICATION BARRIERS MENTIONED IN LITERATURE**

In literature the following application barriers have been mentioned: *fixed alternatives, unknown value, complex application, additional costs, lack of top management support, discounted cash-flow is a proven method, prompt decision-making, novelty of the method* (See section 2.2.5). This is linked to the barriers mentioned during in this interviews, as it can be noted that most of these barriers were also mentioned
in the interviews. What is remarkable is that the interviewees did not see novelty as a strong barrier, they seemed open-minded to try a new method. This concurs with the changing context which is demanding a necessary change to the current decision-making process. Furthermore, they also mention that times have changed, organisations and decision-making are a bit less hierarchical. It would be possible to increase the awareness of this method from the bottom of the organisation.

6.3 CONCLUSION & DISCUSSION
This section provide the conclusion and subsequently discusses the impact of the approach on the results.

CONCLUSION
This section strived to answer the following question:

Does the real option approach fit in the decision-making process and what do the outcomes and differences between evaluation with and without real options mean for the decision-maker?

Based on the interviews it can be concluded that ROA can be a valuable addition to the current decision-making process in certain situations and for certain projects. It became clear through the interviews that the real option value is not considered to provide crucial highly needed information, however, it could be something to enrich the decision-making information. Especially real option thinking is considered valuable.

If flexibility plays an important role in transportation infrastructure project decision-making, it certainly is good to take this value of flexibility into account. ROA can be especially useful to gain insights in the consequences of certain decisions and possibilities to add flexibility. Quantifying the consequences creates awareness on the fact that there are more possibilities instead of the cheapest alternative. This quantifying has to happen at the right moments in the decision-making process in order to be valuable.

However, according the interviewees it is important to not see ROA as an obligatory additional instrument, but as an additional tool to optimise the decision information. If it is decided to apply ROA, then it is the best not to start with a too complex method. First perform the Simplified Decision Tree and then investigate if the Binomial model could add something to the results. To stimulate the applicability of ROA it is important to clarify in what situations it is valuable and what efforts and information is needed to deliver the results. A balance between the added value, the current available information and the additional effort is needed. It is also important to pay close attention to the precondition, information needed and accessibility of this information to conduct ROA.

To conclude it is important to keep in mind that the decision-making process includes many factors other than the investment policy. After all, a decision is always made based on the political context. Despite this, the decision information points out a value of flexibility which is in favour of a certain alternative, another alternative could however be chosen based on political grounds.
DISCUSSION
Although the interviews were relevant to reflect on the role of ROA in the actual decision-making process, some results could be discussed and influenced by the approach used.

First of all, the interviewees are all people who are responsible for decision-making information, but do not make the decisions themselves. It can be questioned if the findings would be different if the actual decision-makers would have been interviewed. As far as I can say I think that the decision-makers themselves would emphasise even more the importance of prompt decision-making and thus acknowledge the value of another method less. The people interviewed recognised the possible value of ROA, but all noted the major role of political context. I think that the actual decision-makers are even more careful with reacting positively to another decision evaluation method as they are afraid that this conflicts with the need to shorten the decision-making process. However, to actually research this, it would have been interesting to interview decision-makers themselves. Moreover, it would also be relevant to get more insights in the practical need for ROA by investigating the number of situations where the decision-maker actual could benefit from including the value brought by uncertainty or flexibility.

Another point of discussion is that all people interviewed represented Rijkswaterstaat and consequently the same organisation. Although this could have led to an unilateral opinion, Rijkwaterstaat is in the Netherlands ‘the’ party responsible for the transportation infrastructure. However, it could be interesting to interview other parties involved with transportation infrastructure decision-making. Finally, to improve this research it could be interesting to let people involved in the decision-making process actual experience ROA within a workshop. In this way they could reflect on ROA and the methods based on their own experience.
7 CONCLUSION, DISCUSSION & RECOMMENDATIONS

At the start of the research the goals and questions were formulated. This section will answer the main question of this research after first answering the concluding sub-question 5. These results will then be reflected upon in the discussion in section 7.2. This discussion includes the reliability of the results as well as the limitations of this research specifically. The third section will discuss the contribution of this research to both science and practice followed up by presenting the recommendations in section 7.4. Lastly, a personal perspective on this research will be presented in the fifth section.

7.1 CONCLUSION

Before the general conclusion is provided, sub-question 5 will be answered first. This question was formulated in the beginning of this research and presents important elements for the final conclusion.

7.1.1 ANSWERING CONCLUDING SUB-QUESTION 5

Sub-question 5 is a conclusive question that involves different elements of this research. For that reason, it belongs in this conclusion.

Sub-question 5: What advice can be given to infrastructure project decision-makers regarding ROA?

5a. In what circumstances does ROA improve the infrastructure decision-making?

ROA can improve the decision-making transportation infrastructure projects that meet the characteristics mentioned in Table 36 on the next page.

5b. What is the most suitable approach to value real options in infrastructure projects?

In this research the Simplified Decision Tree and the Binomial Option Pricing Method were applied and compared. Both methods have advantages and disadvantages which determine the applicability of the method per project. As both methods are based on a Decision Tree, it is recommended to start structuring the projects decisions, decision-moments and uncertainty with the Simplified Decision Tree. When a yes or no uncertainty needs to be dealt with, as for example, the fresh or salt water or the dike breaks or not, the Simplified Decision Tree is very useful to calculate the value of flexibility or regret of a certain decision. If the uncertainty is continuous, such as traffic growth, the Binomial Option Pricing Method can be used to determine the most optimal moment of investment based on the dominant uncertainty by calculating the value for each moment in time. However, in the Netherlands the context of the transportation infrastructure is changing; most decisions are not based anymore on the dominant traffic growth uncertainty, but on many other effects. For both methods the uncertainty has to be simplified to be able to be captured in the model. If the number of decision-moments increases the Binomial Option Pricing Methods becomes more appealing as in the Simplified Decision Tree these have to be included manually while the Binomial Model does this automatically. To conclude, it is not possible to select one dominant preferred method for all projects, this will differ for each project.
TABLE 36: CHARACTERISTICS LINKED TO LITERATURE AND PRACTICE

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Literature⁴</th>
<th>Practice (Case study &amp; interview)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Uncertainty</td>
<td>Uncertainty regarding the outcome exists.</td>
<td>In order to apply ROA, this uncertainty should consist of one dominant uncertainty in order to be captured in the method easily. Furthermore, the uncertainty has to be potent, so that it will be distinctive in the outcomes.</td>
</tr>
<tr>
<td>2 Managerial flexibility</td>
<td>Actions can be taken to influence the final outcome.</td>
<td>These are usually the option to defer, expand or phase the investment. The case study showed that if option costs are high (e.g. high investment costs for expanded highway), it is usually more beneficial to invest in the expanded alternative directly. If the option costs are low, it could be worth to wait and see if this expansion is actually needed.</td>
</tr>
<tr>
<td>3 Irreversible investment costs</td>
<td>Investments to be made are irreversible and can lead to sunk costs.</td>
<td>Only projects with large investment costs that are irreversible justify to research additional methods, such as ROA.</td>
</tr>
<tr>
<td>4 Asymmetric payoffs</td>
<td>The final payoffs depend on this uncertainty and can largely fluctuate.</td>
<td>If the CBA results cast a doubt between the most optimal alternative, due to the asymmetric pay-offs, ROA can provide new insights. The bandwidth of these pay-offs has to be large.</td>
</tr>
<tr>
<td>5 Limited importance of non-monetary costs</td>
<td>Non-monetary costs cannot be captured in the ROA.</td>
<td>As ROA gains insights in the investment policy, it can only include monetary aspects.</td>
</tr>
<tr>
<td>6 No no-regret alternative</td>
<td>ROA could help the decision-making if there is no no-regret alternative.</td>
<td>ROA can calculate the NPV of the different alternatives, so helps deciding on the most beneficial alternative. If the CBA already leads to a most optimal no-regret alternative. There is no need to investigate the possible value brought by uncertainty.</td>
</tr>
</tbody>
</table>

5c. What are the lessons learned from applying ROA?

Although in literature ROA is stated as complex and time consuming, the application is based on simple calculations. The actual challenge is to gather and identify the relevant information and structure this into the decision-making context. Furthermore, the application requires assumptions, but this is usually the case for any method. As it is a new method, the interpretations of the results is sometimes difficult and not transparent. More expertise with this method could increase the valuable addition. The Simplified Decision Tree can be useful at every stage and to every person who deals with decision-

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⁴ See Infrastructure decision-making & real options: A Literature study
making information, but it is especially relevant when dealing with yes or no uncertainties. The Binomial Option Pricing Method is more applicable when dealing with a continuous uncertainty. For both methods it can be said that some effort is required to get familiar with the method, but after all it is not that complex. Guidelines would be helpful to support the break-through of this method.

5d. What are the implications for future infrastructure decision-making?

ROA can be useful for certain projects. It is for a reason that this method has been noted as having potential in the literature and has been mentioned in the project evaluations guidelines since 2000. However, it is mainly the standardised, extensive and time-consuming current infrastructure project decision-making process that holds back the break-through of this method. The introduction of a ‘new’ method to gain additional decision information is complex. Essentially, the civil servants responsible for the decision information just perform the required methods to deliver the decision information they are asked for. Thus, it is first the decision-makers who have to has a need for the results of ROA, next the awareness of the possibilities of this method has to grow and then the method could be implemented in the decision-making process. Although this is a long-term process, it could be expected, with the growing tendency to become more adaptive, that the application for real option methods could grow.

7.1.2 Main Conclusion

The main research question of this thesis is:

How and to what extent can real option analysis be a valuable addition to transportation infrastructure projects decision-making within the Netherlands?

The extent to which ROA can be valuable depends on the characteristics of a project. ROA is only relevant for projects that are characterised by uncertainty, managerial flexibility, irreversibility, asymmetric pay-offs, limited importance of non-monetary costs and no no-regret alternative. However, the strength of these characteristics vary per project, therefore, for each project a trade-off between the potential added value of ROA and the additional efforts required to apply it has to be made. If including the value of flexibility and uncertainties by performing ROA only changes the project value with a small difference, it can be questioned if it is worth to make the additional effort of conducting the method. In case the option costs are expected to be compensated by higher future benefits, it could certainly be worth to research the optimal investment decision with ROA.

This research demonstrated with two case studies the added value conducting ROA could have. For both cases, ROA resulted in additional decision information to support the decision-making, where the CBA did not lead to a clear yes or no decision.

- In the case study on ‘widening the A27 highway’ it became clear that deferring the investment was valuable. The Binomial Option Pricing Method showed the most optimal moment to invest based on the uncertainty and the bandwidth of the possible values. The Simplified Decision Tree was mainly relevant to generate insights into the value of flexibility, in this case a phased investment, and consequences of a certain decision.

- In the case study on ‘the Replacement of the Kaagbrug A44’ the Simplified Decision Tree was mainly useful to quantify the consequences of the different decision possibilities by calculating the value of
each branch. This concluded that based on cost-effectiveness it is recommended to defer the investment until 2028. However, if the bridge has to be replaced before 2028, a replacement by a bridge is always preferred over an aqueduct as an aqueduct eliminates the option to expand. The Binomial Option Pricing Method illustrated that expanding the A44 highway could only be considered after 2018, in case of a high traffic growth.

It can be concluded that both projects benefitted from these additional decision-making information. In general, for these cases ROA led to more valuable alternatives and richer insights in the possible consequences of certain decisions.

The second part of the main question investigates how ROA can be valuable to transportation infrastructure projects decision-making. In this study, two different methodologies were analysed and applied; The Simplified Decision Tree and the Binomial Option Pricing Method. These two methods both have their own pros and cons, but also lead to different insights:

- In general, the Simplified Decision Tree is mainly relevant for every project influenced by uncertainties, as the tree can manually be adapted to each project specifically. This is ideal for real-option thinking. Calculating the NPV for each branch is time-consuming and is less reliable as the results highly depend on the assumptions of the scenario probability. Especially for the case regarding the ‘replacement of the Kaagbrug’ the Decision Tree was relevant to indicate the possible regret of an early investment and thus the value of deferring the replacement. Note that this regret can also be determined with the Binomial Option Pricing Method per node.

- The Binomial Option Pricing Method is helpful to calculate the possible value brought by flexibility and uncertainties accurately and can determine the optimal investment moment in time. For example, it resulted in stating that widening the A44 could be beneficial from 2018 onwards and generated insights in the bandwidth of this values. This method is especially applicable for projects that are influenced by one dominant continuous uncertainty that can be captured in the volatility. However, it could be possible to create different tree models and combine these.

To conclude, it is not possible to select one dominant preferred method for all projects, this will depend on each project. In general the Simplified Decision Tree is useful for projects with a yes or no uncertainty while the Binomial Option Pricing method is useful when the uncertainty mainly consists of a continuous dominant uncertainty. Based on transparency, it can be recommended to start with using the Simplified Decision Tree as this method can also be useful to support real option thinking. If the number of decision-moments increases the Binomial Option Pricing Methods becomes more appealing as this automatically involves all decision-moment, while this has to be manually included in the Simplified Decision Tree.

This research demonstrated that ROA can be valuable for projects that meet the characteristics mentioned as it leads to optimised decision-making, to additional strategic insights and it supports adaptive decision-making. For many projects it is expected that including the value of flexibility and uncertainty only increases the value of a project with a limited increase, so a trade-off between the additional effort and improved result is important. There are also still practical barriers mentioned in the interviews with the people responsible for decision information at Rijkswaterstaat. These are mainly the
standardised, extensive and time-consuming current infrastructure project decision-making process that desires prompt decision-making, the opinion that the method is complex, not transparent, time-consuming and not required and most importantly, the political will and pressure to deliver projects instead of improving the decision information. It would be possible to overcome these barriers, especially with the current growing attention towards adaptive management.

7.2 DISCUSSION

In this section this research and the related conclusions are discussed. Firstly, the meaning of the results and its significance will be discussed. Secondly, the limitations and how these had an effect on the outcomes of the research project will be addressed. Note that the conclusions to the two case studies are already discussed in their specific sections.

7.2.1 DISCUSSING THE FINDINGS

This research resulted in acknowledging the added value of ROA for certain Dutch transportation infrastructure projects decision-making. This conclusion is drawn based on a literature review, on an analysis of performed case studies, on two new case studies and on the interviews with the people from Rijkswaterstaat responsible for decision-making information. This section discusses elements that could have influenced the reliability of the results.

SELECTED CASES

In this research two projects were selected to use as a case study, selecting those case studies specifically could have influenced the results. In the ‘widening of the A27 highway’ case it was already acknowledged that applying ROA would generate new insights, however this case was still relevant to gain insights in the difference between the methods. The second case, ‘Replacement of the Kaagbug A44’, seemed appropriate to study based on the requirements and criteria, as there was no CBA conducted yet and it would be possible to include the flexibility within the alternatives from the beginning of the project. However, it turned out that options to include flexibility were limited and that the option to expand did not involve significant option costs. Furthermore, the shipping traffic turned out to be low which made the aqueduct less interesting. It was difficult to know this in advance as the information for example on shipping volumes and plans was not directly accessible and not all criteria could have been checked as no CBA had been conducted yet. When linking this to the requirements for the application of ROA after conducting this case study, this case scored low on managerial flexibility and irreversibility. The managerial flexibility and additional costs involved to expand the bridge at a later stage are not significant enough and for that reason the consequences of the irreversibility are limited.

COMPARISON METHODS

Both ROA methods were conducted and this enables to compare both methods in general. A fair quantitative comparison between the methods was made in the ‘widening the A27 highway’ case study. For this project the two methods led to approximately the same optimal decision and a similar value of flexibility. But it cannot be concluded based on one study that two methods lead to the same value, as this might be accidental. The second case study was mainly relevant to gain insights in applying the methods instead of a quantitative comparison.
THE LACK OF EXPERTISE WITH DETERMINING THE INPUT VARIABLES

Another point to mention is the determination of the input variables for both methods. The experience with applying both methods is not very extensive, there is also less known about how to determine the input variables. The more certainty about the input variables, the more reliable the findings become. However, the CBA method currently used requires similar input variables, so it can be questioned how significant this point of discussion is. After all, it is never possible to capture all characteristics of a project into a model. However, it is important to realise that the probabilities of the uncertainty used in the Simplified Decision Tree directly influences the results. For the Binomial Option Pricing Method the volatility is an influential input variable with no common guidelines on its determination.

RESULTS OF THE INTERVIEWS

Also, the results from the interviews can be disputed. The intention of this research was to verify the results and research the added value by discussing these with the people responsible for the actual decision-making process. However, it turned out that it was difficult to discuss the different ROA methodologies in detail during one interview. The interviewees reflected on the suitability of ROA in the decision-making process, but were not able to understand the complete methods and certainly not able to compare the methods. Although overall, they seemed open and willing to try the new method, it can be discussed if this was influenced by the purpose of the interview. Furthermore, it can be discussed whether the results are affected by the people interviewed. They all represented Rijkswaterstaat which could lead to a unilateral opinion. Moreover, they were all responsible for the decision information and there were no interviews held with people conducting the economic analysis and the decision-makers themselves. To build on this research, it could be recommended to add interviews with people from other organisations and perform the methods in a workshop to be able to reflect on the methods in detail.

Although this research narrowed the knowledge gap, it did not result in an exact conclusion that revealed for what specific infrastructure projects what specific ROA method is valuable. There is no clear-cut choice among all the methods for all cases; per project the relevance of ROA has to be considered. This agrees with the statement from Lander & Pinches (1998, p. 22): ‘But the bottom line is, there is no one right or best decision-making framework to always use. Finally, although Decision Tree and influence diagrams models may be alternative ways of bringing real option analyses into the practical arena, possibly other alternative decision-making frameworks would also be useful or even more appropriate. This is an area worthy of future time and effort.’

7.2.2 DISCUSSING THE LIMITATIONS

This study had to be performed in a limited time and for that reason the cases were selected within this scope. The major limitations of this study are discussed in this section.

ANALYSIS OF EXISTING CASE STUDY

There were seven Dutch case studies found which were accessible to analyse. Although there are probably more examples of ROA applications, those were not publically available and not taken into account. The case studies analysis in this research only include the options to phase, defer and expand, so other types of options were not studied in this thesis.
LIMITATION OF THE CASES SELECTED
Based on the literature review and analysis of existing case studies, two projects were selected for conducting ROA. The goal was to use these case studies to answer the general research questions. However, it can be questioned if two case studies are sufficient to generalise the conclusions to all transportation infrastructure projects within the Netherlands. The cases included a replacement and a widening project, while there are also other types of infrastructure projects decision-making. Furthermore, only the option to defer, phase and expand were included in these cases.

LIMITATION OF THE METHODOLOGIES INCLUDED
In this research two methods, the Simplified Decision Tree and the Binomial Option Pricing Method were taken into account, after being selected as the most promising during the literature review. Following this research and having more knowledge on this topic, it could be that it would have been relevant to include the Monte Carlo Simulation method as well, as this method is able to deal with more types of uncertainties.

LIMITATION OF THE SIMPLIFIED DECISION TREE RESEARCH
The Simplified Decision Tree method in this study did not take into account a risk-adjusted discount rate. This was done because Dutch infrastructure projects are recommended to use a fixed discount rate of 4.5%. However, some say that the discount rate should be adjusted when options occur, as the risk characteristics of a project change (Brandão et al., 2005, p. 72). The optimal way to what extent and in what situations to adjust the discount rate should be researched further, as this could also have an influence. The Binomial Option Pricing Model includes adjusting for difficulties in risk.

7.3 CONTRIBUTION OF THIS RESEARCH
7.3.1 CONTRIBUTION TO SCIENCE
There are several reasons why this research contributes to science. First of all, many studies argue for the addition of ROA. This is often done in a qualitative way by researching the potential applications of ROA. Only a few studies are done that actually conduct the method on a case itself. This study does apply ROA and is therefore also able to reflect on the application and the addition in a quantitative manner.

Secondly, the few examples that apply ROA usually consist of one specific method applied to one infrastructure project. This research contributes to science as it compares two different methods applied to two different cases and is therefore able to make a comparison between the methods applied.

Thirdly, and most importantly, this research makes an actual link between the methodology, the application and the actual decision-making environment. Through the interviews, it was possible to reflect on the addition of ROA and the way it fits in the current decision-making process.

7.3.2 CONTRIBUTION TO PRACTICE
This research forms a contribution for practice as it continues on the studies recently conducted into the addition of ROA to transportation infrastructure decision-making in the Netherlands. The CPB report concludes that the Simplified Decision Tree is the best way to take the value of flexibility and uncertainty into account with transportation infrastructure decision-making. However, previous research also
mentioned the Binomial Option Pricing Method as valuable. This research demonstrates that both methods could be relevant, but that this varies per infrastructure project.

Rijkswaterstaat aims to improve the decision-making information and is curious to what extent and in what manner ROA could be useful. This research provides insights both in what situations ROA could be useful and makes a comparison between two methods which are recently acknowledged as having potential. In short, it brings Rijkswaterstaat one step further to including real options.

This research was relevant for Stratelligence specifically as they are a pioneer in the Netherlands in the field of real options and infrastructure decision-making. This study provides additional and new insights on this topic and supports the position of Stratelligence as ROA expert.

7.4  RECOMMENDATIONS

7.4.1 FOR PRACTICE

This research concluded that ROA could be a valuable addition to transportation infrastructure project decision-making. For that reason, it is recommended to use ROA during project evaluation for projects that are characterised by uncertainty, managerial flexibility, irreversibility, asymmetric pay-offs, limited importance of non-monetary costs and no no-regret alternative. In a situation where the CBA does not lead to a preferred alternative, ROA provides additional insights. Especially if the pay-offs per decision vary significantly as they are influenced by the uncertainty and the possibilities for managerial flexibility involve high option costs, ROA is highly recommended.

RECOMMENDATIONS TO SUPPORT ROA WITHIN TRANSPORTATION INFRASTRUCTURE DECISION-MAKING

However, there are some steps recommended that could increase this value and the implementation of ROA. These recommendations are relevant for Rijkswaterstaat, but also for other organisations dealing with transportation infrastructure decision-making.

- **Categorising projects:** Firstly, it is valuable to have more insights in the number of projects that meet the characteristics to benefit from ROA in general. Accordingly, it would be relevant to investigate these projects and categorise them to have more insights in the applicability of the suitability of the different ROA methods.

- **Checklist for ROA:** Based on the categorisation in the first recommendation, it can be determined if the Simplified Decision Tree or the Binomial Option Pricing Method could be valuable when applied. This leads to the second recommendation to create a checklist that can support checking whether a project is appropriate for ROA.

- **Guidelines for the methodology:** After more insights have been gained in the number and type of upcoming projects that could benefit from ROA, it would be helpful to support its application. A further recommendation is to create guidelines for a smooth and transparent conduction of the method. This is available for the Simplified Decision Tree in the CPB report, but does not exist for the Binomial Option Pricing Method. However, the Simplified Decision Tree could also use additional explanation. Currently, people are discouraged by the term ROA, and guidelines can help to demonstrate that applying the method is feasible.
For Rijkswaterstaat the main recommendation is to overcome the practical application barriers for ROA. A first step is to start using the Simplified Decision Tree. This method is transparent and can be implemented quickly. If after a while, people become accustomed with including flexibility and uncertainty by real option thinking a next step to calculations can be made. Based on the structuring of the decision-making situation it can be determined if there is a need for quantified decision information. In that case it has to be determined if the uncertainty can better be captured in the Simplified Decision Tree or in the continuous Binomial Option Pricing Method.

With respect to ROA there are also recommendations for Stratelligence. Most importantly, Stratelligence should use their ROA expertise as a sales tactic. Stratelligence believes in the added value of ROA and should pass this conviction. Especially the application of the Binomial Option Pricing Method is rarely known by others. As one of the few experts in the Netherlands, it would be interesting to develop ways to promote this. Furthermore, it is recommended to create more awareness on the possibilities and benefits from ROA. For example, this can be done by placing an overview of a few successful applications of ROA on their website.

7.4.2 FUTURE RESEARCH
ROA is relatively new and currently widely researched. Although this research offered additional insights in the application within the Netherlands specifically, there are still a lot of knowledge gaps that require additional research. The following recommendations which follow from the discussion of this research are made for future research.

A first recommendation is to research the effects of the assumptions per methodology. As the application for both methods is relatively small, a lot of additional insights per method would be relevant to optimise their application. For the Simplified Decision Tree method, it could be especially interesting to research the effects of using an adjusted discount rate and make another a comparison with the Binomial Option Pricing Method. The Binomial Option Pricing method could notably benefit from research into determining the volatility and the up and downwards probability as well as their sensitivity.

In addition, the Simplified Decision Tree and Binomial Option Pricing Method both fit best for projects influenced by one dominant or a limited amount of uncertainties. However, from the decision-making environment there is a need for methods that are able to include many types of uncertainties. Research into methods that are able to include the value brought by different uncertainties is recommended. For example, the possibilities of Monte Carlo Simulation could be researched. Another option would be to investigate the possibility to combine different ROA methods, for example calculate one branch of the Simplified Decision Tree with the Binomial Option Pricing Method when this deals with a continuous uncertainty.

Moreover, it is recommended to test the methods by taking into account other options than the option to defer, expand or phase. These could be the options to abandon, grow or switch. Attention should be
paid to the suitability of each model per option. The overall expertise of ROA into transportation infrastructure projects could benefit from this.

Lastly, this study focused on the application of ROA on infrastructure projects that are currently evaluated by means of the CBA method. There are different types of infrastructure projects decision-making as construction, maintenance, replacement and procurement. It would be interesting to investigate the applicability of ROA on all these types of projects and its suitability to different variations of CBA methods as Life-Cycle Costing or Best Value Procurement.

7.5 PERSONAL REFLECTION

In this section I reflect on the research process and content from my personal perspective. In general I am satisfied with the research process. Beforehand, I was warned by other students that it is always difficult to find a balance between the aims of an external company and TUDelft. For that reason I focused on clear communication about expectations to all parties. All considered, I must admit that I am glad with the way it went, as I did not experience any problems with this. I also should thank Stratelligence for this. As Stratelligence is quite scientifically oriented, this offered a great graduation environment. During the research I felt I was leading of the process, but also received the support I needed from my supervisors. I was actually positively surprised by their willingness to help and I felt that they were always there for me.

Reflecting on the content of this report, I was able to perform the research according to the way it was planned in the project plan. Personally, I am a planner, so was focused to stick to the plan. Unfortunately, I had a small delay as I had to postpone the interviews for a few weeks due to the Christmas holiday. However, I was happy about this, because this additional time gave me some more space to conduct the case studies.

One of the main challenges during this research was conducting the calculations of the ROA analyses. Beforehand, I lacked experience with economic evaluations which made me uncertain and made me doubt about my own abilities. Luckily, my supervisors gave me the confidence and the advice needed to do this and I was able to do so. Of course, I have to say that there are probably points to improve which would increase the reliability of this analyses. However, I am satisfied with the results for the purpose of this research. Another main hurdle for me was the English language. I always experienced difficulties with English, and writing a complete report in English has costs me a considerable amount of time and effort, especially due to the size of this report.

If I would have to perform this research again, I think I would do it in same manner apart from a few things. First of all, I would not fear certain elements before actually trying it, in my case the calculations. I was scared by all the people and literature stating that conducting ROA is difficult, while if you just do it, the basic principles are achievable. Secondly, I would have taken more time to select a case study or allow myself to change to another case. After a certain time, I discovered a few issues regarding the case study the Kaagbrug, as I was not able to compare both methods quantitatively in this case. Furthermore, it would have been more interesting for the project if the case study would have involved higher options
costs. After all, there might have been projects that would be more interesting to use, but I was committed to stick to this case.

Overall, I am satisfied with the work I have done and the results I have achieved. This research was a good experience and learning process. I really enjoyed the conversations with all the inspiring people and I am proud of the fact that I can count myself in the limited amount of people who have experience with ROA in infrastructure projects.


Reitsma, R. (2010). *Valuation of Real Options in Infrastructure Projects: The cases of Broadening the A27 Highway and Deepening the Twente canals*. Utrecht School of Economics.


APPENDICES

INDEX
A. Overview of Dutch Case Studies
B. Simplified Decision Tree A27
C. Case study Kaagbrug
D. Interview
A. OVERVIEW OF DUTCH CASE STUDIES

This appendix provides an overview of seven case studies on the application of ROA conducted in the Netherlands. Probably there are more applications of ROA in the Netherlands, but these case studies are analysed as they together form a variation of projects gaining from ROA. Next these cases are especially selected to learn from applying ROA which is also a goal in this research.

TABLE 37: OVERVIEW CASE STUDY ‘WIDENING THE A27 HIGHWAY’

<table>
<thead>
<tr>
<th>Case</th>
<th>Widening the A27 Highway</th>
</tr>
</thead>
<tbody>
<tr>
<td>By</td>
<td>Roos Reitsma (2010) – Stratelligence</td>
</tr>
<tr>
<td>Method</td>
<td>- Binomial Option Pricing Method</td>
</tr>
<tr>
<td></td>
<td>- Risk-Adjusted Decision Tree</td>
</tr>
<tr>
<td>Goal</td>
<td>Widening the highway to support the large traffic flows between Lunetten &amp; Hooipolder.</td>
</tr>
<tr>
<td>Alternatives</td>
<td>4 alternatives based on:</td>
</tr>
<tr>
<td></td>
<td>- Different tracks</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>Volume of future traffic flows</td>
</tr>
<tr>
<td>Type of options</td>
<td>Option to phase (compound option): Widening of different tracks</td>
</tr>
<tr>
<td>Conclusion</td>
<td>- The ROA showed the value of the option to defer the construction instead of an immediate investment. The CBA concluded that it was not interesting to widen the highway, as the NPV was negative. The ROA showed, that it was not interesting to widen the highway yet, but that it would be in the future. ROA showed insights in the moments it could be interesting to consider a widening. The surprising thing was that after the construction of the first track, one would start constructing the other tracks as well.</td>
</tr>
<tr>
<td></td>
<td>- Binomial Option Pricing Method is the easiest approach, but requires some restricting assumptions:</td>
</tr>
<tr>
<td></td>
<td>o It is difficult to determine the volatility.</td>
</tr>
<tr>
<td></td>
<td>o There is just one volatility possible while freight &amp; passenger actually would have a different value.</td>
</tr>
<tr>
<td>Discussion</td>
<td>- Although ROA can give insights in the preferred order of the investments, this was not tested due to the fixed order.</td>
</tr>
<tr>
<td></td>
<td>- Determining the variables is complicated.</td>
</tr>
<tr>
<td></td>
<td>- The Binomial Option Pricing Method cannot use different volatilities for either freight and passenger transport.</td>
</tr>
<tr>
<td></td>
<td>- The Binomial Option Pricing Method is preferred. But when an option is encountered that cannot be modelled using this approach, the Risk-Adjusted Decision Tree might be a solution.</td>
</tr>
</tbody>
</table>
### TABLE 38: OVERVIEW CASE STUDY ‘DEEPENING TWENTE CANALS’

<table>
<thead>
<tr>
<th>Case</th>
<th>Deepening Twente Canals</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>By</strong></td>
<td>Roos Reitsma (2010) – Stratelligence</td>
</tr>
</tbody>
</table>
| **Method** | - Binomial Option Pricing Method  
- Risk-Adjusted Decision Tree |
| **Goal** | Deepening the canals to allow more heavy ships to pass through with the benefit to decrease the transportation costs. |
| **Alternatives** | 8 alternatives varying on:  
- Different tracks  
- Depth of the canals |
| **Uncertainty** | Bulk transport volume |
| **Type of options** | Option to phase (compound option): expansion path of deepening different tracks. |
| **Conclusion** | - The option value to expand further is always higher. This can be explained as the value increases after deepening a certain track and this flexibility expansion is costless.  
- Compared with the Risk-Adjusted Decision Tree, the Binomial Option Pricing Method is recommended. There are very small differences between the results from both methods, but the Binomial Option Pricing Method was a way easier to conduct. |
| **Discussion** | - For a better value calculation, additional costs for flexibility should be included which will lead to a decreased option value. For example the additional costs of equipment that has to be rented for a longer period.  
- Especially choosing the appropriate dividend and volatility are main points of attention. |

### TABLE 39: OVERVIEW CASE STUDY ‘EXTENSION VOLKERAK-SLUICES’

<table>
<thead>
<tr>
<th>Case</th>
<th>Extension Volkerak-sluices</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>By</strong></td>
<td>Bos &amp; Zwaneveld (2014) - CPB</td>
</tr>
<tr>
<td><strong>Method</strong></td>
<td>Simplified Decision Tree</td>
</tr>
<tr>
<td><strong>Goal</strong></td>
<td>Expanding the capacity of the sluice to make sure the maximum waiting time does not exceed the restricted 30 minutes.</td>
</tr>
<tr>
<td><strong>Alternatives</strong></td>
<td>4 different alternatives to extent the capacity</td>
</tr>
<tr>
<td><strong>Uncertainty</strong></td>
<td>Future shipping volumes by the use of high and low growth scenario</td>
</tr>
<tr>
<td><strong>Type of options</strong></td>
<td>Option to defer</td>
</tr>
</tbody>
</table>
| **Conclusion** | - Depended on the high or low growth scenario the construction should take place in either 5 or 10 years. The real option theory can give insights in the right moment to invest.  
- It is recommended to not invest directly in a fourth pond, but wait for increased delays and waiting times as a result of growing shipping volumes. |
| **Discussion** | - After 5 or 10 years the exact economic scenario is not clear either, so why defer if no new information will be known.  
- Waiting to invest might lead to increased waiting times and could lead to negative external effects. |
TABLE 40: OVERVIEW CASESTUDY ‘REPLACEMENT SALT-FRESH WATER SEPARATION KRAMMERSLUICES’

<table>
<thead>
<tr>
<th>Case</th>
<th>Replacement salt- fresh water separation Krammersluices</th>
</tr>
</thead>
<tbody>
<tr>
<td>By</td>
<td>Bos &amp; Zwaneveld (2014) - CPB</td>
</tr>
<tr>
<td>Method</td>
<td>Simplified Decision Tree</td>
</tr>
<tr>
<td>Goal</td>
<td>Replace the obsolete separation system which causes long waiting times for ships in the Volkerak-Zoommeer</td>
</tr>
<tr>
<td>Alternatives</td>
<td>Bubblescreen, 1 on 1 replacement for new sluice or combination of those</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>- State of the Volkerak-Zoom Lake (fresh or salt water)</td>
</tr>
<tr>
<td></td>
<td>- Knowledge about water separation techniques (effectiveness bubblescreen)</td>
</tr>
<tr>
<td>Type of options</td>
<td>Option to defer</td>
</tr>
<tr>
<td>Conclusion</td>
<td>- Real option approach gives insights in the possible decisions moment and value to defer.</td>
</tr>
<tr>
<td></td>
<td>- If the Volkerak-Zoomlake remains filled with freshwater, it is recommended to invest in a bubble screen.</td>
</tr>
<tr>
<td></td>
<td>- Direct 1-on-1 replacement is not recommended and even a temporary acceptance of salt water damage is a preferred alternative.</td>
</tr>
<tr>
<td>Discussion</td>
<td>- The results do no to lead to new insights as in this case real-option is used a way of thinking without providing a calculation.</td>
</tr>
<tr>
<td></td>
<td>- The salt or fresh water state is an uncertainty that can be captured well within the Simplified Decision Tree.</td>
</tr>
</tbody>
</table>

TABLE 41: OVERVIEW CASESTUDY ‘REPLACEMENT OF THE MEPPELERDIEP SLUICE’

<table>
<thead>
<tr>
<th>Case</th>
<th>Replacement of the Meppelerdiep sluice</th>
</tr>
</thead>
<tbody>
<tr>
<td>By</td>
<td>van der Pol, Bos &amp; Zwaneveld (2015) - CPB</td>
</tr>
<tr>
<td>Method</td>
<td>Simplified Decision Tree</td>
</tr>
<tr>
<td>Goal</td>
<td>Possible replacement of the current sluice as this type of sluice as this sluice is obsolete and closing this sluice leads to direct traffic delay.</td>
</tr>
<tr>
<td>Alternatives</td>
<td>Three different types of sash sluices with different dimensions or maintaining the current sluice</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>Growth of traffic flows which lead to different traffic delay damages:</td>
</tr>
<tr>
<td></td>
<td>- shipping flows</td>
</tr>
<tr>
<td></td>
<td>- road traffic flows</td>
</tr>
<tr>
<td>Type of options</td>
<td>Option to defer</td>
</tr>
<tr>
<td>Conclusion</td>
<td>Real option thinking influences the decision as it prefers the option to defer the replacement.</td>
</tr>
<tr>
<td></td>
<td>- The more expensive sash sluices are only preferred when the amount of traffic delay damages is more than 40 days</td>
</tr>
<tr>
<td></td>
<td>- In most scenario it is worth to first maintain the sluice and invest after 10 years in a sash sluice</td>
</tr>
<tr>
<td>Discussion</td>
<td>- There is a lack of information on the different scenarios. This knowledge is important as the scenario determines the alternative.</td>
</tr>
</tbody>
</table>
### Table 42: Overview Case Study 'Enlarging Ramspol Bridge'

<table>
<thead>
<tr>
<th>Case</th>
<th>Enlarging Ramspol bridge</th>
</tr>
</thead>
<tbody>
<tr>
<td>By</td>
<td>van der Pol, Bos &amp; Zwaneveld (2015) - CPB</td>
</tr>
<tr>
<td>Method</td>
<td>Simplified Decision Tree</td>
</tr>
<tr>
<td>Goal</td>
<td>Enlarge the Ramspol bridge so it can handle more traffic, both shipping and road way flows</td>
</tr>
</tbody>
</table>
| Alternatives                   | - Different bridge heights (7, 10, 13 m)  
                                 | - number of lanes (2x1 or 2x2) |
| Uncertainty                    | Growth traffic flows:  
                                 | - container shipping  
                                 | - recreational shipping  
                                 | - road traffic flows  
                                 | Scenario: Expected increase, large increase |
| Type of options                | Option to defer |
| Conclusion                     | The scenarios have a large influence on the preferred alternative and for that reason the option to defer the decision has a value.  
                                 | - There is a value of a later decision moment of heightening the bridge. At a future stage more certainty exist of the traffic flows. This is relevant as heightening is only valuable in a scenario with a large increase of traffic flows.  
                                 | - Based on a 50% chance of both scenario the expected option value of heightening the bridge to 10 meters are 1.4 million. When the chance on this scenario is 10%, the value is 0.3 million. |
| Discussion                     | - The mentioned values do not include risk adjustments. |

### Table 43: Overview Case Study 'Expansion of the Highway and Tunnel Amsterdam'

<table>
<thead>
<tr>
<th>Case</th>
<th>Expansion of the highway and tunnel Amsterdam</th>
</tr>
</thead>
<tbody>
<tr>
<td>By</td>
<td>van der Pol, Bos &amp; Zwaneveld (2015) - CPB</td>
</tr>
<tr>
<td>Method</td>
<td>Simplified Decision Tree</td>
</tr>
<tr>
<td>Goal</td>
<td>Improve the traffic flows by expending the traffic capacity on the corridor Schiphol-Amsterdam-Almere (SAA)</td>
</tr>
</tbody>
</table>
| Alternatives                   | Alternatives based on the following variables:  
                                 | - Amount of road lanes  
                                 | - Tunnel: (No tunnel, 3 km tunnel, 6 km tunnel)  
                                 | - Reserved space for future increase |
| Uncertainty                    | Economic scenario (extremely high, high, low) → Growth traffic flows |
| Type of options                | Option to expand, option to defer |
| Conclusion                     | The standard CBA only included the traffic flow growth of a high economic scenario. The Decision Tree shows that this economic scenario is not met, the benefits would remarkably decrease. |
| Discussion                     | - The Decision Tree can be adopted to the amount of decision moments |
B. SIMPLIFIED DECISION TREE A27

This annex presents the representation of the Simplified Decision Tree of the ‘Widening Highway 27’ investment decision. As mentioned in the main text, an important challenge was to simplify the tree to a few decisions, decision-moments and uncertainties expressed in scenarios.

The following figures present the steps to simplify the situation into a Simplified Decision Tree.

- Figure 20 presents the Decision Tree with all the possible decisions, thus the alternatives B3, B2, B1, B and R. R refers to the alternative ‘do not expand’. The figure does not display the decision possibilities after R, but in fact this R should be replaced by the decision possibilities one step before. The tree just includes 4 decision moments (T1,T2,T3,T4), those can be filled in by moments in time.

- Figure 21 presents the Decision Tree whereby the alternatives B2 and B1 are excluded. As described in the main text, this is done because alternative B3 which includes one track, involves the highest investment costs. The other tracks are combined and seen as one track. Furthermore the decision-moments: 2013,2018 and 2018 are added.

- Figure 22 images the scenario tree; there are two scenarios included. A low and a high scenarios which represent a low and high traffic volume growth.

- Figure 23 present the complete Simplified Decision Tree with the different decisions, decision moments and scenarios included. Hereby there is chosen to just image the scenarios at the end node.

LEGEND SIMPLIFIED DECISION TREE

<table>
<thead>
<tr>
<th>Decision node</th>
<th>Uncertainty node</th>
<th>End node</th>
<th>Moment in time</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Widening</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>4 tracks: Complete highway</td>
</tr>
<tr>
<td>B3</td>
<td>3 tracks</td>
</tr>
<tr>
<td>B2</td>
<td>2 tracks</td>
</tr>
<tr>
<td>B1</td>
<td>1 track</td>
</tr>
<tr>
<td>R</td>
<td>0 tracks: Do not expand</td>
</tr>
</tbody>
</table>

To select the most optimal alternative probabilities of the scenarios had to be added. Before this could have been done, the NPV of the different alternatives had to be calculated. The following elements have been included:

- Costs: Investment costs and maintenance costs
- Direct Benefits: Travel time benefits, reliability and travel distance costs
- External effects: Air quality, sound, safety, climate

There is assumed that the uncertainty, the traffic volume growth, just directly affects the travel time benefits and that the effects on the other benefits are small enough to ignore. Moreover, the travel time benefits are the main part of the complete benefits. Then the NPV after including the defer had to be
determined. In order to make this calculation the CPB used for example percentages to recalculate the new values (van der Pol et al., 2015).

- Defer of 5 years: 25% less costs, 5% less benefits
- Defer of 10 years: 50% less costs, 15% less benefits
- Defer of 15 years: 75% less costs, 25% less benefits

As can be noticed from the mentioned percentages the costs decrease much more than the benefits. This can be explained by the fact that the costs decrease with the discount rate of 5.5% and the benefits decrease with the same discount rate but also increase with a growth factor, in this case the traffic volume growth. After applying those percentages, it was obvious that the longer there has been deferred, the more an alternative would be worth. As can be derived from the performed CBA, the growth factor which is included in those mentioned percentages is way too high for this case. (The benefits decrease more than the percentage say). Therefore the costs and benefits are recalculated just based on the discount rate of 5.5% where after the benefits had to be adapted to the growth factor. This growth factor could have been derived from the performed CBA, since the Present Value of the benefits decreased on a yearly base with the discount rate and traffic volume growth.

To perform a scenario analysis the RC and GE scenarios are used to include uncertainty of the traffic volumes. Hereby the recommendations from the institution of mobility are used (Rienstra, 2012). For the RC scenario a yearly growth of 0.8% for road traffic is expected till 2020, followed by a decrease of -0.18% per year in the years after 2020. The GE scenario includes a yearly growth of 1.7% for road traffic till 2020, followed by a decrease of -0.95% per year from 2020 on till 2040. After 2040 stabilisation is assumed in all scenarios. In this calculation the growth percentage are adjusted to the percentages used in the Binomial Option Pricing Method which consist of a growth of 1.5% until 2020 followed by an increase of 0.85% in the GE scenario.

The interpretation and discussion of the results are discussed in the main text.
FIGURE 20: DECISION TREE A27
FIGURE 21: SIMPLIFIED DECISION TREE A27
FIGURE 22: SCENARIO TREE A27
FIGURE 23: SIMPLIFIED DECISION TREE WITH UNCERTAINTY
C. CASE STUDY KAAGBRUG

C1. IMPORTANCE EXTERNAL EFFECTS KAAGBRUG

The following table demonstrates that the non-monetary effects from the Kaagbrug are from limited importance. The only two significant effects are spatial impacts and nature and landscape. To limit the effects on nature and landscape there will be chosen to construct the bridge on the other side then the important bird area as depicted with the green area in Figure 24.

TABLE 44: IMPACT EXTERNAL EFFECTS - KAAGBRUG (ARCADIS, 2014, P. 40)

<table>
<thead>
<tr>
<th>Theme</th>
<th>Criterium</th>
<th>Current</th>
<th>Min</th>
<th>Basic</th>
<th>Plus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space</td>
<td>surface</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>width</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>length</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Noise</td>
<td>increase/decrease noise</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Air</td>
<td>improvement/dilapidation airqulity</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Climate</td>
<td>improvement/dilapidation climate</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Nature</td>
<td>less or more disturbance nature</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Landscape</td>
<td>less or more disturbance landscape</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ground</td>
<td>less or more disturbance ground</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Water</td>
<td>less or more disturbance groundwater and surface water</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Archeology</td>
<td>encroachment of archeological values</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cultural history</td>
<td>cultural historical values</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>External safety</td>
<td>impact on risk</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

FIGURE 24: KAAGBRUG IN RELATION TO NATURE (ARCADIS, 2014, P. 42)
C2. ALTERNATIVES REPLACEMENT KAAGBRUG

The following figures present the cross sections of the current situation and BASIC and PLUS alternative to give an impression.

FIGURE 25: CROSSSECTION - CURRENT SITUATION (ARCADIS, 2014, P. 14)

FIGURE 26: CROSSSECTION - ALTERNATIVE BASIC (ARCADIS, 2014, P. 15)

FIGURE 27: CROSSSECTION - ALTERNATIVE PLUS (ARCADIS, 2014, P. 16)
C3. INSIGHTS IN THE DATA COLLECTION

This annex provides some insights in the collected data.

COSTS

The following three tables show the costs that has been used as input for the CBA.

**TABLE 45: INVESTMENT COSTS, IN € MLN** (ARCADIS, 2014; STRATEGILENCE, 2015, COST EXPERT, 2015)

<table>
<thead>
<tr>
<th>#</th>
<th>Alternative</th>
<th>Direct costs</th>
<th>Building costs</th>
<th>total costs inclusive BTW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bridge Basic</td>
<td>13.7</td>
<td>22.2</td>
<td>26.9</td>
</tr>
<tr>
<td>2</td>
<td>Bridge Plus</td>
<td>14.8</td>
<td>23.9</td>
<td>29.0</td>
</tr>
<tr>
<td>3</td>
<td>Bridge Basis --&gt; later plus</td>
<td>15.3</td>
<td>24.7</td>
<td>29.9</td>
</tr>
<tr>
<td>4</td>
<td>Aqueduct Basis</td>
<td>29.1</td>
<td>47.5</td>
<td>57.0</td>
</tr>
<tr>
<td>5</td>
<td>Aqueduct Plus</td>
<td>33.5</td>
<td>54.7</td>
<td>65.7</td>
</tr>
</tbody>
</table>

It is important to realise that the costs are an estimation to make a comparison, but cannot be used as a budget. Next, it should be noted that the costs are not complete as mentioned in the Arcadis report. Also note that the additional costs to expand the bridge from Basic to Plus are relatively low.

**TABLE 46: COSTS WIDENING ROAD, IN € MLN** (ARCADIS, 2014; STRATEGILENCE, 2015, COST EXPERT, 2015)

<table>
<thead>
<tr>
<th>#</th>
<th>Road between exits 2-3</th>
<th>Total costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bridge Basic</td>
<td>11.9</td>
</tr>
<tr>
<td>2</td>
<td>Bridge Plus</td>
<td>41.6</td>
</tr>
<tr>
<td>3</td>
<td>Bridge Basis --&gt; later plus</td>
<td>11.9 + 29.7 = 41.6</td>
</tr>
<tr>
<td>4</td>
<td>Aqueduct Basis</td>
<td>11.9</td>
</tr>
<tr>
<td>5</td>
<td>Aqueduct Plus</td>
<td>41.6</td>
</tr>
</tbody>
</table>

**TABLE 47: MAINTENANCE COSTS, IN € PER YEAR** (ARCADIS, 2014; STRATEGILENCE, 2015, COST EXPERT, 2015)

<table>
<thead>
<tr>
<th>#</th>
<th>Alternative</th>
<th>Bridge replacement</th>
<th>Road between 2-3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0-alternative</td>
<td>75,000</td>
<td>92,000</td>
<td>167,000</td>
</tr>
<tr>
<td>1</td>
<td>Bridge Basic</td>
<td>118,000</td>
<td>92,000</td>
<td>210,000</td>
</tr>
<tr>
<td>2</td>
<td>Bridge Plus</td>
<td>140,000</td>
<td>122,360</td>
<td>262,360</td>
</tr>
<tr>
<td>4</td>
<td>Aqueduct Basis +</td>
<td>177,000</td>
<td>92,000</td>
<td>269,000</td>
</tr>
<tr>
<td>5</td>
<td>Aqueduct Plus</td>
<td>210,000</td>
<td>122,360</td>
<td>332,360</td>
</tr>
</tbody>
</table>

**BRIDGE OPENINGS KAAGBRUG**

**TABLE 48: NUMBER OF BRIDGE OPENINGS KAAGBRUG** (RIJKSWATERSTAAT - WNN, 2015)

<table>
<thead>
<tr>
<th>Year</th>
<th>Total</th>
<th>Summer (april-okt)</th>
<th>Winter (nov - mar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>822</td>
<td>758</td>
<td>64*</td>
</tr>
<tr>
<td>2014</td>
<td>919</td>
<td>813</td>
<td>106</td>
</tr>
<tr>
<td>2013</td>
<td>862</td>
<td>735</td>
<td>127</td>
</tr>
</tbody>
</table>

*the number of bridge openings in the winter 2015 is an estimation as the data last till the 8th of December 2015.
### TABLE 49: DATA REGARDING SHIPPING

<table>
<thead>
<tr>
<th>Variable</th>
<th>Number</th>
<th>Resource</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratio Commercial recreational shipping</td>
<td>5% commercial, 95% recreational</td>
<td>(Rijkswaterstaat [data file], 2008)</td>
</tr>
<tr>
<td>Benefits per hour shipping</td>
<td>€83.50 and €10 for recreational shipping</td>
<td>(Rijkswaterstaat - AVV, 2006; Rijkswaterstaat, 2015b)</td>
</tr>
<tr>
<td>Average duration bridge opening</td>
<td>2 minutes</td>
<td>(Rijkswaterstaat - WNN, 2015)</td>
</tr>
<tr>
<td>Average waiting time ship</td>
<td>10 minutes</td>
<td>(Rijkswaterstaat - WNN, 2015)</td>
</tr>
<tr>
<td>Growth recreational shipping</td>
<td>1% between 2005 and 2020, 0.5% between 2020 and 2040, 0% after 2060</td>
<td>(Rijkswaterstaat - AVV, 2006; Waterrecreatie Nederland, 2014)</td>
</tr>
</tbody>
</table>

**Additional Information Shipping Benefits**

The shipping benefits are really low. This can be explained as the Haarlemmermeer Ringvaart is part of the ‘staande mastroute’ and only local commercial shipping uses this canal (Rijkswaterstaat DVS, 2011). The benefits per hour shipping are €83.50 and €10 for recreational shipping (Rijkswaterstaat - AVV, 2006; Rijkswaterstaat, 2015b). The average opening duration of the bridge is 2 minutes and in general a ship has to wait 10 minutes before the bridge opens. Based on this information the yearly travel time benefits for shipping have been determined. To calculate them over the years a growth for the recreational shipping of 1% between 2005 and 2020, growth of 0.5% between 2020 and 2040 and a growth of 0% after 2060 is expected (Rijkswaterstaat - AVV, 2006; Waterrecreatie Nederland, 2014). The number of ships passing the bridge is larger, as the bridge is not opened for every ship, but there are no numbers known about the total number of passing shipping traffic. However, the bridge does not influence the travel time of those ships as they are not influenced by this bridge. It can be discussed if the travel time benefits of recreational shipping can be expressed in a value, however, as this is an example the assumptions made in the Ramspolbridge are used.

**Impact Widening the A44 on Travel Time Losses**

For the A44 study the hourly travel time losses per alternative are calculated and monetised. The following tables are adapted in this annex to provide some more background information on the effect. The tables represent the intensity/capacity ratio whereby a I/C ratio over 0.8 represents a chance on traffic jam (orange) and a I/C ratio over 1.0 represents structural traffic jam (red). Nr. 3 and 18 are the counting points next to the Kaagbrug. From Table 50 can be concluded that the intensity/capacity ratio is high in both the morning and evenings rush hours. Table 51 represents the situation whereby the highway is widened to a 2x3 road and demonstrates that all I/C bottlenecks will be solved. This provides some insights in the effect on the hourly travel time losses.
**TABLE 50: INTENSITY AND I/C RATIO - 2X2 (ARCADIS, 2014, P. 30)**

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Capacity</th>
<th>PAE Ochtendspits</th>
<th>I/C</th>
<th>PAE Avonds pits</th>
<th>I/C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4418</td>
<td>3180</td>
<td>0.72</td>
<td>4499</td>
<td>1.02</td>
</tr>
<tr>
<td>2</td>
<td>4418</td>
<td>3105</td>
<td>0.70</td>
<td>4036</td>
<td>0.91</td>
</tr>
<tr>
<td>3</td>
<td>4197</td>
<td>3990</td>
<td>0.55</td>
<td>4515</td>
<td>1.06</td>
</tr>
<tr>
<td>4</td>
<td>4197</td>
<td>4089</td>
<td>0.97</td>
<td>4278</td>
<td>1.02</td>
</tr>
<tr>
<td>5</td>
<td>4197</td>
<td>3756</td>
<td>0.89</td>
<td>3931</td>
<td>0.94</td>
</tr>
<tr>
<td>6</td>
<td>6544</td>
<td>4833</td>
<td>0.74</td>
<td>5080</td>
<td>0.78</td>
</tr>
<tr>
<td>7</td>
<td>4197</td>
<td>4079</td>
<td>0.97</td>
<td>3675</td>
<td>0.88</td>
</tr>
<tr>
<td>8</td>
<td>6544</td>
<td>3605</td>
<td>0.55</td>
<td>3278</td>
<td>0.50</td>
</tr>
<tr>
<td>9</td>
<td>4197</td>
<td>2260</td>
<td>0.54</td>
<td>1885</td>
<td>0.45</td>
</tr>
<tr>
<td>10</td>
<td>4197</td>
<td>2898</td>
<td>0.69</td>
<td>2064</td>
<td>0.62</td>
</tr>
<tr>
<td>11</td>
<td>4197</td>
<td>3435</td>
<td>0.82</td>
<td>3626</td>
<td>0.85</td>
</tr>
<tr>
<td>12</td>
<td>4197</td>
<td>2662</td>
<td>0.63</td>
<td>2690</td>
<td>0.64</td>
</tr>
<tr>
<td>13</td>
<td>6544</td>
<td>3666</td>
<td>0.56</td>
<td>4010</td>
<td>0.61</td>
</tr>
<tr>
<td>14</td>
<td>4197</td>
<td>3858</td>
<td>0.92</td>
<td>4128</td>
<td>0.98</td>
</tr>
<tr>
<td>15</td>
<td>6544</td>
<td>4699</td>
<td>0.72</td>
<td>4832</td>
<td>0.74</td>
</tr>
<tr>
<td>16</td>
<td>4197</td>
<td>3686</td>
<td>0.86</td>
<td>3722</td>
<td>0.89</td>
</tr>
<tr>
<td>17</td>
<td>4197</td>
<td>3859</td>
<td>0.92</td>
<td>4068</td>
<td>0.97</td>
</tr>
<tr>
<td>18</td>
<td>4197</td>
<td>4457</td>
<td>1.06</td>
<td>4153</td>
<td>0.99</td>
</tr>
<tr>
<td>19</td>
<td>4418</td>
<td>4000</td>
<td>0.91</td>
<td>3313</td>
<td>0.75</td>
</tr>
<tr>
<td>20</td>
<td>6544</td>
<td>4651</td>
<td>0.72</td>
<td>3305</td>
<td>0.51</td>
</tr>
</tbody>
</table>

**TABLE 51: INTENSITY AND I/C RATIO - 2X3 (ARCADIS, 2014, P. 31)**

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Capacity</th>
<th>PAE Ochtendspits</th>
<th>I/C</th>
<th>PAE Avonds pits</th>
<th>I/C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6544</td>
<td>3180</td>
<td>0.49</td>
<td>4499</td>
<td>0.69</td>
</tr>
<tr>
<td>2</td>
<td>6544</td>
<td>3105</td>
<td>0.47</td>
<td>4036</td>
<td>0.62</td>
</tr>
<tr>
<td>3</td>
<td>6544</td>
<td>3990</td>
<td>0.51</td>
<td>4515</td>
<td>0.69</td>
</tr>
<tr>
<td>4</td>
<td>6544</td>
<td>4089</td>
<td>0.82</td>
<td>4278</td>
<td>0.85</td>
</tr>
<tr>
<td>5</td>
<td>6544</td>
<td>3756</td>
<td>0.57</td>
<td>3931</td>
<td>0.60</td>
</tr>
<tr>
<td>6</td>
<td>6544</td>
<td>4833</td>
<td>0.74</td>
<td>5080</td>
<td>0.78</td>
</tr>
<tr>
<td>7</td>
<td>6544</td>
<td>4079</td>
<td>0.97</td>
<td>3675</td>
<td>0.88</td>
</tr>
<tr>
<td>8</td>
<td>6544</td>
<td>3605</td>
<td>0.55</td>
<td>3278</td>
<td>0.50</td>
</tr>
<tr>
<td>9</td>
<td>6544</td>
<td>2260</td>
<td>0.54</td>
<td>1885</td>
<td>0.45</td>
</tr>
<tr>
<td>10</td>
<td>6544</td>
<td>2898</td>
<td>0.69</td>
<td>2064</td>
<td>0.62</td>
</tr>
<tr>
<td>11</td>
<td>6544</td>
<td>3435</td>
<td>0.52</td>
<td>3626</td>
<td>0.55</td>
</tr>
<tr>
<td>12</td>
<td>6544</td>
<td>2002</td>
<td>0.41</td>
<td>2690</td>
<td>0.41</td>
</tr>
<tr>
<td>13</td>
<td>6544</td>
<td>3666</td>
<td>0.56</td>
<td>4010</td>
<td>0.61</td>
</tr>
<tr>
<td>14</td>
<td>6544</td>
<td>3858</td>
<td>0.59</td>
<td>4128</td>
<td>0.63</td>
</tr>
<tr>
<td>15</td>
<td>6544</td>
<td>4099</td>
<td>0.72</td>
<td>4632</td>
<td>0.74</td>
</tr>
<tr>
<td>16</td>
<td>6544</td>
<td>3666</td>
<td>0.56</td>
<td>3722</td>
<td>0.57</td>
</tr>
<tr>
<td>17</td>
<td>6544</td>
<td>3859</td>
<td>0.59</td>
<td>4068</td>
<td>0.62</td>
</tr>
<tr>
<td>18</td>
<td>6544</td>
<td>4467</td>
<td>0.68</td>
<td>4153</td>
<td>0.63</td>
</tr>
<tr>
<td>19</td>
<td>6544</td>
<td>4000</td>
<td>0.61</td>
<td>3313</td>
<td>0.75</td>
</tr>
<tr>
<td>20</td>
<td>6544</td>
<td>4651</td>
<td>0.72</td>
<td>3305</td>
<td>0.51</td>
</tr>
</tbody>
</table>
C4. SIMPLIFIED DECISION TREE – KAAGBRUG

FIGURE 28: DECISION TREE KAAGBRUG
**Uncertainty**

**Figure 29: Traffic Growth Road**
- High growth road traffic
- Low growth road traffic

**Figure 30: Traffic Growth Shipping**
- High growth shipping
- Low growth shipping

**Figure 31: Decision Regarding the A44**
- Downgrade to N-road
  - Keep 2x2
  - Expand to 2x3
Simplified Decision Tree, Relevant

FIGURE 32: COMBINED DECISION TREE
FIGURE 33: SIMPLIFIED DECISION TREE KAAGBRUG (ZOOM)
D. INTERVIEW

D1. PLANNING INTERVIEW

<table>
<thead>
<tr>
<th>Wanneer</th>
<th>Wie</th>
<th>Functie</th>
</tr>
</thead>
<tbody>
<tr>
<td>11-1-2016 13:30</td>
<td>Henk de Jong</td>
<td>Projectmanager RWS</td>
</tr>
<tr>
<td>11-1-2016 16:00</td>
<td>Kees Roelse</td>
<td>Programmabureau Planuitwerkingen en Verkenningen (PvP) RWS</td>
</tr>
<tr>
<td>12-1-2016 9:00</td>
<td>Carmen Peletier</td>
<td>Programmabureau Planuitwerkingen en Verkenningen (PvP) RWS</td>
</tr>
<tr>
<td>12-1-2016 16:30</td>
<td>Kingson Wu</td>
<td>Consultant (Projectmanager A44)</td>
</tr>
<tr>
<td>15-1-2016 9:00</td>
<td>Maaike Beerepoot</td>
<td>Bestuurstaf RWS</td>
</tr>
</tbody>
</table>

D2. INTERVIEW: TOEGEVOEGDE WAARDE REËLE OPTIE ANALYSE

De daadwerkelijk gestelde vragen zijn per interview en achtergrond van de persoon aangepast.

DEEL A: ALGEMENE VRAGEN

Introductie:
1. Kunt u kort uzelf voorstellen en uw functie beschrijven?
2. Kunt u iets vertellen over het huidige besluitvormingsproces binnen uw functie? Maakt u hierbij gebruik van de KBA?
3. In hoeverre kan ‘flexibiliteit’ een rol spelen?

Reële Optie Analyse:
4. Bent u bekend met Reële optie analyse? Zo ja, wat weet u ervan?
5. Heeft u wel eens reële optie analyse toegepast? Zo ja wanneer, en hoe? Zo nee, waarom niet?

Toepassing Reële Optie Analyse:
6. Er zijn verschillende opties welke zouden kunnen voorkomen bij transport infrastructuur beslissingen. Welke van de volgende vormen van flexibiliteit bent u weleens tegengekomen?
   - Besluit tot uitstel
   - Besluit tot uitbreiding
   - Besluit tot fasering
   - Besluit tot wisselen
   - Besluit tot schalen

7. Er zijn doorgaans twee manieren om met ROA en het adaptief denken te gebruiken. In welke van de twee ziet u de meeste potentie?
   - Reële optie denken – inzichten in mogelijkheden van flexibiliteit
   - Reële optie berekeningen - exacte nauwkeurige cijfers die de waarde van flexibiliteit uitdrukken

8. Er zijn verschillende methodes van ROA, wat zijn voor u belangrijke criteria voor het gebruiken van ROA? Bijvoorbeeld: Relatie met de MKBA, Transparantie en toegankelijkheid, Eenvoud van de implementatie, Realisme (bruikbare aannames)
**DEEL B: REFLECTIE OP RESULTATEN**
In mijn project heb ik gebruik gemaakt van twee verschillende methodes toegepast op twee verschillende casussen. De verschillende methodes zijn oplopend in complexiteit en tijd, maar ook in accuraatheid.

**Toelichten methodes (gebruik figuren)**
1) MKBA
2) Simpele beslisboom
3) Binomiale model

**Toepassing per casus**
A. Toepassing algemeen
B. Verbreding A27
C. Vervangingsopgave Kaagbrug

**Beslisinformatie**
9. Leiden de extra methodes voor u tot nieuwe inzichten?
10. Zijn de resultaten voor u bruikbare beslisinformatie?
11. Wat voegt deze informatie toe aan de besluitvorming?
12. Wat is voor het belangrijkste aan beslisinformatie? (vb. transparantie of accuraatheid)
13. Welke methode spreek u het meest aan? Waarom?

**Waardering beslisinformatie**
14. Hoe waardevol vindt u de extra informatie?
15. Hoeveel moeite/ tijd bent u bereidt hier in te steken? Hoeveel zijn bepaalde stappen u waard?

**DEEL C: OVERIGE MOGELIJKE VRAGEN**
16. Wat is volgens u de reden dat ROA beperkt wordt toegepast?
17. Uit vorige onderzoeken blijken er verschillende barrières voor de toepassing van ROA, welke van de volgende barrières denk u dat spelen (onbekendheid, complexiteit, extra tijd, politieke barrières)
18. In welke fase van besluitvorming ziet u met name belang bij de toepassing van ROA?
19. In hoeverre verwacht u dat de context verandert en deze meer vraagt om het toepassen van ROA?
20. Denk u dat er een verschil zit tussen lokale en nationale besluitvorming?

**Afsluiting**
21. Is er nog iets dat u kwijt of wilt toevoegen?
1. Maatschappelijke Kosten Baten Analyse (MKBA)

**Methode:** De verwachte kosten en baten voor verschillende alternatieven worden afgewogen met behulp van de NCW, waarna de meest voordelige oplossing wordt gekozen.

**Beslisinformatie:**
- Meest rendabele alternatief
- Vergelijking waarde van verschillende alternatieven

2. Simpele Beslisboom

**Methode:** Met behulp van een grafische boom worden de vastgestelde beslismomenten en onzekerheden in kaart gebracht en wordt per tak de NCW berekend.

**Extra beslisinformatie:**
- Inzicht en structuur in de keuzemogelijkheden en onzekerheid
- Inzicht in situatie waar geen ja/nee beslissing mogelijk is
- Waarde van spijt van kiezen alternatief in bepaald scenario
- Mogelijkheid onderzoeken flexibele alternatieven + waardering hiervan

3. Binomiale model

**Methode:** Een continue beslisboom die de waarde (inclusief flexibiliteit) per alternatief in de toekomst op basis van de ontwikkeling van de onzekerheid berekend waarbij rekening wordt gehouden met verschillen in risico’s.

**Extra beslisinformatie:**
- Berekening van meest optimale investeringsmoment
- Waarde van flexibiliteit
1. Maatschappelijke Kosten Baten Analyse (MKBA)

Voordelen:
- beproefde methode
- impact onzekerheid kan worden getest m.b.v. gevoeligheidsanalyse

Nadelen:
- houdt geen rekening met flexibiliteit
- niet altijd een ja/nee beslissing mogelijk
- houdt geen rekening met verschillen in risico

2. Simpele Beslisboom

Voordelen:
- biedt inzicht in de spijt bij het kiezen van ‘verkeerde’ alternatief
- inzicht in de mogelijkheden van flexibiliteit en onzekerheid
- transparant wegens de grafische weergave

Nadelen:
- beslismomenten en kansen moeten zelf gekozen worden, hierdoor conclusie sterk afhankelijk van aannames tijdens analyse

3. Binomiale model

Voordelen:
- kan meest optimale investeringsstrategie
- de waarde van flexibiliteit wordt berekend en kan worden meegenomen als baat (optie waarde)
- houdt rekening met verschillen in risico

Nadelen:
- tijdrovende en complexe berekeningen
- specifieke data benodigd
1. Voorbeeld: Maatschappelijke Kosten Baten Analyse (MKBA)

**TABLE 52: EXAMPLE MKBA FOR INTERVIEW**

<table>
<thead>
<tr>
<th>Alternatief</th>
<th>Baten</th>
<th>Kosten</th>
<th>Saldo</th>
<th>B/K ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>87</td>
<td>50</td>
<td>20</td>
<td>1,4</td>
</tr>
<tr>
<td>B</td>
<td>100</td>
<td>110</td>
<td>-10</td>
<td>0,9</td>
</tr>
<tr>
<td>C</td>
<td>60</td>
<td>50</td>
<td>10</td>
<td>1,2</td>
</tr>
<tr>
<td>D</td>
<td>100</td>
<td>90</td>
<td>10</td>
<td>1,1</td>
</tr>
</tbody>
</table>

**Beslisinformatie:**
- Meest rendabele alternatief
- Vergelijking waarde verschillende alternatieven
- Eventueel gevoeligheidsanalyse om het effect van groei op de alternatieven te testen.

**Conclusie:**
- Alternatief A heeft het hoogste Saldo en B/K ratio en wordt gekozen.
2. Voorbeeld: Simpele Beslisboom

![Diagram](image)

**Conclusie:**
- In hoog scenario kiezen voor alternatief B
- In laag scenario gekozen voor alternatief A
- Op basis van gemiddelde scenario gekozen voor alternatief B, maar dit kan leiden tot spijt.

Dus alternatief sterk afhankelijk van scenario

**TABLE 53: EXAMPLE SDT FOR INTERVIEW**

<table>
<thead>
<tr>
<th>Alternatief</th>
<th>Scenario</th>
<th>Baten</th>
<th>Kosten</th>
<th>Saldo</th>
<th>B/K ratio</th>
<th>Spijt</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Laag</td>
<td>120</td>
<td>100</td>
<td>20</td>
<td>1,2</td>
<td>0</td>
</tr>
<tr>
<td>A</td>
<td>Hoog</td>
<td>140</td>
<td>100</td>
<td>40</td>
<td>1,4</td>
<td>30</td>
</tr>
<tr>
<td>B</td>
<td>Laag</td>
<td>150</td>
<td>150</td>
<td>0</td>
<td>1,0</td>
<td>20</td>
</tr>
<tr>
<td>B</td>
<td>Hoog</td>
<td>220</td>
<td>150</td>
<td>70</td>
<td>1,5</td>
<td>0</td>
</tr>
</tbody>
</table>
2. Voorbeeld: Simpele Beslisboom met flexibel alternatief A

Alternatief A wordt zo ingericht, dat het mogelijk is deze uit te breiden naar alternatief B. De extra kosten voor dit flexibeler alternatief A zijn 10.

![Diagram of decision tree]

**Conclusie:**
- Bij een laag scenario kiezen voor B, spijt: 10
- Bij een hoog scenario kiezen voor A, spijt: 20
- In een hoog scenario is het rendabel om in een later stadium te verbreden. Dit heeft een waarde van 20 (van 50 naar 30). Dit flexibele alternatief moet vooraf worden vastgesteld.

**TABLE 54: EXAMPLE ADJUSTED SDT FOR INTERVIEW**

<table>
<thead>
<tr>
<th>Alternatief</th>
<th>Scenario</th>
<th>Baten</th>
<th>Kosten</th>
<th>Saldo</th>
<th>B/K ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Laag</td>
<td>120</td>
<td>110</td>
<td>10</td>
<td>1,1</td>
</tr>
<tr>
<td>A → B</td>
<td>Laag</td>
<td>140</td>
<td>160</td>
<td>-20</td>
<td>0,9</td>
</tr>
<tr>
<td>A</td>
<td>Hoog</td>
<td>140</td>
<td>110</td>
<td>30</td>
<td>1,3</td>
</tr>
<tr>
<td>A → B</td>
<td>Hoog</td>
<td>210</td>
<td>160</td>
<td>50</td>
<td>1,3</td>
</tr>
<tr>
<td>B</td>
<td>Laag</td>
<td>150</td>
<td>150</td>
<td>0</td>
<td>1,0</td>
</tr>
<tr>
<td>B</td>
<td>Hoog</td>
<td>220</td>
<td>150</td>
<td>70</td>
<td>1,5</td>
</tr>
</tbody>
</table>

**FIGURE 35: EXAMPLE ADJUSTED SDT FOR INTERVIEW**
3. Voorbeeld Binomiale model

De waarde van flexibiliteit kan worden bepaald (Verschil basisvariant t.o.v. flexibel alternatief)

- I.p.v. gemiddelden worden alle mogelijke waarden geëvalueerd.
- Geen vaste beslissing: er zijn flexibele alternatieven.
- Automatische risico correctie: dus niet constant dezelfde risico factor

FIGURE 36: EXAMPLE BOPM FOR INTERVIEW (REITSMA,2010)